SUSTAINABLE URBAN AREAS
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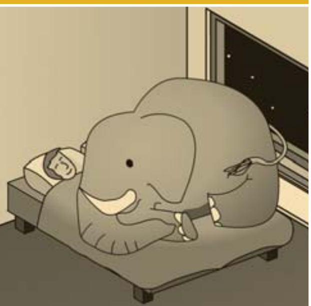

Health performance of housing

Indicators and tools

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Contents

Acknowledgement

In 1995 healthy housing became my occupational field. In the period of the National Insulation Covenant the strategy was to support active tenant groups in dealing with complaints about maintenance, technical building services and moisture. Many of these problems can be solved with better insulation. Because tenants associated certain health problems with the indoor environment, the relation between housing and health needed further study. Pieter Brandsma introduced me into this field by sharing his experience as an occupational environmental hygienist. It was Professor Annelies van Bronswijk of the Eindhoven University who guided the first steps into the scientific work on housing and health. She supported the review of literature on Legionella in domestic water systems and gave weekly private lectures. Sharing a room with August van Vliet in those days created an inspiring research environment. The topic of healthy housing at OTB Research Institute of Housing, Urban and Mobility Studies of the Delft University of Technology started with a conference in December 1998. In 2001 the PhD thesis project started, after publication of a workbook "Hoe gezond is de Nederlandse woning?" (How healthy is the Dutch dwellling?). Both PhD supervisor professor Hugo Priemus and co-PhD supervisor Geert Vijverberg, who at that time was the coordinator of the research group of Sustainable Housing Management and Quality Assurance, had great influence on forming this rather new field for OTB and Delft University of Technology. They contributed with their encouragement and lending much freedom in taking a position in the discussion on ventilation, maintenance and housing health performance.

The period between 2001 and 2006 passed with more than two final years with a heavy focus on the thesis. This period gave stress, 6-day working weeks and vacation periods skipped. Els, my dearest friend and partner of 38 years, shared a keen interest in healthy housing and presented a stop sign and a mirror when needed. In the meantime, she took care of many things. We are still happy together. It's a great gift of life to be the parents of two sons, Bas and Thijs, both working on their PhD thesis. The desire to bring the process to a positive end (and to be first to finish) has to do with the role of being their father.

The study group Sustainable Building and Health of VIBA became the playground for creative projects. The challenge to focus on the bedroom became one of the turning points in the research and the "taste of air" became the next creative challenge. Kees Snepvangers of the study group spent days on reading the manuscript and gave valuable feedback.

The colleagues at OTB and the research partners in "Sustainable Housing Management and Quality Assurance" have given much encouragement. Geert Vijverberg and Frits Meijer have read numerous versions of chapters and the manuscript. They put much energy into helping me over the stepping stones. With Jan van Ginkel I found balance and respect in sharing the field of work. Jan's critical advice was inspiring and many of his ideas and research findings have been included in this thesis.

Many people shaped the conditions that led to this result. Mieke Weterings and Josine van den Bogaard of the Health Department of Rotterdam and Frans Duijm of the Groningen Health Department commented on indicators and pilot versions of the Healthy Housing Checklist. Mike Hady of GGD Utrecht was a partner in fieldwork on house dust mite. SenterNovem commissioned research on ventilation and on the Health module of the Energy Performance Advice tool. Ron Spreekmeester of the Habitat Platform stimulated thinking about the relation between the poor and the rich in housing. This may lead to the next endeavour: research on healthy habitats in the context of international housing.

This research is positioned in the Delft Research Centre for Sustainable Urban Areas (SUA) of TU Delft and which activities are coordinated by the OTB. The programme 'Innovative Land Use', submitted in collaboration with the Habiforum Foundation, provided substantial research funding and is co-financed by Corpovenista, a cooperation between 8 housing associations, Aedes, SBR, the Universities of Utrecht and Amsterdam and OTB. SBR formed a project group for the design of instrumentation for health performance evaluation. Hans Vingerling and Atze Boerstra and others of SBR, Fattah Kabbaj of the housing association Staedion, Nico ten Bosch of Het Oosten and Onno van Rijsbergen of the Woonbond have given their input to the Healthy Housing Checklist. Piet van Luijk of the Dutch Ministry of Housing, Spatial Planning and the Environment created critical encounters that resulted in a clear profile of ideas.

Gouda and Delft, Evert Hasselaar

Part A
Theory

1 The research project

1.1 Introduction to Part A

Part A presents the theoretical basis for the research: environmental health, the problem definition and research questions, the methods of data collection and analysis and the outline of the PhD thesis. The frameworks of Chapter 2 describes the relations between topics of the research: the context of housing health performance evaluation and the focus on the relationships between housing, occupancy and health. The data collection, the analysis of both quantitative data and qualitative observations and the study on parameters of hazard conditions is explained. Chapter 3 deals with the state-of-the-art of performance evaluation. An important section is the inventory of references for health performance quality: the limit values of the concentration of agents in indoor air, the health impact of noise, the importance of thermal comfort and of safety. The state-of-the-art of health performance evaluation tools is summarized in four important tools. Chapter 3 includes a set of state-of-the-art indicators, that forms the starting point of the study on indicators.

1.2 Introduction to environmental health

Historical developments show a constant improvement of the knowledge about environmental health and improvement of the quality of the environment. The health discipline contributed a great deal to higher life expectancy in post-industrial societies. The relationship between the environment and health has shaped modern housing. Engineers and medical professionals have worked together since the 1850s to change the urban landscape and promote legislation on housing, work environments and healthcare. In the Netherlands, the Health Act (1865 and 1917) and the Housing Act (1901) were a result of new awareness about the role of the environment on health. The Housing Act facilitated high-quality social housing in the Netherlands, by the formation of social housing associations, stricter quality requirements and financial regulations. In recent years, the public awareness of the health risks that result from factors such as poor indoor air, noise and safety problems in the home is increasing. These trends can be observed particularly in countries that, since the 1970s, have improved energy standards, which resulted in poor indoor air quality as a side effect. We can see shifting paradigms: in the period 1850-1920, the paradigm of sanitation, in the period 1920-1970, the paradigm of bacteria and recently the prevailing paradigm is of lifestyle and social economic factors.

Since the 1992 world summit in Rio de Janeiro, the pattern of environmental health hazards and associated health risks is moving from 'traditional hazards' to 'modern hazards'. Traditional hazards relate to poverty and poor development. Polluted drinking water and bad hygiene contribute to 80% of illness in poor rural areas (Kilmartin 1992). In some of the poorest countries, 50% of children will die before reaching the age of 10. Up to 20% of the population of poor countries do not have access to adequate infrastructure for drinking water, waste disposal and fuel. Modern hazards relate to air pollution and depletion of natural resources. Half the world's population lives in cities, and that number will increase to 75% within 50 years. Europe's main concern is the pollution of the soil and water basins, outdoor and indoor air quality, noise, radiation and safety (WHO, 2006).

"Health impact no longer predominantly involves clear mortality risks or reduction of life expectancy, but influences the quality of life in a broader sense, such as aggravation of disease symptoms, e.g. asthma, chronic bronchitis, cardiovascular disease or psychological disorders, sleep disturbance, as well as a reduced ability to concentrate, communicate or perform normal daily tasks, feelings of insecurity or alienation, unfavourable health perception and stress in relation to poor quality of the local environment and perceived danger of large fatal accidents...." (Hollander, 2004).

In 150 years, the life expectancy in the Netherlands doubled from 40 to 81.4 years (women) and from 38 to 76.9 years (men) (Tabeau 1997, corrected on the basis of CBS Statline, 2005). Even in the last 50 years, the increase in life expectancy has been enormous. The present population is expected to reach old age: more than 40% of men and 60% of women now living will survive to be over 80 years old. The increase in life expectancy now depends primarily on the development of life expectancy among 80-plus people, and this trend is greatly attributed to lifestyles.

The major improvement of population health between 1875 and 1920 came from the reduction of childhood mortality and mortality of women and is attributed to better control of the infectious diseases typhoid fever, scarlet fever, measles and scurvy (Wolleswinkel-Van den Bosch, 2000). Better hygiene in the home, together with safe drinking water and sewer systems, contributed a lot to the decrease of infection diseases. The period 1920-1950 showed a decrease in diseases transferred through air: tuberculosis, diphtheria and whooping cough (Wolleswinkel-Van den Bosch, 2000). Better housing conditions and medical treatment have contributed to this decrease: food storage (refrigerator), ventilation, and medical innovations such as penicillin or new chemicals such as DDT (the chemical formula is $C_{14}H_9Cl_5$) had great effects on food related diseases, infections and malaria. The progress made does not mean that problems are over: new diseases such as SARS (Severe Acute Respiratory Syndrome) are transferred through the air (Ho, 2004). Childhood mortality, low as it is, can still be improved. The disease pattern changes as certain diseases are overcome through proper treatment or prevention. In modern society, lifestyle is responsible for the largest preventable health loss: smoking (15% of mortality), dietary habits such as high saturated fat and inadequate intake of fruits and vegetables (10% of mortality), sedentary lifestyles

Table 1.1 The determinants of health

The determinants of health		
Health	The individual	genetic and biological characteristics values coping skills spritual well being individual behaviours
	Physical environment	natural environment built environment
	Social environment	childhood experiences and environment family, friends and communities health care work leisure societal relationships and influences

Based on a presentation of James Irvine (2005), summer school on Health Promotion, Identity, Culture and Power at the University of Saskatchewan, August 15-18)

and lack of physical activity (6%). Obesity (6% of mortality) and hypertension (6%) are important sources of preventable disease burden. Severe obesity doubled in two decades and this is alarming, especially in the light of the diabetes type 2 epidemic (Hollander, 2003; Deben, 1988; Lawrence, 2004; Poppel, 1999 and 2005; Vos, 2002).

In 1978, the World Health Organisation (WHO) started the action programme 'Health for All by the Year 2000'. The Healthy Cities Project of 1986 tried to bring the responsibility for health policy back to the local community level. The Healthy City is not a state or result but a process: 'a healthy city continually creates and improves those physical and social environments and expands those community resources which enable people to mutually support one other in performing all functions of life and in developing to their maximum potential.' (Duhl, 1999). The Netherlands followed this strategy of WHO with the Parliamentary document Nota 2000 (Ministerie van WVC, 1998), in which a health prevention policy was adopted, with focus on biological and genetic factors, factors of the physical and social environment, lifestyle and healthcare (see Table 1.1).

Physical environment: indoors and outdoors

Indoor air has been recognised for 30 years as an important health factor. We spend about 85% of our time indoors and pollutant concentrations indoors tend to be higher than outdoors.

In this study, we focus on the house and adjacent private space such as gardens and balconies and access paths. In this environment, we are exposed to air, soil (through food or dust or direct intake by children), drinking water, light, acoustics, pests, radiation, visual images, pets and other people. The outdoor environment influences the exposure to health risk, because the indoor-outdoor relationship of agents is very strong and indoor pollution adds to the ambient concentrations. Noise enters the house through ventilation openings. Soil pollution can be emitted through openings in the floor or penetrates plastic water pipes.

According to WHO, proven irreversible health effects of indoor air pollution are allergy and other respiratory effects caused by mould, microbes (*Legionella pneumophilae*), biological waste material including house dust-mite allergen, or caused by peak exposures to nitrogen dioxide (NO_2). Cancer is caused by volatile organic compounds (VOCs), radon and asbestos. Formaldehyde causes irritation of mucous membranes and the lungs. Exposure to carbon monoxide (CO) changes blood conditions, with chronic or life-threatening effects. Less irreversible health effects, but with proven relationships, are the irritant effect from man-made mineral fibres (MMMF) and the respiratory effects from aerosols and volatile organic compounds (VOCs). Potentially or hypothetically harmful effects with suspected relationships are asthma attacks from gases and fumes, cancer from PACs, biocides, formaldehyde, nitrosamines, irritation from reactive products, endotoxins and neurotoxin effects from VOCs and biocides (WHO, 2006). Environmental triggers commonly found indoors include tobacco smoke, dust mites, moulds and pests. Infectious disease hazards can stem from inadequate food storage and exposure to pests. Two basic human activities, defecation and cooking, produce potentially health-endangering waste products. When human excreta are not completely removed from the household environment and isolated from drinking water supplies, a high risk of diarrhoea and other waterborne diseases ensues (WHO, 2006). Indoor climate hazards, notably excessive cold or heat, may cause health problems, especially in the elderly and children. Excess winter deaths due to temperatures below 16 °C in dwellings have been reported from the United Kingdom, with fuel poverty being the main cause. Excess summer deaths due to overheating was reported in France (15,000 excess deaths in the summer of 2003), mainly among elderly people whose water intake was neglected (Bonnefoy, 2005).

The built environment

The health impact of unhealthy housing includes infections of the respiratory tract and other infections, vector-borne diseases, injuries and poisonings and mental problems. Respiratory symptoms are the most evident phenomena of pollutants in the indoor air. Other predominant phenomena are allergic reactions in general, lung cancer and sick-building syndrome (Auge, 2001; Bronswijk, 1997 and 1999; Luxemburg, 1997; Pernot, 2003; Säteri, 2003; Voûte, 1995).

Both the poor outdoor and indoor air quality, including tobacco smoking, are responsible for the major health effects (Fast, 2003 and 2004; Hollander, 2004). Noise is now recognised as an important environmental health problem. The study of health hazards in the UK highlighted the importance of personal inju-

Table 1.2 Parameters of healthy housing and health risk

Parameters of healthy housing	Parameters of health risk
Air quality	Biological and chemical agents, aerosols
Acoustics	Noise from outdoors, neighbours, appliances
Comfort	Temperature, air currents, light and view
Safety	Falls, smoke and fire, poisoning
Quality of social environment	Privacy, security, social support

ry over the traditional hazards of (biological) air pollutants (Ormandy, 2005). Mental disease and especially depression is among the predominant reasons for absence of work and school in Europe (Bonnefoy, 2005) and is a parameter of the social environment. In the Netherlands, the health effects of noise, aggravation of asthma and other respiratory symptoms due to particulate air pollution and lung cancer contribute most to the number of healthy life years lost (DALYs, Disability-Adjusted Life Years) for the whole population. The effect of ozone is also important. The least significant effect is from chemical air pollution.

Renovation, sustainable building and health

During their life cycle, houses are renovated several times. The neighbourhoods of the 1950-1970s are mostly under reconstruction now: physical conditions are improved and social problems are also attacked. Reconstruction and renovation provide opportunities to improve the health performance, but what opportunities is not clear. Because of the scale of the efforts and the magnitude of the physical and social ambitions, it is important to understand the relationship between the environment and health and more specific the relationship between housing and health.

The modern notion of building is sustainable building. The broad definition includes health, in addition to the ecological ‘streams’ of energy, materials and water. The role of health issues in sustainable building in the Netherlands is described by many researchers: Dongen (2003), Duyvestein (2002), Guerra Santin (2006), Klunder (2005), Itard (2005), Pernot (2003).

Innovation in sustainable building techniques has shown conflicts with health, mainly in terms of noise and poor indoor air quality. Energy-efficient ventilation systems are not used well by occupants, because of poor user comfort. Solving poor use requires better insight into the interaction between ‘man and machine’.

Vulnerability and health needs

The relationship between housing and health can be viewed from two directions: the risk that the home environment makes healthy people ill and also from the viewpoint of housing needs: when health-related needs are not fulfilled and create stress or functional disability. We look at both directions and include the match between the needs of vulnerable groups and the housing services in the research. We will not deal with the needs of groups extremely sensitive to environmental stimuli, but will focus on large groups in the population that represent 15-20% of households: the airway-sensitive, children and elderly people. Vulnerability is liability to be damaged by environmental conditions, which is influenced by age, genetics, nutrition, metabolism, exposure levels, existing diseases, and many other factors. Older people are at particular risk for adverse effects on the cardiovascular systems; asthmatics are vulnerable to allergens and also to many other substances such as tobacco smoke, diesel exhaust fumes, scents and even sudden changes in air temperature (Marinkovich, 2004). A weakened mental or physical condition makes a person more susceptible to health threats of chronic problems like sleep disturbances or stress from noise. Pregnant women and their foetuses and infants are high-risk groups, especially with risks of infectious and parasitic diseases. The reproductive system is particularly sensitive to adverse environmental conditions. Limited mobility makes people vulnerable to personal injury. Where there are high levels of indoor air pollution, it is generally young children who spend long periods indoors, and women because they have been allocated most household tasks (WHO 2001).

The elderly

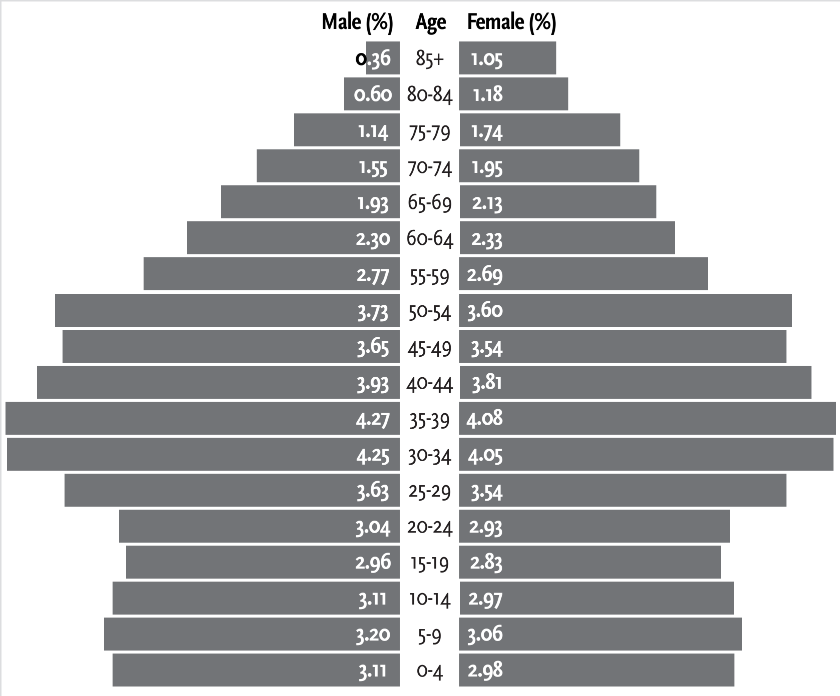
The Dutch population pyramid shows that about 40% of the population is in the age period between 30 en 55 years (see Figure 1.1). This section of the pyramid moves up with time, meaning that during the next 25 years we can speak of a grey wave. Multiple health disorders create a need for an environment that is adapted to specific health needs including help from caretakers. Mental problems are widespread among the elderly. The desire to age in place increases with age (Ahn 2004). The lifetime spent in relatively good health is about 60 years, both for men and women. This means that an average 20 years of a lifetime is lived with some physical or mental disability that tend to become more serious with higher age, requiring more help.

The relatively higher average age of women creates a large group of single elderly women with multiple disabilities, many of them living independently in their own home (Vliet, 2004). Irritation of mucous membranes tend to decrease with age. COPD and emphysema tend to increase. Exposure to chemicals earlier in life, that have taken many years to influence health, is more likely to cause suffering at higher age. The elderly are susceptible to health effects of extreme heat and low metabolic rates make the elderly more vulnerable to low temperatures. The Dutch housing stock is poorly adapted to the needs of the elderly (Ekamper, 1994; Graat, 2003; Rogers, 2000; Singelenberg, 2003; Valent, 2004).

Children

Children breathe more air, drink more water, and eat more food per kilogramme of body weight than adults do. An infant's respiratory rate is more than twice an adults rate. The number of particle 'hits' per unit lung surface is an important health impact metric. The alveolar surface area increases from approximately 3 m^2 at birth to about 75 m^2 in adulthood, causing the dose de-

Figure 1.1 Population per age group in the Netherlands



Source: CBS (2006)

livered per lung surface area for infants and children to be much higher than in adult's. In the first six months of life, children drink seven times as much water per kilogramme of body weight than an adult does. Deficiencies of dietary iron and calcium can increase lead absorption. Some toxicants more readily penetrate children's skin, especially in the newborn period when the skin is highly permeable (e.g., dermal exposure to lindane and hexachlorophene, with subsequent development of neurotoxicity). Many possible contaminants settle near the floor: mercury, pesticides, formaldehyde (new synthetic carpet), and radon. Ingestion, dermal contact and food intake have more influence than for larger and older people. The (however limited) experimental and epidemiologic studies currently available identify the early post-neonatal period of lung development as a time of high susceptibility for lung damage created by exposure to environmental toxicants. This is the likely reason for the high rate of respiratory infectious diseases in young children (as discussed by Plopper (2001)). Of great importance for the newborn is the condition of the father and mother at pre-conception and the environment of the pregnant woman, including a longer history in the family cycle.

Health perception

Health is usually viewed from a scientific perspective, making it possible to demonstrate for instance microbes or chemicals and relate these to physiological changes in humans. Other factors reflecting human health are perceptions of health. Perceptions are mental constructs of reality: when a person feels healthy, this person is healthy from an individual viewpoint. A person's perception of health risk even increases the actual harm suffered by that person (Broadbend, 2006; Kamp, 2003). Certain self-reported health effects are believed to be the result of constructed health risks, meaning that the occupant is deceived by (false) information about risk agents and projects these risk on negative perceived health. Exposure risk to the electromagnetic fields of high voltage power lines (Lebret, 2006) and multi-chemical sensitivity (MCS) has been associated with these 'constructs'. But perceived risk can also point out environmental conditions that remain (still) without proof from epidemiological studies or from individual medical diagnosis. Over-sensitive people are affected by conditions or concentrations in the order of 1/1000 of conditions that effect healthy people. Perception is influenced by phenomena that trigger the senses: sometimes below the awareness level on the subconscious level. Uncertainty about cause and effect may cause anxiety and enlarge the risk perception of exposures. Also, certain agents that influence health may not be sensed directly, for instance carbon monoxide. When this type of condition cannot be sensed, the perception of the risk depends on information. Information and communication is very important for health perception and it can lead to behaviour to prevent risk and it can also create positive health perception.

Position of health in housing

Health is one of the cornerstones of the Dutch building decree. However, the quality regulations tend to reflect the needs of society more than 15-20 years ago. Also, the policy of deregulation and leaving certain housing and health issues to 'the dynamics of the market' creates new problems, which would normally require improved building standards and codes of practice or more effective control and application of requirements. Health impact is poorly integrated into tools for the inspection of building quality or in tools for life cycle evaluation and sustainable building design. Health performance of existing housing could play a more prominent role in policymaking for renovation of houses. Restructuring of post-war urban areas presents a great challenge. The housing stock of the period 1950-1980 is now being replaced or renovated. The health impact of new materials and appliances that support sustainable quality needs to be studied, so opportunities can be used to improve the health performance of housing (Visscher, 2004). The occupant has an active role in creating and maintaining a healthy environment. User-friendliness influences the occupants' perception and the willingness to create healthier environments. The housing market is producer oriented and shows 'design dictatorship' and product performance that conflicts with the need of occupants. In the field of healthy and sustainable housing there is discussion about the need to change roles, to focus more on occupants needs and on the need to make the process of development of new housing estates more transparent. Product developments of sustainable renovation were during many years since 1989 derived from new construction, but in recent years we see more priority for the improvement of the housing stock.

Discipline

The research has a position in housing studies. The education as an architect resulted in a wide interest in the construction of buildings, in the hydrothermal properties, the technical installations and the interaction between the different actors in housing construction and management. The work experience over the 28 years before the PhD project started, is of great importance for the expertise used. This work period started with about 7 years of advocacy planning including a focus on urban renewal. There then followed 2 years of action-research on allocation of housing. The second period of 9 years focused on research, product development and consultancy on energy conservation and sustainable building. This period resulted in practical knowledge of technical building features. The third period of about 10 years focused on maintenance issues, which resulted in the involvement in the indoor environmental field. The practical experience shapes the result of this thesis. Expertise in human health is not available for this research. Literature on health effects has been reviewed to select the agents and conditions that create hazards. The discipline of architect provides the background for the study of the physical building properties and occupancy that create these hazards.

Problem definition

The physical housing conditions and also occupant behaviour point out exposure to many health risks. Better insight into the setting of priorities for health issues and a clear framework and common language in diagnosing health related problems of housing can improve the position of health in maintenance and renovation.

This leads to the central research question: *What physical parameters and which occupancy patterns and behaviour result in exposure to health risk and how can health risk be diagnosed and reduced?*

1.3 Introduction to the research project

1.3.1 Research questions

Goals

In the study, we try to isolate specific effects of housing conditions on health. The focus is on indoor health hazards. The research deals with the physical environment in the first place and especially the technical services and components of the individual dwelling: structural components mainly and the performance is the responsibility of owners and housing managers.

The study is motivated by 1) improving the understanding of the relationship between housing, occupancy and health; 2) the development of instrumentation that will support occupants and housing managers in identifying health hazards and selecting the proper remediation measures; 3) the promotion of health-conscious maintenance and renovation; 4) the generation of ideas for user-friendly products, services and for integrated concepts for sustainable healthy housing and renovation and finally to 5) to contribute to better matching of health-related housing needs and housing quality, by using information on housing health performance in the allocation of houses, both in the rented and in the owner occupied sector. These goals have shaped activities in the recent years that have contributed to results, but the thesis is shaped by more specific questions.

Research questions

The study deals with five research questions:

1. What is the state-of-the-art knowledge about housing and health?

Because the relationship between housing and health is complex and poorly understood, we try to find more evidence in scientific literature and in field projects on this issue.

2. How can we evaluate housing health performance?

Making an inventory of indicators and of examples of health performance evaluation tools supports the development and implementation of improved performance evaluation tools.

3. How do occupants use the house?

The occupants' use of the house is in many ways in conflict with housing performance. By studying user behaviour, we can understand when the occupants' use is poorly adapted to the physical parameters and which conditions of the house are in conflict with the needs of the occupants.

4. Which physical housing conditions are associated with health?

The house has thousands of components, physical properties and user interfaces. It is important to know which features create health hazards. The main focus is on those components for which the housing manager/owner is responsible, because these components are part of the 'public' arena. The decorations and furnishings supplied by the occupant are part of individual lifestyles, but general interior elements like sofas and mattresses will be included in the study.

5. Which indicators mark the health hazards of housing?

The selection of simple and robust indicators is the major challenge of the re-

Table 1.3 The research topics seen from within the house and including the indoor-outdoor relations

Outdoors		The house				Occupants
neighbourhood	location	envelope	lay-out	construction	services	occupancy
the physical environment	traffic, public access, outdoor space, other buildings, climate, outdoor air, acoustics, light, water and soil	indoor-outdoor relation, insulation, infiltration, control of openings	functions, rooms, dimensions, space, hazards	materials, hydrothermal quality, acoustic insulation, absorption, cleanliness, emissions	ventilation, heating, hot water, bathing, cooking, laundry handling	number of occupants and pets, health conditions, needs, perceptions, housekeeping activities
the social environment	social contact, privacy, identity, status and type of change	security, view, status, maintenance quality	privacy, social meeting places	acoustic insulation	emergency help, health care, support for the elderly	social activities

search. A comprehensive set of indicators will facilitate health performance evaluation. Many research activities and chapters add indicators to the list.

1.3.2. Limitations and definitions

The grey areas in Table 1.3 show the research topics that focus on the physical qualities of the house

Theoretical framework
Theoretical concepts applicable to healthy housing in general and to the selection process of indicators and instrumentation for health performance evaluation in particular have been reviewed. Four concepts or frameworks are connected: the framework of learning-by-doing, of health risk evaluation, systems control in housing management and of communication between occupants and inspectors/housing managers.

Research methods
The study is explorative and by no means epidemiological. The focus is on performance of houses, and the performance is limited to health aspects. The discipline is architecture, the main direction is building technology and with attention to occupancy. The research is an integrative explorative study of housing health hazards, with focus on the physical properties.

For the research a large amount of 'historical' data is used: the reports and case descriptions collected in a period of many years, trouble shooting in houses with problems. The experience is based on 28 years of work in the field of housing and is considered to be expert knowledge. The challenge is to cluster and position these data and experiences, to create a theoretical framework that supports the analysis and to develop a critical evaluation of acquired expert knowledge. The research did not start with theory and data collection and analysis on the basis of a well prepared research design: most of the material was already there. The data are collected in the context of different technical, socio-economical and legal conditions and it is important to deal with this context. The research has a strong integrative character: both the physical building and occupancy and in relation to use and management.

The research methods are 1) desk research, 2) field research and 3) laboratory experiments.

1. Desk research includes analyses of scientific literature on agents and hazards, indicators and health risk evaluation. Desk research is the only method applied in collecting medical information related to exposure to agents and hazardous conditions.
2. For fieldwork, a combination of methods for data collection is used: project evaluation, home visits, laboratory experiments and active involvement in complaint handling processes. Datasets are based on technical inspections, interviews and monitoring with data acquisition instruments (ad hoc and periods of up to four months). About 600 occupied houses were visited. The inspection visits cover almost a decade and deal with diagnosing the causes for complaints of tenants about maintenance problems or health risks. More than half of these visits provide data on many variables and were collected into a database of houses used to analyse the main topics of the research: occupancy, ventilation behaviour, variables of house dust mite concentration, mould prevalence, legionella growth conditions, noise and thermal comfort conditions. These visits also provide a rich experience in communication with occupants and housing managers.

   Field data are collected in the Netherlands. Dutch houses are fully adapted to wind and rain in the moderate and humid sea climate. Urban neighbourhoods are densely built with narrow and small houses. The housing stock of 6.9 million is relatively new, with 70% built after 1950.
3. Laboratory work was executed in four test houses in the Netherlands (Ecobuild Research and ICT test house) and in a specially constructed test chamber at the International Laboratory of Air Quality and Health (ILAQH) of Queensland University of Technology (QUT) in Brisbane, Australia. This laboratory work provided data on air change rates, aerosol distribution and deposition, comfort parameters like overheating and the noise levels of modern technical installations.

Statistical procedures are used to analyse the dataset of houses and quantitative data of the experiments. The analysis leads to correlations between variables which are used to construct models of these relationships, models which in turn are used to make a qualitative selection of health performance indicators. The datasets and the methods used are explained in Section 2.3 and 2.4: the collection of field data. The research follows both methods of explorative statistical analysis of sets of variables, and qualitative methods of integrative descriptive analysis. Observations and interviews are the major methods used in the field. Qualitative exploration of the observed phenomena leads to better understanding of cause and effect. Repeated observation of identical phenomena in a large variety of complex conditions, for instance in different seasons, with different occupancy, different temperatures or ventilation, resulted in expert knowledge that was tested and validated by calculation and by statistical analysis of collected data. Fieldwork resulted in involvement in troubleshooting and in application of remedial measures. The success and failure of the diagnosis of problems and of these measures led to evolution of particular phenomena into general concepts, following the concept of abductive reasoning.

The role of indicators

In houses, the concentrations of pollutants are often quite low and it is hard to establish dose-response relationships. These relationships are often derived from extreme occupational environments. Modelling of these extremes results in permissible concentrations in houses. Exceeding these concentrations supposedly increases health risk, without proof on the basis of an individual house. This lack of dose-effect information leads to the necessity to use markers that substitute dose-effect studies in the home environment by 'indication' of exposure to hazard conditions. These indicators point out health risk, while the dose-effect relationship that supports evidence on health risk is derived from scientific literature. Official standards and criteria are also derived from dose-effect studies in other than home environments, and these criteria support the selection of indicators in this study (see Chapter 3 (Agents, effects and performance criteria)). The use of indicators instead of dose-response studies in the individual house means that health performance evaluation represents an indirect and qualitative method.

The approach to health performance evaluation

When does a condition acquire the potential to cause a health effect? The first step is to collect evidence on the health effects of certain conditions. We must understand what turns a condition into a hazard. For example of stairs: taking any stairs is a hazard, but steep stairs with slippery steps are a greater hazard. The risk increases when going down on slippery steps after certain medication, etc. The health risk is estimated on the basis of the likelihood of something happening, how long or intense a person is exposed to the event and how serious the consequences can become. The risk can be comparative and ranked on a scale. In evaluating the exposure to risk, we can base the risk ranking on the actual person living in the house, who can be old or ill or sensitive, or we can refer to a 'default' person, for instance a healthy adult. In housing policy, the reference person tends to be a healthy person. We

Figure 1.2 Pathway from housing condition to risk ranking

4. How important is the risk?	Risk ranking	↑	instruments of health performance evaluation
3. What turns a hazard into risk?	Performance evaluation		
2. Which conditions cause hazards?	Selection of indicators		research on indicators
1. What are the potential hazards?	Review of hazards		

choose a default population with health problems (15-20% of the population) that require suitable housing conditions. Because occupying a house involves hundreds of hazard conditions, we try to identify the major health risks. This impact pathway of conditions in a house is represented in Figue 1.2

Definitions clarify the terminology used in the research. Definitions are given for: Health, Shelter, house, housing and occupancy, Healthy housing, Hazard, Agents, Indicator and Performance evaluations.

Health

The World Health Organisation definition of health has not changed since 1946: “Health is a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity. The enjoyment of the highest attainable level of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic and social condition.” (WHO, 1946, formally ratified by the United Nations in New York on 7th April 1948). The WHO looks at a broader spectrum than the house: community and family are part of the concept of ‘housing’. The WHO relates environmental health also to process: the creation and improvement of those physical and social environments that support people in performing all functions of life and in developing to their maximum potential. Enjoyment of community resources and investing and using social capital are parameters of the environment (WHO, 1998).

Shelter, house, housing and occupancy

The second UN Habitat conference in Istanbul (1996) described shelter as providing adequate privacy, adequate space, physical accessibility, adequate security, security of tenure, structural stability and durability, adequate lighting, heating and ventilation, adequate basic infrastructure, suitable environmental quality and health-related factors; adequate and accessible location regarding to work and basic facilities. WHO includes social factors affecting human wellbeing: those related with protection and privacy feelings, social bonds, identity, perceptions of safety and fear of crime, accessibility and usability (WHO, 2004).

A house is a human-built dwelling with enclosing envelope, rooms and technical services. Housing is the distribution, use and maintenance of houses in their neighbourhood setting and with regard to the needs of the occupants. A house cannot be seen without the occupants and the occupant not without the household and social relationships. Occupancy is the use of rooms and technical services. Behaviour is looked at from the perspective of understanding how the indoor climate works, how occupants control appliances and how they ventilate. The interaction between occupant behaviour and building services is an important topic.

The research deals with occupied homes, here and now. The scale is the individual house. We look only at the outdoor-indoor relationship from the indoor position. Housing is categorised into two groups: rented and owner-occupied. Without further mentioning where this is required, we implicitly refer to rented social housing. This means that we relate to the occupant as a tenant, who deals with professional housing managers. The typical division in responsibility between the tenant and the housing association is used, meaning that we also deal with the typical confusion and conflicts concerning complaints and perceptions of occupant behaviour. Owner occupants can view the research in the combined role of occupant and manager.

Healthy housing

The European basic requirement for healthy housing is: "The building must be designed and constructed in such a way that hygiene and health of occupants and neighbours are not at risk because of: emission of toxic gases, air pollution with dangerous particles and gases, pollution of water or soil, poor removal of sewage, smoke and moisture in the construction or on interior surfaces." Housing is more than the house, it includes the management of the house and the adaptation to (changing) needs. We select a definition of healty houses that is based on Bronswijk (1999) and we add process aspects: "Healthy housing provides a house free from building-related risk of illness, while supporting proactive behaviour to take control over the home environment and to adapt behaviour to the individual needs, for the enjoyment of comfort and safety and a large degree of freedom in occupancy and behaviour."

Hazard

A hazard is something with the potential to cause harm. The harm is measured on the basis of probability of occurrence multiplied by the seriousness of the effect: the hazard level.

Hazards are related to the physical dwelling, to the maintenance level, to the organisation of circulation areas, cleanliness, lighting. Hazards can be created by behavioural patterns, such as not turning on the lights when walking down stairs at night. The exposure to a hazard is occupant-related; the hazard itself is dwelling-related or personal condition- and behaviour-related.

Agents

Agents are stimuli of health effects or stress. Agents include all stimuli that are transported: materials, noise, radiation. Stimuli that are fixed in the layout, the construction, etc. are called conditions. Health risk is the likelihood of a hazard. The definition of risk by the Dutch Health Council (Health Council of the Netherlands, 1996): "Risk is the possibility, with a certain degree of probability, of damage to health, environment and goods, in combination with the nature and magnitude of the damage. Risks are ultimately caused by human demands and needs which generate human action.".

Indicator
In general, an indicator is a sign or marker that points to a condition to be measured, in order to evaluate specific qualities (Cole, 1998).

For the research project we choose the following definiton: Health performance indicators of housing are markers, selected from a large variety of building features and occupancy characteristics, with the power to summarise or represent the emission, concentration and exposure to agents and risk conditions. An indicator that aggregates different parameters and may even refer to indirect conditions is called a proxy indicator. Proxy indicators are ideal in situations where it is hard to prove cause and effect, which applies to the relationship between housing and health. Indicators that are strong markers of exposure to health risk are called robust indicators.

Performance evaluation
Performance is the condition of objects, compared with previously set targets. Housing health performance evaluation is the inspection of the indoor environment of dwellings with the goal of describing the condition on the basis of indicators. Because we focus on indicators of health risk, performance evaluation is an activity to identify potential hazards. The research includes the study of instrumentation for health performance evaluation.

1.3.3 Outline

Phases
The research followed an exploration phase and a phase in which available results were analysed.

Phase 1
The dedication to the subject of healthy housing of OTB Research Institute for Housing, Urban and Mobility Studies of Delft University of Technology was marked by a conference in December 1998 (Philipsen, 1998). In 1999 and 2000, a work document in the Dutch language was produced: *Hoe gezond is de Nederlandse woning? (How healthy is the Dutch dwelling?*) (Hasselaar, 2001a). The book presents a wide range of health aspects of housing: agents and environmental diseases, health topics in building regulations and health risks in different housing periods. Ideas for tools and concepts for improvements to housing performance were presented. Phase 1 resulted in a 'health-conscious' version of the energy performance calculation tool for existing houses (EPA+Health

Figure 1.3 Phase 1: Problem solving combined with data collection and tool development

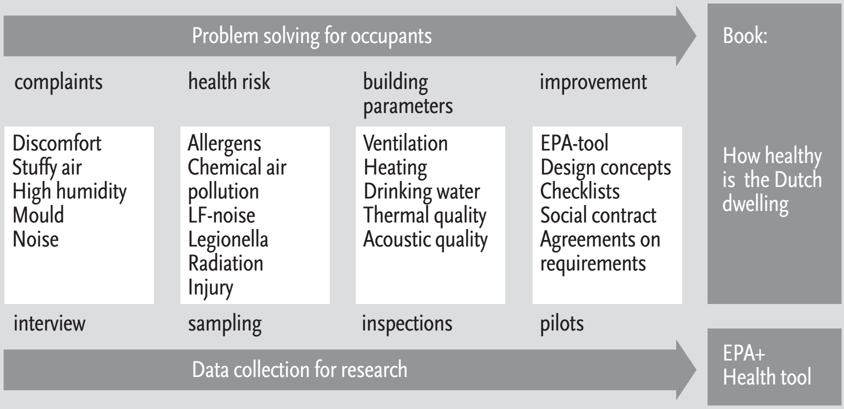
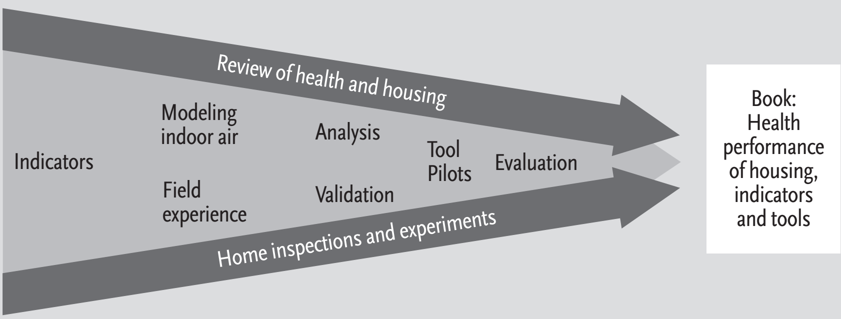


Figure 1.4 Phase 2: Synthesis of theory and practice resulting in the PhD thesis



tool, Hasselaar, 2000). The EPA+Health tool promotes the selection of measures that serve both energy and indoor quality. The tool was tested in the field and received credit for its relevance and simplicity, but was never introduced, because non-energy topics did not match the European Energy Performance Directive for existing buildings (EPBD, to be introduced in the Netherlands in 2007). A contribution to the development of a Ventilation Checklist, published by the national tenant organisation (Woonbond) was based on the evaluation of ventilation systems in the workbook (Rijsbergen, 2000). The results of the EPA+Health tool and the Ventilation Checklist are used in the design of a tool for health performance evaluation.

Phase 2

Phase 2 continues the work of Phase 1 and focuses on the synthesis of field data with theory and analysis. The research focuses on health performance indicators. The Figures 1.3 and 1.4 show how work since 1999 developed into the PhD thesis *Health performance of housing, indicators and tools*.

The indicator selection begins with the state-of-the-art indicators and the research claim is to end up with more robust indicators, that are easy to use and contribute to a better understanding of health hazards in houses. The

Table 1.4 Relationship between the research questions and the chapters

<table>
<tr><th rowspan="2">Research questions</th><th colspan="4">Chapters</th></tr>
<tr><th>theory</th><th>practice</th><th colspan="2">synthesis</th></tr>
<tr><td>What is the state-of-the-art knowledge about housing and health?</td><td>1, 3</td><td></td><td>9</td><td rowspan="5">8, 10</td></tr>
<tr><td>How can we evaluate housing health performance?</td><td>2</td><td>6</td><td></td></tr>
<tr><td>How do occupants use the house?</td><td></td><td>4</td><td></td></tr>
<tr><td>Which physical housing conditions are associated with health?</td><td></td><td>5</td><td></td></tr>
<tr><td>Which indicators mark the health hazards of housing?</td><td>4</td><td>7</td><td>8</td></tr>
</table>

relationships between individual indicators are connected by constructing models, leading to the identification of relevant proxy indicators and priority indicators. Indicators of indoor air quality are studied in greater detail, using field data and experimental data.

During the study, field experience with the tool Healthy Housing Checklist has become available.

The structure of the research reflects the outline of the dissertation: three parts and ten chapters. 'Part A. Theory' presents the context and design of the research project. 'Part B. Practice' presents the use of a health performance tools and results of fieldwork, pilot projects and experiments. This material is used to study the parameters of housing health risk. 'Part C Synthesis' evaluates the research project: the main output of the research, discussion on results and finally conclusions and recommendations.

Chapter 2 builds a general framework. Chapter 3 presents the performance quality references and state-of-the-art indicators. Chapter 4 presents field data on occupancy and Chapter 5 on physical components. The state-of-the-art and field experience with health performance evaluation tools is presented in Chapter 6. Field data is used in a study on models of exposure risk in Chapter 7. Chapter 8 presents a summary of the results including a new list of indicators. Chapter 9 discusses the performance of each room and the optimal feasible health quality. The thesis ends with a conclusion and with recommendations for different actors in the field of housing.

Several chapters follow the major parameters mould, house dust mite, legionella, aerosols, chemical agents, acoustics, comfort, safety and social quality. This structure may give the impression that information is being repeated. However: the information is organised within the context of each chapter, with minor repetition to produce clear explanations.

Table 1.4 presents the position of each chapter and how research questions are dealt with in different parts and chapters.

1.4 Conclusion

This research deals with occupied homes, here and now. The scale is the individual house and the focus is on the indoor environment. The discipline is building technology; the medical profession is not involved. The research does not deal with dose-effect relations and it is by no means an epidemiological study. The goal is to identify factors that create health hazards, in order to diagnose health risk exposure in the house. To reach this goal, indicators of health performance are selected and instrumentation for evaluation is studied. Problem identification is the major issue, while problem solving receives little attention. The data for the research are collected by the author in different field projects, that are combined to form a comprehensive dataset. This dataset and also the practical expert knowledge aquired during 28 years of involvement in the field of housing management, both from the perspective of technical management and of the role and position of occupants shape the results. The scientific challenge is the critical selection of available data and to improve the theoretical approach to analysis and understanding of this data. The work experience is a treasure, but in the scientific approach it seems like a burden: to solve this conflict is one of the challenges.

2 Framework, material and methods

2.1 Introduction

The research question for this chapter is: *How can we evaluate housing health performance?*

Environmental problems are placed in the context of interaction between housing managers and tenants. Communication is the key to succesful complaint management. The principle of self-efficacy is integrated into the framework, to deal directly with occupant perception of control over the indoor environment. The goal of the exploration into theory, strategies and relationships is to support the indicator selection and tool development. This exploration results in section 2.2 in a model of relationships which integrates four frameworks: the DPSEEA (driving force, pressure, state, exposure, effect and action) framework of performance measurement, the ITOO (input, throughput, output and outcome) framework of actions for problem solving, the learning by doing framework and the communication framework. An important part of this chapter deals with data collection. Data are derived from different projects that cover a long period of time. It is important to get an overview of the subdatasets and the reliability and validity of the data. The position of this chapter is presented in Table 1.4.

2.2 Relations in health performance evaluation

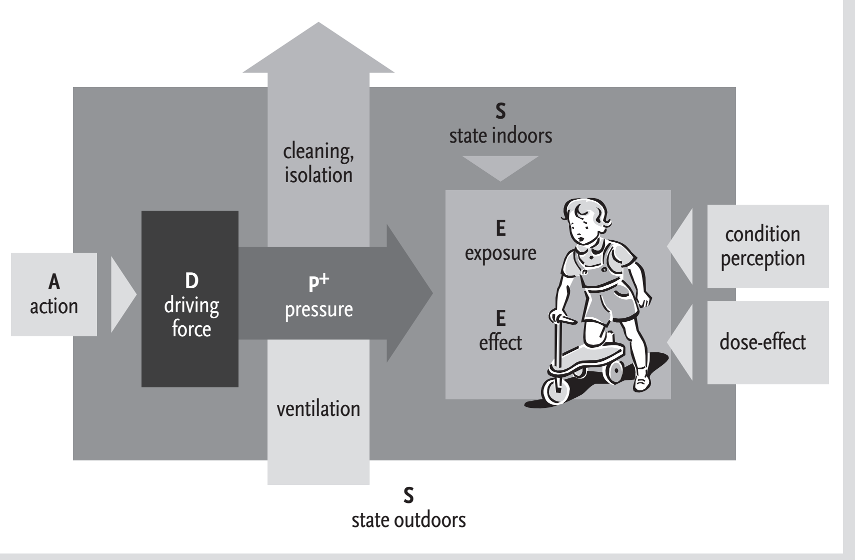
2.2.1 Frameworks

The DPSEEA framework

The DPSEEA framework (Figure 2.1) was developed over many years in the field of health risk evaluation. The starting point was a simple pressure-state-response sequence applied by OECD (Organisation for Economic Co-operation and Development in developed countries) as a framework for state-of-the-environment reporting. It has been extended to include the 'driving forces', the effects and actions.

When applied in the home environment, the driving force component (D) represents the sources of agents and risk conditions. The driving force generates pressures (P) on the environment: hazards. In response to these pressures, the state of the environment (S) changes: there is a resulting concentration of pollutants or certain hazard levels. For air quality, which is important in this research, Pressure is equal to Emissions and State is equal to Concentration. Transport of Emissions (air flows, diffusion and also ventilation and cleaning) influences the Concentration or State. Environmental hazards, however, only pose risks to human well-being when humans are exposed (Exposure =E1). It requires that people are present both at the place and at the time that the hazard occurs. Exposure is by inhalation, ingestion or physical con-

Figure 2.1 The DPSEEA framework



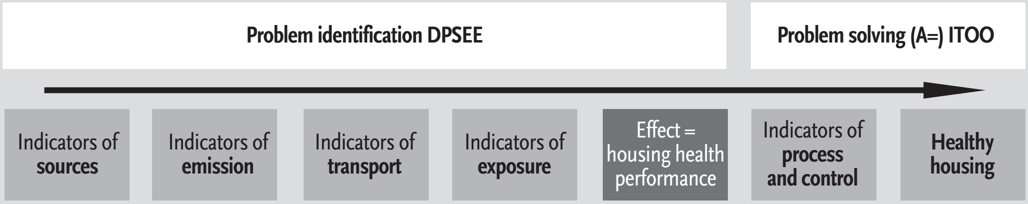
tact and also includes mental exposure, for instance to threat. In the home environment, the exposure may differ in each room. Exposure to health hazards can lead to a wide range of health effects (=E2). The least intense effects are sub-clinical, merely involving some reduction in function or some loss of well-being. More intense effects may take the form of illness or morbidity. With known exposures and knowledge of dose-response it is possible to make reasonable estimates of the potential health burden of specific pollutants. However, dose-response relations are very hard to establish in the home environment, so we use indicators instead, that provide more rapid estimates of the health impact of specific environmental exposures. In the face of these impacts, a range of Actions (A) can be taken.

In this research project the main focus is on diagnosis of health risk, with minor attention to remediation. Evaluation of the health performance of houses is limited to DPSE of DPSEEA framework. DPSE for air quality can be interpreted as Source (D), Emission (P+), Transport (P-), Concentration (S) and Exposure (E). The DPSE framework supports problem identification and diagnosis. The activity of problem identification requires a protocol for data collection and data analysis, including evaluation criteria to support risk ranking. It is important that housing managers can 1) easily understand and use the protocol, 2) can value indicators on the basis of general information, 3) can recognise emissions and hazard conditions on the basis of visual inspection and 4) know how to aggregate exposure to a potential hazard into a score.

The ITOO framework

The ITOO framework represents the Input-Throughput-Output-Outcome sequence and is developed in the field of performance measurement (Leeuw, 2000). Performance of systems is measured and a system can be an organisation, but also the house or the indoor climate. The final outcome is the re-

Figure 2.2 The model of health performance management



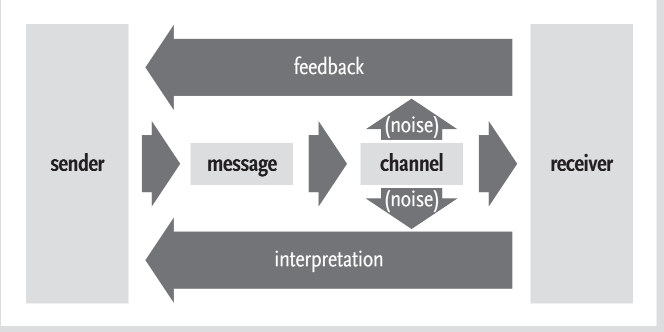
alisation of goals, for example a healthy house. In Figure 2.1 ITO (without the last O of Outcome) is presented as the Action to reduce the driving forces, pressure or exposure. Input is for instance money and people to perform activities to reach an output (product) defined by actions and milestones. Input includes for instance human capital to do home inspections. Throughput is a sequence of activities and milestones to improve a dwelling. These activities have effects on health performance: the output. In this study, performance evaluation is to check whether output is in line with the desired outcome, which is a healthy house. ITOO is an action-taking framework: the action of problem solving.

The combination of problem identification and problem solving results in a framework in which the action (A) of DPSEEA becomes input-throughput-output- (ITOO), in other words: DPSEE-ITOO or the framework of health performance management. Indicators have a key role and are used in each step of the model (see Figure 2.2).

The LEDO framework

Learning-by-doing (LEDO) was developed in the field of citizen participation in urban planning in the 1970s (Kalk, 2002). LEDO is the involvement in problem diagnosis and problem solving matters and is organised to stimulate the learning process that leads to action: pro-activity. When applied to healthy housing, action is oriented towards control of the pressure from driving forces, adapation of behaviour and remediation. Allowing people greater control over the indoor environment has resulted in significant positive impacts on comfort (Bräger, 1998). Increasing user control over the indoor environment potentially provides greater occupant satisfaction. Psychologists have clearly demonstrated that adverse or noxious stimuli are less irritating if the subject perceives to have control over them. Lack of control over the environment produces stress. Under stress, bodily defences against environmental hazards, e.g. infectious agents, toxic or irritating chemicals, glare, loud noise) are diminished. Thomson (2005) concludes in a review that improvements in mental health are consistently reported following housing improvements. Kleinhans (2005) states that personal guidance in relocating people after demolition of houses reduces the stress and dissatisfaction caused by the forceful change in the environment. Evaluation of the use of the Ventilation Checklist by tenants shows that the use of the Checklist leads to better understanding, more action towards the home owner (more communication) and even change of ventilation behaviour. Self-learning works for those tenants who are motivated to fill out the Ventilation Checklist. Lawton proposes the 'environmental

Figure 2.3 The model of communication



Based on Shannon, 1948

pro-activity hypothesis'. Pro-activity is the person's competence to determine the environment. When the person becomes more competent, the environment affords more resources to meet the person's needs. Personal resources are regarded as means by which one can engage in proactive behaviour, whereas reactive behaviour is simply a response to environmental press. Pro-activity results in more competence to adapt the environment to needs, and to control environmental quality. Because the health performance of the environment can be improved by both physical means and by cognitive change, we include the strategy of 'learning by doing', to stimulate this process of deliberate adaptation and of taking active control. Research findings that support this strategic choice are derived from Ravesloot (2005), Silvester (1999) and Someren (1994). Learning-by-doing is used in training of personal skills (Essence trainings, 2006) and in citizen participation processes (Kalk, 2002).

Learning from a condition that causes stress requires as a first step that a person stops a habit, the automatic routine. Sickness often acts as a stop sign, forcing a person to evaluate the condition (Look) and take a rest or go to the docter (Correct and Take Action). Any diagnosis leads to new perception and associated behaviour including change of external conditions (Correct and Take Action). Setting goals (to reach a higher indoor environmental quality) is an example of the 'Correct'-step, filing a complaint by tenants is an Action. To facilitate the 'learning-by-doing' process, the occupant can be provided with information on hazards or with tools that support the diagnosis of health risks at home. The strategy followed to promote action taking via learning-by-doing is via evaluation by occupants, or by professionals who communicate with the occupants.

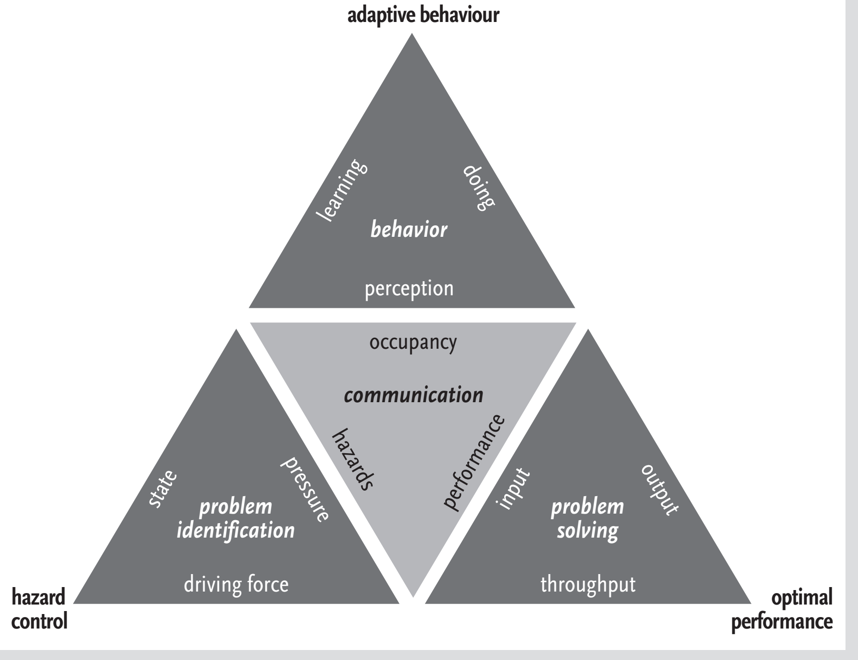
The communication framework

In the 1940s, researchers at Bell Telephone Laboratories devised a model of the process of human communication. Communication theory identifies a message, sender, receiver and desired feedback.

In the field of rented housing the responsibilities of the manager/owner and occupant are not clearly defined and certain conditions are the shared responsibility. For example the responsibility for dampness or noise, that show certain problems in conditions where the occupants follow a normal life style. Communication is essential about cause and effect and about who must take steps when these problems occur.

In the study, the sender is the tenant with a complaint, who needs interac-

Figure 2.4 Main model of the relations between occupancy, performance and hazards



tion with the housing association to get recognition for the problem and agree on diagnosis and actions. The home owner can also be the messenger, for instance to promote occupant behaviour that prevents problems. The desired feedback is a change in perception which may result in change in behaviour. Filing a complaint is action taking after being aware of a problem. This awareness is the result of a learning process. When the problem is not easy to solve and an individual complaint may not have effect on reducing the risk, then other people in the estate may get involved and community action may be initiated.

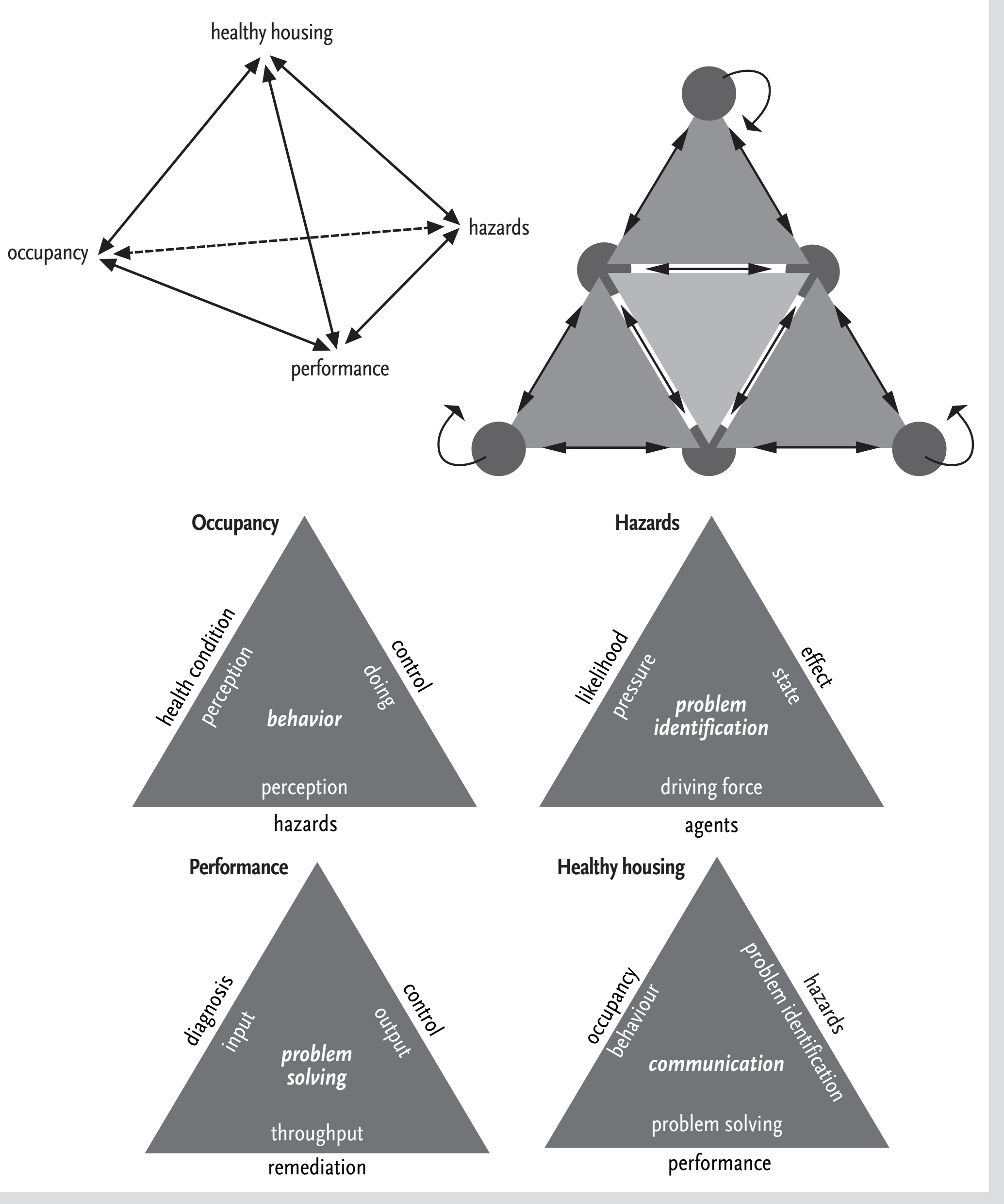
The communication framework is called the CIA-framework: complaint, interaction and action (see Figure 2.3).

2.2.2 Model

An overall model of relations is constructed. The diagram is adapted from Duijvestein (2005) (people/planet/profit/project diagram). The four points of the pyramid represent occupancy, hazards, performance and healthy housing. The fields represent behaviour, problem identification, problem solving and communication. The theoretical frameworks are placed in these fields.

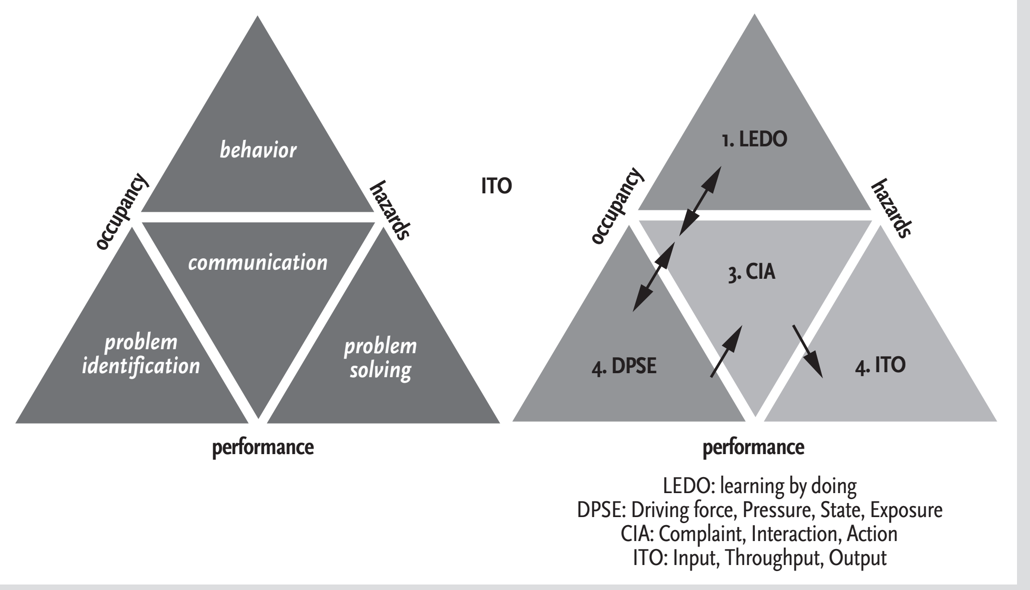
The fields of the pyramid and all connecting lines between the corners represent relevant topics in the research. The relationships between the fields exist in the three dimensional figure and in the two-dimensional representation. The main three aspects in this figure are occupancy, hazards and performance. The result is the main model of relations in the research (see Figure 2.4). The stepwise development of the main model is presented in the Fig-

Figure 2.5 Relations in the field of occupncy, hazards, performance and healthy housing



ures 2.5 and 2.6. We refer in the research to behaviour, problem identification, problem solving and communication, which framework includes steps from the perception of a problem to the initiative for action and one step for problem solving. The identification of hazards and interaction to reach agreements on the diagnoses and actions are crucial for improving healthy housing. Actions to improve the health performance represent a new step in the process, and will often involve other people and departments.

Figure 2.6 Steps in the protocol for health performance evaluation



The problem identification process is hazard identification. This model does not include the topic of health: this requires a new dimension of exposure to hazards (dose) and the dose-effect relationship. Dose-effect relations are no part of the study. Exposure has attention, but performance evaluation is oriented towards the concentration or condition (State in the DPSEEA framework).

Route through the model

Perception of indoor environmental problems can lead to performance evaluation of the house and of behaviour (see Figure 2.6 and Table 2.1). Learning means: start the problem identification process. Taking action includes adaptation to what the housing conditions require and also to change the physical aspects of the house. When actions are the responsibility of the owner, then the occupant can file a complaint. A complaint creates a maintenance problem for the housing manager. The problem identification field highlights the major items of performance evaluation: scan for driving forces, assess the pressure and come to a conclusion about the state. In the communication field the items represent the three major topics of the model (see Figure 2.5): occupancy, performance and hazards, or in other words: occupant behaviour, the conditions of the house and the health risk. The next step is initiative to take action for solving the problem and improving the performance. These actions require means (input) for problem solving, activities (throughput) and a clear output. The output is a problem solved. The ultimate goal (the outcome) is healthy housing.

The corners can be folded to create a three-dimensional pyramid. The three aspects hazard control, adaptive behaviour and optimal performance create healthy housing (see Figure 2.5 once more).

Table 2.1 Topics of the main model of healthy housing

Framework	Steps	Strategies (the lines in the model)
Behaviour		
Learning-by-doing (LEDO)	stop and look	perception
	correct	learning
	take action	doing (adaptation, filing a complaint, initiative for action)
Problem identification		
DPS (E)	check agents, conditions	driving forces
	inspect	pressure
	diagnosis of hazard	state (exposure top state leads to health effects)
Communication		
Send-Receive	complaint	occupancy
	interaction tenant/owner	hazards
	action	performance
Problem solving (Action)		
ITO (O)	input	input
	throughput	throughput
	output	output
	(outcome)	**(healthy housing)**

The type of indicators

In the research we are primarily interested in identifying the hazards related to housing and behaviour: the connection between LEDO and DPS(E) in Figure 2.6. In the field of housing management, the interaction (CIA) to reach agreements between the tenants and the housing association on the diagnoses and on remediation actions is considered essential for the promotion of healthy housing. The home inspector deals in the first place with 'State', which is the result of the driving force and pressure. After agreement on the diagnosis, the discussion on the remediation measures starts. The communication between the occupant and inspector (or manager) does not deal with health directly, not with exposure, but with hazards and who is responsible for remediation.

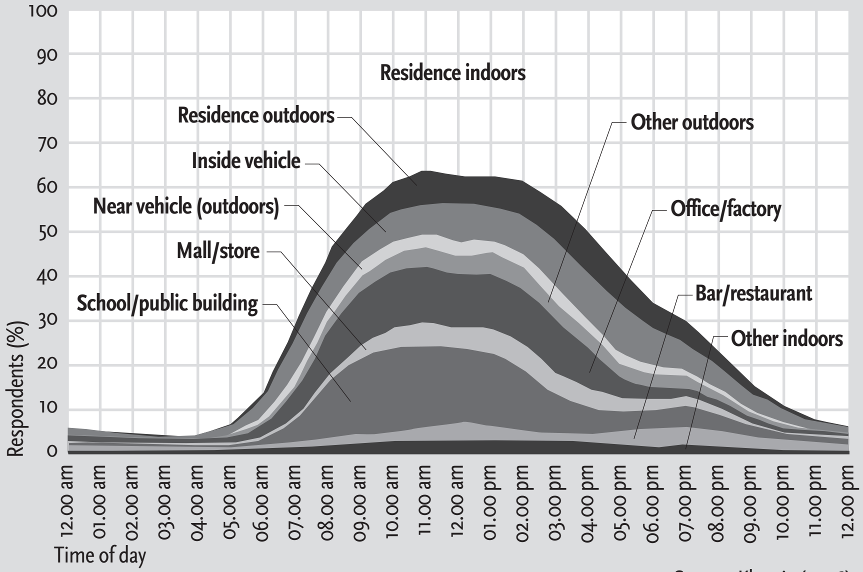
Indicators of sources

In the application of health performance evaluation tools, the identification of sources of pollutants or nuisance can be based on a checklist of the main pollutant sources and physical hazards caused by technical features and occupancy. In the research project this checklist is compiled.

Indicators of emissions

The emission strength depends on the amount of material, the type of bonding in the material, the surface layer and the emission characteristics, and emission strength may depend on temperature, on the concentration (gas pressure) and humidity already existing in the room. Ventilation is important in regulating the final concentration in a room (the State). Instead of assessing many potential driving forces and pressures, we take proxy indicators of emissions and look at a potential peak level, for instance in the period during and shortly after application or during overheating (the 'baking out' process).

Figure 2.7 Average human activity patters



Source: Klepeis (1996)

Indicators of transport: airflow, ventilation and cleaning

The main transport mechanism is air flow, caused by temperature differences and wind or movements; then come ventilation. A transport mechanism of dirt is cleaning: the removal of dirt from floors and dust pockets, wiping off grease and mould, etc. Cleaning effects pollution sources: lower emissions of smelly gases or irritating substances from dirt layers. Ventilation is the replacement of polluted (used) air by fresh air.

Indicators of exposure

In general, health risk depends on exposure. Figure 2.7 shows the average distribution of time spent in 10 locations in the USA. At night, the largest part of the population is at home, but even in the middle of the day almost 40% is at home.

Ikeda (1999) studied time spent indoors and respiration volume among males mainly working and females not working in Japan. People over 15 years of age spent 90% of the day indoors on weekdays and 88% at weekends. On average, about 58% of time is spent at home. Up to 60% of the males' activity on weekdays in homes was sleeping.

Types of exposure

Types of exposure are: time period-dependent, threshold-dependent, peak-dependent. With time-dependent exposure, the health effect is in linear proportion with the period of exposure. Many hazards have impact from a certain threshold, and after higher exposure the repair mechanisms cannot counteract the physical or mental burden any more. This threshold depends on personal condition. The third type is the exposure during a specific moment of activity, the peak or the activity itself (for instance taking the stairs). The type of exposure leads to specific requirements for monitoring of exposure: peak exposure cannot be evaluated on the basis of long-term average concentrations, period-dependent exposure cannot be evaluated with a single measurement, when the conditions measured are variable, etc. Intake of substances can have an increasing effect on health with accumulation of toxic materials. The exposure level to some air pollutants depends on respiration volume (e.g. SO_2), and this volume differs between adults or children, or between people mainly sleeping or doing physical exercise at home. Respiration volume is complex: the inhalation rate of an adult is 1.5 x the rate of a child of 15 kg, but the body mass is likely to be 4-5 times higher.

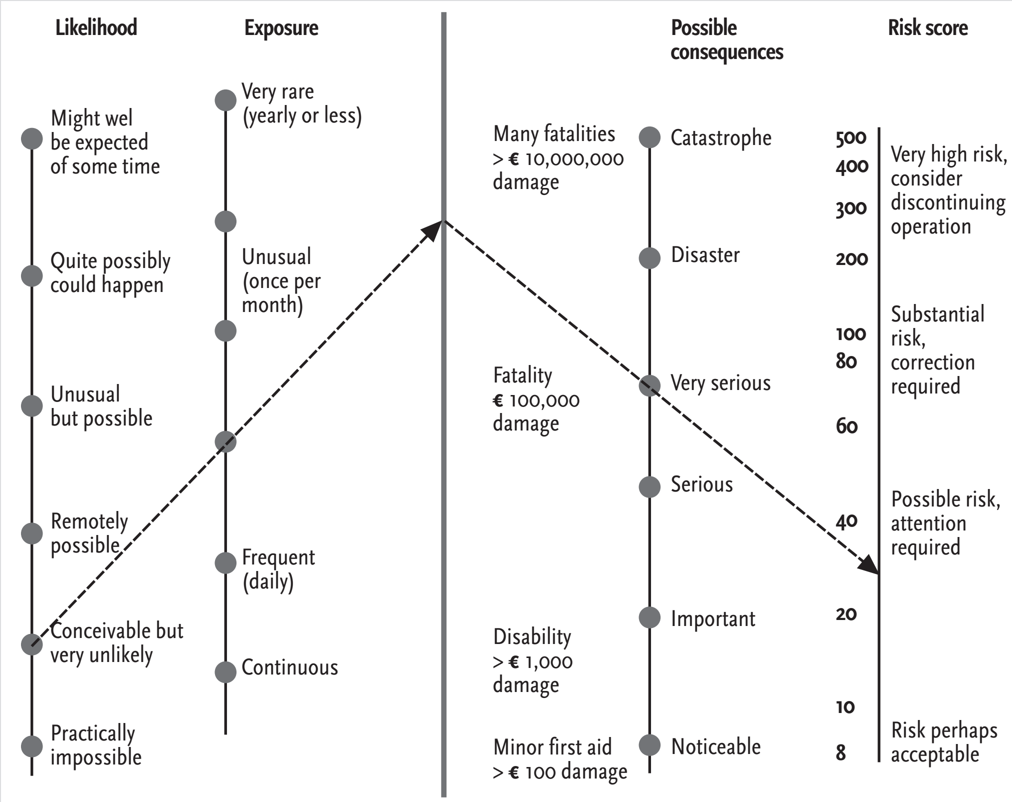
Because of these complexities we prefer to select simple ‘overall’ exposure indices. For air pollutants we select the exposure period as the major measure and neglect respiration volume and take the peak exposure levels into account. Peak exposure are especially relevant for biological agents and many pollutant gases, for instance NO_2. For exposure to personal injury the type of activity is relevant, but complex too: taking the stairs only once a day (non-routine) may pose a risk that is similar to the routine of taking stairs many times a day.

Risk ranking

Risk ranking is the final step of problem identification. Risk can be quantified in a score, to facilitate communication and the setting of priorities. Weighing of the risk can be based on standards, codes of practice, qualitative information and rules of thumb. Ranking by comparison with standards is supposedly an ‘objective’ ranking, whereas ranking on the basis of qualitative criteria is an ‘intuitive’ ranking. Most risk scores are the result of intuitive ranking and relative to certain described risk levels. Relative ranking is based on a combinations of measurable quantities and the likelihood, exposure and severity of possible accidents. Likelihood is the probability of an occurrence (of the hazard) over, for instance, a 12-month period following the evaluation.

Murray (1994) suggests that, to the greatest extent possible, any health outcome that represents a loss of welfare should be put into a measure and included in indicators of health status. Murray draws a distinction between potency-based, severity-based and proxy indicators. Potency-based indicators do not point out a quantitative health measure and are expressed in equivalence factors, allowing for qualitative evaluation. Potency-based indicators require data on the uptake, distribution and metabolism of the substances for humans and the effects of the substances on humans (Krewitt, 2002). Severity-based indicators express the health effect as a measure, for instance DALY or QALY. A DALY combines premature death and illness, or YLD (Years Lived Disabled) and YLL (Years of Life Lost) in one index. QALY measures the health quality. Proxy indicators aggregate different parameters and may even focus on indirect conditions. Proxy indicators are ideal in situations where it is hard

Figure 2.8 Risk score calculation chart



Source: Kenney (1993)

to prove cause and effect, which applies to many relationships between housing and health. Proxy indicators are important for health performance evaluation protocols and this research.

Hollander (2004) defines the 'uncertainty' of risk. "The concept of risk consists not exclusively of objectively measurable qualities of systems. Risk is also a social construct; in which qualitative, social-psychological attributes may be decisive in our acceptance of health risks. There is no universal, unequivocal measure to quantify health risk; picking a measure always implicates a choice of normative points of departure for policymaking."…. "Risk assessments are always uncertain to some extent; incertitude may range from statistical inexactness, construct or model uncertainty and indeterminacy, all the way to ignorance. However, we still think risks can be adequately characterised, at least to a certain extent, applying a (limited) set of quantitative and qualitative attributes, such as probability, nature and magnitude of consequences, spatial and temporal scale, persistence, irreversibility, inequity, delayed consequences, and potential to provoke societal turmoil. The composition and extensiveness of the set will depend largely on the characteristics of the risk problem" (Hollander 2004). A useful approach is illustrated in the risk score calculation chart published by Kenney (1993) (see Figure 2.8). The risk score chart requires the scoring of likelihood, exposure and possible consequences. These scores result in a position on a relative risk scale.

However important it is to characterize and measure risk, detailed characterisation is not feasible for all the (hundreds of) potential risk situations in the home, while doing a home inspection. We follow a strategy of simplification by using a ‘relative score’ for the exposure level and possible consequences. Additional qualities are considered by Bergs, such as the size of the at-risk population; the possibility of controlling or preventing the hazard, and the perception of risk by the stakeholders (Bergs, 2002). Because we focus on single houses and specific occupants, we do not include the size of the population at risk. The possibilities of controlling or preventing the hazards is important in the practical field. In the study we focus on risk identification primarily.

2.3 The collection of field data

In the period 1994-2004 a large amount of field data on housing was collected. During the first period of 1994-1998 data was collected in ‘one-day-consult’ visits to housing estates all over the Netherlands. Each visit included the inspection of 3 to 5 houses to diagnose the reasons for complaints. Visits to some neighbouring houses were also included to see whether these problems were specific and occupancy-related or linked to general structural features for the block. About 60 housing estates were visited during this period of 1994-1998, with inspection of more than 200 houses, 300 interviews with tenants, about 25 meetings with housing managers and about 50 meetings with tenant groups to discuss strategies. This fieldwork resulted in better insight into technical problems, in occupant behaviour, in maintenance levels and in the interactions between tenants and housing managers.

In 1995-1996 a project in Rotterdam on indoor environmental problems (Hasselaar, 1995a) resulted in the design of an inspection protocol and questionnaire on indoor environmental conditions and occupancy. In this estate of 150 houses 50 houses were inspected and in a smaller number of houses samples were taken of CO, NO_2, formaldehyde, mould and bacteria, radon and exhaust volumes. In some houses, the air change rate was calculated using CO_2, produced by occupants, as a tracer gas.

In 2001 a new period of fieldwork started, now as part of the PhD-research project. New cases were added to a dataset that followed a protocol for inspection and an interview based on the protocol of 1995, but including more variables. This Indoor Inspection and Interview Protocol (see Annex) leads to different types of data:

- quantitative data on conditions, e.g. the type and orientation of the dwelling, number of occupants and pets, years lived in the house etc.;

- measured data, e.g. temperatures, air velocity, allergen concentration in house dust;
- observed data by the inspector: simple observed facts (the set-point of a boiler, the type of kitchen) and interpretation of many interrelated data points of complex phenomena: thermal bridges, including constructed data on user patterns of the occupant over periods other than the inspection moment, for instance: which ventilation openings used for how long in the heating season, how much time spent at home, efficacy of the use of sun shades on hot summer days, etc.

Projects that provide cases for the dataset

Data was acquired in different projects, sometimes with limited time to follow the protocol, so a project-specific selection of variables was documented. Each project allowed use of some equipment for quantitative data collection. Over a period of several years, several subdatasets were created, for instance on ventilation volumes, water temperatures and conditions related to house dust mite concentration.

Data appear as the 333-dataset (documented home inspection visits), subdatasets of distinct research projects and observations and experiences. The 333 dataset is composed of different projects (see Table 2.2):

1. The Rotterdam research project on indoor environmental problems (1995-1996) was the first project to follow the protocol (Hasselaar 1995) and resulted in 50 cases for the dataset.
2. Reports on 'one-day consultations' (1995-1998) added 26 cases.
3. Involvement in fieldwork on domestic water heating (n=365) (2000) gave the opportunity to follow the protocol in a number of houses and 33 cases were added to the dataset.
4. Piloting the special version of the energy performance tool that included indoor environmental issues (EPA+Health tool, Hasselaar (2001)) resulted in 27 cases for the dataset.
5. Troubleshooting on indoor environmental problems (2001-2005) resulted in 11 cases for the dataset.
6. Piloting the Healthy Housing Checklist (2004) resulted in 12 cases for the dataset.
7. In the city of the Hague, data was collected on exhaust volumes in 60 houses (2002) that were delivered and inspected between one and 11 years ago. In a number of houses the protocol was applied, which added 25 cases to the dataset.
8. In Utrecht fieldwork on house dust mite (2003) allowed a quick (15 minutes) scan of parameters of house dust mite concentration, in combination with collecting dust samples. A limited number of important variables were documented and 65 cases were added to the dataset.
9. Small projects on air heating and heat-recovery ventilation systems added

16 cases (2002-2005);
10. Projects in Utrecht and Amsterdam on the transformation of shunted collective natural ventilation systems into mechanical systems added 8 cases (2003).
11. Some projects (2000-2005) on piloting health performance tools (n=15), on a questionnaire based on the protocol (n=19), and indoor environmental investigations by other home inspectors (n=29) were documented well, but the author did not visit these estates. On the basis of these reports 63 cases were added.

The cases and subsets involve housing estates distributed over many regions in the Netherlands and with three large cities well-represented: Rotterdam, the Hague and Utrecht. In about 500 houses of the 600 visited, each room has been inspected and the occupants interviewed by the researcher. The dataset includes all visits with information on major variables and was closed with 333 cases in 2004.

The 333 dataset is the basis for statistical analysis of the relationship between many variables: the correlation between agents and physical parameters, the use of ventilation services, occupancy, the period spent at home, smoking, pet keeping, number of showers, etc. Because the cases do not include data on all variables, the population for many of the statistical explorations is (much) smaller than 333.

The conditions for data collection in these projects put certain restraints on the quality of the data. The most important consequence is that the data cannot be used for results that are representative of the Dutch housing stock. We also limit the use of data analysis for exploration of variables and correlations between variables, in order to improve the insight into complex phenomena. Models will not be validated, but model parameters will be studied. The exploratory nature of the data analysis is combined with use of qualitative experience acquired during many years of practical involvement in the field of technical housing management.

Information on specific sets of field data used for the study of mould and moisture, ventilation, house dust mite allergen, particulate matter, legionella, radon and comfort is included in Appendix 1.

2.4 Methods of data analysis

Statistical analysis

Wherever possible, the variables were dichotomised to facilitate regression analysis. The total number of variables was reduced by leaving out data on the third bedroom and the hobby-workroom, because of low response. 165 variables were used to create results. The variables with highest correlation

Table 2.2 The projects that provided cases for the 333-dataset

	Project	Analysis in visited houses	With data	Visit	Cases in dataset
1	Rotterdam indoor air	NO_2, CO_2, exhaust volumes, ACH, mould, moisture problems, noise, nuisance, occupancy	150	50	50
2	One-day-consults	inspection and interview, some exhaust volumes and dust samples	300	200	26
3	Domestic water systems	inspection, interview, water temperatures, dust sampling, exhaust volumes	363	35	33
4	EPA + Health	inspection, interview, dust sampling, exhaust volumes	50	46	27
5	Troubleshooting	inspection, interview, temperatures, air change rate, dust samples	60	60	11
6	Piloting checklist HH	inspection and interview	6	6	12
7	The Hague exhaust volumes	inspection, interview monitoring exhaust volume, ACH, dust sampling	450	60	25
8	House dust mite, Utrecht	inspection, interview, dust sampling (analysis guanine, Der p1	65	65	65
9	Balanced-flow ventilation and air heating	inspection, interview, air volumes, dust sampling, mould and bacteria sampling	40	31	16
10	Shunted ventilation Utrecht and Amsterdam	inspection, interview, air volumes	150	35	8
11	Visited, reported by other inspectors	inspection and interview, some mould samples	56	0	60
	Total		**1,693**	**588**	**333**

are the basis for regression analysis. The results of this regression analysis are used to select parameters for models of relations. Models combine parameters of source, emission, transport and exposure. The outcome is optimised by stepwise improvement of the parameters in the model, until a satisfactory result has been obtained and the parameters can be rephrased as indicators. This optimisation process follows a qualitative strategy. Modelling, or the parameter study, is an essential step in the selection of indicators.

The software programs Microsoft Excel and the Statistical Program for the Social Sciences (SPSS) are used for data analysis.

Integrative descriptive analysis

The analysis of the 333 dataset and subdatasets expands the practical experience acquired in the field and otherwise: the statistical analysis points out correlations that were not visible during fieldwork. Quantitative and qualitative exploration go together in support of better understanding of complex phenomena that reflect the relationship between health hazard conditions, the physical properties of housing, occupancy and occupant behaviour. The concept of abductive reasoning is followed (Coffey and Atkinson, 1996): starting from the particular phenomenon and relating it to broader concepts. The theory of abduction was suggested by Charles S. Peirce (1839-1914). Abduction can be viewed as 1) the logic of generating (discovering, creating) a new hypothesis, 2) the logic of selecting (justifying, evaluating) a new hypothesis in comparison with other rival hypotheses, and, finally, as 3) the theory that describes those criteria and conditions on which a new hypothesis is accepted as a plausible account of an unexplained (surprising) experience. In the research project, plausible descriptions of the complex phenomena of healthy housing are developed. An example of abductive reasoning is: we encounter indoor air problems in houses with mechanical ventilation and discover that these systems are not used well because occupants tend to avoid the noise that these systems produce, while they prefer to open the window instead. From these observed phenomena we define the hypothesis that noise is a parameter of user behaviour of mechanical ventilation systems and that the quality of 'compensating' ventilation services determines indoor air quality. When, while diagnosing the cause of complaints of occupants about indoor air quality in modern houses with mechanical heat recovery ventilation systems and discover that the noise level is high and the quality of compensating natural ventilation services is poor, we find a satisfactory explanation of the complaints, using this hypothesis. We look at other potential explanations for the complaints, before we accept the perceptual judgment. This method reflects the research better than the falsification method as proposed by Popper (1902-1994) and that focuses on empirical analytical methods. Popper proclaims deductive reasoning: "... a theory which tells us more, that is to say, which has the greater amount of information; which is logically stronger; which has the greater explanatory and predictive power; and which can therefore be more severely tested by comparing facts with observations." (Popper, 1959).

Data on health

In a few projects (Rotterdam 1994-1996, domestic hot water 2000) the occupants were interviewed on self-reported health and medication taken. Triggering any expectation with the occupants about the diagnosis of their health problems was avoided, because a home inspector is not qualified to give feedback on medical issues. Health information can, however, be included in certain description of complaints. Medical environmentalists were involved in some of the projects and they refused to draw conclusions on the specific relationships between housing and health, but they supported the remediation strategies. In the domestic water project a questionnaire on self-perceived health was used, based on Sonia Hunt's approach (Hunt, 1980). The results did not contribute to risk analysis. Questions on personal health were for that reason deleted from the protocol, except for general questions to indicate the type of health-related housing needs.

2.5 Modelling and parameter studies

The purpose of modelling is to make complex phenomena more transparent, in other words: a model supports simplification, which is a process that supports the limitation of the number of indicators.

Model studies follow the theory of abductive reasoning: use of information from data analysis and experiments, combined with plausible explanations of relationships. An example: the analysis of variables of house dust mite concentration revealed that mattresses are a major source of allergens. Because dust builds up in the mattress over a period of years and new mattresses do not contain house dust mite allergens, the age of the mattress gives a plausible account of exposure risk. However, field data on the age of mattresses is not available. In the construction of models of house dust mite exposure, we have not limited the information to validated variables (the dust samples with known allergen concentration) but also included the result of abductive reasoning (the age of the mattress). In this example the statistical exploration leads to the occupancy of the house as a proxy indicator and abductive reasoning leads to the age of the mattress as a more robust indicator of house dust mite allergen concentration, even without validation of this robustness. This strategy is followed because for performance evaluation we need a comprehensive set of indicators, even when only a few indicators are validated.

Structure of the models

The models in this chapter predict the concentration for each parameter of air quality and the likelihood of a condition or event for physical qualities. The result is summarised in a measure on a three-point scale: low, medium and high. Then the concentration is compared to exposure: unusual-regular-intense for hazardous events and ad hoc (typical less than 15 minutes), regular (typical 1 to 3 hours a day) and long (6 hours or longer per day) for pollutant concentrations in air quality. The final result is a score of the risk level. The overall model is presented in Table 2.3 and 2.4.

The score is chosen for two shifting scales that account for healthy and vulnerable occupants. The score is not a simple 4-point scale, but is logarithmic. In calculating a final score, weight 1 is no risk or low risk, accepted by society. Weight 2 is a double weight: warning for susceptible people, while attention and improvement, for instance via maintenance is advised. Weight 4 indicates alert for susceptible people and a warning for healthy people and remediation is advised, while susceptible persons better avoid exposure. The risk score 8 reflects an emergency situation for which immediate measures are needed, while occupation before remediation is not advised for anyone.

The parameters in these models represent indicators for a specific parameter of health risk. In a stepwise qualitative process these indicators are reformulated and improved on the basis of new data. Criteria for improvement

Table 2.3 Parameters of concentration or likelihood and related health consequences

Parameter	Source indicators	Emission indicators	Removal indicators	Indicators of concentration, or likelihood
Agents	Source of air, water pollution	Amount of source material, emission characteristics	Ventilation, cleaning	Pollutant concentration noticeable, important or serious
Conditions	Hazard condition	Activity level, distribution of obstructions, dangers	Prevention, warning, control	Likelihood Low/Medium/High
Concentration or likelihood				Low/Medium/High
Possible consequences				Low, possibly substantial, serious

Table 2.4 Model of health risk exposure

Exposure risk score		Exposure: ad hoc/unusual	Exposure: regular	Exposure: long, intense
Likelihood and possible	**conceivable, noticeable**	1. no or low risk	1. warning for susceptible people	2. alert for susceptible, warning for healthy
consequences of the condition	**possible, important**	1. warning for susceptible people	2. alert for susceptible, warning for healthy	4. alert for all people
or concentration	**expected, serious**	2. alert for susceptible, correction required	4. alert for all people and correct instantly	8. extreme risk, avoid and correct instantly
Score			1 2	4 8

are relevance for the model, clarity in explaining the concentration or consequences and applicability in inspection visits, without the use of sophisticated instrumentation. Modelling leads to a new version of the list of indicators.

2.6 Conclusions

The research question: *How can we evaluate housing health performance?* results in a framework that connects the field of housing management, communication and occupant interaction with the environment. The framework supports the selection of strategies for performance evaluation. Stimulation of pro-active behaviour, communication between housing managers and occupants, a solid diagnosis of health hazards and action toward change of behaviour or of physical conditions shape these strategies. The framework influences the topics of the study.

Involvement in fieldwork has provided a great amount of data collected into several subsets with enough cases to allow numerical analysis of a number of variables. Because the data collection followed different goals, sometimes with only a short time per case for inspection, sampling and interview on health aspects, cases do not cover all variables and the coverage is different for each subset of cases. Air quality-related variables and certain occupancy-related variables are well-documented: especially conditions that influence the concentration of mould, house dust mite and the use of ventilation services. Some subsets provide data on aerosols or domestic water temperatures or technical services. Because the dataset is not representative of the Dutch housing stock, the results of the analysis are used for exploration, not for testing or validation. The focus is on descriptive models that explain the occurrence of hazards, rather than on models that could be used to calculate risk scores. These circumstances make the thesis the result of exploratory studies.

Health performance evaluation requires indicators for all important health topics and for relevant topics (based on abductive reasoning) we used literature reviews and qualitative field observations to fill gaps.

3 State-of-the-art of housing and health

3.1 Introduction

3.1.1 Research question

The search for robust indicators starts in this chapter with a literature review of performance quality references and indicators. This is the only chapter in the PhD thesis where health effects are linked with pollutant concentrations or physical conditions. The research question is: *What is the state-of-the-art knowledge about housing and health?* We try to find more evidence in scientific literature on the relationship between housing and health. We look at quality criteria, set by government bodies, research institutions and experts. These criteria represent minimum qualities and functional requirements for housing and permissible values for pollutants. Official standards often indicate the lowest risk level acceptable to society. This refers to levels that do not cause irreversible health effects during the lifetime of a healthy person, or a mortality rate of 1 in a million, etc. The performance criteria deal with air quality (biological and chemical agents), acoustics, comfort, safety and social quality respectively, similar to the structure in other chapters. Table 1.4 highlights the relationship between this research question and Chapter 3.

The importance of quality criteria
There are important limitations on the use of existing performance criteria. First, standards mainly relate to products, not processes, so the subsequent operational phase in which environmental problems tend to become more serious receives less attention. Second, standards are based on negotiation between parties, on what is feasible and the standards do not tell how strong or weak the evidence is. Official performance criteria are based on health effects of healthy people, with extra safety margins (mostly reduction of the concentration level with 90%). Information used to set standards is often old, sometimes 15 to 20 years and this information may not reflect actual conditions. Because compliance is poorly controlled or standards are not enforced, many buildings do not comply with the quality criteria concerned. Fire safety, legionella safety, ventilation exhaust capacity and thermal and acoustic quality are some examples for which field research points out major quality conflicts. The consequence is that official criteria do not secure a healthy environment for everyone.

As occupants are exposed to a mixture of agents and conditions and certain effects add up and eventually may cause a multiplier effect, we have little knowledge of dose-response relations. Because of this lack of knowledge, the precautionary principle has developed into a leading strategy: reduction of the exposure and the concentration where it is possible and as low as achievable for sensitive people. "'Don't know' is not a good answer in the context of integrated environmental health risk assessment" (David Briggs, INTARESE meeting at Paris, September 2006).

The criteria in this chapter are used as a reference, as information that helps in the setting of priorities, while in performance evaluation we will follow the strategy of prevention and precaution rather than drawing the line between 'meeting or disagreeing' with official requirements.

In dealing with complaints of occupants it is common practice to compare the performance with the standard requirements that prevailed during the construction period of the house. These requirements are of practical value in the communication process on housing maintenance issues. The minimum requirements of the building decree for new construction are often used by housing associations as a target quality for renovation plans. This quality level is higher than the building decree requires for existing dwellings. The Dutch Rental Price Act is important for maintenance quality, in particular because it forms the legal basis for penalties when certain complaints of tenants are persistent (Rueb 1994, Straks, 1994). Substandard qualities that lend penalties to tenants according to the Rental Price Act (OVH, 2004) are:

- no ventilation service in either the toilet, kitchen, living, bedroom or bathroom;
- serious moisture and mould problems in the kitchen, living or bedrooms;
- poor exhaust of fumes of heaters;
- leakage of rainwater (damage and growth of biological agents);
- no flush toilet (individual homes);
- no bathroom with bath or shower or basin, or no running water;
- no sewage connection either for toilet, bathroom or kitchen sink, or poor functioning of system;
- poor overall maintenance quality.

3.1.2. Data collection

Requirements are documented in:

- laws and regulations, for instance the Housing Act, which includes the Building Decree;
- codes and standards, e.g. ISO standards (International Standards Organisation) and CEN standards (Comité Europeen de Normalisation), limit values and administrative standards;
- quality assurance systems covering the issuance of permits (KOMO quality certification for building products, KIWA quality of drinkwater related products, VEG quality for gas application, etc.);
- civil law (where the Housing Act does not give requirements).

Many quality references are based on a study by the ISIAQ-CIB Task Group 42 (Säteri, 2003), a joint effort of a working group of the International Society of Indoor Air Quality and the Centre International du Bâtiment, CIB). Best practices from different countries were compiled in 'Performance criteria of buildings for health and comfort'. The document also includes state-of-the-art guidelines for houses (Säteri, 2003). Most criteria deal with indoor air. RIVM in the Netherlands developed health-based guidelines for chemical and certain physical substances in houses (Fast, 2003). Substances were selected on the basis of product use in houses or the fact that they cause problems in indoor environments other than dwellings. The 'guidelines' are based on the Maximum Permissible Risk (MRP), according to Dutch Environmental Policy (Dusseldorp, 2004). Permissible health risk is the no-effect or acceptable effect during the lifetime exposure for healthy people. For materials with a threshold level, this value represents a no-effect level over 70 years, every day of the year and 24 hours/day. For materials that can cause cancer, the permissible health value is the risk of the death of 1 person per million, meaning that the death toll in the Netherlands attributed to the exposure value must be below 17 per year. For materials without threshold level (for instance, the genotoxic effects of carcinogenic materials) the maximum acceptable risk level is 1 case (of cancer) per million people exposed (as mentioned before) or one case per 10,000 during a lifetime of 100 years. Values are not available for all indoor agents, for instance because uncertainty about the health impact does not allow us to draw lines.

3.2 Quality references for health performance

3.2.1 Air quality

Air quality is the cornerstone of healthy housing. We breathe air as much as we drink and eat food. Air quality has considerable influence on our well-being, and the influence goes very deep: certain substances in air can heal, give pleasure, cause illness and influence our social relationships. The alarm function of smell is very important, because we can smell most substances that can create health risk at very low concentrations, much lower than is likely to cause health effects. Certain dangerous substances cannot be smelled, for instance carbon monoxide, so the warning system is not complete. The chemical quality and the sensory quality are relevant. For instance: many smokers do not like the smell of smoke (Hasselaar, 1995), but the association between smell and the pleasure of nicotine is so strong that the smell is connected with pleasure. People can sleep in malodorous bedrooms with all openings closed, and still the alarm function does not have effect (Kempski, 2006).

Cleanliness
Criteria for cleanliness in homes are not available. Review of literature reveals that the level of tidiness after a cleaning job in a room is used as a standard, and that cleanliness refers more to frequency of cleaning and to visible

litter rather than to uniform quality criteria. The house can be divided into three different cleaning zones. The ‘dirty zone’ consist of the hall and kitchen, while a bedroom should belong to the ‘clean zone’, free from dirt and allergens. The bathroom or toilet is ‘half-clean’.

Cleanliness influences the concentration of mould, house dust mite, VOC, and aerosols such as dust, containing lead and many chemical substances.

Cleanliness of inlet air ducts

The German VDI6022 requires that the concentration of bacteria and mould in air ducts does not exceed the concentration of ambient air. The ducts must be broom-clean, which is considered to be less than 4 g/m^2 of surface material. A layer of 20 g/m^2 of dust will conceal the metal surface, so cleaning is required when the metal cannot be seen at the bottom part of the duct. The two guideline values for microorganisms are: <15,000 CFU/m^2 for mould and <30,000 CFU/m^2 for bacteria.

Typical concentrations of deposited dust in the field are 1.2 to 18.8 g/m^2) and the concentration of microorganisms ranging from 2.5×10^5 CFU/m^2 to 1.5×10^6 CFU/g.

Mould

Little is still known about the relationship between mould concentration and health problems. The potential role of bacteria, in relation with mould, induces the use of ‘dampness’ (Sundell, 2006) instead of the effects of dampness, of which mould growth and houses dust mite are evident. For the moment, we choose to relate to mould and house dust mite as agents that are resposible for health reactions and the opinion among health professionals that mould should be prevented in the indoor environment. The adverse health effects result from inhalation of viable as well as nonviable hyphal particles. Among these, fungal spores are of considerable importance, since they tend to serve as a reservoir of low molecular weight toxins produced by the fungi (Cooley, 2004; Jaakkola, 2004; Marinkovich; 2004; Molhave, 2003; Tabak 2002). Allergenic moulds can cause allergic or asthmatic symptoms such as wheezing or runny nose. Mycotoxic moulds can cause serious health effects in humans and animals. The species *Stachybotrys chartarum* can lead to pulmonary haemorrhage (Dearborn, 1999; Novotny, 2000; Vesper, 2000). Health effects of *Aspergillis* have been reported from the Netherlands. Health effects range from short-term irritation to immunosuppression to cancer and even death. Pathogenic moulds can cause serious health effects in people with suppressed immune systems, people undergoing chemotherapy, and people with HIV/AIDS (Forensic Inspections, 2001).

With visible mould in the house, the concentration tends to be higher than 5000 colony-forming units/m^3 (CFU/m^3). Without any mould in the house, the concentration is likely to be lower than 200 CFU/m^3. Verhoeff (1994) found

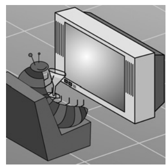
Table 3.1 Correlation between Der p1, index of the Acarex test and guanine concentration

Allergen Der p1 threshold levels	Acarex test	Guanine
2 μg/g dust (sensitisation)	1 low (yellow)	0.6 mg/g dust
	2 medium (orange)	2.4 mg/g
10 μg/g (asthma attack)	3 high (red)	10 mg/g

large differences in CFU/m³ in 84 houses. The sampling method and also the analysis by laboratories tend to give large differences in outcome.

RIVM states that it is not possible to select a concentration value. For the study on healthy housing, a no-visible mould level in occupied spaces and only minor levels (up to 100 cm²) in bathrooms and other spaces with direct exhaust into ambient air is accepted. Also: hidden mould (in crawl spaces with open connections, in cavities of constructions or behind furniture are not accepted in the reference quality level. The underlying opinion is that mould and healthy houses do not match (Duijm, 2005). However, many people may not be affected by exposure to mould, because many species may not pose health threats.

House dust mite allergen



Allergenic material can be expressed in the protein guanine and in the *Dermatophagoides pteronyssynus* type 1 (Der p1). There is a nonlinear correlation between guanine and Der p1. The level of allergen Der p1 corresponds to certain guanine levels that form the basis of the Acarex test (Koren, 1995) (see Table 3.1). There is sufficient proof that mite allergen causes respiratory problems (secondary causation), but no solid proof of the correlation between mite allergen concentration and sensitisation (primary causation) (Heinrich, 2002; Peat, 2004). The WHO proposes a guideline of 10 mg guanine per gramme of dust for the (primary) atopic sensitisation of asthma and predictable astma symptons when exposed and 2 mg/g for potential symptoms in allergic people. Discussion reveals that these values are valid for a small group only and may be too high for the general population. In Germany, the maximum permitted level is 0.6 mg/g dust. We follow the WHO suggestion to achieve a concentration for Der p1 <2 μg/g house dust, including dust from mattresses, which is believed to result in a relatively high allergen concentration per unit of dust.

The guanine concentration in house dust in the Netherlands is around 0.6-20 milligram/gram (Dongen, 1993). The correlation with the humidity level of the house is strong. Verhoeff found the highest concentrations in mattresses (average 5405 ng/g Der p1, 337 samples), soft carpeting around the bed (3626 nanogram/gram Der p1, 339 samples) and in the living room (5378 nanogram/gram Der p1, 230 samples). The cover under the mattress tends to show the highest allergen concentration.

Pet allergen

Cat allergen is carried on particles ranging from less than 1 micrometres to greater than 20 micrometres in mean aerodynamic diameter. Although estimates have varied, studies agree that at least 15% of airborne cat allergen is carried in particles less than 5 micrometres in size. Airborne levels and particle size distribution for dog allergen appear to be very similar to those of cat allergen, with about 20% of airborne allergen being carried in particles less than 5 micrometres in diameter. These smaller particles stay airborne for prolonged periods after disturbance, which explains why individuals often experience symptoms from the very moment they enter environments containing these animals. The health effects depend on factors such as the amount of pollutant inhaled, the duration of exposure and susceptibility of the individual exposed. Male cats produce more allergen than female cats, castrated cats produce relatively the lowest amount of allergen. The skin (fur) is productive, not the saliva (Charpin, 2006).

Deng collected samples in Japanese homes. Cat allergen was found in all of the dwellings with or without a pet, but the density of the cat allergen in the house with pet was about 80 times higher: 0.74 ng/m³ on average. The concentration of mite allergen (Der p1) in houses with a pet was more than twice ($p<0.01$) as much as houses without a pet. The ratio of Der p1 and particles in this field survey was 1.67×10^{-3}, and of Fel d1 and particles was 1.5×10^{-2}. However, no correlation between Der p1, Fel d1 and particles was found (Deng, 1999).

Exposure to cat and dog allergen in early childhood (Heinrich, 2003) is believed to have a corrective effect on sensitisation to asthma, but in other people the allergenic material will cause asthma-like symptoms. This paradox needs further study. No values are available. 52% of Dutch households keep a pet and 18% keep birds. An estimated 1.5% of the population have clinical reactions, and about 7-8% suffer from skin reactions caused by pet animals. Given this information, we can use ‘no pet’ as a quality criterion. However, pet allergens will still enter the house via clothing. Information about the prevalence of pests on cats and dogs (lice, fleas) is not available. Literature indicates that cockroaches and mice produce allergen as well, but mice tend to be not abundent.

Particulate matter

Particles with a size of up to 10 micrometres can be respired, but the main size distribution for inhalation is <1 micrometre. Aerosols with a diameter smaller than 1 micrometre penetrate deep into the lungs and may damage delicate lung tissue and access the bloodstream. Particles between 1 and 3 micrometres are more likely to be deposited in the higher respiratory tract, but can also cause irritation or damage. A large proportion of particles larger than 3 micrometres are deposited in the upper respiratory tract, mainly the nose. The deposition rate applies to healthy people only. Studies have indicated that a material that was low in toxicity in the form of fine particles could be toxic in the form of ultrafine particles (Katsouyanni, 1995; Obersdörster, 2005). Ultrafine particles, however, are most difficult to measure and study.

Table 3.2. shows collection efficiencies representative of several particle sizes in the respirable mass fraction. The resistance to particles is less for people with respiratory diseases or a damaged respiratory tract, for instance caused by tobacco smoking. Recent studies show a correlation between increase in PM10 concentration and respiratory disease (like asthma) and cardiovascular disease. In studies in different cities all over the world, the effects are visible but different, probably in part due to different substances, for instance the amount of diesel fumes, the effects of Ozone, rainfall and relative humidity, etc. The specific metal composition of particulate matter could be important in determining both the type and severity of lung injury that may occur, for instance zinc (Cassee, 2003). Attached chemicals seem to enhance the inflammatory potential of the particles and modulate the nature of the adjuvant activity. Whereas attached chemicals and metals add to the inflammatory capacity of the particle, carrying antigens may have quite different effects. Ormstad (1998) presents the hypothesis that the increased presence of DEP and similar airborne pollution may cause those with the appropriate genetic predisposition to become sensitised to allergens to which they may not otherwise have become sensitised. Co-exposure to allergen, particulate air pollution and complexes of particles with (possibly altered) allergen contributes to this increased risk of sensitisation (Zijverden, 2001). A great amount of research is dedicated to the effects of fine particles, and evidence of the effect on the respiratory and vascular cardic diseases is piling up, though the specific components and size distribution are not known. Particle count is more relevant than particle mass, however, coarse particles (abrasion from tires and roads) are responsible for certain health effects as well (based on presentations at the International Conference on Environmental Epidemiology and Exposure, September 2-6, Paris, 2006).

Table 3.2 Relationship between particle diameter and respirable mass

Particle Aerodynamic Diameter (micrometer)	ACGIH Respirable Particle Mass (RPM) (%)
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1

Source: Australian Standards (1989)

Combustion processes and especially diesel engines are a major source of ultrafine particles: in automobiles, industry and activities indoors (Morawska, 2000, 2002, 2004). Particles from indoor (and outdoor) sources such as fireplaces and stoves, kerosene heaters, burning of incense and candles, air fresheners emitting solvents and oily aerosols and cooking with butter, oils or fats, house dust mites and mould, or caused by release from indoor surfaces, add to the number of particles from outside, and in most houses the indoor concentration is higher than outdoors. Pets and insects cause aerosols, wear and tear of carpets, furnishings, clothing, etc. produce fine particles, and even shaking someone's hand causes delicate monitoring equipment to react. Each person has a 'human fog' with increased particle concentration near the body,

from clothing and the skin. Hot instruments, e.g. the motherboard of a computer, monitors and TVs emit fire retardants and many other aerosols including toxic chemicals. People lose skin flakes and spread aerosols while coughing. Pollen, algae, protozoa and dander are much larger: several tens to hundreds of micrometres in diameter (Baron, 2001). Fungi and plants are unique in their ability to produce enormous quantities of spores and pollen. Since spores and pollen are relatively large, they are deposited within a relatively short distance from the source, but can still be dispersed over long distances by airflows (wind). Only when pollution outdoors shows peaks, for instance because of a heavy traffic peak in the morning, can the aerosol concentration indoors be reduced by temporary reduction of the ventilation volume, but only if the peak and ventilation reduction is a temporary phenomenon.

Guidelines refer to the weight of aerosols (microgrammes/m³), but the number distribution is probably more relevant as an indicator of health effects (Morawska, oral communication at QUT, Brisbane, 2003). The size range that is important for health effects may just start from PM2.5 or even PM1 and lower, in the range of extremely low mass. The typical size ranges of aerosols is between 1 and a million. The guidelines for air quality in the Netherlands refer to mass of PM10. Guidelines in the US are both in mass of PM10 and PM2.5. The WHO recommends keeping the exposure values of PM10 as low as reasonably achievable (ALARA).

National Ambient Air Quality Standards in the US for PM2.5 [Source: EPA (2003)]

Annual arithmetic mean	15 μg/m³
24-hour average	65 μg/m³

Bacteria and viruses

The effect of bacteria is well-known, but threshold values are not available. Exposure to endotoxins, a byproduct of Gram-negative bacteria, induces asthma-like symptoms. It is difficult to monitor endotoxin levels in house dust, and limit values are not available. RIVM (Dusseldorp, 2004) suggests to follow the Health Council guideline for work environments, which is 50 EU (endotoxin units) per m³ (about 5 nanogram/m³). Viruses are the smallest potentially live particles, about 0.02-0.3 micrometres in length. Bacteria and fungal spores cover the size range of about 0.3-100 micrometres.

Bacteria in drinking water

Water contains a few to many bacteria. Breathing water vapour could infect people. Pontiac fever is flulike, non-lethal and does not cause inflammation of the lungs. The incubation period is short and almost 100% of contaminated people will fall ill. *Legionella pneumophila* (=lung-loving) bacteria cause legionellosis. The contamination by certain species causes a fever, a cough and serious intestinal problems. Legionellosis does not grow into a large epidemic outburst like Pontiac fever, but about 8% of infected people who get ill will die (a few years ago, the mortality rate was as high as 15%). The risk of pneumonia caused by polluted drinking water is twice the maximum admissible risk level, so an important measure is to secure legionella-free drinking water. Owners of collective water systems are required to perform a risk inventory, including monitoring the concentration at regular intervals if risk factors have been identified, or they can reduce the risk factors by taking measures instead. One rule is that hot water pipes of less than 5 m^1 do not need special requirements, because regular heat and flush will reduce the health risk (Fast, 2004a).

The legionella outbreak in Bovenkarspel in the Netherlands in 1999 (more than 240 cases, 32 casualties) resulted in new legislation on all but individual domestic water systems. Law enforcement is poor, however. The maximum permissible concentration is 100 legionella bacteria (kve) per dm^3 of drinking water.

In 4-15% of homes, increased legionella levels are found, indicating that many systems have sources that have the potential to grow into a high concentration if the conditions support optimal growth. We consider any domestic hotwater system with a buffer a potential hazard.

Ozone

Ozone can damage the lungs and trigger asthma attacks. Because ozone is a reactive gas, secondary substances such as aldehydes and nitrate radicals are produced, and terpene and glycol ether oxidation products that are potent contact allergens have been found. The products of ozone-initiated chemistry can serve as carriers for some of the more volatile reaction products. Ozone changes the particle chemistry and may produce more aggressive inhalable substances. The effects of exposure to such products may be of greater concern to human health than exposure to ozone itself (Weschler, 2004).

National Ambient Air Quality Standards in the US for O_3 [Source: EPA (2003)]

1-hour average	0.12 ppm (235 µg/m^3)
8-hour average	0.08 ppm (157 µg/m^3)

Sulphur dioxide SO_2

Sulphur dioxide is detectable to the human nose at concentrations of around 0.5–0.8 parts per million (1400–2240 µg/m^3). Concentrations of SO_2 in ambient air typically occur as a result of combustion processes, in particular the burning of high sulphur fuels. In certain place the gas from vulcanoes contain SO_2 mainly. Asthmatics are generally considered the most sensitive group, other sensitive groups include those exercising. This is because SO_2 is very reactive and consequently the distribution of SO_2 along the conductive airways of the respiratory tract depends on breathing volumes and types.

National Ambient Air Quality Standards in the US for SO_2 [Source: EPA (2003)]

Annual arithmetic mean	0.03 ppm (80 µg/m^3) Primary
24-hour average	0.14 ppm (365 µg/m^3) Primary
3-hour average	0.50 ppm (1,300 µg/m^3) Secondary

Asbestos

Exposure to fibres from asbestos is limited to a maximum of 100,000 fibre particles per m^3 per year.

In Dutch regulations a building is free for use after removal of asbestos, when the particle concentration is lower than 5000 fibres/m^3 (time weighted average of 8 hours) (Dusseldorp, 2004).

Lead

Prolonged exposure can cause damage to the nervous system, digestive problems, and in some cases cause cancer. It is especially hazardous to small children.

Standard permissible risk value of lead [Source: EPA (1997)]

Yearly average	500 nanogrammes/m^3 (Dusseldorp, 2004)
Quarterly average	1.5 µg/m^3

Carbon Monoxide CO

The formation of COHb reduces the amount of haemoglobin available for the transportation of oxygen around the body. This can impact on the brain, nervous tissues, heart muscle and other specialised tissues that require large amounts of oxygen to function. As a result of oxygen deprivation, these organs and tissues may suffer temporary or permanent damage. Those most susceptible to the health effects of ambient air exposure to CO include those with cardiac disease including heart disease, lung disease, vascular disease, those with anaemia and haemoglobin abnormalities, children, and developing foetuses. Recent epidemiological studies, suggest that effects may occur at concentrations lower than indicated by toxicology (Dennison, 2000). Sources are combustion processes: traffic, heaters, tobacco smoking.

Maximum permissible concentrations for CO [Source: Dusseldorp (2004)]

Exposure period	maximum concentration
15 minutes	100 mg/m^3
30 minutes	60
1 hour	30
8 hours	10

The 8-hours outdoor levels should not be exceeded more than once a month and the 1-hour maximum outdoor level no more than once a week. Levels found in Dutch houses (Lebret, 1983, Van der Wal, 1988, information in Hasselaar, 1995a) are in the average range of 1-2 mg/m^3 (about 250 samples) but range from 0-9 mg/m^3. Hasselaar took 21 samples (1995) and found averages of 2.6 mg/m^3 (range 1.2-3.5) in the living room and 5.9 mg/m^3 (range 0-17.4) in 16 houses in Rotterdam (minute averages). Comparison between weekly averages, 8-hour averages and minute-averages is not possible. The peak levels are important and peak conditions were probably not measured during inspection visits.

Nitrogen Oxides (NO_x, NO_2)
Laboratory studies show that susceptible people, such as asthmatics who are exposed to high concentrations of NO_2, can suffer lung irritation or even lung damage. Sources are combustion processes.

Permissible risk values of NO_2 [Sources: 2 Dusseldorp (2004), 22 EPA (1997)]

Exposure period	maximum concentration
1 hour	200 $\mu g/m^3$
yearly average	40 $\mu g/m^3$ [2]
yearly average US	100 $\mu g/m^3$ [22]
Dutch regulations for outdoor air allow a maximum of:	
24 hours	150 $\mu g/m^3$
1 hour	300 $\mu g/m^3$

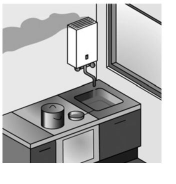


Table 3.3 Gas concentrations in inhaled and exhaled air

	Outdoor air and inhaled air		
Component	**Outdoor air (%)**	**Exhailed air (%)**	**Reduction**
N_2 inert	78,62	74,90	-4,73
O_2	20,85	15,30	-26,66
CO_2	0,03	3,60	+119,00
H_2O	0,50	6,20	+11,40
Total	**100,00**	**100,00**	**99,00**

Source: Wikipedia (accessed May 7, 2006)

Samples taken in four cities in the Netherlands (1982-1995) are in the range of 32-102 μg/m³, but range from 9-227 μg/m³ (Lebret, 1983; Van der Zee, 1994; Hasselaar, 1995). High levels are found in connection with kitchen geysers and with gas heaters that have no or poor functioning exhaust systems. Indoor winter concentrations are higher than summer conditions. Outdoor conditions can become high during heavy traffic and cold periods, when heaters produce a large volume of exhaust gases.

CO_2

Humans are emission sources of heat, carbon dioxide, moisture and other bioeffluents. The amount of CO_2 produced is related to the food intake and the activity level of each individual person. The typical CO_2 outdoor concentrations vary between 350 to 575 ppm. Concentrations in the bedroom reach maximum levels of 2,300 to 5,480 ppm. (Hasselaar, 1995a). Malcolm (1994) describes continuous measurements in inspired air during the sleep of 22 children. CO_2 concentrations as high as 20,000-30,000 ppm were observed in the prone position when the infant's head was under a blanket and when the lower face was obscured by bedding. The recommended concentration varies between 800 and 1,200 ppm, but this level is used as indicator of other pollutants than CO_2. High levels indicate stuffy air, with loss of concentration.

VOC and TVOC

VOCs, or volatile organic compounds, are chemicals used to manufacture and prepare many building materials, interior furnishings, textiles, cleaners, personal care supplies, and pesticides.). 'Volatile' is a term meaning that these chemicals evaporate easily at room temperature. If the VOC is a mixture without one or a few major compounds, we speak of TVOC or total volatile organic compound concentration.

Many VOCs are irritants and can result in headaches and eye, nose and throat irritation, and dizziness. Some VOCs are toxic. Many of these types of chemicals are flammable. The main interest is in compounds that have an effect on the reproduction system or that irritate airways and mucous membranes.

Consumer products which contribute the most to indoor VOC concentrations include mothballs (p-dichlorobenzene), air fresheners (decane, methyl

chloroform), and dry cleaning of clothing (perchloroethylene). Common VOCs in homes include formaldehyde, decane, limonene, styrene, xylenes, methylene chloride, toluene, vinyl chloride etc. Some moulds and fungi can give off VOC gases known as microbial VOCs. These VOCs are responsible for the characteristic odours produced by moulds characterised as musty or earthy.
In Dutch houses, the concentration of TVOC was 0.3 mg/m³ on average (based on Lebret (1982) and Van der Wal (1992) as reported in Hasselaar, 1995a).

A study in the UK involving the monitoring of 14,000 children even before their birth focused on volatile organic compounds that can be found in solvents, floor adhesives, paint, furnishings and cleaning products. The daily use of air fresheners (sticks, sprays and aerosols) caused incidences of diarrhoea to jump by almost a third over homes that used them just once a week. Daily aerosol use (polish, deodorant, hair sprays) resulted in about a third more health problems for babies and their mothers. Mothers were 26 per cent more likely to suffer from depression and 10 per cent more likely to have headaches (Medical News Today, October 19, 2004).

TVOC can be easily measured in the air. Results are usually compared against the following guide:

TVOC guide

Less than 0.20 mg/m³	No irritation or discomfort expected
0.20-3.0 mg/m³	Irritation and discomfort may be possible
3.0-25.0 mg/m³	Discomfort expected and headache possible
Greater than 25 mg/m³	Toxic range where other neurotoxic effects may occur

Below 0.16 mg/m³ health effects are not suspected. In the Netherlands benzo(a)pyrene is used as the marker pollutant of TVOC (Hollander 2004). The Finnish Emission Category 1 follows a different approach: a minimum of 70% of the compounds of TVOC shall be identified and the emission of carcinogenic compounds belonging to category 1 of the IARC monographs (IARC, 2006) shall be below 0.005 mg/m²h, while dissatisfaction with odour shall be below 15% (Säteri, 2003). The European Collaborative Action (ECA) Report No. 11 titled Guidelines for Ventilation Requirements in Buildings (ECA, 1993) presents a list based on Seifert's work on the ten most prevalent compounds in each of seven chemical classes (in Carrer, 2005). The TVOC concentration is calculated by adding the totals from each class. Seifert gives a target TVOC concentration of 300 µg/m³ which is the sum of the above listed target concentrations. The author also states that no individual compound concentration should exceed 50 per cent of the guideline for its class or 10 per cent of the TVOC target guideline concentration. However, Seifert states that "...the

The maximum concentrations per class of VOC [Source: Carrer (2005)]

1. Alkanes	100 μg/m^3
2. Aromatic hydrocarbons	50 μg/m^3
3. Terpenes	30 μg/m^3
4. Halocarbons	30 μg/m^3
5. Esters	20 μg/m^3
6. Aldehydes, ketones	20 μg/m^3 (not including formaldehyde)
7. Other	50 μg/m^3

proposed target value is not based on toxicological considerations but - to the author's best judgment."

Benzo(a)pyrene (BaP)
While laboratory studies show that BaP is a known carcinogen in animals, epidemiological studies have only been able to evaluate the effect of a mixture of PAHs, including BaP found in soot, tars and oils. The mutagenic effect refers to the ability of a chemical to induce mutations in DNA and in living cells. Benzo(a)pyrene is a promutagen, which means it needs to be metabolised before it can induce mutation. Benzo(a)pyrene can also react with ozone to produce strong mutagens such as benzo(a)pyrene-4,5 oxide (CARB 2006). In the Netherlands, the risk of cancer from VOCs is expressed in the concentration of benzo(a)pyrene (Dusseldorp, 2004).

Ambient air quality guideline value for benzo(a)pyrene

annual average	0.0003 μg/m^3

Benzene
The major effect of long-term exposure to benzene is on the blood. Benzene causes harmful effects on the bone marrow and can cause a decrease in red blood. With exposures from less than five years to more than 30 years, individuals have developed, and died from, leukemia. It can also cause excessive bleeding and can affect the immune system, increasing the chance for infection. Short-term exposure to high levels of benzene can cause drowsiness, dizziness, unconsciousness and death. Sources of benzene in ambient air include motor vehicle emissions and industry. Benzene is used in the manufacture of plastics, detergents, pesticides and other chemicals (Dusseldorp, 2004).

Guideline value for benzene	
annual average	10 µg/m³

Maximum allowed exposure of formaldehyde [Source: Dusseldorp (2004)]

Exposure period	Maximum concentration
30 minutes	100 µg/m³
VROM, 30 minutes	120 µg/m³
VROM, yearly average	10 µg/m³
RIVM, MRT	1.2 µg/m³

People can smell formaldehyde at a concentration between 60-120 µg/m³.

Samples taken over 8 hours in living rooms in two cities result in concentrations between 5-60 µg/m³ in Rotterdam and between 20-130 µg/m³ (no smokers) or 30-220 µg/m³ (smokers) in Den Bosch (based on Lebret, in Hasselaar, 1995a).

Environmental tobacco smoke (ETS)

Over 50 compounds in tobacco smoke are either known or suspected carcinogens. Studies using electrostatic filters have revealed that, contrary to popular belief, most of the irritation and the odour from tobacco smoke comes from the gaseous pollutants and not the particulates. Of concern are the small respirable particles that can penetrate deep into the lungs and cause acute or chronic health effects. Environmental Tobacco Smoke (ETS) has no safe exposure level. Acute and chronic respiratory effects on children have been demonstrated even in houses with occasional smoking (0.1-1 mg/m³ nicotine in the air) (Säteri, 2003). The recommended action is no smoking inside the house.

3.2.2 Acoustics

Except for hearing loss, there is no illness directly caused by noise, but noise has been identified as an important cause of physical and psychological stress, which is linked to many of our most common health problems, for instance cardiovascular disease. Noise is also suspected to interfere with children's learning. Noise is an increasing environmental problem, related to motorised traffic and mechanical installations inside homes.

Noise from houses causes more nuisance than from traffic noise (Dongen, 1993). One quarter of 4,072 respondents experiences serious nuisance from noises in the dwelling, 80% hears noise from neighbours and 26% is frequently seriously disturbed by noise from neighbours, compared to 20% serious disturbance by traffic noise. Major source of disturbance from neighbouring houses are the sound of doors, walking, radio and TV and also the drainage system. All mechanical systems in the house cause nuisance, ranging from 13-36% annoyed and 1-6% seriously annoyed. About 30% of occupants are disturbed by noise from a fan in their own house, when mechanical ventilation is applied. A smaller part is seriously annoyed, but it is not clear how many are not annoyed because they turned the system down or off, thus preventing the nuisance. (Bond, 1996; Dongen, 1993).

About 95% of the Dutch population is exposed to levels above the no-effect level of 40 dB(A)/24 hours (RIVM, 2006). The Dutch Health Council suggests a threshold level for nuisance of 42 dB(A) and the WHO chooses 50 dB(A). In general the well-being of occupants indoors is affected at 35 dB(A) indoors in the daytime, 30 dB(A) at night and 50 dB(A) outdoors. Clinical effects such as damage of the hearing function, hypertension and heart disease occur above 65 to 70 dB(A). Sharp values between effects are not known. Self-reported sleep quality is below an exposure of 40 dB(A), awakenings occur around 55 dB(A) but certain sleep stages require 35 dB(A) (Gezondheidsraad, 2004). Dusseldorp proposes limit values of 30 dB(A) for technical noise from inside and outside the house during the night and 35 dB(A) in the daytime or with open windows (day and night) (Dusseldorp, 2004). Leidelmeijer (1997) revealed that the 'heaviness' of the insulation has poor predictive value of the individual noise annoyance from neighbouring dwellings, but percentages of affected people fall in proportion to the measure of the insulation. Leidelmijer claims that further scope for reducing noise annoyance by behavioural changes and raising tolerance levels is limited. In many cases, the annoyance is difficult to prevent in terms of building quality (Leidelmeijer, 1997).

3.2.3 Comfort

Criteria for an acceptable thermal climate are specified as predicted mean vote (PMV) and percentage of people dissatisfied (PPD), or PMV-PPD. Basis is the operative temperature (air and mean radiant temperature), air velocity and humidity and local thermal discomfort (draught, mean air velocity, turbulence intensity, vertical air temperature differences, radiant temperature asymmetry, surface temperature of the floor). The reference temperature for Dutch houses is the required temperature levels of 1960: living room 20°C, bathroom 22°C, kitchen 15°C and other rooms 12°C. Bedroom temperature requirements increased stepwise from 12°C to 16°C to 18°C, while in modern houses 20°C is normal.

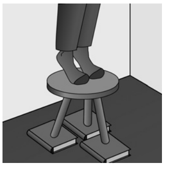
Table 3.4 Hazards and conditions

Health/safety hazards	Conditions
Risk of falls, cuts, bruises	Design and layout, disrepair, structural stability, lighting, obstructions
Fire and smoke safety risks	Fireproof separation, fire precautions, smoke detection, means of escape
Burn and scald hazards	Design and layout (kitchen), heating systems and controls, disrepair
Electric shock	Disrepair (services etc), outlets, electrical heaters
Injury from doors and windows	Design and layout, disrepair (architectural glass), lighting
Kitchen safety	Kitchen facilities, sink etc., water supply, design and layout, disrepair

Optimal relatieve humidity ranges supposedly are between 45 and 65%, while the range 30-70% is expected not to cause comfort problems. In maritime climates the summer RH levels are often well above 70% RH. Higher levels cause higher emissions of formaldehyde and more house dust mite and mould problems. Lower levels are associated with dry mucous membranes. The effect of irritating substances in (even) humid conditions are often perceived as ‘dry air’ (Boerstra, oral communication at SBR, 2005).

3.2.4 Safety

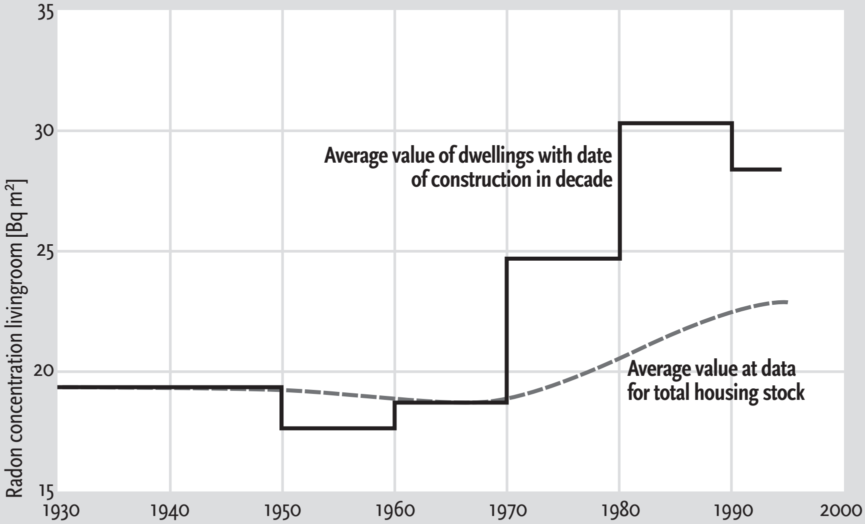
Safety hazards can result in injury. Regulations are effective in the prevention of collaps, fire, electrocution, water pollution, falls from high levels (see Table 3.4). The ‘default’ occupant is a person who is vulnerable to the characteristics of the house. Falls account for roughly 50% of all domestic accidents, many fatal and affecting the young and the elderly especially (Ormandy, 2003).



Lighting
Daylight and lighting make obstacles in circulation areas visible. Good lighting supports safer use of stairs. The required overall luminance is 200 lux, with higher levels at (local) work desks (lux = lumen/m^2). The lighting level requirements increase when getting older, with 500 lux at work desks for the elderly, while 300-400 lux is sufficient for the young (Bommel, 2003). Exposure to clear morning light supposedly regulates sleep patterns and reduces mental retardation. Outdoor levels in the daytime are in the range of 2,000-10,000 lux.

Ionizing radiation
Ionizing radiation is radiation in which an individual particle (for example, a photon, electron, or helium nucleus) carries enough energy to completely remove an electron from its orbit. These ionisations can be very destructive to living tissue (dictionary at www.laborlawtalk.com, accessed Sept. 26, 2005). Examples are the use of x-rays for medical research and radon. Epidemiological studies of miners exposed to high levels of radiation have defined the dose response relationship for radon-induced lung cancer at high exposure levels. Extrapolation of this data has been used to estimate the excess risk of lung cancer attributable to exposure at the lower levels found in homes. These estimates indicate that radon is an important cause of lung cancer even at its ‘natural’ concentration in soil and building materials. The WHO considers

Figure 3.1 Average radon concentrations in Dutch dwellings built in different periods



Source: Stoop (1998)

10% of lung cancer worldwide to be caused by radon. Radon gas changes into a particle or attaches onto another particle that, while inhaled, can deposit on lung tissue, where the radiation increases the risk of lung cancer. People with damaged lung tissue or reduced particle removal function of the airways (smokers, COPD patients) have a higher risk of lung disease from radon than healthy people. The 'Unit Risk' as defined by WHO (the probability of excess cancer for lifetime exposure to 1 Bq/m³) is estimated to be 3-6 x 10-5; this means that a person living in a house with 50 Bq/m³ has a lifetime lung cancer excess risk of 1.5-3 x 10-3. The WHO proposes a maximum radon (including thorium) level of 100 Bq/m³, which seems pragmatic, taking high ambient levels in certain countries into account. The Dutch government prposes a limit of 20 Bq/m³ in the indoor environment, to be reached by 2015. This Dutch level is based on Permissible Risk Levels of 1 mortality case per million population per year. The Dutch preliminary proposed standard (VROM, 1993) is 0.65 mSv/y. This standard combines the exposure to radon with exposure to gamma radiation (expressed in millisieverts/y) (1 Bq/m³ = 25 x 10^{-3} mSv/y. The outdoor level is about 3 Bq/m³ and indoor concentration range from 8-100 Bq/m³, depending on the ventilation efficiency and the buildings materials used.

Radon concentration in Dutch dwellings
In 1995 and 1996, radon concentrations and effective airflows were measured in about 1,500 Dutch dwellings built between 1985 and 1993 (see Figure 3.1). The increase is alarming and the Dutch government decided to set a goal of 20 Bq/m^{-3}.

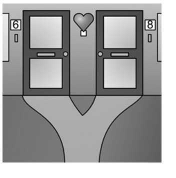
Non-ionizing radiation
Non-ionizing radiation refers to electromagnetic radiation that does not carry enough energy to ionise living material. Visible light, near ultraviolet, infrared,

and radio waves from mobile telephone antennas are all examples of non-ionizing radiation, though visible and near ultraviolet can also ionise some molecules. The health effect is still debated, but because exposure levels increase, a precautionary approach is suggested by the Health Council of the Netherlands Gezondheidsraad, 2000). The Dutch health council takes thermal effects into account and suggests to limit increase in body temperature due to radiation with 1°C maximum. The Specific Absorption Rate (SAR) in Watt per kilogramme of body mass (W/kg) is the measure for thermal effects. Exposure during 20-30 minutes to SAR = 2-4 W/kg results in 0.1-0.5°C increase in body temperature. The maximum exposure is set to 4 W/kg. Taking more precaution for professional exposure, the limit value of SAR = 0.4 W/kg and for the general population SAR = 0.08 W/kg is suggested (Gezondheidsraad, 2000). These references are precautionay, as no evidence on health aspects is available.

3.2.5 The social environment

The social environment has influence on heart rhythm, blood tension, cholesterol, immune reactions and coping with stress. Unsafe feelings, isolation, discrimination and lack of support are indicators of these health effects. Stress, slower wound healing and poorer sleep efficiency were measured as effects of social isolation (Cacioppo, 2003). Social isolation is a potent but little understood risk factor for morbidity and mortality and its negative consequences are most profound among the elderly, the poor and minorities. Improvement in personal capacity and network expansion is correlated to less loneliness (Dijkstra, 2005).

Unsafe feelings are more prevalent in larger cities. On average, 25% of the Dutch population know places they will avoid frequenting at night, 8% are afraid of being robbed or molested, about 6% perceive a high chance of burglary and more than 3% feel unsafe in their home. In the four largest cities, these percentages are 42% (places to avoid), 18% (fear of robbery), more than 9% (burglary) and 5% (unsafe at home) (VROM, 2003).



Overcrowding
Overcrowding has been an indicator of poor housing conditions and health risk for ages. In the Netherlands, overcrowding is a problem in the large cities and mainly among immigrant groups. Poor immigrants and refugees crowd with many people a apartments to share cost of living. When questioned, the occupants will deny this is a permanent situation: uncles and nephews visit the family all the time. Overcrowding is often connected with poverty: a larger group of people sharing a house to save on cost of living. Overcrowding is related to the number of showers, washes, use of water for cooking and moisture emission by perspiration, creating a higher moisture level and the associated problems of bioallergens (Office of the Deputy Prime Minister, 2004a).

Table 3.5 Inventory of indicators

Theme	Aspect	Agents, conditions	Indicator	
Air quality				
Microbial material	Emissions from crawl space	Smell, mould, moisture	Air tightness of separation above crawl space	1
			Ventilation of crawl space	2
	Vegetation	Pollen	Pollen producing trees in neighbourhood	3
	Industrial or agricultural and Neighbour activities	Smell from outside, decaying material, sewers	Smell from industrial activities and traffic	4
			Smell from neighbours	5
			Distance of air inlet and exhaust	6
	Sunlit rooms	Microbe reduction	Period and level of direct sunlight	7
	Biological agents	Mould, bio-effluents, pet saliva and dander, viruses, microbes, house-hold waste, sewage system emission	Visible mould	8
			Permanent wet wood from leakage or condensation	9
			Mould risk in construction, on basis of smell and type of construction	10
			Surface material of cold surfaces, indicator for mite and mould	11
			Deposited dirt in inlet openings and supply air ducts	12
			Occupancy load of persons and pets	13
			Pests	14
Chemical emissions	Fuel burning appliances	NO_2, CO, SO_2, fine dust	Use of un-vented geyser, heater, oven	15
			Fireplace, wood burning stove, grill or barbecue indoors	16
	Emissions from road traffic	NO_2, CO, VOS, fine dust	Exhaust gases	17
			Aerosols (fine dust)	18
	Emissions from construction materials	Formaldehyde, Radon, asbestos, benzene and other VOC	Emissions from chipwood, multiplex, mineral wool, glues	19
			Emissions from concrete, soil, other building materials	20
			Tear and wear from asbestos containing materials	21
			Emission from adjacent garage of workshop	22
	Pollutants from occupant activities	Fragances, additives in detergents, alcanes and many other VOC, formalde-hyde, fine dust and smell	Smell from cooking	23
			Air refreshers, smell from hobby-activities	24
			Tobacco smoke	25
			Emission from use of Cleaners, pesticides	26
Ventilation	Ventilation services	Dilution and removal of air pollutants of all kinds	Contribution of uncontrolled infiltration and cross ventilation	27
			Inlet capacity per room	28
			Exhaust capacity per room, incl. kitchen, bathroom, toilet	29
			Circulation quality	30
			Peak ventilation services	31
	Controls	Removal of peak levels and basic levels of all kinds of pollutions	Controls of natural inlet, circulation and exhaust	32
			Controls of mechanical inlet and exhaust services	33
			Control and capacity of peak ventilation services	34
			Quality of ventilation in bedroom during sleep	35
Hygiene	Sanitation and cleaning	Removal of allergens, disease vectors and chemicals	Dust pockets, dirty bio-container or dirty waste basket	36
			Cleanliness of surface materials, furniture	37
			Cleanliness of air inlet systems and inlet air ducts	38
			Upkeep of fan capacity by cleaning and adjustment	39
Acoustics				
	Acoustic level of ambient sources	Social and technical noise	Heavy traffic, commercial and recreational activities, frequency, level and period	40
	Acoustic level of appliances	Technical noise	Elevators, doors, containers, shafts (collective services)	41
			Noise of drainpipes, appliances including fans, water conduits, door	42

Theme	Aspect	Agents, conditions	Indicator	
	Noise from neighbours	Social noise	Noise through walls and floors and ceilings	43
			Indirect noise through windows	44
Thermal comfort				
Tempera-ture and air velocity	Extreme temperatures	Perceived nuisance of extreme indoor temperatures	Living rooms without proper heating (lower than 16 °C)	45
			Rooms with extreme and disturbing warm temperatures	46
	Temperature differences	Nuisance of extreme discrepancy	Insulation quality of envelope of heated areas	47
			Single glazing and large cold surface area's	48
	Draught	Nuisance of turbulence and temperature difference	Air tightness, sealing, construction details	49
			Location and height of air inlet opening above the floor	50
			Surface area of windows	51
			Distribution quality of heating system	52
Light	Daylight	Visibility, day-night cycle	Exposure level to sun and daylight inside the house	53
Safety				
Functio-nality and userfriend-liness	Privacy	Undisturbed personal space	Size and orientation and access to private outdoor area	54
			Quiet place for activities and rest with individual privacy	55
	Access to other levels	Safe access to other levels	Functional safety ramps, steps and stairs	56
			Hand grips and support between levels	57
	Access on same level	Safe access and enough space to move around	Safe layout of kitchen	58
			Safe circulation areas, lighting and free from obstacles or glass panes	59
			Roughness of wet pavements and floor surfaces	60
	Functionality	User safety and ergonomics, fresh air	Safety and ventilation of occupied attics or basements	61
			Ergonomic furnishing of place for study, work or hobby	62
			Peak exhaust of substances of activities anywhere	63
			Daylight for safety	64
	Domestic water quality	Safe drinking water, aerosols not contaminated	Temperature of stagnant cold water system really cold	65
			Temperature, volume and flush rate of water system	66
			Lead pipes	67
	Warning of hazards	Automated warning systems, control features	Smoke detector	68
			Emergency exits	69
			View on outside area in front of entrance door	70
	Protection trespassing	Safety against burglary even with open inlet of air	Level of protection with open and closed doors and windows	71
Social quality				
Service for care of health needs	Access	Easy and safe circulation in-out, fast access for emergency helpers	Access of house and rooms on wheelchair and personal lift	72
			User friendliness of house with wheelchair or roller support	73
			Parking location of plugged-in electrical powered cart	74
	Flexibility	Adaptation of house to needs	Extra space for services in support of mobility impaired	75
			Even floor access to bathroom and toilet from bedroom	76
	Social network	Information on health needs, help when urgent, prevention of loneliness	Social support during crisis and when in need of help	77
			Two-way visual contact with neighbours	78
			Interaction with neighbours, children disturbing	79

Source: Hasselaar (2005)

3.3 State-of-the-art indicators

In this section a list of indicators is presented that reflects the state-of-the-art indicators at the start of the development process of the Healthy Housing Checklist in 2004.

Indicators make complex phenomena accessible, so that the information can be communicated. Environmental health indicators must meet the following criteria (as reported by Goldman 2004):

- simple and one item;
- measurable and comparable, quantifiable and rankable;
- defensible;
- understandable and able to access information in a usable form;
- credible and from 'unbiased source', best science;
- comprehensible;
- actionable;
- responsive to local needs;
- reflective of societal values on environment and health (Goldman, 2004).

The structure of the list of indicators is similar to the structure suggested by the Dutch Ministry of Housing, Spatial Planning and Environment (Bergs, 2002; Nieman, 2004). The list of indicators is presented in Table 3.5. The indicators in this section reflect the state-of-the-art of indicators in the Netherlands in 2004. The list forms the starting point for the research presented in the next chapters.

3.4 Conclusions

3.4.1 Conclusions of Chapter 3

The research question of this chapter is: *What is the state-of-the-art knowledge about housing and health?* Chapter 3 is the last chapter of Part A, and connects definitions, instruments and methods with literature reviews on quality references for housing. The references are presented in the form of performance levels for air quality (biological and chemical agents), acoustics, comfort, safety and include some explorations on social quality.

Quality references are retrieved from widely accepted sources applicable to conditions in dwellings. Limit values apply to healthy adult people. The safety margin (typical 10% of proven effects) does not account for people who are affected by concentrations as low as 0.1% of concentration applicable to healthy adults. In general, little is known of the specific dose-effect relationship in the home environment. This means that the reference qualities are not very reliable, but the best available.

Table 3.6 Topics of the list of indicators

Parameters	Agents or conditons creating health hazards
Air quality	Mould and biowaste
	House dust mite
	Pollen
	Smell, bioeffluents
	Bioeffluents
	Legionella bacteria
	PM2.5, NO_2, CO
	VOCs, benzene, benzo(a)pyrene
	Fuel-burning exhaust
	Formaldehyde
	Ionizing radiation
	Asbestos
Acoustics	Ambient noise
	Technical noise
	Social noise
Comfort	Extreme temperatures
	Radiant asymmetry
	Draught
	Extreme relative humidity of air
	Light and view
Safety	Personal injury: falls, cuts, bruises
	Scalds, burns, shock
	Poisoning
	Suffocation
Social quality	Trespassing
	Privacy
	Personal safety

The cornerstone of the indoor environment is air quality. Traffic and certain industrial plants and indoor smoking contribute most to the particle burden with unknown chemical composition, while indoors it is mainly tobacco smoking and in some cases the use of biofuels. Traffic and industry together with open combustion systems in some houses cause a high level of NO_2, which is directly linked with respiratory problems. The effect of noise on health differs per person and research evidence ranges from 'effect not clear' to 'influence on heart disease and mental health'. Water pollution and ionizing radiation are important for large regions in Europe, but are less important for the Netherlands.

Criteria in the Dutch Housing Act, including the Building Decree are not strict or missing for existing buildings and leave certain indoor problems unresolved by legal means, for instance noise, poor insulation (thermal bridges), low ventilation volumes and poor means of control, poor prevention of burglary, heaters with emission of exhaust gas indoors, steep stairs and other features that induce the risk of personal injuries and comfort (overheating). Also, only few reference qualities for biological and chemical agents are available for indoor conditions in homes. Certain safety requirements for existing houses are left to the responsibility of private owners or the tenant, however, with legal background from civil law to prevent damage or injury.

The list of indicators covers the traditional aspects of air quality, acoustics, comfort and safety. Comfort is important to understand behaviour and perception, but provides only a few indicators,. Social quality is added to include attention to privacy, help and support for the health needs of the growing elderly population. The topics of the list of indicators are presented in Table 3.6.

3.4.2 Conclusions of Part A

Part A begins with an introduction to health and housing, to the discipline of environmental health and to the historical context of shifting paradigms from bacterial diseases to lifestyle-related disease today. Environmental health is a complex phenomenon that includes quantitative aspects such as exposure to pollutants and hazardous physical conditions, but also qualitative aspects such as health perception. The three main topics of the research are introduced: occupancy, performance of houses and health hazards, with focus on physical building properties and on the user patterns of the house by occupants. Human health is not studied directly. The preoccupation is with the housing stock and housing features that can be observed and measured. Data for the research are collected through experiments, fieldwork, interviews and observations. The analysis of data is both quantitative and (integrative) qualitative, making this PhD thesis an exploratory study.

The boundaries of the research are:

- the building construction discipline: design and construction, maintenance and renovation;
- the environmental sciences: sources, transport and concentration of agents;
- the human-environment dialogue: occupant use of the house, interaction with technical services;
- the institutional context: ownership, participation, responsibilities and communication.

The research focuses on markers, selected from a large variety of building features and occupancy characteristics with the power to summarise or represent the emission, concentration and exposure to agents and risk conditions. This study is the search for robust indicators.

The four theoretical frameworks provide a theory of indicator selection (the source-emission-transport-concentration-exposure-effect or DPSEEA framework), of performance measurement (system theory, the input-throughput-output-outcome framework), communication (sender-receiver-feedback of messages) and occupancy, with the topics learning, self-efficacy and action towards improvement of environmental conditions and towards change of behaviour. Theoretical explorations lead to the main model of relations in the research, that is used to position the different fields of attention of the house, the occupants and health issues. Chapter 3 presents literature reviews on performance quality and the state-of-the-art indicators.

Part B
Practice

4 Occupancy and occupant behaviour

4.1 Introduction to Part B

Part B constitutes the specific contribution of the research to new knowledge about occupancy and physical housing parameters: the information is based on the practical experience and data collection by the author, especially on technical features of houses. The chapter on occupancy reconstructs field observations and presents a qualitative analysis of the motives, the capacities and the experience of occupants in dealing with their house.

Part B has three chapters: on occupancy, on the physical aspects of houses and on model parameters. The main source of information is the dataset based on home inspection reports, and observations of occupancy and how occupants interact with home owners and housing managers. Chapter 6 on physical conditions follows the structure of the list of indicators: biological, chemical, physical and mental hazards. Chapter 5 and 6 present the basics for model construction in Chapter 7. The result is a series of exposure models in which different parameters interact. These relationships show the importance of specific parameters that point out indicators. Parameters of air quality are studied in greater detail, because many field data are available on mould, house dust mite, aerosols and legionella. These data allow validation of selected indicators of air quality.

4.2 Introduction to Chapter 4

4.2.1 Research question

In housing the occupant is polluter, actor and subject: emitter of bio-effluents, actor in control of the indoor environment and subject to the health hazards involved in using the house. In this chapter, we view the triangle housing - occupants - health in the model of performance evaluation from the occupants' perspective. Occupancy is an important parameter of healthy housing, yet only few studies focus on occupancy in relation to health. We know how many people smoke or have asthma, not in how many houses someone smokes in the presence of someone with asthma. Studies on ventilation, on mould and moisture problems often point out the important impact of behaviour without analysing how this behaviour is influenced by the qualities of the building. When innovative building concepts do not perform as required, the analysis often stops with the conclusion: occupant behaviour influences the performance. This problem definition leads to the research question: *How do occupants use the house?* We describe how much moisture is produced, how occupants control heating and ventilation and what is done to prevent conflicts with the indoor environment. Table 1.4 highlights the relationship between this research question and Chapter 4.

4.2.2 Data collection and analysis

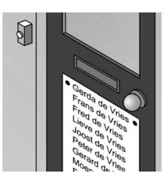
The analysis focuses on reported and observed user patterns rather than on perception or lifestyle: number of people present, the number of showers and laundry cycles, etc., the use of heating and ventilation. Some data is precise, e.g. the number of occupants, while much data is qualitative, e.g. the control of the ventilation volume. Visual inspection of the house and interviewing the occupant revealed much of the actual conditions. When occupants are asked to picture how they use inlet openings and temperature setpoints in the heating season, many show no problem in recollecting the conditions in different seasons and tend to give clear answers to questions relating to occupancy and user behaviour in the critical climate conditions. Also, the inspection protocol enables double-checking to avoid misinterpretation of information given by the occupants.

Literature reviews support the understanding of occupants use of the house and include the following topicss: sleep, universal design, safety hazards, effects of noise, understanding of technical appliances for ventilation of climate control, comfort needs.

4.3 Occupancy

Occupancy and number of rooms
The occupancy level is associated with concentrations of all kinds of pollution caused by human activity in the house and with privacy. Also we can think of impact on social interaction, risk of loneliness, positive feeling of security against trespassers. The occupancy in the dataset is 3.36 people per dwelling on average (for the housing stock in the Netherlands 2.31 in 2004 (ABF, 2004, accessed on http://www.abfresearch.nl, July 20, 2006). The main reason for the difference is probably the selection of the houses: higher occupancy leads to more indoor environmental problems. This difference does not need to cause bias: the dataset is used to select indicators, not to draw conclusions for the housing stock of today.

High occupancy is defined as more than one person average per room. High occupancy is found in 17.5% of the cases, more in rented houses than in private houses. Rented houses have both a smaller number of rooms and rooms with smaller dimensions than owner occupied houses.



The newer the houses, the lower the occupancy, with a smaller number of children. However, the 333 dataset show only a gradual difference. About 43% of households in the dataset have children younger than 12 years: a sign that this period in the household career presents many environmental hazards and that relatively young people with children are active in understanding and trying to solve problems. The average period lived in the house at the moment of inspection is 6.7 years. In the rented houses this period is 6.4 years. This outcome is influenced by the number of new houses in the dataset. For houses 25 years and older (45% of the dataset) the household had lived an average 9.5 years in the house. The period already lived in the house is positively correlated with the number of rooms.

Pets

In almost half of the households of the 333 dataset we find pets, in almost all cases with soft fur or feathers. Higher occupancy is related with more pets. Parents like to bring their children in contact with pets. The combination of pets and children will result in higher pollution levels. Pet keeping is more obvious in single-family houses than in apartment buildings.

Smoking

Heavy smoking results in complaints about undefined bad smell or foul air and insufficient ventilation, even from the smokers. In 40% of the houses of the 333 dataset the occupant or visitor smokes. The smokers in the dataset smoke an average of 5.5 cigarettes a day in the house, 15% of the smokers smoke 15-30 cigarettes per day. Smoking correlates with keeping pets (with hairs or feathers, n=180) and more smokers live in rented houses (n=178) than in owner-occupied houses. Smoking has no correlation with building type and number of occupants. In households with children <12 years 20% is smoking. A significant correlation between number of cigarettes smoked and having children is not found. In about 6% of houses with small children the pollution load of 15-30 cigarettes per day is produced. In houses without report of someone with respiratory problems 55% has someone smoking (n=64), in houses with a reported respiratory patient 56% has someone smoking (n=43). There is no exposure threshold to the hazards of tobacco smoke, which means that the indicator of smoking is anyone smoking indoors.

4.4 Occupant behaviour

4.4.1 Moisture production

Bathing

Since showers became widely available in the 1950s, the habit of washing at the washbasin changed into taking a bath or a shower, at first one or twice a week, but in the 1990s daily showering became customary. Showering twice a day is not considered an extreme lifestyle any more. Positive effects of a shower are warming up, refreshing by removing waste material from the body through the skin and receiving a soft massage. We smell different and the skin feels smoother. Negative effects increase with frequent showering. The protective flora of bacteria that is normal for the skin can be destroyed, especially when soap is used, and more harmful bacteria have a chance to grow. Many cosmetics to replenish the skin and put on a protective layer contain harmful solvents. A damaged skin gives free access to bacteria, materials and gases. Apart from this direct health effect, showering produces moisture indoors which indirectly affects dampness and higher risk of mould growth and a high concentration of house dust mite allergen.

Experimenting resulted in the moisture production per shower. Drying the skin of an adult loads a towel with about 100 cm^3 of water. The wet surfaces in the shower cubicle represent 200-300 cm^3 of water and without cubicle the amount of water left behind to evaporate may result in 500 cm^3 of water per shower of 3-6 minutes. The amount of water in the warm and humid air in the bathroom is only 100-130 cm^3. The absorbed water content in absorbing surface materials is quite low, due to several layers of paint, found in most bathrooms. The estimate for absorbed water per shower in materials is 50-150 cm^3 of water, depending on the surface material and area. One shower leaves a total of 500 to a maximum of 1,000 cm^3 of water in the bathroom that will evaporate into the indoor air. Stripping the water from tiles after a shower is quite effective against the moisture load, because 100-200 cm^3 can be drained. Drying the tiles in the shower with the towel prevents mould growth and hanging the towel to dry outside reduces the moisture load with 150-200 cm^3.

In one third of the dataset (n=333) the number of showers is more than 20 a week (on average three or more showers a day). In almost 20% of the houses the number of showers is 4 or more a day, the maximum in de dataset is a bathroom with 8 showers a day. The number of showers is related to the number of people over a certain age in the household, and one shower per person per day.

Half of the bathrooms also have other moisture sources: laundry drying is the most prevalent source.

Laundry

Each kg of laundry dried within the house can release 500-700 cm^3 of moisture, depending on the size and speed of the spinner in the washing machine. A filled washing machine contains about 4.5 kg of laundry and this load produces 2.3 to 3 litres of moisture. The moisture load indoors depends on the location of laundry drying and the equipment used. First we have the difference between drip dry (hand wash) and from the spinner (machine wash). Drying on washing lines means releasing the moisture into the indoor air. A dryer with exhaust duct will remove the moisture from the indoor area. Some condensation dryers are well-sealed and release water into the sewage systems, other (cheaper) types release damp warm air and create a peak moisture load. The estimate is emission of 10-35% of the moisture of a wash load in the indoor air, and up to 100% when exhaust air is emitted indoors. This means that the moisture production of one shower is roughly equivalent to the moisture production of one (dry) kg of laundry dried indoors and one machine load the moisture equivalent of three to four showers. The frequency of the washing cycles is not related to the number of occupants, but is related to lifestyle and also to number and age of children. Lifestyle creates large differences: some households with four people use the washing machine every day, others twice a week.

About one quarter of the households dries laundry outside, or with exhaust dryer. A quarter uses the attic or a separate room, 18% uses the bathroom for drying on racks and in the condensing dryer and 32% dries the laundry in the living room, stairwell, etc. (n=254). The frequency of laundry drying is:

- 23% with 0 or 1 wash loads per week (n=169);
- 47% with 2, 3 or 4 wash loads per week;
- 30% with 5 or more wash loads, and about 20% has 6-7 wash loads a week (daily washing).

Vapour pressure differences will cause moisture to move from a location with high pressure to locations with lower pressure, in general these are cooler places. Peaks in one room are followed by peaks in other rooms, with a time delay of less than one hour.

Plants

Plants are in most houses of the 333 dataset few in number and small in size. Bedrooms generally do not have plants of substantial size. The effect on indoor climate is minor: some negative effects such as emission of moisture (less than 500 cm^3/day in the house) and from mouldy soil and some minor positive effects of absorption of gases and deposition of aerosols. An occasional 'greenhouse type vegetation' is encountered, with a moisture production of more than 2 or even 3 litres a day. The effect of air cleaning and oxygen production is of little importance compared to the effect of ventilation. The main quality of (healthy) plants seems to be the identity they give to rooms, creating more privacy and more variety in space, colour and texture and better acoustics.

Aquarium

Only in a few cases we found an aquarium. A fishbowl and a tropical aquarium with a top (for lighting) emits a minor amount of moisture: less than 50 cm^3 a day, depending on the quality of the lid and the water surface area. In damp houses a tropical aquarium has a positive effect on the indoor environment, because it is a low-temperature heater: the temperature of 23-25°C sustains a constant temperature in the room, which reduces moisture problems, provided there is enough ventilation. There is some legionella risk: the temperature allows legionella growth and the aerator creates aerosols that could be inhaled when the lid is taken off the aquarium.

Cooking

Cooking habits changed in two generations from using organic food to fast growing industrial food, from wood or coal burning stoves and kerosene heaters via gas burning equipment to radiation heaters and microwave ovens. Food of the season became any food available in the world and more exotic cooking styles introduced a variety of cooking methods: the wok, the grill, steaming. The air pollution from heaters and ovens is replaced by electromagnetic radiation. Fast cooking (microwave) reduces the emission of substances, especially greasy aerosols. European cooking habits tend to produce more organic aerosols, while Mediterranean styles tend to produce more moisture. Data is collected on the cooking frequency and for how many people someone cooks. However, this information does not provide much insight into pollution levels. The variety of food prepared and equipment used makes it hard to use the cooking habit as indicator of indoor air pollutants and risk of injury. In the 333 dataset less than 2% of the households cook two or more hours a day. In general, cooking takes a maximum of 45 minutes for the warm meal and altogether less than one hour a day: 3-4 hours a week for a small household and 6-8 hours a week for a large household.

The health risk indicators of cooking are:

- the use of gas ovens (or other fuels that emit into the indoor environment);
- the number of people cooked for (as indicator of time per day and emission load);
- the type of kitchen (as indicator of exposure level);
- the ventilation system (exhaust function, peak transport).

Moisture production

In this section the moisture production by occupants is summarized. A moisture scenario is presented, based on a household with two adults and three children. The activity schedule: the male and two children take a shower in the morning, the female and the youngest child in the evening. The male leaves the house at 08.00 hrs and is back at 17.30 hrs, whereas the children arrive from school at 15.30 hrs. Preparation of the dinner takes place between 17.30 and 18.00hrs. Between 18.00 and 20.00 hrs the family is at home for dinner, washing dishes and having tea. Bedtime is between 20.00 hrs (for the youngest child) and 23.00 hrs for the adults. The combination of moisture production and this activity scenario results in the moisture production schedule over a 24 hour period and per room (see Table 4.1).

The moisture production in this scenario is high in the living room, because of five people present, in the bathroom and circulation areas including attic. This mechanism causes moisture to move from warm to cooler rooms, and the load in the attic and in bedrooms is likely to be even higher than the table is showing. These data are input for the moisture balance in Section 6.3.

Table 4.1 Moisture production in cm³ by occupancy of a five person household over a period of 24 hours (based on experiments and estimates by author for one specific scenario)

Moisture production per activity	Living room	Kitchen	Bedroom I	Bedroom II	Bedroom III	Bath-room	Attic/ hall
Sleeping 8 hours (2, 1, 1, 1 person)			640	400	200		
Shower 2x morning						570	
Washing at washbasin 1x						60	
Tea making, use of water cooker	15	15					
Cleaning floor and using kitchen sink	80	160					
Watering plants (2x/week 1,500 cm³)	500						
One person present 08.00-16.00 hrs	600						
Laundry 4 kg						30	
Drying in attic							2000
Hand wash 0.3 kg						50	
Drying 0.3 kg on door rack						100	
Three people 16.00-18.00 hrs	450						
Cooking between 17.30 and 18.00 hrs		500					
Five people 18.00-20.00 (23.00) hrs, dinner	1,100				100		
Dishwashing 19.00 hrs, coffee, tea 20.00 hrs	20	200					
Two wet coats in hall							300
One shower around 21.00 hrs						400	
One bath at 22.00 hrs						300	
All wet towels in bathroom						200	
Production by occupancy	**2,765**	**875**	**640**	**400**	**300**	**1,710**	**2,300**

4.4.2 Use of technical services

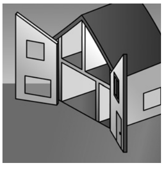
Ventilation

The following remarks are based on observations in 600 houses. Occupants in general do not know how much air change is required and how well a ventilation system works. They tend to overreact: the window is opened widely after sensation of bad smell, but closed again after a short while. Permanent ventilation is problematic when this function is associated with noise, draught or cost of electricity and heating. Air quality problems tend to increase after infiltration is reduced. Maintenance of mechanical systems is often poor, causing major reduction in capacity and also more noise production. The better the inlet functionality, especially in fine-tuning of the inlet capacity, the better the openings are used. Line inlet grates are the best used inlet openings in the winter. Larger openings like sash windows or one-sided hinged windows are used for flushing, for 15-30 minutes a day in the winter period. Larger windows cause draught, rain may blow indoors and they allow burglars to trespass.

The circulation of air and especially sensation of draught stimulates closing of the inlet opening near the location of the sitting person. Higher indoor temperature can reduce the feeling of discomfort, but higher temperatures increase the problem of draught, due to larger temperature differences with fresh air.

Fear of draught while in bed is often a reason for sleeping with closed inlet openings. Poor circulation in the houses is in the first place the effect of low exhaust capacity, and in situations where the stairwell does not act as a large duct with stack effect. The second major reason is tightness of separating doors which reduce the exhaust function of individual rooms.

When separating doors are kept open with closed inlet openings, the risk of condensation increases. This effect is poorly understood. Cross-ventilation and flushing are well-understood, implying that problems may occur mainly in airtight houses and in houses without large line inlet grates. The large seam length of large windows and doors in two opposite façades in older houses provides enough 'basic' uncontrolled ventilation to prevent smell and dampness. The living room does for that reason not receive much attention regarding active ventilation, but does not present major indoor air problems either. In 56% of the cases (n=109) the grates, flaps or windows stay closed in the heating season. In the master bedroom 43% does not ventilate in the winter season, 57% has a small or large grate, sash or hinged window open for a longer time each day. In 82% of the master bedrooms 2 people are sleeping. There is no difference in ventilation behaviour between one or two people sleeping in the master bedroom.



Mechanical ventilation with individual control is often kept on the lowest setpoint. Collective systems provide the 'norm' value 24 hours/day. New mechanical systems tend to be used longer and even for 24 hours, but this habit is likely to change within one year after new installation.

Of the houses with mechanical ventilation (58%, n =324) 14% has turned the system off for 23-24 hours a day. Of the 86% that uses the system, the lowest setpoint is on for an average period of 17 hours a day, the highest setpoint on average for 7 hours a day. This includes collective systems without individual controls. Individual systems are switched on to a high set point for a relatively short period per day. If we take account of the low capacity, then the mechanical exhaust system does not control airflows in the house. The nominal exhaust capacity is between 42 and 63 dm^3/sec, while around 9–15 dm^3/sec is the practical value, considering the period of use of the lowest setpoint. The poor use has three major reasons: 1) the occupants are convinced that the system does not function properly, 2) the system makes too much noise on higher than the lowest set-points and 3) the system uses electricity, which can be avoided by applying natural cross-ventilation instead. Of all cases with mechanical ventilation 21% has a mechanical cooker hood, in houses with natural ventilation this is 18%. In rented houses a cooker hood is often not allowed and in combination with mechanical ventilation often not feasible. The cooker hood is used during cooking, for a maximum period of 45 minutes per day.

Heating
Of cases with central heating (records of n= 134), 27% heat all the rooms, 51% only the living room and occasionally one bedroom, 16% maintains a very low average temperature, for instance because these people prefer a cool indoor climate, or to save energy costs. About 5% of these houses are sparsely heated because the occupants spend little time at home. About 14% heat the living room during the night, and of this group, one third also heats the bedroom at night. About 80% do not heat the bedroom during the night.

4.4.3 Activities

Use of the living room
The living room represents the myriad of functions that we like to identify the house with. But the exposure time to the environment in the living room can be quite short compared to the bedroom or a study: varying from 10 to 60% of the time spent at home. The living room is the best-preserved environment in the house: clean and well-furnished for visitors, heated and often cross-ventilated through openings in two façades, with sun pouring in through large windows. The household spends ‘quality time’ here: dinner, parties, lounging with the family. The living room can be a source of pollutants, when occupants smoke, keep pets indoors and perform activities that are driving forces of pollutant sources. Due to the size and the activities of going in and out and the important infiltration rate, the concentration of pollutants is on average rather low, however, with peak concentrations.

Use of the bedroom
The Dutch bedroom is rather small and often used by two persons. Elderly use the bedroom only for sleep and may watch tv there, younger persons more often do homework or play or watch tv in their room. Children tend to have a packed room with many (pollutant emitting) toys and furniture and materials that are hard to clean. Besides periods for play, their major activity is sleep, in prolonged periods and mostly for a single period of 5-9 hours. When we sleep, our heat production pattern changes: we get colder hands and feet. This happens while room temperatures tend to get lower during the night. The body regulates the temperature by transpiring, not by widening blood vessels. This means that a hot bed is inconvenient. A cool environment increases active sleeping patterns of neonates at the expense of quiet sleep. In warm environments the oxygen consumption drops during quiet sleep (Bach, 2001). Fine dust, the ambient temperature, the bed environment and sleeping position of the small infant are associated with the sudden infant death (SID) syndrome (De Ronne, 2000).

Every few (1.5) hours, we automatically change the position of our body and covers, to stimulate the blood circulation in parts of the body that may suffer from obstruction.

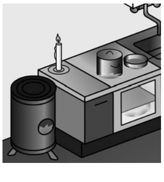
People get up from their beds during the night to go to the bathroom. In the Netherlands about 500 people each year visit hospitals because of wounds and broken bones from hitting the bed. Hundreds of hospitalisations are caused by hits and falls (Stichting Consument en Veiligheid [Consumer Protection and Safety Foundation] 1999). Elderly people who break a hip have an increased chance of dying within one year.

During the day, the senses stimulate active regulatory mechanisms to control the temperature, remove or isolate sources of bad smells and nuisance. At night, we do not act in control of the environment and in the morning we tend to walk away from environmental stresses.

A bedroom just for sleep gives an exposure period of 6 to 12 hours a day. In the 333-dataset, 44% sleep with closed inlet openings during the heating season, while 20% of the bedrooms are heated at night, at relatively low levels. The rest of the bedrooms are not heated during the winter nights. The temperature control of the bedroom is a 'slave' of the control of the central thermostat in the living room, which means that the temperature tends to be much lower than in the living room. Many people never heat the bedrooms at all. An effect of a cold bedroom is that ventilation with high volumes does not cost much energy and low temperatures are not favourable to house dust mites, whose activity level will slow down below 15°C.

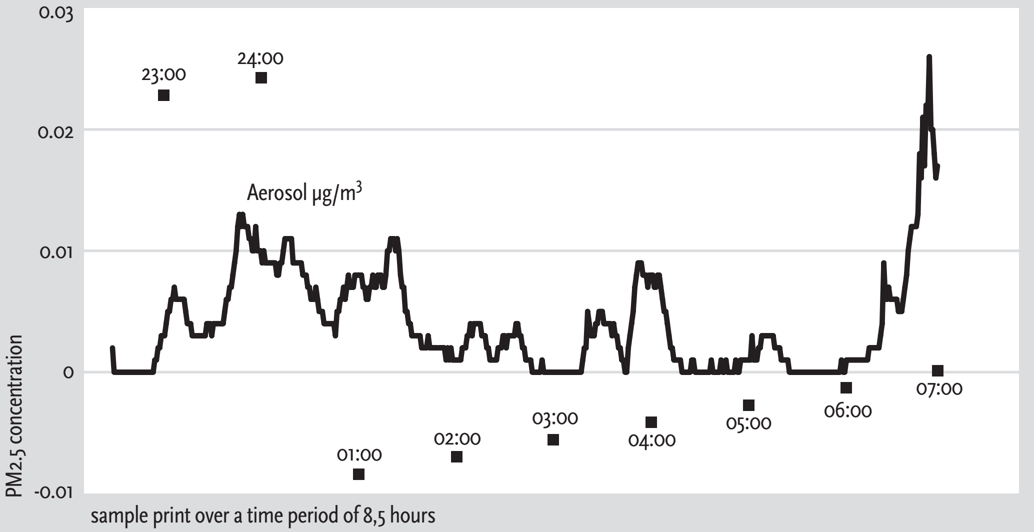
Sleeping in aerosols
Figure 4.1 shows how the aerosol concentration near the bed is related to sleep patterns. A PM2.5-monitor was placed on a seat next to the bed and recorded the movements of the sleeping person (the author) in bed, until getting up. The inlet openings were kept closed. The pattern shows periods of deep rest and periods with relatively higher levels of movement. The aerosols were produced by the mattress and bed covers. Monitoring with open windows showed both lower levels from moving around in the bed (aerosols were vented away) and higher levels caused by wind turbulence and traffic in the streets.

Use of the kitchen
The kitchen shows a great variety of identities and user patterns: from large kitchens, where a household spends all day to a small corner or 'kitchen island' in the living room. Cooking differs from frequent fast-food-in-microwave-oven users to slow food lovers who take the time to socialise at the dinner table. Cooking takes no more than 30-45 minutes a day. 54% of the inspected houses have a closed kitchen, while the rest is open or semi-open-type. Semi-open means that there is a door connection, but the door has been removed.



The surface areas range from 7 m² in older houses, to 10-14 m² in many

Figure 4.1 Aerosol concentration (PM2.5) next to the bed of a person asleep



houses of the period 1965-1980 and houses since 1975 more often have an open connection between kitchen and living room. The room with the kitchen function must have an exhaust opening with direct access to ambient air.

Use of the bathroom

Bathrooms in mass-produced houses since 1955 are very small (3-4,5 m^2) and only have room for a washbasin, a shower and sometimes not even space for a Laundromat with a tumble dryer, which finds a place in the kitchen or storage place. Small bathrooms do not support an elaborate bath culture, meaning that this room is used for a daily shower and quick wash and brushing teeth. About 80% of people over 12 take a shower every day, meaning that the number of showers (and the moisture load) is in proportion with number of occupants. The second function is laundry drying.

4.4.4 Extreme behaviour

Extreme (low) heating behaviour was encountered in apartment buildings with collective heating and a cost distribution system based on temperature measurement (or evaporating oil filled meters) on radiators. Selective heating leads to occupants' demands for higher circulation temperatures, which results in higher fixed costs paid by those occupants who tend to use a fraction more 'variable' heat than average. Some people stop using the collective system, reduce the ventilation volume and use individual electric radiators instead. Health hazards are created with the use of kerosene heaters which are more cost-effective than electric radiators. These burners emit black smoke and moisture and kerosene gases that pollute the air with VOCs.

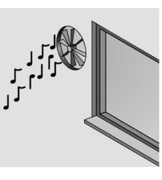
Other observed extreme behaviour is keeping mould surfaces untouched, because mould can be effective in attempts to block rent increases.

Indoor air problems have been diagnosed in houses that were used as a 'hotel'. Occupants leave for work or study after a shower in the early morning, after a quick hand wash of laundry that is left drying in the house, they keep the heater low and the inlet openings closed for fear of burglary and to minimize the cooling down process. After coming home at night, the heater is turned up, but it takes hours for the cool building mass to get warm. The short period at home does not remove enough moisture from the furniture, beds and the construction and moisture-related problems occur. These phenomena are also found in houses occupied by people who spend weekends on the campsite or in a second home: the house is poorly ventilated and not heated and small moisture sources from leakage, an open connection with a damp crawl space including other small sources like plants can create problems. A minimum permanent ventilation rate, either by infiltration or a permanently open inlet and exhaust is essential in preventing these lifestyle-related problems.

Older users and some other groups fail to use present-day technology due to the mismatch between the technology experience they acquired through life and the knowledge they need to use a new device. The electromechanical generation is used a speedy trial-and-error strategy in which they tackle menu-related bottlenecks mainly by navigation. On the contrary, the older ones handle bottlenecks mainly by manipulating of controls. Both young and old generations have problems controlling menu-style functions they never learned (Docampo Rama, 2001). User problems are encountered with modern ventilation systems, clock-controlled thermostats and alarm systems.

4.4.5 Noise and behaviour

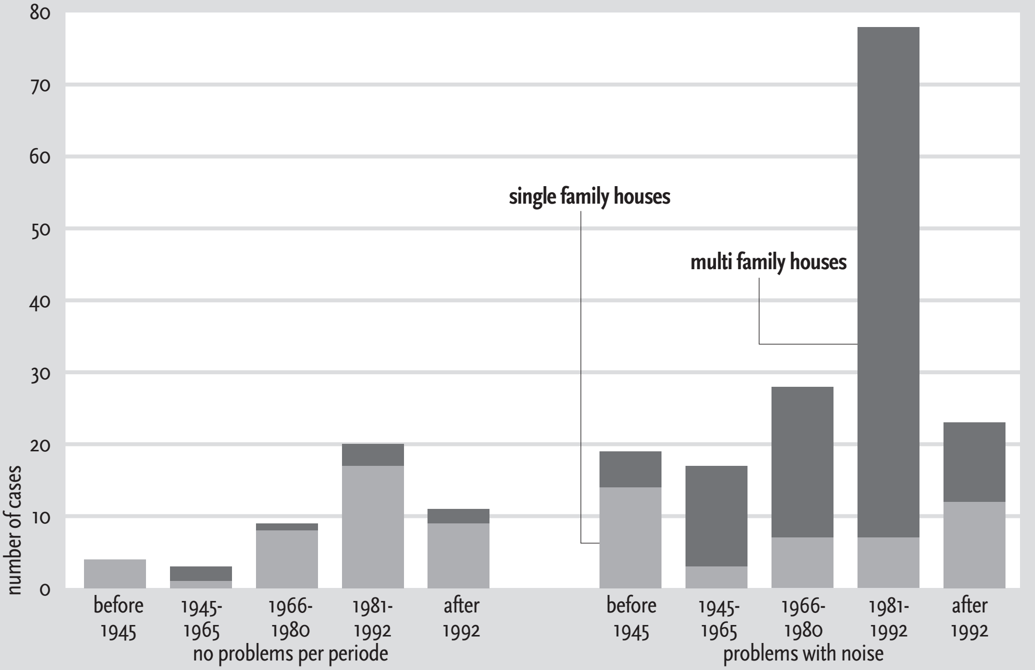
Installations that cause noise but have no individual control features cause complaints, especially when the problems are perceived as preventable and technical solutions are within reach: insulation of pumps, shockwave breakers in water pipes, releasing pipes that are tightly stuck in floors and walls, automatic door controls, rubber suspension of fan boxes, etc. Low-pitched sounds do keep people awake at night and cause irritation when it comes from fans on the roof or on the dividing wall of the bedroom. Nuisance of noise is very personal and the 'quality' of the noise is also important: loud live music can be nice, noise of people having arguments is more likely to cause emotional stress. From the analysis of the dataset, the relationship of noise complaints with health is not clear.



During cooking the exhaust noise of the cooker hood or the highest set-point of the fan is accepted for about 30-45 minutes: fans are turned low or shut off at the start of dinner. Fan noise and damper noise induce almost permanent use of the lowest set-point, or the system is switched off completely.

When noise is caused by poor maintenance or vandalism and antisocial behaviour, complaints will be reported to the housing association, in partic-

Figure 4.2 Noise and building periods



ular when occupants perceive that the problem can be solved by technical measures or interaction with the housing manager.

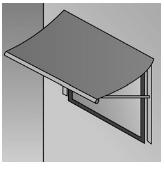
Of the responding occupants, 32% (of n=146 in the 333 dataset) are affected by noise and 31% change their behaviour to control the noise (of n=134 in the 333 dataset). Some 2% of respondents (of n=87 in the 333 dataset) without complaints about noise controlled the noise sources; of the occupants that hear noise and responded to questions about behaviour (of n=36 in the 333 dataset), 83% adapted their behaviour to prevent noise, for instance by closing the windows or turning down the exhaust ventilator. Control is possible at individual installations: turning down the thermostat so the heater does not fire during the night, turning off the fan powered heat pump that recuperates heat from exhaust air, turning down the individual mechanical exhaust.

4.4.6 Comfort and behaviour

In the research project, comfort is limited to thermal comfort, daylight and view primarily, not aesthetic quality or luxury. Thermal discomfort is caused by draught and poor temperature distribution, and variations in hot water temperatures in the shower. Most problems have a technical background. Draught has both a technical and behavioural background. Draughts are often caused by concentrated air inlet, when few inlet openings are used. Diffuse infiltration can reduce the risk of draught, depending on the locations of seams. Without opening the pressure difference over chinks and airstreams over the floor are larger, which can cause discomfort from air currents around the ankle and neck. Chinks around the door to the balcony or garden in the living room create a high seam length with risk of draught, because this corner place is a preferred seating place with often the best view outside. Draught by temperature differences increases with poor insulation of the envelope and selective heating of rooms.

Many occupants use controls too late and then desire an immediate response: the window wide open for a short time to remove a smell, or a large fan over the cooker, is preferred over permanent mechanical ventilation. The heater is turned up when feeling cold and the occupant desires an increase in temperature within 15 minutes. Overheating can be the result of a late response: the sun must be blocked starting in the early morning, otherwise it is too late to prevent overheating in the evening. Night-time cooling with ambient air is needed to cool down for the next day. Indoor appliances that create a heat load must be controlled, etc. Often the extreme conditions can be prevented, but it may require behaviour that is not feasible, for instance because the occupants are not at home. Without control, the building conditions define the comfort level.

Comfort optimisation is an important factor for understanding ventilation behaviour: the occupant searches for the best comfort of the senses: seeing, feeling and hearing. When the ventilation creates noise, the system is turned down and ventilation is compensated via the use of natural ventilation functions, or no ventilation at all when openings allow noise to enter. Inlet openings are closed when draught intervenes with comfort. When the indoor air is smelly, flushing is applied for as short as possible, to exchange the air while draught is accepted and the flushing opening can be controlled against trespassing. These experiences are collected during the heating season mainly. During warm weather and while occupants are at home, the doors and windows are open more often.



4.4.7 Safety and behaviour

Housing conditions are a hazard primarily for visitors who are not familiar with or aware of safety conditions. Risk awareness can motivate action or behaviour to reduce risk. Risk awareness is high with young children in the house (protection from electrical contacts or appliances, hot surfaces, stairs, hinges, storage), after an accident happened or when age-related mobility problems create handicaps (use of handles and railings, removing thresholds). Domestic gas fired appliances and electrical networks used to be tested by utility organisations when these were public domain. Now everyone has individual responsibility to check heaters and chimneys, fire, gas and electrical safety, but safety inspections are not customary and commercial services are not used.

For many occupants the non-routine activities create many hazardous conditions. Do-it-yourself jobs not only relate to redecoration or renovation, also cleaning the windows, work in the garden, use of sharp mechanical tools and knives. The exposure to emissions tends to be highest during removal of or application of paint, glues, sealants and cleaning chemicals.

4.4.8 Social environment and behaviour

Overall satisfaction with the home, with indoor climate, with involvement and with the neighbourhood was questioned. The scores (n=175 in the 333 dataset) show that 41% are completely satisfied and 59% complain about one or more qualities. About 75% (of n=155) are satisfied with the home and 91% (of n=129) are satisfied with the quality of the neighbourhood. The quality of the neighbourhood is considered good, with many social interactions or few interactions but in a friendly atmosphere. 9% perceive the neighbourhood as unfriendly, hostile or dangerous. The perceived neighbourhood extends over a small area: the part of the street primarily where the respondent lives, including the way out of this area to shops, work, school, etc. 76% (of n=122) fear burglary through open windows in the living room, while 24% is safe and does not influence the use of openings. Burglary is a widespread problem in urban areas. A tour through Spangen in Rotterdam (March 1997, cool but dry weather, no strong winds) to check the type of windows that stay closed because of risk of trespassing resulted in an inventory of windows that are considered unsafe and stay closed when not in the room: all windows on the ground floor and on galleries, also on private balconies with separations, next to a balcony on the first floor and up to the third floor that can be reached via a row of balconies, windows in a sloped roof plane, when the roof is accessible because it is only one floor higher than a public level. Fear of trespassing influences the ventilation behaviour and when only sash and hinged windows and not line grates are available for ventilation; this fear supposedly has a direct effect on air quality in the bedroom.

4.5 Conclusions

Dealing with occupant behaviour is essential in a study on healthy housing: insight into the relationship between physical parameters and behaviour is poor. The research question of Chapter 4 is: *How do occupants use the house?* The results are based on 500 interviews and the analysis is explorative.

Occupant behaviour can result in health hazards: smoking, use of solvents and cleaning materials, laundry drying indoors, keeping inlet openings closed, etc. The performance of equipment often limits a proper use. Mould is caused by a combination of constructions, sensitive to condensation, or high periods of wetness (in the bathroom) and ‘normal’ moisture production by the occupants.

Comfort problems can be created by a combination of behaviour and physical factors: draught, extremely low temperatures in the winter and overheating in the summer, and lack of daylight because of vegetation. The risk of injury is a normal consequence of occupancy, but many injuries can be prevented by a combination of risk awareness and physical conditions that support safe use of the house.

Ventilation behaviour is influenced by comfort optimisation: occupants prefer a closed inlet over draught, low fan speed over noise, saving money (energy) over fresh air. Ventilation is poorly understood by occupants and some services are not user-friendly: in 43% of the master bedrooms and 56% of the living rooms the ventilation openings are used to flush for only a short period per day in the heating season, without permanent ventilation except what infiltration causes. Often, the ventilation services cannot be used for fear of burglary or because of conflict with noise level. Small inlet openings, especially line grates, are used for longer periods than large openings such as one-sided hinged windows.

Natural ventilation is in general better appreciated by occupants than mechanical conditions. Occupants prefer to use a flush opening during cooking with whatever ventilation system is available.

A summary of occupancy and behaviour-related indicators that point out conditions with high exposure levels:

1. over-occupancy (more than one person average per room), including pets;
2. smoking in the house while others are present;
3. poor use of exhaust ventilation, low permanent ventilation in winter;
4. moisture peaks from showers and laundry drying indoors influence biological agents in bedrooms;
5. peak exposures, caused by vacuum cleaning, painting, redecoration, the use of gas ovens or emissions from greasy dirt layers (cooker hood);
6. poor cleaning, for instance not removing (visible) mould, either old or viable;
7. obstacles, slippery surfaces and poor maintenance that increase the risk of personal injury;
8. do-it-yourself jobs without experience in the use of tools or stairs and scaffolds etc.;
9. uncontrollable noise;
10. experience of trespassing or antisocial behaviour or discrimiation.

5 Physical housing conditions

5.1 Introduction

5.1.1 Research question

In Chapter 4 the triangle housing management-occupants-health hazards was viewed from the occupant perspective, in this chapter 5 the three sides of the triangle are viewed from the perspective of housing. The building parameters that cause hazards are described. The research question is: *Which physical housing conditions are associated with health?* The physical conditions of Dutch dwellings are described and construction details, applied materials, lay-out and technical services are typically Dutch, so health related properties may not apply to houses in other countries.

The building is scanned from foundation to roof. Building-related features that influence air quality, acoustics, discomfort, safety and social interaction are described. The quality of design details, the implementation quality in the construction phase, the impact of poor maintenance and the impact of do-it-yourself work and renovation of houses has been evaluated. The delicate balance between the indoor climate and environmental problems is described on the basis of conditions in which this balance was disturbed. The house is viewed as a complex mechanism rather than a set of separate details. However, not the physical aspects of the house, but hazards give structure to this chapter. This chapter starts with air pollution by looking at pollution sources: emission from the crawl space, mould occurrence and house dust mite in relation to the moisture balance and condensation, emissions from fuel-burning appliances, from construction materials. Building-related discomfort is analysed and safety conditions are scanned. Social interaction is included, to highlight building parameters that influence the perception of social interaction and privacy. However, ‘deterministic’ evidence of the impact of the physical environment on social interactions is poor.

The chapter begins with an introduction to building physiology. Construction methods and materials have developed slowly over the past 100 years, and information about the building period reveals certain materials and construction details that, when recognised, make the identification of hazards easier. Table 1.4 highlights the relationship between this research question and Chapter 5.

5.1.2 Data collection and analysis

Data on the cause and effect of a specific problem sometimes started as anecdotal information in a single case. For example: the first report on headaches caused by an open combustion type heater in the living room was anecdotal, but more reports followed, pointing out similar causes. Further diagnoses revealed a structural problem with old chimney-tied atmospheric central heaters situated in the living room. Other examples of anecdotal information are problems with heat-recovery ventilation systems, with bottom side-hinged window systems, with legionella risk from domestic heaters. These phenomena have been diagnosed since the first field experience as 'structural' hazards in houses with these features. Some field experience still has not been diagnosed and point out new research topics. For example: in 500 inspection visits not one bedroom with large single-glazed windows on the sunny side of the house had indoor environmental problems. A possible explanation is that enough ultraviolet light penetrates through single layers of glass to reduce the number of bioorganisms, while the heat influx creates a dryer environment and consequently fewer biological agents.

Many diagnosed problems point out structural phenomena. The diagnosis often was available before statistical evidence was available. The dataset allows statistical analysis of some of these phenomena and supports or differentiates the field experience. Indicator selection in this Chapter 5 is based both on statistical explorations and descriptive field experience.

5.2 Building physiology

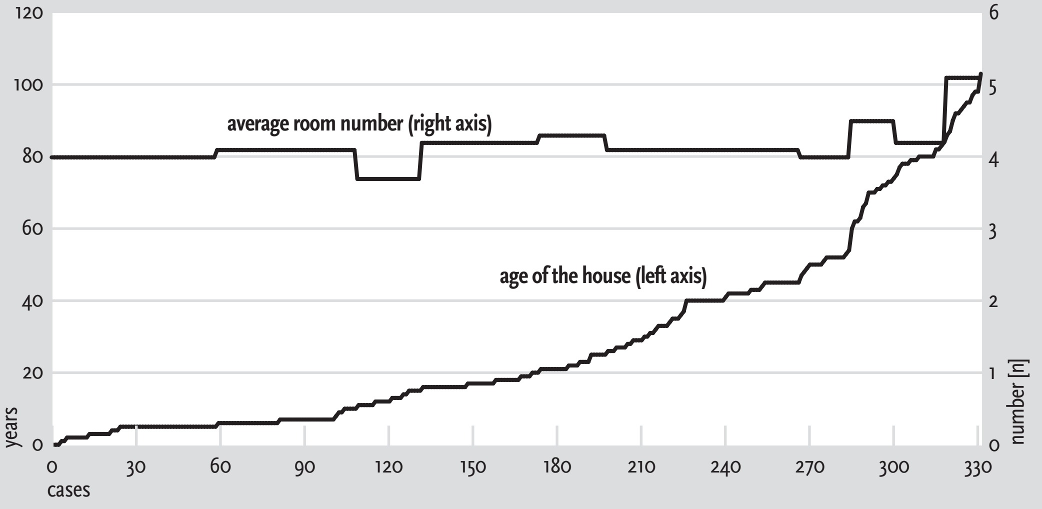
5.2.1 Building type

The building type and the building period are useful indicators of the likelihood of certain hazards. The building period is related to changes in building requirements and changes in construction principles. These changes are the effect of economic development, availability of goods, innovations, and are the result of regulations, requiring other solutions and permitting a market opportunity for new products or construction methods. As phenomena did not change overnight, the periods are not strictly separated. For instance, a Dutch dwelling built in 1965 can be the result of modern industrialised building methods and also of traditional methods, resembling prewar type dwellings. The building period facilitates inspection and evaluation and nothing more. Houses in the prewar period have often been retrofitted or remodelled a few times and only the major construction details will be unchanged, for instance wood framed floors, and a certain thickness of walls.

Major changes in building physiology are:

- larger dwellings with better floor plans as a result of the new Requirements of 1965 (V&W,1965);
- increased thermal insulation quality, in smalls steps, starting in 1965 with roof insulation and after the energy crises of 1973 and 1979 gradual increase of R-values and finally in 1998 the introduction of energy performance regulations, with a performance coefficient that started at the state-of-the-

Figure 5.1 Age of house and average room number per age period (of 5 to 20 years) in the 333 dataset



art level 1.4 and was lowered to 1.2 in 2000, to 1.0 in 2002 and 0.8 in 2006;

- open layout for kitchen/living room since the regulation of mechanical ventilation in 1975;
- the new Building Decree of 1991 (with frequent minor revisions up to the present day), with requirements for better airtightness, reduction of thermal bridges, better acoustic insulation and burglarproofing requirements that resulted in the application of improved inlet grates.

The houses in the 333 dataset show that the number of rooms did not change: over the last century three bedrooms and a living rooms mostly, with more rooms in older houses (that have been preserved because of their size and functionality) (see Figure 5.1). The surface area of newer houses is probably larger, due to regulations, but data about surface areas is not available from the 333 dataset.

Layout

Of the inspected houses 56% is detached, located at the end of a block, under a roof or above a crawl space, the other 44% is located in between, indicating that only two façades (and a roof) are connected to ambient conditions. The larger the number of rooms, which is in single-family houses, the longer is the period lived in the house. The rented sector has smaller houses and more apartment houses than in the owner-occupied sector. Almost none of the inspected houses has an annex garage, or is located above shops or next to a large parking garage.

The floor plan reveals how air will circulate, how moisture from the bathroom diffuses to bedrooms and how emissions from the kitchen pollute other areas. Air pollutants tend to spread throughout the house due to complex airflow patterns and diffusion.

Some parameters, for instance openings that permit cross-ventilation, the stack effect of the open stairwell and the location of the kitchen, tell how the (natural) ventilation will work, in combination with exhaust functions.

The number of rooms is more relevant for the occupancy load than the surface area of the rooms: separate rooms provide privacy and different microclimates, to suit everyone's needs. The surface area of rooms in Dutch houses is generally quite small, compared to German, French, Swiss and Austrian houses. The surface area increased in 1965, stimulated by new Dutch regulations, and the trend is still upward, especially during the affluent period since the early 1990s.

Type of kitchen

In many houses, an open connection between the kitchen and the living has been created, for more social interaction while preparing food and also for spatial effects. Since 1975 open-type kitchens are applied, made possible by a change in the Building Decree that allowed an open kitchen when central mechanical exhaust ventilation was supplied. It supported a successful market penetration of mechanical exhaust ventilation. The practice is that open kitchens pollute the house, but the peak concentration is lower than in separate kitchens. The cooking habits change, open gas heaters are replaced by microwave ovens and electrical heating plates, hot water comes from combined heater/hot water systems or an electrical close in boiler, dishes are cleaned and dried in a sealed dish washer, so the pollution level in kitchens tends to reduce gradually.

Airway-sensitive people do not like to get exposed to strong smells, to aerosols of baking and the grill. A closed kitchen is preferred in certain (Muslim) cultures where cooking is by tradition separated from the room where dinner is served.

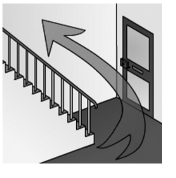
Hydrothermal problems prevail in connections between floors, walls, the roof with the envelope: houses at the end of a block, above the crawl space or outdoor area and under the roof tend to have more moisture-related problems than apartments that are situated in-between.

Infiltration differs by building type: more infiltration in single-family houses with sloped roofs and cross-ventilation facilities than in multifamily houses with a double separation between rooms along both façades. In multifamily houses relatively more maintenance and indoor environmental problems were inspected than in detached houses: occupancy is higher, the infiltration and the ventilation is sometimes lower. Tenants in multifamily blocks with maintenance problems are likely to be organised in a neighbourhood committee, resulting in greater involvement in social action.

Floor plans until 1985 are often mirrored along the north south axis to provide an equal share of sunlight on the façades and to create sunlit streets. The effect is that low evening sun from the west enters the house at the warmest period of the day, causing higher risk of overheating in the summer. The heat influx from the east and west orientation is equal, but the house and the environment are cooler in the morning so the eastern orientation does not cause overheating. Modern designs (since late 1980s) prefer south and north orientation, with a large difference in sunlit quality (and temperature and dampness) between bedrooms.

Vertical openness
Experiments in the Ecobuild-Research project indicate that a stairwell serves as a large stack, creating a vertical airstream with high capacity, provided that the stack has outlet upstairs and supply downstairs. A sloped roof tends to have chinks and seams that permit exhaust by infiltration. The stack effect provides enough air volume for summer night cooling and support of the air inlet in bedrooms, provided the bedroom door allows enough air to pass. The negative pressure in the stack causes a constant pressure difference over the façade and the ground floor. When inlet openings are closed the pressure difference can draw air from the crawl space if sealing is not complete. Small inlet openings could also cause draught problems. When stairs start in the living room and reach two floors higher, draught problems are likely to occur in the living room, but ventilation/circulation will not be a problem. One third of the database has a stairwell which is open into the attic and is open over more than two floors, while almost one third is open over two floors.

Narrow houses are likely to have deep rooms that 'compete' for a place along the façade. The Dutch building tradition shows large windows, located near the ceiling. Windows typically cover 35-60% of the façade in the living room and 25-40% in bedrooms. Competition for light implies that the living and bedrooms connect with the façade and that the bathroom is likely to become an enclosed interior space. Because of the large glass surfaces, the orientation and type of glazing have great impact on sun irradiance and day-lighting. Lack of daylight sometimes occur in attics that have been transformed into bedrooms. Some circulation areas do not receive daylight. Day lighting problems can be caused by large trees, and there are accounts of forceful thinning out of branches to give more daylight to neighbouring houses.



5.2.2 Construction type

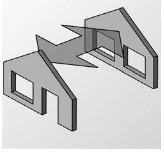
Constructions changed gradually on the basis of technological breakthroughs. Examples are:

- concrete constructions since the beginning of the 20th century;
- cavity wall introduced around 1915;
- steel window frames from the mid-1930s until 1960;
- asbestos roof slabs and sheeting in the 1930s until 1975 (in practice) and 1993 (forbidden);
- wood replacing building materials and components in the early post-war period: hollow brick floor slabs, pressed straw sheeting, flax- or cement reinforced wood-wool sheeting;

- industrial building methods, starting on a large scale in 1963, introducing high-rise buildings and new construction techniques (concrete pouring technique and composition with large prefab concrete slabs are still popular today).

The Second World War draws a major demarcation line between old and new constructions. From 1948 to 1963, Dutch housing production increased from about 40,000 to 80,000 per year. In 1963, a new industrial building period started, bringing the production to more than 120,000 houses in 1966, with a production peak of 155,412 houses in 1974. In the period between 1950 and 1980 almost 3 million houses were built, half of them single-family houses and the other half multifamily houses. About 70% of all Dutch houses are newer than 40 years, much like the age distribution in many other Western European countries. Of the total stock 48% is in the rented sector and 52% in the private sector. Part of the stock of 1950-1980 is in the process of restructuring. Dampness, mould, draught are widespread in these houses.

The building period since 1991 shows better acoustic and thermal insulation and better prevention of burglary. Some problems still prevail in modern houses since 1991 or have worsened: low infiltration improves energy efficiency and reduces comfort problems, but requires active control of ventilation. Modern energy-efficient appliances such as heat-recovery ventilation and heat pumps create noise indoors. Stairs need much floor space and are therefore steep and often of the spiral type; foot space is small and the steps are often slippery, creating fall hazards.



Walls

Houses of the period before 1965 are based on brick or brick-like construction of load bearing walls and separations. The industrialisation of housing construction (Priemus, 1970) introduced in situ fabricated concrete walls and floors and flat roofs. The façade elements changed from cavity brick structures to wood frames in the 1960s. Since the 1980s the outer wall segment is likely to be of brick, the indoor segment is a wood frame filled with insulation material.

A small market share of concrete prefabricated façade elements of the period 1960-1980 had a thin layer of insulation material integrated into the elements. These constructions often show hydrothermal problems. The connections are not airtight and with thermal bridges; effects are mould, uncontrolled infiltration and acoustic problems. Wood frame facades of this period are not airtight and poorly insulated. Brick walls of the period until 1980 are more likely to show capillary moisture problems than modern facade systems. Many of these facades have been replaced or improved since.

Roof

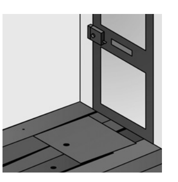
A sloped roof effectively drains all rain and hardly ever suffers from leakage.

The large space under the roof acts as a buffer zone that is likely to be well-ventilated, because the connections between the floor/wall and the roof structure and also the top of the roof are not airtight. All angled roofs are made of lightweight building materials, with an increasing insulation quality, starting with improved quality in 1968 and stepwise from Rc = 0.68 m^2K/W to Rc=3 in the 1980s and in practice up to Rc=4 or 5 m^2K/W since 2002 (Stofberg, 2006). Flat roofs show more leaks or more internal condensation problems. Almost half of the houses in the database have a sloped roof, more than 10% a combination of flat and sloped roof and only 16% has a flat roof. About one quarter of the houses in the database has no direct contact with a roof.

Floors

Wooden structures are hollow and do not cause thermal bridges, but old floors have low acoustic and thermal insulation quality. Wood beams and flooring were applied until 1945 and changed due to lack of wood after the Second World War. Since the 1990s many floors are prefabricated. Concrete floors and the supporting beams of the foundation are very likely to create a thermal bridge until 1992.

Since around 1915 (and really starting in 1918), Dutch houses were built with a cavity wall. In the period until 1975, the cavity wall passed deep below the ground floor and open joints allow water from within the cavity wall to flow into the soil. Since the 1970s the distance between the bottom of the cavity and the floor was reduced to the height of one brick, to allow an S-curved ventilation device to make a connection between ambient air and the crawl space, but nowadays the floors slabs are positioned directly on top of the concrete foundation beams. Often, the bottom part of the cavity next to the floor slab is filled with cement spoils and dirt, while the traditional open joints between bricks, meant to release water, disappeared. The consequence is that the water that permeates the brick outer wall in periods of wind and rain which creates a damp floor support area and consequently a thermal bridge, with condensation risk in the lintel area. When the floor support is wet, the floor is likely to be cold in the winter and the higher moisture level supports the growth of house dust mites, notably the only period of the year that allows the removal of live mites. Capillary water from the foundation in older houses or water penetration from outside or both can also cause a wet floor area. The conditions responsible for a wet floor support are found in 9% (of n=257) of inspected houses and 13% of houses with a crawl space. All constructions with cavities, for instance wooden beam structures, timber frames and covered walls and shafts, etc. build up a layer of dust, sometimes with insects or mice. Wind pressure differences and vibrations cause re-entrainment of dust and spread of bio-aerosols from these dusty cavities into the indoor environment.



Materials

Asbestos

Asbestos additions especially in ducts and sheet material and fire protection applications were introduced in the beginning of the 20th century and banned in 1993 in the Netherlands. As the call for banning the product was heard since 1955 and the health risks became evident in the 1970s, the practical application gradually ended, with a push in 1983 from the legal ban on non-integrated asbestos applications in new products. Asbestos-containing products are, for instance:

- large surfaces of sheeting inside the roof structure in the period 1960-1970;
- exhaust pipes for flue gas and exhaust air in the period 1920-1970;
- vinyl floor tiles between 1958-1970;
- protective sealing fibres in heaters and in exhaust pipes, between 1920 and 1980;
- roofing products of barns (undulating sheets) and houses (tiles).

Much of the loose fibres have been removed (sealants in heaters and hot gas exhaust ducts). Asbestos-containing building products in houses do not cause a health risk, except when broken down or damaged during drilling or cutting, when sanded before painting or in case of fire. Many occupants do not know where asbestos is applied.

5.2.3 Building services

Building services are ventilation, heating, domestic cold and hot water and sanitation.

Ventilation

Ventilation is the result of three functions: inlet, circulation and exhaust. Three ventilation systems prevail in the Netherlands: natural, mechanical exhaust/natural inlet and balanced mechanical inlet and outlet. These systems are applied as individual systems in individual dwellings mainly and about 15% is applied as collective systems in a vertical row of dwellings.

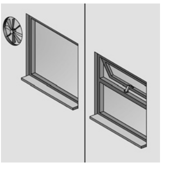
Of the total building stock of 2006 (around 6.9 million houses) in the Netherlands, 43% has a natural ventilation system, which includes vertical natural exhaust canals to the roof in the kitchen (traditionally separated from the living room), in the bathroom and often also in the toilet, in combination with windows that can be opened. About 53% is equipped with a central exhaust fan that extracts air from the kitchen, bathroom and toilet, in combination with natural inlet through (more modern) grates and windows. Since 1998, many new houses are equipped with balanced-flow, heat-recovery ventilation systems, and the number amounts to approximately 280,000 houses, which is about 4% of the stock in 2006. (see overview in Table 5.1) The systems in the

Table 5.1 Distribution of ventilation systems in the Dutch housing stock per 2006 (estimates by author)

Building period	<1945	1945-1965	1966-1980	1981-2006	Total 2006
Social rented sector					
Single family dwellings	A 150,000	A 135,000	A 250,000	A 125,000	
	C 25,000	C 60,000	C 155,000	C 502,000	
			3,000	D 25,000	
Multi family dwellings	A 55,000	A 85,000	A 170,000	A 50,000	
	C 25,000	C 110,000	C 270,000	C 250,000	
			10,000	D 20,000	
Subtotal social rented sector	A 205,000	A 220,000	A 420,000	A 175,000	A 1,020,000
	C 50,000	C 170,000	C 425,000	C 752,000	C 1,397,000
			13,000	D 45,000	D 58,000
Total social rented sector					**2,475,000**
Private rented sector					
Single family dwellings	A 160,000	A 30,000	A 30,000	A 35,000	
	C 35,000	C 18,000	C 40,000	C 130,000	
				D 15,000	
Multi family dwellings	A 100,000	A 25,000	A 20,000	A 25,000	
	C 40,000	C 17,000	C 30,000	C 80,000	
				D 10,000	
Subtotal private rented sector	A 260,000	A 55,000	A 50,000	A 60,000	A 425,000
	C 75,000	C 35,000	C 70,000	C 210,000	C 390,000
				D 25,000	D 25,000
Total private rented sector					**840,000**
Owner-occupied dwelling	A 725,000	A 200,000	A 380,000	A 220,000	A 1,525,000
	C 125,000	C 120,000	C 580,000	C 1,050,000	C 1,875,000
			3,000	D 194,000	D 197,000
Total owner occupied					**3,597,000**
Total Dutch housing stock	A 1,190,000	A 475,000	A 850,000	A 455,000	A 2,970,000
	C 250,000	C 325,000	C 1,075,000	C 2,012,000	C 3,662,000
	D 0	D 0	D 16,000	D 264,000	D 280,000
Total number of dwellings					**6,912,200**

type of ventlation system
A natural inlet and exhaust
C natural inlet, mechanical exhaust
D balanced flow: mechanical inlet plus exhaust and heat exchange

333 dataset represent approximately 45%, 50% and 5%. In the dataset, heat-recovery ventilation (n=14 of 295) is in proportion with the stock, but still very low in number, not allowing for numerical analysis. Natural cross-ventilation is quite effective in the windy Dutch climate, but is not considered a system in the Building Decree, because it implies transport of pollutants to other rooms. The same goes for single fans for the kitchen and bathrooms. More information about ventilation is presented in Chapter 8.



Heating

Heating is for comfort and removal of humidity in combination with ventilation. In the Netherlands, we find no reports of increased mortality from extremely low temperatures in houses, unlike for instance reports from the UK. Heating provides more usable space (rooms) in the house, thus improving privacy. When heating in combination with ventilation make the habitat of mould and mite too dry to grow, heating indirectly influences respiratory diseases. The heating system involves certain hazards with low probability: emissions of flue gases including toxic CO, personal injury caused by hot surfaces, and fire. A heater with open-flue duct works as extra ventilation exhaust, increasing the ventilation rate. When the heater is located in the living room or kitchen, the extra exhaust can have a positive effect on air quality, provided the pressure difference does not draw polluted air from the crawl space. Low temperature radiant heating surfaces (floor slab or wall) solves the problem of thermal bridges of the floor support, limiting the growth of house dust mites in flooring material.

The categorisation of heating systems is possible on the basis of hazards involved (percentages are estimates by author, partly based on the 333-dataset):

- flueless gas, oil and kerosene heaters emit smoke and fuel residues indoors (in 0,5% of stock). One dm^3 of liquid fuel produces 1.3 dm^3 of water (in gas phase) mixed with carbon particles, SO_2, NO_x;
- atmospheric heaters create the hazard of emission of smoke (in 40% of stock);
- fireplaces and wood-burning stoves create the hazard of aerosols, VOCs, fire (in 8% of stock);
- radiant heaters and stoves create the hazard of scalds and burns and aerosols from hot surfaces (in 30% of stock).

Highly efficient heaters emit more CO than traditional heaters, because of the reduced air volume in the gas-air mixture. CO can penetrate through leaks in the pressurised exhaust ducts or may enter the house again via inlet air openings. The condensation process in long ducts can cause (partially) blocking of exhaust ducts by deposition of corrosive substances in bends, as was discovered in Rotterdam in 2003 (oral communication of Heeger, OTB, in 2003). This type of hazards has high probability and may cause chronic health effects. Oil or kerosene heaters without exhaust duct (promoted as having '100% efficiency') emit pollutants that can destroy (nylon) fabric such as carpets. Most (old) chimney-tied central heaters in the living room ('moederhaard') have a cast-iron heat exchanger that, with minor cracks and when 'wet' create the risk of black smoke that can block the exhaust of flue gases, with possible exhaust of toxic substances including CO into the living room. Complaints about headache and illness were in some cases reported in the first weeks of the heating season. In this period, the chimney is wet and cold and the exhaust capacity is not enough for the large fuel-burning capacity of this type of heater. Also: inlet air becomes relatively colder and occupants tend to close the inlet openings that may reduce the capacity of exhaust systems.

Central heating is found in 89% of cases (n=150 of 333 dataset) and 11% use individual local heaters, not in all rooms.

Domestic cold and hot water

The health aspects of cold and warm domestic water are lead toxicity, bacterial contamination and scalding by hot water. Only a small percentage of houses still have lead pipes (or sections of lead).

The shockwave caused by motorised valves or fast-closing 'one handle' taps can produce noise. Water heaters based on natural gas work similarly to space heaters, with identical hazards except for the peak level: modern heaters modulate between 4 and 20 kW for space heating, but use the full capacity of 23-28 kW for domestic hot water (providing 6-8 dm^3/min of 60°C). The age of the heater is an indicator of the technology used, the risk of potassium in boilers, possible emissions of exhaust gases and not reaching temperatures of 60°C. Kitchen geysers have a flow rate of only 2.5 l/min. When not chimney-tied and used for showering, the peak emission of NO_2 and moisture and possibly CO may be high and hazardous. In 20% of rented houses, domestic hot water is produced by a kitchen geyser (Ministerie van VROM, 2000a) without flue gas exhaust pipes. The pollution in the kitchen is equivalent to a gas-fired cooker, because both consume 60-80 m^3 of gas per year. When the geyser produces hot water for showers, the user periods change from 1-2 minutes to 5-10 minutes and the effect is a higher peak of emissions. The closed combustion type heater is used in two thirds of cases (of n=274), about one third has an atmospheric heater that in unfavourable conditions causes leakage of flue gases, mostly in small quantities. Wood-burning stoves and open fires are infrequently used as permanent heating, mostly for up to 200 hours a year to support a cosy atmosphere. Of the cases reporting extra heaters (n=172), 3% have a wood-burning stove, 4.7% a fireplace, 2.3% a kerosene heater (n=4), while three of these kerosene heaters are used for more than 100 hours a year; 6.4% use an auxiliary electric radiator or fanned air heater in individual rooms.

Sanitation

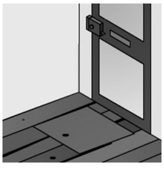
Waste disposal via waste bins and sewers has reached a high quality in the Netherlands. During the last few years, the few remaining remote houses have been connected to a sewerage system. Traditionally since the late 19th century, waste disposal was part of the hygiene policy and received proper attention. The only remaining problems are exhaust of sewer gas into the house (when shallow water-locks in the bathroom dry out) and from sewer exhaust systems on roofs, where gases may pollute the intake of fresh air from flat roofs that act as sink basins during certain climatic conditions. Collecting kitchen waste creates the risk of exposure to mould, because the waste bin is wet and warm and often not regularly cleaned, with a high concentration of active mould spores. Lifting the lid of the waste bin can produce a cloud of mould material that is emitted into the kitchen. Collective garbage collection zones in dense urban areas or high-rise buildings may become a source of pollution or a nuisance because of smells or noise or pests.

5.3 Physical parameters of air quality

5.3.1 Emission from crawl space

In the Netherlands, the foundation of houses is either on solid ground or on poles and beams, but always deep enough under the ground level to prevent deep frost from lifting the building from its foundation (at least 60 cm under ground level). The space between the ground floor and the soil(-cover) has the size that allows a person crawling around and which is used as a flexible service area: sewer, water conduits, heating circulation pipes. In most houses, a hatch is located behind the front door which gives access to the crawl space. Of the houses in the 333 dataset with connection to the crawl space (n=218), 57% have openings to the crawl space that allow polluted air to be emitted into the house. Probably more than half of these crawl spaces are moisture sources: monitoring resulted in relative humidities between 80-98% with temperatures in the range of 8-13°C: which results in 1 to 6 kg.10^{-3}/m^3 higher moisture content than in outdoor air during year-average conditions. Hot circulation pipes increase the temperature to 13-23°C (high temperature with district heating pipes). The amount of air through an opening in the floor of 20 cm^2 can amount to 3-5 dm^3/s, producing up to one third of the moisture produced by occupancy in the house. Many crawl spaces contain mould and produce bad smells.

Ventilation of the crawl space

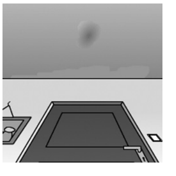


Until the 1980s' the crawl space is ventilated with four openings mostly, about 40 cm^2 opening per façade. Under average conditions, these openings create a cross-flow of 4 dm^3/sec: with a volume of 30 m^3 for a regular crawl space the air change rate per hour is 0.5 [ACH], with wind pressure on the façade the ACH will double. However, the soil is a highly productive moisture source and the moisture production is always higher than ventilation can remove. Starting from ambient temperatures lower than 16°C, dampness in the construction in the crawl space can be reduced if conditions are favourable. This winter period is essential in preventing mould-related deterioration of a wooden floor construction and the ventilation openings are indispensable in the case of wooden floor constructions.

Capillary moisture production

The 333 dataset contains 275 cases with information on the crawl space and wetness of floors and walls. 32 cases show wetness of the walls near the foundation, either visible from the outside or inside. Of these 32 cases, 20 have a moist crawl space, 2 have no and 6 have a dry crawl space. Of 3 cases the wetness seems to come from outside, while in 17 cases the inspection points at capillary moisture from the foundation. Of the 20 cases with wetness near the foundation and a wet crawl space, 14 have a wooden floor construction and 5 a concrete floor (1 case no information). The results point at quite a large number of houses with moisture load from the crawl space, considering that wooden floors are not airtight and that also concrete constructions contribute to moisture, especially when the material has large capillaries. Considering these data, 4-5% of indoor environments has an extra moisture load from the foundation.

Condensation and mould occurrence



Moisture creates indoor dampness and consequently higher risk of being exposed to allergen from mould and house dust mites (and bacteria) and moisture is a threat to the quality of constructions. Thermal bridges create surfaces with damp conditions and consequently mould hazards. The first signal of potential thermal bridges is the presence of balconies, galleries and other concrete based constructions that protrude from the façade without consoles. Roof overhangs and segmentation of high brick walls at floor levels with a visible concrete connection may disclose a (partial) thermal bridge. Information about the building period facilitates the diagnosis of thermal bridges. Problems can be expected in concrete floor segments starting around 1918 and until the mid-1980s. Better insulation and especially the temperature difference calculation of thermal bridges required by the Dutch building decree solved the thermal bridge issue. The inspection must reveal whether point-type or linear thermal bridges are present and how well these constructions are designed and manufactured. Dark leakage marks on walls and signs of moisture under carpets near doors can point out condensation. A thermal bridge is no hazard: dampness and mould growth on thermal bridges is a hazard and for that reason visible mould can be used as indicator of health risk exposure. In 43% of cases (in the 333 dataset), attention to this problem is needed: 14% have cold ‘line’ bridges along balconies or galleries, 20% large cold surfaces and in 4% of the dataset cold corners were indicated, primarily because of massive brick walls. The building period now being reconstructed (1950-1980) is notorious for thermal bridges. Via thermal insulation of cavities, the outer wall will be colder so heat loss increases on bridges that used to stay warm

Table 5.2 Moisture production by occupancy, by the crawl space and wet walls in g/24 hrs

Building related production	Living room	Kitchen	Bedroom I	Bedroom II	Bedroom III	Bath-room	Other
Moisture from crawl space	1,000	600					900
Moisture from wall/floor support	235						100
subtotal	**1,235**	**600**					**1,000**
Moisture production by occupancy in g/24 hours (see Section 4.4.1)	2,765	875	640	400	300	1,710	2300
Total moisture production	**4,000**	**1,475**	**640**	**400**	**300**	**1,710**	**3,300**

enough before the insulation was applied. Properly designed and executed insulation prevents mould growth on internal surfaces. Not all cavities can be filled with insulation materials without creating condensation risk.

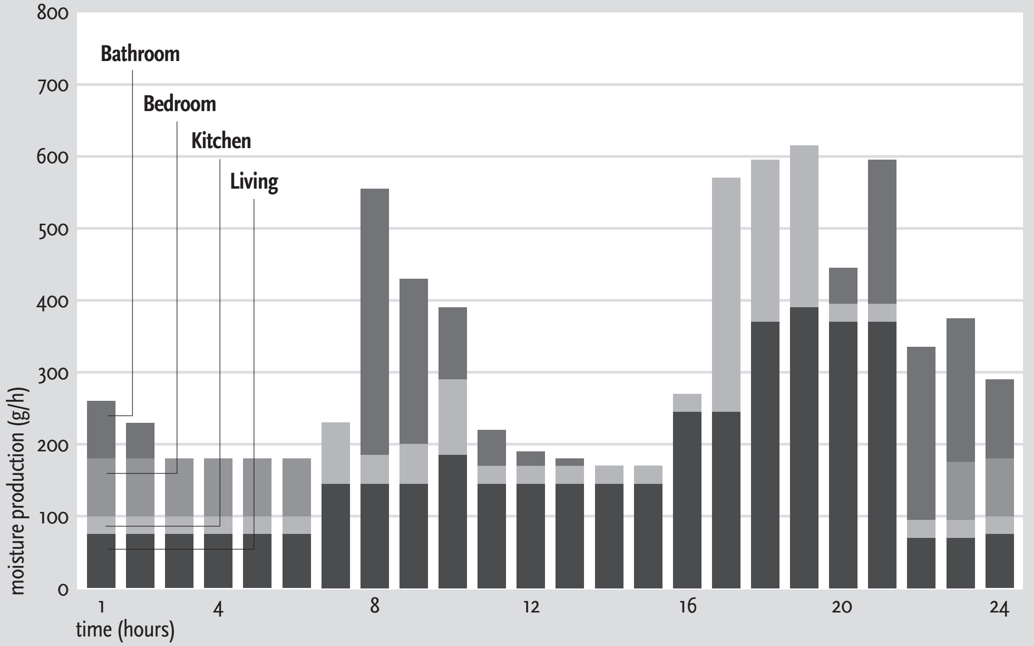
Vapour transport
Vapour is transported by air flows (large contribution) and by differences in vapour pressure (relatively small contribution). Vapour transport works fast enough (delay in the order of one hour) to show increased moisture level throughout the house after a shower or after cooking. Vapour pressure differences tend to create a flow from the living room to the kitchen and from the bathroom to all other parts of the house. Because of the dynamic character of heating, ventilation and moisture production, the moisture flows are dynamic, but with one main direction: from warm rooms and the bathroom to cold bedrooms and the attic. Extreme conditions occur in the kitchen after a long period of cooking, in the warm bathroom after a shower, in the master bedroom at the end of the night, and in combination with low ventilation rate.

5.3.2 Moisture balance

Moisture production by the building
The moisture production by occupancy was presented in subsection 4.4.1, Table 4.1. A moisture balance is created by adding building-related moisture emissions and then looking at the moisture removal by ventilation. The average air change rate of the house is set to 0.5 ACH, but is differentiated for each room. The volume for the central exhaust ventilation represents a practical condition: 1 hour at the highest setpoint, 23 hrs/day at the lowest setpoint: kitchen exhaust 21 dm^3/sec, bathroom 14 dm^3/sec, toilet 7 dm^3/sec volumes at peak setpoint (but lower in practical conditions). The data for moisture emission from the crawl space is based on Stoop (1998) and is set at 2.5 dm^3/sec, RH 90% and T=13°C. The emission from the foundation and the crawl space is estimated by the author, based on inspection of certain conditions (not measurements) in the field (see Table 5.2). The moisture content of the outdoor air is 6 g/m^3, the moisture content indoors varies in each room and over time.

The calculation of the moisture production and removal processes focuses on the living room, kitchen, bedroom and bathroom. The total production is

Figure 5.2 Combined moisture production in different rooms [g/h]

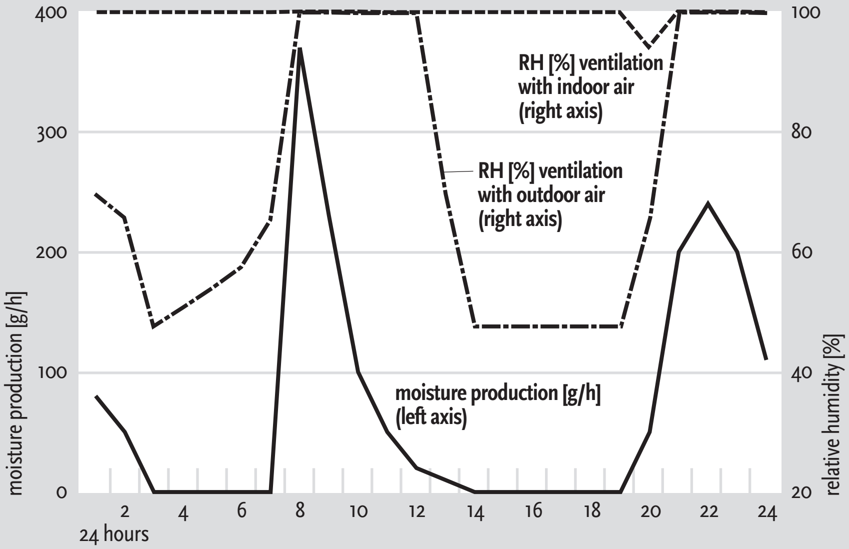


placed on a 24-hour time scale in each room (see Figure 5.2). The second step is to look at removal processes: temporary condensation, absorption and ventilation, evaporation. The processes involved are complex and therefore simplified. An example of the complexity of these processes can be illustrated on the basis of someone taking a shower. Within a few minutes, the bathroom air has reached the maximum moisture concentration. Meanwhile, the shower surfaces are wet with droplets of water that start running into the sewer system. Some of the surfaces absorb water. The absorption process depends on the roughness of the surface, the absorption characteristics (type and thickness of layers of paint) and the moisture content of the material at the start of the absorption process. The absorption process continues after the shower stops, until a balance is reached near the surface. At a certain moment after the shower stopped running, the reverse process of drying will start: first on one spot, while other surfaces are still absorbing water, and then over a larger surface. Dry air allows water droplets to evaporate and surfaces to dry. When all droplets have disappeared, the absorption into surfaces will end and the reverse process of emission starts. It takes several hours before the condition in the bathroom is completely restored. One long shower or two consecutive showers do not change this cycle in a significant way, but a shower three hours later will create a new cycle. This process may result in a long 'time of wetness' of materials, which is the key to the germination of spores and mould growth, because nutrition and also mould spores are likely to be available.

Moisture removal

Ventilation is the dominant function for removal of moisture from the shower surfaces that is not drained away into the sewer. The rate of moisture remov-

Figure 5.3 Moisture production PR and relative humidity in the bathroom, ventilation with outdoor and indoor air, calculated on the basis of the moisture production in Figure 5.2



al can be estimated from the air exchange rate and the differences in relative humidity between the indoor and outdoor air. The calculations for the scenario are in Appendix 3. We used a standard Dutch single-family house with a garden-facing living room to model these rates.

When the production exceeds the removal, the RH is 100% and condensation occurs. This can be observed in the bathroom with the scenario of ventilation with indoor air (see Figure 5.3). Then condensation occurs in the time span in which showers were taken. Ventilation with indoor air results in higher RH levels which prevail over a longer period compared to ventilation with outdoor air.

The results show that mould growth can be expected with indoor air ventilation in the bathroom. In this scenario, the indoor air in the bathroom is almost constantly saturated with water vapour. In the bedroom, mould growth is also more likely with indoor air ventilation. The general floor plans in houses built after 1981 often have a bathroom situated in the centre of the house and without windows. This means that the bathroom is ventilated with warm indoor air with a higher moisture content than outdoor air. The balance in the living room and kitchen tends to be relatively even, but depends on the active use of ventilation services. These calculation agree with data analysis of mould occurrence in the 333 dataset (see Chapter 7).

5.3.3 Ventilation services

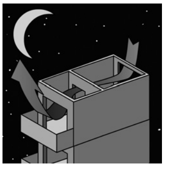
The distribution of systems services have been presented in subsection 5.2.3 under building services and the occupants' use of services has been presented in Chapter 4. In this section we focus on physical properties of ventilation services.

The control mechanisms are listed in Table 5.3. The control features influ-

Table 5.3 Control mechanisms of ventilation services

Ventilation		Control mechanisms
Inlet	Damper (of mechanical inlet)	Setpoints of fan
	Line inlet grate	For each grate: open or closed
	Sash window	Setpoints small range of openings, draught
	Large window	Setpoints small range, draught
Circulation	Obstacles	Layout furniture
	Seam of door	Door ajar or open
Exhaust	Mechanical exhaust opening	Setpoints of fan
	Stack effect	Shaft, staircase
	Capacity	Dimensions, power
	Flow across	Controls of chain of openings
Infiltration	Location	No control
Peak exhaust	Window, door	Open and locked with hook

ence the user-friendly quality. Burglar proofing, draught, cleaning and control of set-points of small openings, including secure control of flush openings are the most relevant quality criteria for optimal use of the services. Because of its effect on indoor air quality, infiltration is also included as a component of ventilation.



Air-tightness and infiltration

Air-tightness is evaluated on the basis or seam length and type of sealing. A door has a typical seam length of about 600 cm, which can be sealed by single or double stripping, or none. The door frame will also have small seams at the connection with the wall (e.g. wood on bricks or panels). Monitoring of pressure differences in the Ecobuild-Research project (Sijpheer, 2005) (data from 2003 and 2004) show average pressure difference of 15-20 Pa during sampling periods of 10 minutes, with extreme 10-minute averages of 65 Pa. The pressure difference increases with smaller openings. In these conditions, chinks and seams cause infiltration and exfiltration. Open seams in high areas in window frames, around doors in combination with leakage of the roof support a basic air exchange that sustains a clean environment even while exhaust systems are turned off. A door in the façade without sealing can create an opening of 30-60 cm² which supports 3-15 dm³/sec of air transport, a door inside the house is designed to have a larger opening of 80-140 cm², allowing 8-35 dm³/sec air transport. The ACH (Air Change rate per Hour) caused by infiltration depends on wind and pressure differences between indoors and outside, but ranges overall between 0.05 ACH (very low for sealed envelopes and opening on one side of the room) – 0.3 ACH average and up to 1 ACH (with large seam length in opposite façades without sealing and in windy conditions) per room. This high ACH shows that infiltration contributes a great deal to indoor air quality. The number and size of windows and doors, the location of openings and the type of sealing, in one or two façades, an open exhaust in the room, etc., are indicators of uncontrolled air change rate.

Constructions that allow infiltration are wooden-floor structures in houses of the period up to 1940, the (poor) Dutch-design timber frame houses (1975-1992) and prefab façade elements in high-rise buildings of 1965-1980 (sealing disintegrates in the course of 15-20 years, while thin concrete floor slabs shrink and hang consequently after many years). About 55% of the living rooms in the cases have enough uncontrolled ventilation through slits to create an indoor environment free of high concentrations of emissions from materials and decorations. Air-tightness is related to the ventilation system: more airtight with mechanical systems: almost 45% of living rooms in the 333 database are airtight, which is based on length of connections/seams of openings in the façades in combination with building period. In these rooms, controlled ventilation is required to keep the indoor air at good quality. Houses since 1998 are more likely to have heat-recovery ventilation and (supposedly) increased air-tightness.

Inlet systems of fresh air

To evaluate the quality of air replacement, it is important to know where fresh air enters a room and how it flows via the inlet point to exhaust points. Openings stay closed more often when the control of set-points is poor, for instance, when the choice is (wide) open or completely closed. 87% (of n=333) of living rooms allow cross-ventilation and 50% of the cases have good overflow openings from the living room to circulation areas or the kitchen. When air can flow to an adjacent space with façade openings, then pressure differences contribute to displacement of air: this is cross-ventilation.

Windows require elaborate user interaction, which creates a user problem in the windy and rainy Dutch maritime climate. The air quality in tight buildings depends on the control of active systems by occupants, so indoor air problems in relatively airtight buildings are strongly related to poor control and occupant behaviour, while with poor air-tightness the occupant does not have to intervene (and does not learn to deal with control). Recent innovations try to solve user problems by demand-controlled ventilation on the basis of CO_2 or 'ventostats' with control scenarios that reflect the needs of the occupants (Op 't Veld, 2006). Certain of these automated inlet dampers do not close into narrow slits, because under these conditions the airflow may cause a whistling sound. This problem is solved by selecting a larger opening and a side effect is more cross-ventilation.

Insect nets in grates get clogged with dirt and the effective ventilation surface decreases rapidly. It is hard to clean many types of grates, but cleaning is essential for the air capacity and prevention of air pollution by the system itself. Filters have a similar effect and need to be cleaned or replaced. Curtains, blinds and sunshades can also block the inlet opening. This obstruction has an impact on the amount of fresh air entering the room, which affects the ventilation rate when people are sleeping in the bedrooms. The height of the inlet opening above floor level is an indicator of the risk of draughts. Natural ventilation does not create noise, but is not effective in preventing noise from outdoors to enter the house. Sound insulation material that lines inlet openings collects dirt and may pollute the air. Burglarproofing is a main issue for the use of large openings.

Ducted inlet systems

Balanced-flow ventilation (equals heat-recovery ventilation or HRV) heats fresh air in a recuperation unit, with exhaust air as the heat source. The preheated air is ducted into each room. Volumes can be controlled in the central unit. According to the Dutch Building Decree the volumes must be based on the surface area of rooms, not on people present, which causes potential insufficient ventilation in bedrooms <15 m² with two adult people. The location of the inlet damper influences the airflow and air change efficiency. A controlled trial with HRV (Howieson, 2003) measured Der p1 allergen and indoor humidity and changes in lung function in 54 subjects. Mechanical heat recovery ventilation units significantly reduced moisture content in the active group, while HDM allergen reservoirs in carpets and beds were reduced by around 96%. Self-reported health status confirmed a significant clinical improvement in the active group. The study can form the basis for evaluating the minimum winter ventilation rates that can suppress RH below the critical ambient equilibrium humidity of 55% to limit dust mite colonisation in maritime climatic regions. These results are in contrast with self-reported respiratory problems in houses with HRV in the Netherlands (cases were reported by occupants and studied in Amersfoort, Arnhem, Eindhoven, Enkhuizen, Utrecht), but these complaints could result from poor natural ventilation facilities to compensate for low air change rates. Complaints in these inspected projects are mainly:

- fresh air is not fresh;
- the ventilation capacity is low;
- the system makes noise, when in use at standard fan speed;
- ceilings or walls become dirty from deposition of particles;
- the system increases the length of periods with overheating.

Health complaints are diverse: headaches, running nose, irritated eyes (contact lenses), itch, fatigue, poor overall condition. Complaints disappear when away from the house for a certain time period.

Also, many occupants do not understand how the system works and how it should be controlled. Because of these problems, heat recovery ventilation is used at low set-point. Occupants use flush openings to compensate for the poor contribution of the mechanical systems. Complaints are related to the quality of these compensations: when flushing cannot be controlled or is not available.

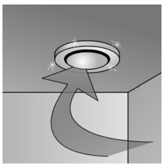
Exhaust systems

The major problems with exhaust systems are:

- the exhaust rate is reduced for energy conservation purposes;
- the use of mechanical systems is influenced by noise;
- the mechanical systems are not well-maintained, causing reduced airflow capacity.

Noise from the systems is in conflict with high volumes, especially at night.

Natural exhaust



Natural exhaust systems use vertical ducts in which a combination of a stack effect, the wind blowing over the duct on the roof and negative pressure on a rooftop cause airflow in the duct. This mechanism indicates that the performance depends on the length of the duct, temperature difference, wind and the location of the exhaust opening on the roof. In single-family houses, the duct that connects the exhaust point in the kitchen with the rooftop is long and has a good exhaust position, supporting a constant exhaust volume except on warm summer days. The measured exhaust volumes indicate that 40-60% of norm values are reached. The bathroom tends to be one floor higher and with less favourable conditions to bring a canal to the rooftop. The natural exhaust volume is often low and with reversed airflows that cause comfort problems.

Natural exhaust ducts are never cleaned in practice, and the capacity is likely to be reduced because even spider webs can block the airflow. Maintenance is also needed to correct the application of horizontal or flexible duct material, dampers and grates that create airflow resistance. The construction of about 30 ducts was inspected inside by video-inspection or other visual inspection. Poor design, wrong inlets and outlets, obstruction of flow by dirt or flexible ducts and bad location of outlets on the roof can be pointed out as indicators of low exhaust flow (Hasselaar, 2001a).

Mechanical exhaust

The exhaust mechanism depends on the control and capacity of the exhaust fan. The capacity of the system is influenced by maintenance of the fan blades, the ball bearings of the fan and also dirt in dampers and certain parts of the ducted system. The capacity often does not meet the minimum requirements, from the moment the system was installed. Figure 5.4 shows inspection results of kitchen exhaust volumes at the completion of the houses. The houses were built under a building standards regime requiring 150 m^3/h of total exhaust volume. The kitchen exhaust volume does not meet the required exhaust volume in 40% of the cases (subset n=80) and the volume for the bathroom does not meet the minimum requirement in 30% at the moment of delivery of the houses.

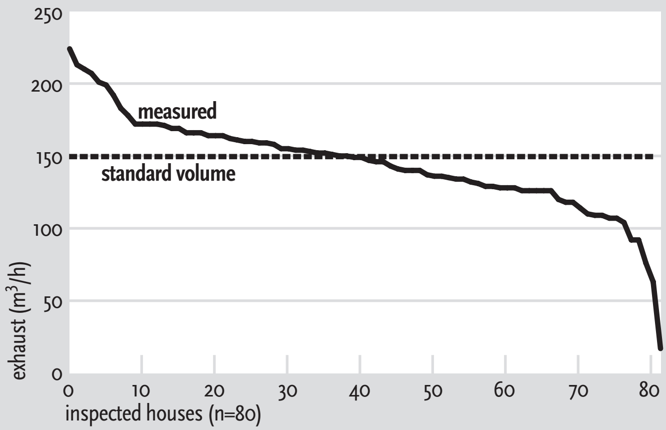
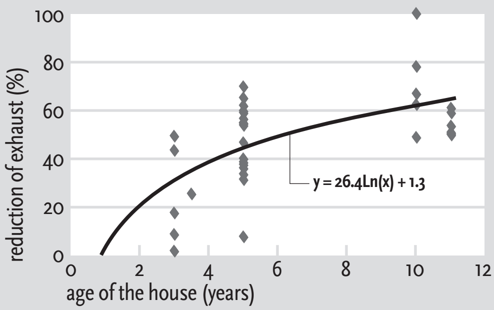


Figure 5.4 Exhauste volume in the kitchen

Ventilation quality

The subset of cases in which the capacity of mechanical exhaust systems at delivery is compare with the capacity after 1 to 11 years deals with relatively new houses, but for ventilation systems this period of operation is rather long, compared to a technical lifespan for the mechanical parts of about 15 years. The fact that one of the participating housing agencies just had cleaned the exhaust fans and dampers constitutes a bias. We must consider that results show relatively high capacities. Because the dataset is also used for the selection of indicators on other topics, for instance on mould in bathrooms and on house dust mite concentration, possible bias caused by the relative newness of the houses must be accounted for as well.

Figure 5.5 Regression line showing 10% reduction in exhaust volume per year average



Source: Ginkel (2002)

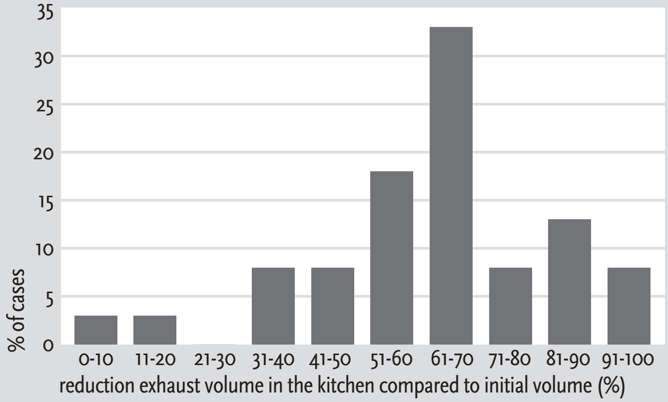
Capacity reduction

The reduction in exhaust volume is about 10% per year average (n=60), due to wear and tear, dirt and change in the air balance due to improper handling of dampers (Ginkel, 2002) (see Figure 5.5).

In the 333 dataset, more than 70% of exhaust fans are more than 5 years old, and on the basis of the reduction in capacity over a time period, we estimate that 50-70% of all mechanical exhaust systems in the Netherlands have a capacity of less than 60% of minimum standard volumes, and 30% less than 40-50% of the intended volume. In the 333 dataset, we found a correlation between the age of the fan box and the period used per day: the older, the shorter the period of use.

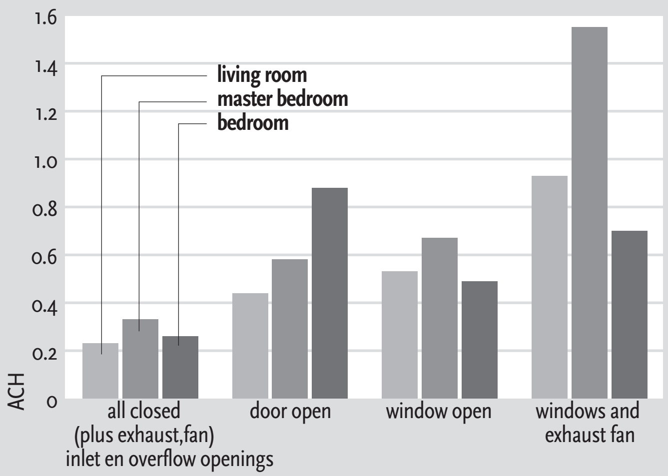
In datasets other than the 333 dataset, both natural and mechanical exhaust volumes were collected. We found indications that the mechanical exhaust volume in the kitchen is in the order of 25% lower than natural exhaust, while the volume is somewhat lower or equal in the bathroom. Because natural exhaust is never constant, the measured conditions may not reflect the differences completely: the natural exhaust was measured during the day, with relatively high outdoor temperatures and therefore lower exhaust volumes.

Figure 5.6 Total % of reduction in exhaust volume in the monitored cases



Source: Ginkel (2002)

Figure 5.7 Air change rate based on CO_2 monitoring



Air change rates and use of openings

A survey in 86 houses in the Netherlands showed 10% of air change rates below 0.3 ACH and 33% below 0.5 ACH (n=82) (Gids, 2004). This is an average ACH, based on passive tracer gas techniques, with samples taken over a period covering three months in the heating season in the living room and the master bedroom.

In 38 houses, the air change rate was monitored using a flowmeter with compensation of intrinsic air resistance for momentary measurements and CO_2 data logging (infrared sensor) over 1-10 days.

Figure 5.7 shows the air change rate per hour (ACH) for the living room and two bedrooms (n=30). The ACH, calculated on the basis of CO_2 monitoring and with high exhaust volumes, was quite low. We found no correlation between ACH and actual exhaust volume, which indicates that the use of windows (and infiltration) determines the ACH (see Figure 5.8).

On the basis of these cases, an estimate was made of the effect of inlet openings on the air change rates in bedrooms with typical surface areas of 8-12 m², well-sealed windows and opening in one façade, meaning that the contribution of infiltration is relatively minor (see Table 5.4).

The results show that a window must be wide open to allow enough exchange of air for two people sleeping in a bedroom: two people in a bedroom of 14 m² require an air change rate of 1.4 ACH to keep the CO_2 concentration below 1,000 ppm.

Reduction by filters in balanced-flow ventilation systems

In the Ecobuild-Research test house, we found an increase from 42 dm³/sec

Figure 5.8 Use of the highest setpoint of mechanical exhaust system in hours/24 hours

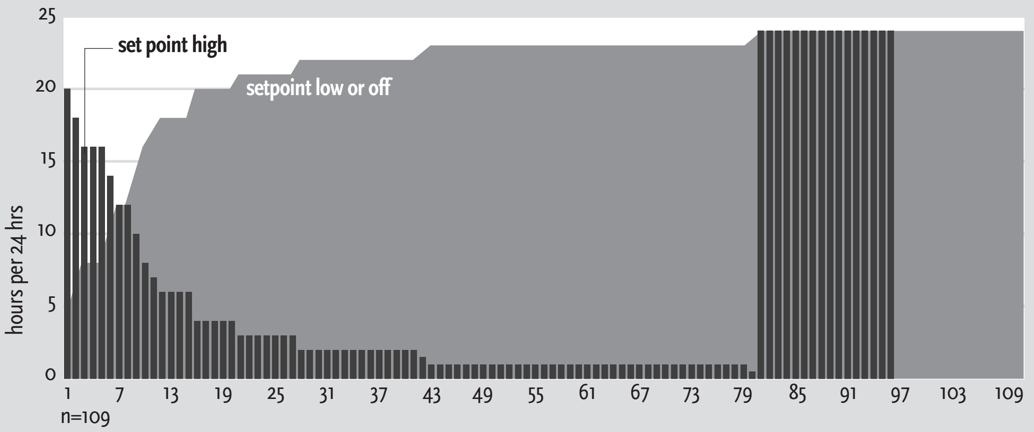


Table 5.4 Inlet openings in bedrooms and resulting air change rate per hour

Opening [cm²]	gross	net
Inlet grate above door 1.8 x 80 cm	140	60
Top/side-hinged 70 x 120 cm, deep in wall	800	500
Top/side-hinged 70 x 120, level to façade	900	800
Resulting air change rate per hour (ACH for normal weather conditions of April/May and November)		
All closed	0.2 - 0.3	
Door open	0.4 - 0.8 (exchange of damp indoor air)	
Window open, door closed	0.5 - 0.7	
Window and door open	0.7 - >1.5	

to 49 dm³/s after cleaning the dirty filters. Dirty filters create more imbalance between inlet and exhaust volumes, depending on the dirt load. The effect of dirty filters on air volume is 15-25%, but fans controlled on the basis of pressure differences correct this effect until the dirt level is too high.

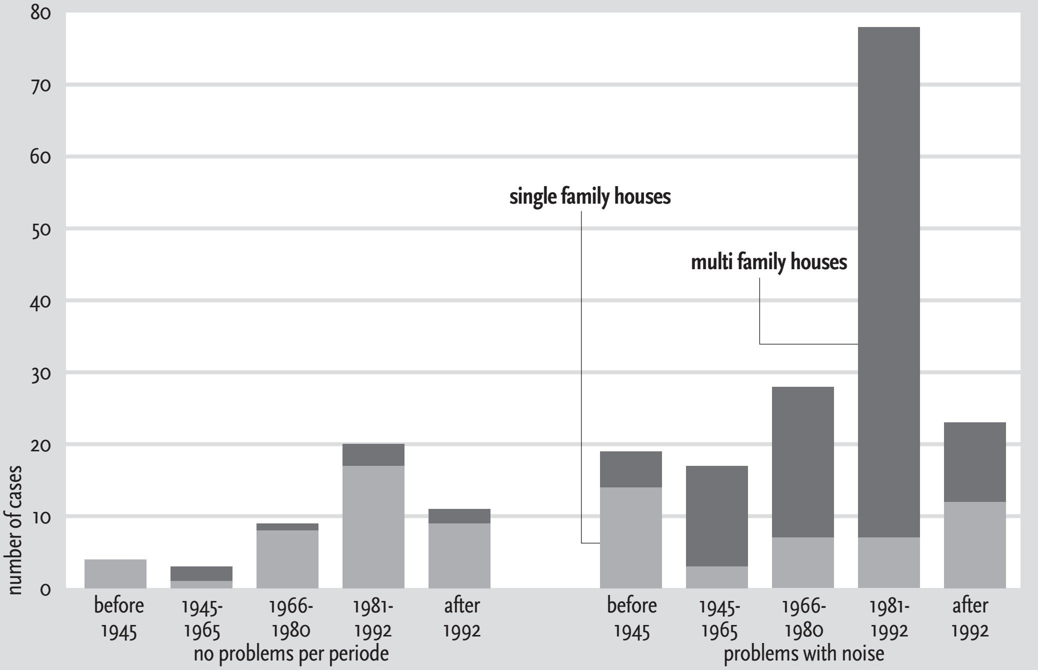
Maintenance visits can restore the capacity, which requires that the capacity is measured and dampers are adjusted. Cleaning the fan alone does not restore the capacity. In the dataset, 4% was cleaned one year before, 38% had never had a visit, 11% was cleaned 1-5 years ago and 4.3% 5-15 years ago (n=115). The maintenance quality in cases of the subdataset is better than in the total stock, due to a group of cases where the fan was cleaned prior to the inspection.

5.4 Technical conditions and physical hazards

5.4.1 Noise

Ambient noise enters the indoor environment through leaks and separations

Figure 5.9 Building period and location in relation to noise, based on the 333-dataset



with poor insulation quality. Small acoustic leaks such as a ventilation grate, chinks, a letterbox, etc. have great impact on the insulation level. Unlike thermal insulation, where every m² counts, the acoustic quality depends largely on the weak spots. Parts of the envelope with poor insulation are single-glazed windows, doors and lightweight constructions, for instance large window frames and sloping roofs (before 1992).

Of the cases (n=300), 60% are located along a quiet road, 40% along neighbourhood access roads or roads with through traffic. The occupants of multifamily houses who complain about noise from neighbours also have problems with noise from outside (traffic) and installations indoors. Of the houses adjacent to neighbours, one third have problems with noise from neighbours (n=143) and 80% of the complainants live in multifamily houses: 24% at the end of a block, 35% under the roof (but in between) and 41% completely surrounded by neighbours. Noise from neighbours is scored especially in apartment blocks built in the periods 1945-1965 (poor acoustic insulation) and 1981-1992 (probably related to urban conditions).

Figure 5.9 shows noise reports per building period in the 333 dataset.

5.4.2 Overheating

The first encounter with social protest against overheating in an 'energy-conscious' project was in The Hague in 1986. Some of these houses had a sun room with large sliding doors that allowed ventilation in warm periods, but the doors were kept closed. The exhaust gases of the heater were used to heat fresh air which, in the summer time, caused extra heat load during a shower. Dutch manufactured systems with 100% bypasses over the heat recovery unit only became available in 2004 but are not often applied (yet) because of their higher cost. An alternative is turning off the inlet fan, which requires that natural inlet openings are available and user-friendly. Problems are aggravated by insufficient flow rates of inlet dampers. Cool night air can remove the overload of heat, provided it is possible to reach ACH = 2.5 or more per individual room during the very early morning hours.

With insulation the 'temperature without heating' increases, compared to poorly insulated spaces. A well-insulated envelope can create uniform indoor temperatures that are above 16°C for most of the year and likely to increase to 18-21°C as soon as the sun hits the windows. In the test houses of the Ecobuild-Research project, that are well insulated (Rc=5 m^2K/W and U-value of glazing lower than 1 W/m^2K) and have large openings facing south, no heating is required even with outdoor temperatures below zero, on sunny days (Sijpheer, 2005). A modern phenomenon is high radiant temperatures from sunlit insulating glazing (U<1.4 W/m^2K). In sunlight, the temperature of the inner window blade reaches temperatures of 33-40°C and the effect is heating load with high radiant temperatures. The temperature also increases behind perpendicular sun screens inside the house or parallel to the façade outdoors, which may heat the natural inlet airflow. Sun shading that allows free airflow under the screens, is more efficient in terms of prevention of overheating.

Ventilation has become a control feature of the temperature in well-insulated houses, in bedrooms all year round and in the living during the summer season. Complaints of overheating cause stress primarily in houses or rooms that do not allow flushing or cross-ventilation. This phenomenon emphasises the need for effective natural ventilation services in each house, regardless of the system.

5.5 Physical parameters of social interaction

The relationship between technical conditions and social interaction is a complex field and the research project only included data collection for a few parameters: the fear of burglary and its effect on the use of openings in the façade, the perceived level of social contact and feeling of safety in the neighbourhood, safe places for children to play and having a private outdoor space. In some cases, the limited access with a wheelchair or rollator to the dwelling were reported, or problematic emergency evacuation on a stretcher.

Privacy requires individual space undisturbed by eavesdropping or noise that allows visual privacy and also easy access from the house, so private space can be enjoyed whenever one wants. One third of the inspected houses (333 dataset) have a balcony, and only 1% have no outdoor private space. Many balconies of houses built before 1965 are quite small.

5.6 Conclusions

The physical housing conditions are viewed from the perspective of influence on pollutants, hazard conditions and occupant behaviour. The research question is: *What physical housing conditions are associated with health?* The overall conclusion is that housing conditions cause hazard conditions, and show many conflicts with occupants needs and user behaviour. We found technical properties that induce hazard conditions and for that reason are associated with health.

An introduction to building physiology highlights hazards for specific building periods. Major problems can be found in any period, including modern housing. Of special interest is the housing stock of 1960-1980: many neighbourhoods are under reconstruction. Some physical features of this old stock are more crucial to hazards in multifamily houses than in single-family houses, e.g. acoustic quality, privacy, lack of control over (collective) services.

Biological and chemical hazards

Pollutant emission from the crawl space (moisture and mould, radon) and moisture emission from the foundation still applies to 4-8 (57%) houses. Mould growth is influenced by poor insulation quality, poorly cleanable (cold) surface materials, heating and ventilation volume. The moisture balance is on average safe on the moisture removal side, but moisture production peaks do create problems such as in bathrooms and cold and poorly ventilated areas in bedrooms. Bedroom ventilation is a problem when the fresh air inlet is closed and the door is open. The overall technical quality of ventilation systems is poor: low capacity, production of noise, control is not user-friendly. Natural and mechanical exhaust systems function with about the same exhaust volume (considering the long periods with the lowest setpoint of mechanical systems). Collective mechanical systems provide the highest exhaust volumes when the setpoint is the level according to the Dutch Building Decree. The general impression is that heat recovery ventilation is not used to potential and that natural openings are used instead, for cross-ventilation and stack ventilation via the stairwell. Complaints are associated with lack of means to intervene in extreme situations: smell, noise, overheating or lack of fresh air.

The chimney-tied atmospheric central gas heaters placed in the living room and flueless domestic water heaters create health hazards.

Physical hazards

The acoustic quality represents a complex phenomenon. Social noise is difficult to solve through technical measures. Noise from traffic and sources inside the house and the acoustic insulation level between (older) houses is correlated with complaints. Noise is caused by individual appliances, which is to an important extent the reason why mechanical ventilation systems are used poorly. Low temperatures are not a problem in Dutch houses, except in rare occasions in houses with collective heating and metering. Overheating is a growing problem in well-insulated houses with large windows and west orientation or with HRV without 100% bypass and in cases in which attempts to compensate for problems by flushing and cross-ventilation are not effective. Some indicators of safety deserve attention: steep or slippery stairs, obstacles and slippery floors of circulation areas, poor kitchen ergonomics, missing handles and ramps. Safety is very important for the elderly and children.

Indicators of mental hazards and social interaction are not included in the selection process of indicators.

The indicators that result from this chapter on housing conditions are:

1. poor hydrothermal quality of the envelope, causing condensation (mould) and overheating;
2. low acoustic quality of the envelope and technical installations, which for that reason are poorly used;
3. poor exhaust ventilation, poor compensation by infiltration, cross-ventilation or stack effects;
4. poor sealing of the crawl space;
5. poor ventilation efficiency in bedrooms, partly caused by a lack of burglar protection;
6. emission from heaters without exhaust connection, or atmospheric central heater in the living room;
7. mould-sensitive surfaces in the bathroom;
8. peak emission of chemical agents from renovation or redecoration and during hot weather;
9. steep and slippery stairs, floors, uneven levels causing falls with personal injury.

6 Health performance evaluation in practice

6.1 Introduction

6.1.1 Research question

The research question for this chapter is: *How can we evaluate housing health performance?*

Instrumentation for health performance evaluations is meant to support occupants and housing managers in identifying health hazards. This involves two lines of study: indicator selection and strategies for instrumentation.

Table 1.4 highlights the relationship between the research questions and Chapter 6.

6.1.2 Data collection and analysis

Practical experience with the Ventilation Checklist of the Dutch Tenant Association (Woonbond) (Rijsbergen, 2000), with the Energy Performance + Health Tool (Hasselaar, 2001a) and the Healthy Housing Checklist (Hasselaar, 2005a) supported an interactive process of developing, implementing and redesigning, including the selection of indicators. The discussion with other tool developers, provided a great deal of information about the state-of-the-art of health performance evaluation tools. The practical experience is placed in the context of the theoretical framework and vice versa: the framework explains the work already done in the field.

6.2 State-of-the-art of health performance evaluation tools

6.2.1 Review of tools

A short review of the state-of-the-art of performance evaluation tools is used. Many tools were collected; only a few dealing with healthy housing are presented as examples. A SWOT analysis of four tools is performed and the results are used for selecting design strategies of a new tool. The Healthy Housing Checklist is one of the stepping stones, the next step being the renewed definition of indicators and then the redesign of the tool.

A variety of evaluation and rating systems for existing buildings is in use around the world. Many publications present evaluation criteria and indicators: Audit Commission (2000) with recommendations for performance measurement, Broeke (2003) with a study for the Dutch Ministry of Housing (VROM) on how to evaluate the health status of houses, Bruggen (1998) about environmental effect screening for urban interventions, Cox (2005) who compared five state-of-the-art tools in the Netherlands, EPA (2003a on exposure evaluation tools including an overview, Flynn (2003) about the application of the UK Housing Health and Safety Rating System, Hasselaar (2000, 2001a and 2001b, 2004b, 2005a and 2005b) with reports on the design and use of recently developed and applied performance evaluation tools, Health Canada (1999) with a handbook on health impact evaluation, Health Council of the Netherlands (1996) on risk evaluation, Hollander (2004) on evaluating the health impact of environmental exposure, Hult (2000) with her PhD thesis on environmental impact evaluation, Hunter (2004) on the individuals' recall of exposure to pollutants, Kort (1997) and Luxemburg (1997) on the health quality classification of houses, Loo (2000) on the design of the health effect screening method for urban interventions, Mänsson (1995 and 1998) about the effect of the compulsory Swedish programme of inspection and maintenance of ventilation systems, McIntyre (1999) with a literature review on health impact evaluation, and Mindell (2001) about robust health impact evaluation. The Dutch Ministry of Housing presented the action plan for health and environment which includes actions to monitor the health status of the Dutch housing stock (2004), Moullin (2004) wrote about the essentials of health impact evaluation, Murray (2002 and 2003) about the concept of DALY, a measure of health impact expressed in disability adjusted life years, Nieman (2004) on a state-of-the-art health performance evaluation tool in the Netherlands, Ormandy (2005) about the Housing Health and Safety Rating System in the UK, and Versteeg (2003) on health risk evaluation tools. The origins and intents of the tools differ, from tools intended for use at the design stage to post-occupancy evaluation tools. Legal requirements for health performance evaluation are not found, except in the UK. A financial incentive is not available.

An exploration of the 'landscape' of tools used in housing reveals that new requirements or tools are not welcomed by housing managers. Managers like to understand the 'big fish', but hesitate to scan individual houses for hazards. Short, 'quick and dirty' scans stand a chance of being used by housing managers, but an interview with the occupants and a scan of all rooms and installations in the house runs up against many practical problems.

The literature review provides insight into the weak and strong points of different applications. Some examples are studied in greater detail, because they have features also applicable to health performance evaluation in housing. The DUWON (Duurzaam WoningOnderhoud [sustainable housing transformation]), TGW (Toets/verbeterlijst Gezondheid Woning [Check/remediation list Healthy Dwelling]), Health Map and the United Kingdoms HHSRS (Housing Health and Safety Rating System) are examples of comprehensive health performance evaluation tools. All are evidence-based and applicable to existing dwellings. The TGW (Versteeg, 2003) and Health Map (Nieman, 2004) are responses to the need of the Dutch government for a uniform method to evaluate and describe the health status of houses.

These tools can be placed on a scale of increasing abstractness, time and expertise involved and from 'objective' status description to qualitative risk exploration.

- DUWON (Duurzaam woningonderhoud) (sustainable maintenance of housing)
  The Dutch DUWON Handbook (WE-consultants, 2003) presents strategies for sustainable renovation of residential housing. The steps are: selection of the ambition level, selection of strategies (improvement concepts) and finally selection of solutions. A measure for indoor environment is included in DUWON. The instrument supports a simple evaluation on the basis of indicators and its goal is to present an overall mark of the quality. Below a certain level, improvement of the indoor environment is necessary. The subjects are indoor air, thermal and acoustic quality, day lighting and humidity. The indicator selection is based on expert opinion. Comfort is a major parameter and not distinguished from health aspects.
- Health Map and Check-Retrofit list for Health of Dwellings
  After a study on health performance indicators (Bergs, 2002), two separate projects were initiated to develop a health performance tool for dwellings. The first to be published was the Check/Retrofit list for Health of Dwellings (Versteeg, 2003). The set of indicators (Bergs, 2002) was adapted and physical parameters were selected that allowed a simple inspection of the dwelling and an evaluation of the performance of indicators. The inspection protocol was simplified, but in the simplification the relationship with health aspects was lost, leaving the inspector in disarray: the tool did not support insight into health performance. The Health Map by Nieman (2004) followed the same set of indicators as Bergs (2002). The tool requires sophisticated monitoring and inspection and evaluation by experts.
- HHSRS
  The Housing Health and Safety Rating System (HHSRS or the Rating System) is the UK Governments new approach to the evaluation of the potential risks to health and safety of any deficiencies in dwellings. It is a form of risk evaluation, of evaluating the severity of any dangers present in a dwelling. The HHSRS, although not itself a standard, was introduced as a replacement for the Housing Fitness Standard and has been in use since April 2006. The Rating System is supported by extensive reviews of the literature and detailed analyses of statistical data on the impact of housing conditions on health. This evidence is summarised in Hazard Profiles intended to inform professional judgment. Because HHSRS seeks to generate a single numeric score or band for each hazard identified, it had to find a way to present hazards of many different types and levels of severity using a common scale. Environmental Health Officers particularly welcomed the fact that it allowed them to address a range of important hazards in housing which are not currently addressed by the fitness standard. The system is complex and makes heavy demands in terms of familiarisation on those who must

implement it. The legal basis and the use of certified inspectors must guarantee the quality of results.

6.2.2 SWOT analysis of tools

A SWOT analysis was made (SWOT = Strengths and Weaknesses, Opportunities and Threats) (see Table 6.1).
Given the exploratory nature of the review, a simple comparison is made of the aspects of concern in the use of tools. The evaluation criteria are derived from the theoretical framework developed in subsection 2.2.2. Criteria also refer to the scope of the health topics and the connection to protocols used in housing maintenance and renovation. Some criteria about detail and precision of the results are used from Cox (2005). The evaluation is on a six-point scale:

- - (or --) does not meet the criteria involved (or miss this criterion completely)
- 0- or 0+ only small parts of the tool (do not) meet(s) the criteria involved (0.5 - or 0.5 +)
- + (or ++) meets the quality (or outstanding performance on the criteria involved).

A positive score indicates better quality. The conclusions are based on simple addition, not on differentiation of weightings. The results are presented in Table 6.1.

Explanation of the evaluation criteria
A health performance evaluation tool is intended to reveal health hazards, not the quality of the building. The evaluation criteria for the tools in this respect are: focus on hazards, identification and diagnosis of all major health hazards and support for better matching of health needs and the house.

The focus on both the building and occupancy is a matter of choice: differences in responsibilities between the owner and tenant and also shared responsibilities can become visible. A tool that focuses on both building and occupancy and supports communication between tenants and managers is expected to have a direct impact on remediation as well as on behaviour. The quality of the results resulting from the protocol depends on these criteria:

- ranking of priority problems;
- data and results can be reproduced by different inspectors with similar output;
- indicators point out relevant, reliable and valid data.

Alignment is essential for application in the field, because there are no incentives or penalties to use the tool. The alignment criteria are: is the protocol easy to follow and understand, is the tool aligned with other housing tools, is

Table 6.1 Comparison of qualities between Dutch tools and the HHSRS from the UK

Evaluation criteria	DUWON	TGW	Health map	HHSRS
Focus on hazards	+	+	0	++
Identification and diagnosis of all major health hazards	-	+	+	++
Useful for better matching of health needs to housing quality	0	0	0	+
Focus on building and occupancy and behaviour	0	-	-	+
Contribution to occupant understanding of health risk	0	+	-	++
Results promote actions to remediate or adapt behaviour	+	0	0	+
Includes identification of priority problems	+	0+	0+	++
Includes risk score (evidence-based)	0	0	0	++
Data and results can be reproduced by different inspectors	+	+	0	+
Indicators point out relevant data	+	+	+	++
Indicators point out reliable and valid data	+	++	+	++
Potential for use				
The protocol is easy to follow and understand	+	0	--	--
The tool is aligned to other housing tools	0	-	+	+
The balance between time, money and results is efficient	+	-	-	0
The output has a legal basis	0	0	+	++
Conclusions				
Overall potential impact on healthy housing	5+	6.5+	1.5+	18+
Overall potential for large-scale use	2+	2-	1-	1+

the input-output balance (time, money and results) efficient and can the output have some legal basis? In Table 6.1, three Dutch tools are compared with the Housing Health and Safety Rating System in the UK. Some criteria were omitted from the table, when the results were almost identical for the five tools and did not contribute to showing differences.

Results of the evaluation

The tools show different health aspects, levels of detail and results in terms of evidence of risk exposure. The overall quality of the HHSRS is good because of the completeness and the risk score. A negative aspect is the complexity, even in the presentation of results. DUWON is simple but limited in scope: it is a quick scan. The TGW and Health Map are complex and the focus on health hazards is not complete. The Health Map suggests inspection by specialists and application of monitoring equipment to evaluate the status, but the protocol results in valuable data on the house.

The TGW and Health Map tools are status-oriented: consultants describe the physical features and installations, without identifying the separate hazards. All tools use a checklist, often designed as a questionnaire. Some questions require yes/no answers. In the TGW (Versteeg, 2003), the most appropriate of three answer categories must be selected, so each question requires the reading and understanding of three answers, which is time-consuming. Some tools lead to quality scores on the basis of indicators, but not to hazards.

The Housing Health and Safety Rating System in the UK serves as an example for the design of the protocol, background information and risk ranking. The legal basis and the involvement of trained professionals has a great impact on its use. Without this basis, the tool would have no chance in the market, due to the cost involved. The use of other tools depends on the added value that housing associations and occupants perceive, and the impression is that professional housing managers have little interest, meaning that the market potential for health performance tools is low.

The traditional way of evaluation is to compare the status to standards and to evaluate the aspects for which no standards are available on the basis of occupant satisfaction. Self-reported information by occupants tends to be collected to evaluate the quality of services and perceived comfort or health.

The difference between quantitative and qualitative evaluation is gradual: quantitative data must be interpreted to understand the risk, which also makes the results qualitative.

User groups and communication

The major users of performance evaluation tools are professionals in housing associations in the social and private sectors, consultants, renovation architects and environmental medical professionals working for regional or community health agencies. However, the occupant who is interested in the performance of the owner-occupied or rented house is an important user of health performance evaluation tools. Potential moments to perform an evaluation are 1) at turnover, 2) during the preparation of the maintenance policy, 3) in the preparation of renovation plans and 4) when dealing with complaints (information based on interviews with housing managers in 2004 and 2005).

The link to remediation was not made in the three Dutch tools, except in general terms. The status is described without specification if the status was influenced by the occupant or by the construction and services.

Design strategy

The picture of the present use of tools is not promising. This situation requires a strategy dedicated to finding a way to support the interest of occupants and professionals. One of the interests is to support the process of dealing with complaints and improve the allocation of housing, in order to find a better match between the health performance of houses and the needs of the occupants. Hazard identification is the bottom line. Status descriptions do not support risk management. Risk ranking is a further step towards risk management. Action taking for improving the housing health conditions is required to achieve improvements. By linking the hazard identification to tips and suggestions for remediation, action taking could be stimulated. Housing associations are confronted in an everyday routine with complaints from tenants. Many of these complaints result in a home inspection visit by the housing manager. Communication between the occupant and owner/inspector is considered to be a prerequisite for recognizing problems and achieving a better understanding of the roles and responsibilities for remediation. However, instrumentations with these qualities will still have low impact. A range of strategies is needed: stricter building regulations and maintaining these regulations, new sets of quality requirements, an action list of major health issues of housing, transfer of knowledge on risk, demonstrations of healthy housing concepts, practical information about do-it-yourself improvements, in the context of popular 'house and garden' tips. With better information risk awareness may develope and housing conditions may slowly improve. The interested professional can be helped with checklists.

6.3 The Healthy Housing Checklist

6.3.1 Design

The application of the framework in instrumentation for health performance evaluation

Many houses have similar sources and they can be evaluated on the basis of a checklist of pollution sources. The concentration is the result of two phenomena: the emission (Pressure +) and the removal of emitted material by ventilation or cleaning (Pressure -). Pressure is evaluated by inspection and interview. The concentrations of gases or aerosols are not visible and hard to evaluate. We use proxy indicators that indirectly represent the concentration. For exposure we take standardised exposure periods. In other words, the health performance evaluation protocol can consist of the following main elements: checklist for Source, inspection and interview in the house for Pressure, indirect evaluation of Condition and concentration on the basis of 'proxy' indicators and finally a default for Exposure. The result of this sequence is the level of exposure to a certain hazard, in other words: the risk level can be ranked. For risk ranking the inspector needs to understand dose-effect relationships or must be provided with standardised information on the risk value.

The Action to reduce the risk is a new step in the process and this step often involves other people and departments of housing associations and other relationships with occupants. The bridge between risk ranking and initiatives for action needs attention.

The position of the Healthy Housing Checklist was influenced by the context of the landscape of tools: the strategy was to develop a simple tool for risk exploration that could be used by tenants and home owners, as compared to other tools for the professional housing managers and consultants. A short television item on health performance evaluation resulted in 1,600 requests for the tool within a few weeks, and it was clear that 'consumers' have great interest in diagnosing the perceived health issues of their house. The consumer version of the health performance evaluation tool was developed first, with involvement of and published by the Dutch tenant association (Woonbond).

Design choices for tool development

Quality criteria are developed in connection with strategic design choices. The quality criteria in the brief of tool development are:

- the tool supports the interest of users, is user-friendly and in line with other tools;
- the tool can be used both by occupants and professionals;
- the tool recognises the connection between technical features, occupant behaviour and health risk;
- a visit with inspection and interview for a single dwelling is required;
- special equipment and expert knowledge is not necessary;
- the input (time and cost) and output balance is perceived as positive by the target group(s);
- the results contribute to better matching of household and house;
- the tool supports communication about and interpretation of complaints and hazards, which becomes evident when both the manager and occupant are satisfied with the process and the agreements reached;
- occupants using the tool are supported in self-efficacy, starting with better understanding and critical perception of quality and consequently taking action as a result of this understanding;
- the tool supports the selection and implementation of technical and behaviour-related measures.

The protocol must guarantee that what is inspected is the actual performance. Indicators must relate to what has the highest priority, not what is easy to evaluate. When the set of indicators is too small with essential features missing (for reasons of user-friendliness), the data may not lead to reliable conclusions.

The tool evaluates the exposure to agents and physical hazards, not the physical structure of the building. For example: dampness is the problem, not the thermal bridge. The condition of the house is relevant and not the age, etc. Risk is more relevant for health performance than status that needs to be interpreted to understand the relationship to risk. The goal is to evaluate for the actual occupants of the house. The check is whether problems in the house could lead to exposure to hazards and pollution with health consequences and what can be done to reduce the health risks. Better matching between occupant needs and houses is set as the outcome. A separate tool for occupants and professionals has been developed, and a set of optimal housing conditions has been described: the optimum for a number of quality themes: free from allergens and hazardous emissions, well-designed for optimal functionality and safety, user-friendly in case of disability and illness, protected against noise and trespassing and providing good privacy and comfort together with free choice of lifestyle and opportunities indoors and outdoors to socialise.

The tool is a checklist. There is a balanced attention to the building and occupancy. A house visit is required. The visit follows the inspection and interview protocol: items to be documented while approaching the house (environment, building type and location), information from an interview with the occupants, inspection tour, evaluating, reporting and presenting the results. The protocol supports integrative evaluation instead of focusing on individual checkpoints. Agents and hazards are clustered along five quality themes, representing single-item conditions: air quality, acoustics, thermal comfort, safety. Each of these qualities is evaluated on two conditions: the 'empty' house and the occupancy. So evaluation does not result in a final single quality score, because this would require a weighting for completely different measures (a house with good features, except for mould in the bedroom, cannot be labelled 'good'), but in eight separate scores. Tips and measures are described. The theme 'quality of the social environment' was not included in the published tool, as evidence on this relation was not clear.

Scoring

The quality score (risk score) is divided into four quality levels: Appropriate A, Conflict B, Health risk C, Emergency D. Appropriate condition means: good enough for most people, but not the highest quality level possible; B. the quality shows conflicts with healthy housing requirements and tips and suggestions for adapted behaviour or remediation measures are given; C. hazard or health risk is predictable with high probability: remediation is urgently required. In the consumer version of the Healthy Housing Checklist, a different quality score for healthy and vulnerable or sensitive people was introduced. The quality score for vulnerable people shifts in the direction of D. This basic idea is applied in the models in Chapter 7. Certain indicators are not relevant for healthy people, for instance the evaluation of house dust mites when nobody in the household is sensitive to dust allergens or noise levels that the occupants do not consider a nuisance.

The report of the health performance consists of:

- answers to the questions of the checklist, prepared for the empty house and the occupancy;
- a list of the major health hazards (all negative answers on issues that have a high score);
- the list of measures to improve conditions;
- a summary in the form of quality scores for each of the quality themes, both for the (empty) house and for occupancy.

6.3.2 Implementation

Two versions of the tool were launched, which differ for occupants and professional users: housing managers and local community officials. The tool for consumers seems to support a more critical behaviour, especially better ventilation of bedrooms. It is not clear whether using the tool leads to a larger number of complaints being filed with housing associations. The small number of 40 tests does not support good evidence on the experience during the first year of implementation.

The Quick Scan to assess the major ten items of the healthy house, which was designed for use by professionals, received positive feedback in pilots and in discussions with housing managers, indicating that the shorter the application the better it is for the professional. However, the expectations of users about the output from a quick scan are unrealistically high. The divided attention to occupant behaviour and technical features does not match the interest of professionals, who are more likely to focus on the empty dwelling. Some professional inspectors seem to be afraid that the interview will result in questions that are difficult to answer or may highlight problems that are hard to manage. The impression from observations in pilots is that when the protocol causes frustration, the tool will not be used. The tool must be rather simple and in line with existing processes for complaint handling and the preparation of renovation plans. Visual inspection without extra instruments is possible with the protocol, but some simple pocket-sized tools are welcome: a thermometer (for hot water temperatures), a measure, a flashlight, a screwdriver and a tablet to write on.

In the pilot period, the balance of the inspection time involved and the output is negative, which points out the need for further simplification. Diagnosing the house while it is occupied requires that the evaluation is not influenced by furniture, surface layers, etc., which is confusing or not possible. The protocol for the house and occupancy will have to become one checklist, with items skipped while evaluating an empty house. The professionals seem to have more trouble accepting the method and terminology than consumers: for professionals, the protocol is not familiar and many quality criteria are new to the inspectors. Occupants are more open to the questions and seem freed from the methods that have been internalised. Better alignment for the professional requires a starter-instruction.

The pilots show a way out of the dilemmas in design choices for a tool. A short protocol to catch the priority hazards is welcome. When risk has been identified on the basis of a Quick Scan, the complete protocol is more likely to be followed for mapping all hazards. Intuitive integrated risk scoring was preferred over 'rational limited' automatic calculation of a score by a personal computer (or handheld computer) during the design stage of the tool, because integrative scoring promotes learning by doing. However, rational techniques can be automated, and this makes the use of a tool more user-friendly. Users prefer automated calculations because they work more simply and automatic quality labelling can be applied.

The tool for consumers can be accessed at www.toetslijstgezondwonen.nl.

The tool was evaluated one year after instroduction in September 2005. Preliminary results are included in Section 9.3.

6.4 Conclusions

Practical experience with evaluation tools developed during the research period (Ventilation Checklist (Rijsbergen, 2000), the Energy Performance+Health Tool (Hasselaar, 2001b) and the pilot versions of the Healthy Housing Checklist (Hasselaar, 2005a) is used to formulate quality criteria and a strategy for a tool for health performance evaluation. The interactive process of developing, implementing and redesigning, including discussion with other tool developers, resulted in better insight into the state-of-the-art tools and how they are used. Fieldwork involving troubleshooting of environmental problems has led to the strategy for tool design that focuses on user-friendliness, communication and stimulation of remediation measures. The strategy is to support all tenants and owner occupants in identifying health risk conditions and learn which conditions can be improved, by filing complaints and taking action. The consequence is that the tool must be accessible, broad and complete. This strategy required a critical appraisal of the marker quality of existing indicators and the definition of a new set of indicators.

7 Parameter studies

7.1 Introduction

7.1.1 Research question

The research question of this chapter is: *Which indicators mark the health hazards of housing?* The parameters that cause agents or produce risk conditions are described, for instance the ecology of house dust mite and mould: the relationship between the agent, the house and occupancy is studied, not the health hazards. Chapter 7 deals with modelling. Models integrate single parameters in complex interactions between building features and occupancy patterns. Risk scores are selected, wich are the result of qualitative comparison and are not based on epidemiological studies. Also, the risk scores are not validated: they reflect expert knowledge on the conditions in houses and on the litterature based dose response relations. The use of the risk scores is required for integrative risk evaluation that covers all major hazards. The application of risk scores is an element in the precautionary principle. Precautionary means (according to the German expression Vorsorgung), looking ahead towards prevention of effects and taking remediation measures, even when it is not yet proven that these measures are effective. This principle presses towards more research and does not substitue further research. Especially in the context of healthy housing, where so much in not known and where occupants ask for advice and interventions, we can apply the precautionary principle.

The Chapters 2, 3, 4 and 5 are used to construct the models. Chapter 4 adds the role of the occupants. Chapter 5 adds the physical phenomena that influence pollutant concentrations and hazard conditions.

Chapter 7 is an important step in the selection process of indicators. Modelling is one of the steps in reducing the number of indicators, while proxy indicators can replace a cluster of single parameters. The models deal with biological and chemical hazards that relate to agents and physical hazards that describe conditions. Models are constructed for exposure to house dust mite allergen, mould, legionella and other aerosols, exposure to physical hazards such as noise, discomfort, injuries. Social interaction is not modelled, because there is not enough information available. The models deal with exposure risk, based on the likelihood of high concentration of a hazard occurring in combination with the type of exposure. Table 1.4 highlights the relationship between the research question and Chapter 7.

7.1.2 The quality of the data used for parameter studies

Observation of the quality of available data indicates that variables related to the model of aerosols, mould, house dust mites and ventilation are well-documented. Variables that cannot contribute to refinement of models are not included instatistical analysis.

- Parameters of the mould model – Data on visible mould, reported during inspections, is used. The correlation between building features, occupancy and mould occurrence is studied both for situations with and without visible mould, to determine which indicators have the best correlation with actual mould problems.
- Parameters of house dust mite allergen concentration – The parameter study is based on 135 samples of house dust mites with known Der p1 concentration from 64 houses. These houses are occupied by an asthmatic child and are located in the same urban environment. This fact requires the consideration of certain effects: a) the house has been cleaned and redecorated to ease cleaning, and when these measures are successful, the concentration of allergens could be low, or b) the conditions in the house cause asthma, then certain building features could reveal a correlation with asthma attacks, and c) the outdoor conditions could contribute to allergen concentration. However, the condition of the occupants is not a relevant factor in the selection process of indicators. We will consider the variables that explain the allergen concentration.
- Growth parameters of legionella – Documentation on the domestic water heating systems provides input for a risk analysis of legionella growth. The predictive quality of indicators for legionella concentration could not be studied, because only a few samples with known concentrations are available. Instead, the conditions for growth are analysed to indicate the risk level, which can be used as a basis for further research.
- Parameters of the model of aerosols – The parameters are selected on the basis of data from experiments in Brisbane and on data from seven houses. Radon is included in the model of aerosols. 28 radon samples were collected in seven houses (different from the seven houses that provided data on aerosols. This dataset is analysed and the results support the selection of indicators, but validation of indicators is not possible.
- Parameters in the model of TVOC – No data are available, so the parameter study is based on literature and the indicators are not validated.
- Parameters in the model of physical hazards - No data are available, so the parameter study is based on literature and the indicators are not validated.

The results of parameter studies are used to improve the models. With specific parameters selected, the models are more compact and have fewer parameters. The parameter study brings the quality of the set of indicators one step ahead.

Ventilation is the key element of air quality. Ventilation has been studied in great detail, both in the field (see Chapter 5) and by reviewing case descriptions and scientific literature. The literature sources used in the study include (in alphabetical order): Bacol (2002 presents a view on maintenance contracts, Bernard (2000) (and some other authors) present the design and operation of demand controlled ventilation, Björkroth (2000) conducts research on pollution in ducts and filters and discusses the change in perceived air quality, Bloemen (1995) gives one of the rare accounts of measured air change rates in Dutch houses, Cooper (1999) supports insight into airflow patterns caused by heated surfaces, Ginkel (2002 and 2005a) produces papers on ventilation of dwellings, on the capacity of systems and on the effect of ventilation of bathrooms on mould growth, based on the 333 datset including the subset of monitored ventilation systems in The Hague, Heiselberg (1999) does experiments on airflow patterns in different types of windows, Howieson (2003) tries to establish a relationship between ventilation and house dust mite concentration, NEN (2001) published the Dutch standards and guidelines for domestic ventilation, Jamriska (2001) of ILAQH experiments with filters and analyse filter efficiency for different particle sizes, Luoma (2000) follows ventilation ducts from the factory into the construction site and determines the amount of dirt acquired before the dusts were used, Mänsson (1995 and 1998) writes a thorough study on domestic ventilation: the practical experience, including evaluation of the Swedish compulsory inspection and maintenance of ventilation systems, Op 't Veld (1996 and 2006) cooperated with W. de Gids (TNO) on a large number of studies on ventilation, recent ones involving hybrid ventilation, balanced-flow ventilation and demand controlled ventilation, Pasanen (2000) studies the effect of dirty ducts and duct cleaning, Rijsbergen (2000 and 2001) writes the Ventilation Checklist and evaluates user satisfaction.

7.2 Biological hazards

7.2.1 Parameters of dampness and mould

Mould problems reflect a mixture of building-related properties and occupant behaviour and both the owner and the tenant are responsible for mould occurrence and remediation. The selection of measures is often complicated because it requires a choice between ad-hoc individual measures or structural improvements of a housing estate.

The model is based on literature findings and field data analysis. Literature on mould is abundent: Bornehag (2002) and Sundell review a large volume of literature on dampness in buildings and health effects, Ekstrand-Tobin (1986) investigates the effect of renovation on allergenic parameters, Gorny (2002) studies fungal fragments, Hägerhed (2002) and others evaluate mould indicators on the basis of 8,681 Swedish dwellings, Haverinen (2000) develops an experimental moisture damage index, Jaakkola (2004) and Jacob (2002) relate indoor mould with asthma, Moon (2003 and 2005) develops performance indicators for mould growth, Nielsen (2000) studies mould growth with humidity as changing variable, Reiman (2003) points out the influence of hidden moulds sources, Storey (2004) creates a guide for identifying mould species, Verhoeff (1994) continues research on dampness and health, Voûte (1995) collects practical interventions to reduce exposure to asthma inducing indoor conditions.

Ecology of mould

Mould is any of various fungal growths, often causing disintegration of organic matter: mildew, fungus. Mildew is a superficial covering of organic materials caused by fungi, especially under damp conditions. Fungus is any of numerous plants of Thallophyta, ranging in form from a single cell to a body mass of branched filamentous hyphae. Hyphal fragments themselves may be responsible for allergic reactions in some people (Forensic Inspections, 2001). Gorny (2002) studied how fungal particulate matter becomes airborne. *Cladosporium cladosporioides* was counted in a chamber. Fungal fragments are simultaneously aerosolised with spores. The fragments are released in higher numbers (up to 320 times) than the spores. The release of fungal particles varied depending on the fungal species, the air velocity above the contaminated surface, and the texture and vibration of the contaminated material. In contrast to spores, the release of fragments from smooth surfaces was not affected by air velocity, indicating a different release mechanism. Fragments and spores seem to share common antigens, which not only confirmed the fungal origin of the fragments but also established their potential biological relevance. Concentrations will differ largely over time and location. When moisture and mould are visible, we can expect that occupants will be exposed to a concentration of spores and live or dead hyphae. Old mould and freshly growing mould are therefore treated as equal.

Little is known about the dose-effect relation, partly due to the dynamic process of the production of toxics or allergen material. Also, some co-variation with bacteria is suspected, but not well understood. The determination of exposure to mould toxins and allergens is very indirect: first by sampling visible mould of surfaces and by catching viable material from the air, hoping that spores will stick to the agar surface in the instrument and germinate in the laboratory. The determination of species is quite difficult, and many mistakes are made in the lab. The Umwelt Bundesamt (Federal Environmental Office) in Germany has tested results from different laboratories and from repeated sampling. Laboratories were considered successful if they were able to identify four out of six known strains of fungi in the offered samples. In total, 109 laboratories participated in four trials. The success score was 32-71% for labs participating for the first time in the trial, and this success score increased to 54-84% of participating labs after successive trials (Szewzyk, 2003). But even if sampling is accurate, information about the concentration of viable mould spores is not enough to predict health effects. As a precaution, medical experts agree that exposure to airborne mould material should be prevented and mould should at least not be visible in the house (Duijm, 2005). Viable mould is by definition an indicator of permanent moisture. Visible mould is an indicator. We also consider the mould that grows within the construction and that will also pollute indoor air. Mould can be wiped off, or painted over, not being visible, but it can come back in only a few weeks. We reviewed studies on the circumstances that cause mould growth in hidden places like cavities.

High moisture is the major contributor to microbiological activity (Park, 2006). Nutrients for spore germination and growth are readily available in most houses. The nutrients can be dirt, dust, wood, paper, adhesives, acoustic fibre, paint, textiles, stored material, carpets, floors, etc. Some fungi will grow on almost everything. Most moulds thrive in dark places such as closets, attics, inside walls, behind wallpaper, behind refrigerators, in attics and basement corners. The actual germination of fungal spores is influenced by time of wetness, free water content, water contamination, nutrients in the substrate, light, temperature, air velocity, moisture level and fluctuations.

It takes 2-3 days for microorganisms to start growing in a Petri dish. The greater the water sources, the greater the microbiological activity.

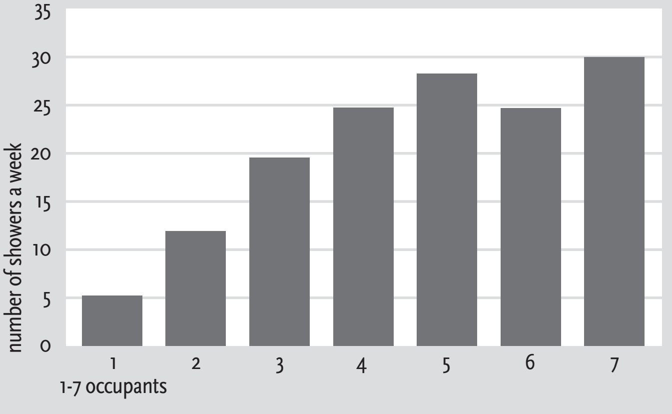
Sedlbauer (2003) studied the moisture content within a spore in relation to ambient humidity, because this is the decisive condition for the germination of the spores. The three factors required for growth – nutrients, temperature and humidity – must exist simultaneously for a certain time period. As spores are present in most cases, mould growth will occur when these three growth conditions are fulfilled. Mould growth is a risk on any surface that is rough or dirty due to a particle deposition layer that grows over time. The key to the relationship between dwelling characteristics and mould lies in water and cleanliness as normal indoor temperatures permit optimal fungal growth (Brock, 1988). Mould can be wiped off effectively from smooth surfaces, so the actual cleanliness is important in conditions favourable for mould growth.

Adan (1994, 2000) reviewed several studies on fungal growth on building materials and concluded that growth ceased if relative humidity drops below 80%. This humidity pertains to the air in close contact with the moulds, at the surface on which mould growth occurs. The relative humidity on surfaces is determined by the vapour concentration, the thermal insulation properties of the material and indoor/outdoor temperatures. The indoor vapour concentration varies along a daily pattern due to ventilation and activities such as doing laundry, cooking and taking showers. Due to this, the relative humidity on interior surfaces shows daily periods with values below and above 80%. Then, the question arises about the minimum daily wet period necessary to allow fungal growth. The minimum wet period is expressed in terms of the time of wetness (TOW) that is defined by the ratio of the cyclic wet period (RH >80%) and dry period (Adan, 1994, 2000). For gypsum plaster, Adan found that a TOW <0.5 does

Table 7.1 Housing characteristics and visible mould with statistically significant bivariate correlation coefficients

Characteristics)	Correlations Kendall's tau_b
Age of house	0.14
Number of occupants normal day/night	0.27
Number of laundry cycles (including hand wash)/week	0.14
Age of fan box	0.20
Heating system	0.26
Age of heater	0.26
Cold surfaces, thermal bridges	0.21
Number of showers	0.18
Airtightness, seams in openings	0.24
Condensation on windows	0.31

Figure 7.1 Number of occupants and showers in the sub-dataset on mould (n=186)



not influence the growth rate, whereas a TOW >0.5 accelerates this rate. These phenomena explain why the number of showers is an indicator of mould growth in bathrooms (Ginkel, 2005). Changes in occupancy can have a predictable effect on mould growth: a larger household, kids growing into the 'shower-taking' age. This information about the risk of mouldiness can stimulate the occupants to continue good cleaning habits and other maintenance activities.

Study of model parameters

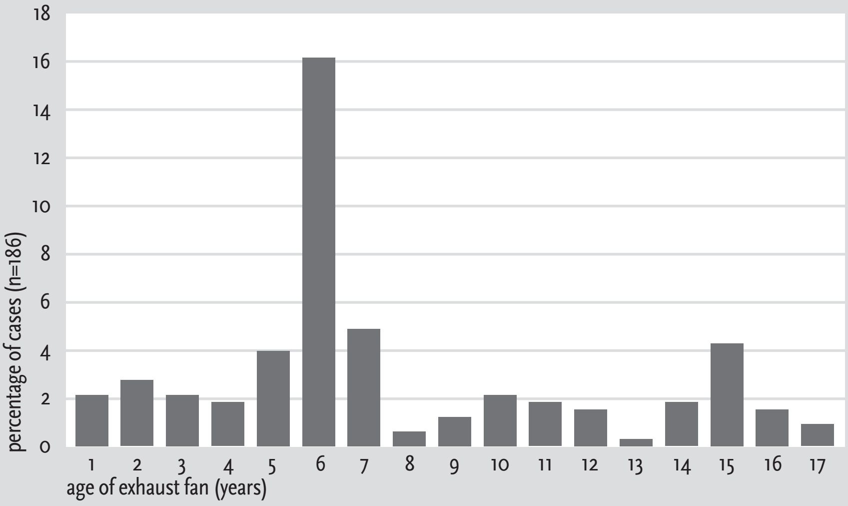
Mould occurrence is predominant in bathrooms, where the exposure period is short, but mould fragments can disperse towards other rooms. Because bathrooms are exposed to extreme moisture conditions and function as a relatively simple microclimate, we construct a model for bathrooms and explore the meaning of the selected indicators for other rooms, especially bedrooms.

A subset of 186 cases with information about mould is used for the study of correlations. The first step is to analyse how well single variables predict visible mould. Removed mouldy spots are consequently treated as 'no mould'.

In 41% of the cases with information about mould (n=186, visible or none visible), mould was detected in bathrooms. This is twice as much as the reported overall moisture problems in houses in the national survey KWR (VROM, 2000). Table 7.1. lists 10 housing characteristics with statistically significant correlation with visible mould, but none of these correlations is strong.

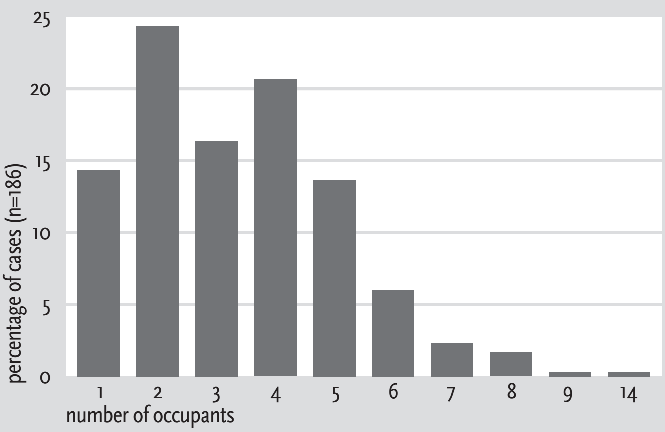
Prior to the logistic regression analysis, the nominal values about observations of mould (dependent variable) were dichotomised. Subsequent logistic regression with characteristics of ordinal type and statistically significant correlation coefficients resulted in the selection of 'number of showers' and 'age

Figure 7.2 Age of the fan box (exhaust fan) in the sub-dataset on mould (n=186)



of mechanical exhaust fan' as indicators of mould occurrence. The best results were obtained if the threshold value of the 'number of showers' was 14 and the 'Age of the fan box' was 6. Then, the Odd Ratios (OR) of these regression coefficients were 7 (2.2–22.8) and 6.3 (1.9–21.0) respectively. The results are in good agreement with 80% of the observations obtained in this survey.

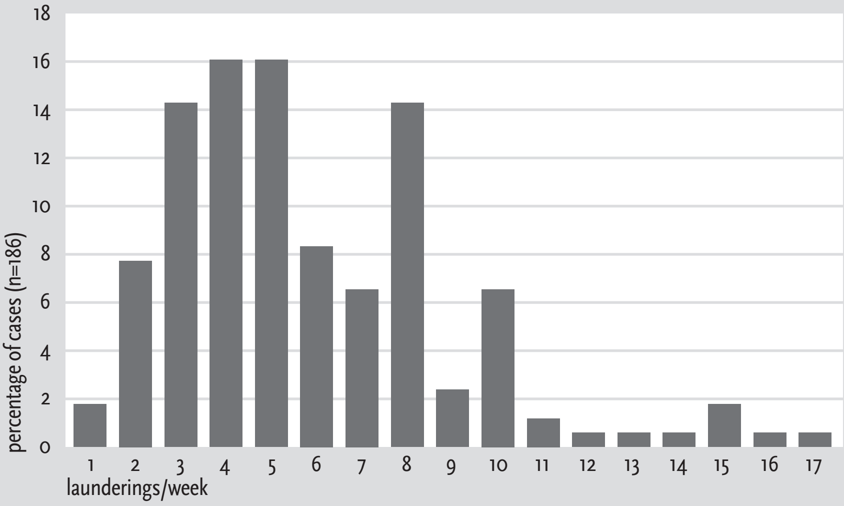
Figure 7.3 Number of occupants in the sub-dataset on mould (n=186)



More than 14 showers does not mean 15 showers, but 20 showers, because the number of showers is related with number of people in a household and (almost) one shower per person per day (see Figure 7.1). The turning point for mould risk in bathrooms is 3 showers a day. The turning point of age of exhaust fans (see Figure 7.2) will probably range from 4 to 6 years or in some cases 10 years, depending on technical deterioration, dirt and maladjustment of dampers. The amount and effect of dirt depends on the intensity of use of the fans, the type of cooking and the amount of fatty deposition and fine dust in exhaust air. We can consider that maintenance so far has had little influence on the capacity, because the cleaning jobs of fans did not restore the required capacity as the air volumes were not readjusted during maintenance. Therefore, the age of the fan box can be used as a proxy indicator of exhaust capacity.

The number of occupants per dwelling in the dataset (see Figure 7.3) is sig-

Figure 7.4 Number of launderings per week in the sub-dataset on mould (n=186)



nificantly higher than in the national survey (Ministerie van VROM, 2003) and is correlated with more showers per day. The large number of 6-year-old dwellings in the dataset may influence the significance with respect to the 'Age of the fan box'. The moisture balance shows that wet surfaces after a shower make the difference: three showers with periods of a few hours apart create a long time of wetness (TOW >50% in connection with absorption or condensation). Laundry drying (see Figure 7.4) is an extra moisture source that is roughly equivalent to 1-3 showers. Stripping the water from the wall reduces the time of wetness. Ventilation speeds up the drying process, and ventilation with fresh air is more efficient than ventilation with warm and relatively damp indoor air. We found no difference in mould occurrence between a heated and unheated bathroom, but there is a difference between a well-insulated bathroom with even surface temperatures and a bathroom with thermal bridges and cold surfaces. The wall-ceiling connection near the roof is often a cold area. We found no mould in bathrooms that have smooth surfaces and were properly cleaned, except minor black coloration of seams between tiles.

The dampness in bedrooms depends on the number of persons, the volume and surface materials and the ventilation in combination with temperature of the room and of the surfaces.

A low bedroom temperature causes vapour transport, adding to the moisture that is produced by people sleeping in the bedroom. Symptoms pointing out high moisture level are condensation on window surfaces and stains in areas with poor air circulation (corners, behind furniture, on clothes, etc. in closets).

Model of mould

The relevant parameters of sources and removal functions of moisture are used to predict the presence of mould in places that cannot be inspected visually (see Table 7.2).

The presence of mould supports the evaluation of the concentration of mould aerosols. Because aerosols will disperse through the house, we need to

Table 7.2 Mould growth and concentration of airborne material

Indicators of moisture sources	Growth indicators	Indicators of drying of surfaces	Indicators of presence of mould
Growth conditions in bathroom			
Showers	Threshold 3/day or 2 plus wet laundry on rack	Mechanical ventilation system >5 years without upkeep,water-stripping from wet surfaces	Surface area of visible mould
Growth conditions in bedrooms			
People, pets, moisture sources	Threshold 2 or more people per bedroom or per room average	Use of openings, volume of indoor or fresh air during sleep and daytime	Surface area of visible mould; smell from invisible mould and cold and damp covered areas
Growth conditions anywhere in the house			
Cold surfaces without air circulation	Humidity, lower temperature behind furniture, or connected to crawl space	Airflow of dry air along surface, ventilation volume, temperature difference with indoor air	Surface area of visible mould; smell from invisible mould, cold and damp covered areas

Table 7.3 Indicators of exposure to mould and possible consequences of exposure

Source	Indicators of peaks in concentration	Indicators of exposure risk
Visible mould	Mould surface area, viability (=spore forming) and release of dry material	Low: with mould any place in the house Medium: large surface any place elsewhere in the house or short exposure period in space with visible mould High: peak exposure in space with visible mould or long period of exposure with in house with large area(s) of mould
Invisible mould	Cavities in construction, water leakage and pressure differences (wind) over cavities, mouldy smell via chinks	Low: mouldy smell any place in the house Medium: mouldy smell any place during strong wind or short period of exposure in space with mouldy smell High: in area with source of mouldy smell or long period of exposure in house with hidden mould
Possible consequences of exposure	Low exposure risk: considered harmful to people in a weak state of health, risk value 2 Medium exposure risk: potential harm to every person, especially children, or in a weak state of health, risk value 4 High exposure risk: considered harmful to every person, risk value 8	

consider the amount of mould material. The exposure level depends on concentration and period exposed. The risk values are not validated. Table 7.3 gives indicators of exposure risk to mould, disregarding actual exposure periods.

Indicators of presence of mould

Mould behaves like aerosols meaning that material is everywhere in the house and causing exposure peaks after being disturbed (air turbulence, vibrations from moving around, cleaning activities). In the diagnosis of complaints and in the communication about visible mould, the following parameters can be used: more than 3 showers per day or more than 2 showers a day in combination with wet laundry on a rack. Mould risk is higher with poor exhaust, which is the case with mechanical ventilation system older than 5 years without maintenance and no inlet air directly from outside or with almost constant use of a mechanical system at lowest setpoint. Indicators of mould risk in bedrooms are: occupancy of more than two people per bedroom or more than one person per room average in the house, in combination with low permanent ventilation rate with fresh air. Mould growth risk in all rooms (living room, kitchen or meter closet and circulation areas) increases when interior surface temperatures are 5°C lower than indoor temperatures, during the winter period with outdoor condition below 6°C average over 24 hours. Old mould that is painted over is an indicator of growth risk. However, layers of paint prevent mould fragments being emitted into the indoor environment, for a short while until continued growth reaches the surface again.

The study of the mould model results in two robust indicators:

1. Visible mould at any location in the house that causes aerosols to diffuse into the living room and bedrooms. Visible means that the surfaces are not cleaned or painted over.
2. Hidden mould from cavities that can be smelled, in combination of positive indication of growth: time of wetness more than 50%, soiled surfaces, emission into indoor air. Open connections to the crawl space because of chinks or cracks point out the risk of mould exposure.

7.2.2 Parameters of house dust mite allergen

Ecology of house dust mites
Many allergy sufferers are sensitive to house dust. The allergenic material is inhaled through aerosols containing broken down faecal pellets and dead material. As far as we know, the live mite does not cause any harm directly.

The three common species of HDMs are *Dermatophagoides pteronyssinus*, *Dermatophagoides farinae* and *Euroglyphus maynei*. Mite densities tend to be highest in warm humid climates and lowest in cold dry climates, but seasonal variations are also important. The mite is not visible to the naked eye. A mite lives for about two months (depending on the species), lays between 30 and 60 eggs and produces 60 times its size in faecal pellets. Mites feed on protein, provided by human or animal skin particles, preferably material that is of high relative humidity and/or predigested by mould. Too much mould is not preferred, because mould toxins are more likely to be produced. For *D. pteronyssinus*, the protein content of dust must be more than 11% (Koren, 1995). In the home environment, food is considered to be abundant in dust, in mattresses, carpets, upholstery and the closet. Mites take up water through active extraction from unsaturated air and little through the skin or food. Water is lost as a result of reproduction, defecation and evaporation. The reproduction rate depends on humidity and temperature and the quality of the food, but humidity is the main factor. In population growth experiments at 25°C and 70% RH, the mean increase in population size was from 4 (2 pairs) to 1,226 +/-131 mites in 126 days (Pretlove, 2001). This indicates a doubling of the population in about 24 days. The reproduction rate is influenced by temperature, where the period between egg and adult lengthens at lower temperatures (Bronswijk, 1981). Growth conditions depend primarily on the balance between intake and loss of water. In the home environment, this equilibrium can more easily be achieved at relatively low temperatures. One study found that the optimal conditions for *D. pteronyssinus* were 25°C and 80% RH, but these mites multiplied between 17°C and 32°C. In very high (over 30°C) and very low (below 15°C) temperature conditions the mite activities will slow down. Above 85%, mould toxins will contaminate food supplies. Below the critical equilibrium of around 60-70% relative humidity (different for each species), but in general, below 55%, mites will dehydrate and eventually die, depending on the level and period of dehydration. Mites can survive in conditions that are considered hostile, provided there are favourable pockets or regular periods with more favourable conditions. Mites are killed in frost by dehydration (frosted up to 48 hours).

Prediction of house dust mite concentration

The concentration of the allergen in house dust is traditionally determined by analysis of dust samples or by counting live mites. These procedures are time-consuming and the results provide no information about the causes of growth explosions and the allergen exposure levels for occupants. The evaluation of HDM allergen concentration by counting mites and analyses of dust samples is not accurate. The coefficients of variation (CV) for allergen concentrations in repeated samples over time was 55.3-82.0% for allergen Der p1 and Der f1/g dust). Determination of allergen mass per square metre of surface instead of concentration per gramme of dust resulted in an even greater CV (72.3-86.7%) (Hirsch 1998 and 2000). Counting live mites will provide only a very indirect way of the buildup of allergens. Excreta and dead mites accumulate over a period of years, and even without live mites the exposure risk can be high. The analysis of dust samples is widely used, but how much allergenic material is airborne and how much is inhaled is not known. The variation and indirectness of valuing exposure to allergens causes a methodological problem: if sampling and measurement is not accurate, then validation of models is not possible. On the other hand, prediction of exposure level on the basis of simple indicators can lead to useful results as well.

Parameters that correlate with HDM allergen concentration are selected on the basis of literature. The properties of heating and ventilation and the construction details of ground floors are important parameters in studies (Pretlove, 2001). On the basis of field studies, we have added new parameters: the type and age of pillows and mattresses and cleaning procedures. As mites will grow any place in the summer period in the Netherlands, due to damp environments everywhere, we must account for allergen buildup during the summer. The allergen is active over a prolonged time period and the effect is that the concentration will increase over a number of years, even in houses with only a small number of live mites during the winter period. The effect is that all mattresses are likely to contain a large amount of allergenic material after a number of years. We have seen high concentrations in mattresses covered with mite-protective layers, and we expect increasing concentrations after some years in mattresses also treated with antimite chemicals.

Study of model parameters

The risk of HDM growth and exposure is evaluated by rating the parameters:

- RH in habitats such as the bed and in carpets on cold floors;
- the support of growth and reproduction and activity level based on nutrition, temperature and RH;
- accumulation of faeces and dead material.

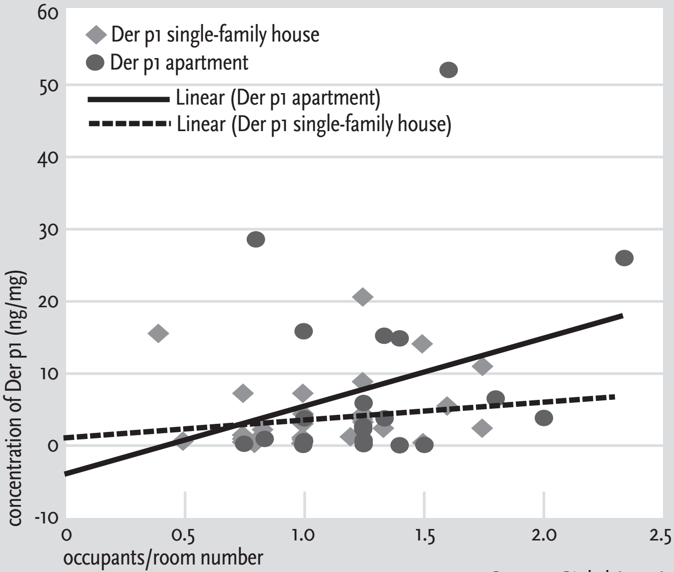
A massive volume of literature has been published on house dust mites. Boer (1997) studies the concentration of mites by cutting mattresses into pieces, Bronswijk (1981, 1991, 1996, 1997 and 1999) is the Dutch expert on house dust mites, Crowther (2000, 2001, 2002) studies house dust mite ecology in detail, Ginkel (2005a) analyses field data on guanine and Der p1 and validates a model to predict house dust-mite allergen concentration, Heide (1997) evaluates the effect of air cleaners and dust mite covers, Heinrich (2002) relates the allergen concentration in mothers' beds to the cord blood of neonates, Hirsch (1998 and 2000) tries to find effects of renovation of houses on mite allergen, Koren (1995) conducts a PhD study on house dust mites, Lynden-Van Nes (1999) points out the need for structural measures in houses to reduce exposure to allergenic material, Maessen (1995) reviewes house dust mite ecology, Oomens (1996) constructs a moisture model to support the evaluation of allergy-free housing conditions, Oosting (2002) studies the effect of mite-protective covers, Strien (1994 and 1996) identifies indicators of the relationship between housing characteristics and house dust mites, Terreehorst (2003) studies the effect of mite-protective covers, Thuis (1998) reports on the field project on house dust mites and other potential environmental sources of respiratory problems and this project provids 65 cases in the 333 dataset, Verhoeff (1994) and Voûte (1995) deals with the effects of damp housing in different research context, Weterings (2000) guided a project for building and evaluation allergy-free housing, Wickman (1997) and Koren (1995) studies the effect of vacuum cleaning of mattresses on the allergen reservoir, and Wilkinson (2002) focuses on the allergen content of mattresses.

The concentrations of Der p1 in dust samples in the subdataset of Utrecht are used to study model parameters. The average concentrations are: sofa: 1.3

(σ=1.6) (n= 24), carpet: 3.78 (σ=9.3) (n=37), mattress: 6.48 (σ=9.8) µg/g (n=64). We show the results for mattresses in Figure 7.5.

The concentration in the carpet was influenced by one 'outlyer', an extreme level of Der p1: 52.2 µg/g dust. Without this extreme, the average concentration is 2.4 µg/g. The concentration in sofas does not show extremes. The average concentration of the mattresses is high and most likely to cause asthma attacks. Der p1 in mattresses are higher in multi-family (73% >2 µg/g) than in single-family houses (45% >2 µg/g), with 9.2 and 4.2 µg/g respectively in the subdataset.

Figure 7.5 Der p1 concentration in mattresses as a function of occupancy on the subdataset on house dust mite allergen in single-family houses and multi-family houses



Source: Ginkel (2005)

The analysis does not allow for better discrimination of predicted concentration than above or below the concentration of 2 µg/g of dust, so the levels low, medium and high were reduced to the levels low and high. Der p1 concentration of 2 µg Der p1/g dust was adopted as a threshold value to distinguish between high and low risk for HDM allergy (see Table 7.4 and 7.5)

Table 7.4 Correlations of house dust mite allergen concentration and building features, based on half of the data in a subdataset on house dust mite allergen (n=35)

Building features with measured Der p1 >2 or ≤2 µg/g	Correlations r
Both pets and visible mould	0.60
Visible mould	0.58
Number of showers >20x per week	0.49
Number of people/room >1	0.49
Thermal bridges	0.48
Location of visible mould	0.33
Laundry cycles >4x per week, laundry drying in/near bedroom	0.32
Mattress >5 years old, no mite cover	0.29
Moisture emission from crawl space	0.22
Relative humidity of floor above crawl space	0.22
Mattress >2 years old, no mite cover	0.22
Low ventilation, not balanced or collective	0.18

The number of people and pets in a house (occupancy load), the number of showers, thermal bridges and mould show the strongest correlation with house dust-mite allergen concentration of >2 µg/g dust. Occupancy is defined as the number of occupants divided by the number of rooms in the house.

In 76% of cases, the model prediction was good; 10% was predicted lower

Table 7.5 Comparison of modelled and measured concentration level in the subdataset on house dust mite allergen (n=70)

	model >2 µg/g	model ≤ 2 µg/g
measured >2 µg/g	45%	10%
measured ≤ 2 µg/g	22%	23%

than measured and 23% was predicted higher than measured (Ginkel, 2005).

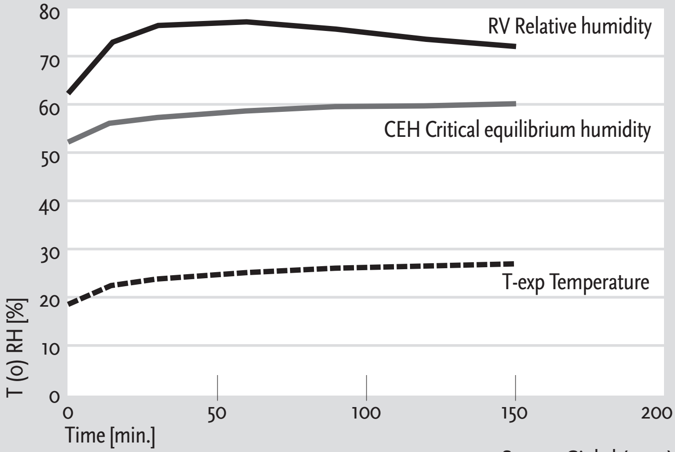
The odds ratio of 5.45 (95% confidence interval and limit values of 1.75 and 69) results in a significant correlation between the occupant load and the allergen concentration. The results of the model and measured levels of Der p1 agreed reasonably. In only 10% of the houses in the second dataset, the quick scan predicted low Der p1 levels, whereas the measured concentrations were higher than 2 µg/g (see Table 7.5). Information about the number of rooms and occupants is easy to obtain. Occupancy is a substitute for moisture production and nutrition (skin scales with protein).

Pets produce extra foodstuff for mites, which could cause a higher concentration and activity level of mites. Data from 86 cases is available on pet keeping and guanine concentration in dust samples. With pets, the average concentration of guanine in the bedroom is 1.8 µg/g of dust; without pets 1.5 µg/g. The living room concentration with pets is 0.6 µg/g of dust, without pets much higher: 2.2 µg/g of dust. We could not find statistical evidence that pets cause an increase in house dust mite concentration. Different mechanisms could be working at the same time: pets are found in houses with higher occupancy, because many parents take a pet for their children and in these houses more moisture is produced and therefore house dust mites can grow faster. With hairy pets (especially dogs), more occupants select smooth and easy to clean flooring material in the living room, with a small carpet under the table. Fieldwork indicates that this small carpet is often quite new, so sampling in the living room does not show mite allergen. Pets and guanine level in the mattress show no relationship.

Because we expected more indicators to present good correlations, we studied some phenomena in greater detail. A mechanical model was constructed of the temperature and humidity in a mattress. The parameters were taken from Boer 1997 (see Figure 7.6).

The mechanical model shows that the diffusion of water vapour into the mattress is much faster than the transmission of heat, implying that in many mattresses the relative humidity, during a certain period and at places near the edges of the bed, is above the critical equilibrium humidity. When people are in the bed and especially after they get out of bed, the house dust mites recover their water buffer, become active, eat and reproduce and also produce faecal pellets, causing a build up of allergenic dust. The calculations indicate that with a person in bed, the conditions for growth are favourable. The daytime humidity level determines the activity level and the difference between low, or high reproduction and allergen production. In other words, if the mattress has the opportunity to dry quickly and thoroughly, the mites may not be active. The temperature in the bedroom could be important for the production of allergen material. A temperature lower than 15°C slows down the activity

Figure 7.6 Temperature, calculated relative humidity and critical equilibrium humidity, a few centimetres deed into the mattres and during sleep



Source: Ginkel (2005)

level and reproduction rate. Since many occupants do not heat the bedroom, the temperature can decrease to levels below 15°C or even down to 7-10°C when the room is well-ventilated and isolated from heat sources in the house. Low temperatures are more likely to occur in poorly insulated bedrooms in single-family houses than in multi-family houses and more likely in older houses than new houses. More studies are required for further validation of these suggested relationships.

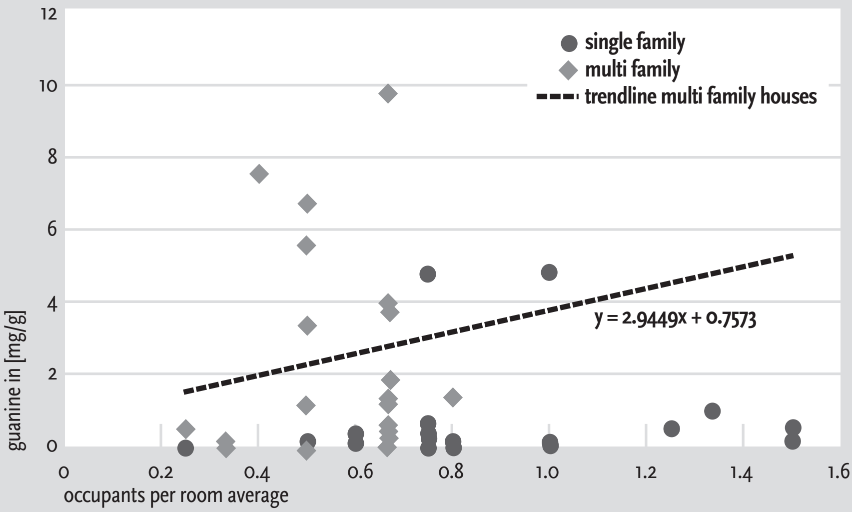
The small number of Acarex tests on dust from mattresses with a mite-protective cover indicates that the rate in which the mattress becomes a source slows down, but a protective cover (except plastic) does not prevent allergen build up. This result is found by other researchers as well. A new mattress does not contain allergens, a 5-year-old mattress may be loaded, and a 10-year-old mattress is almost certainly loaded with allergens under Dutch maritime climate conditions, regardless of the conditions in the bedroom (unless the room has not been slept in). Accumulation depends on the age of the mattress.

Airborne aerosols are ventilated away. Aerosols can be (partly) removed by cleaning (wiping, washing, vacuuming) and more efficiently by replacing the mattresses (and old carpets and sofas that cannot be cleaned). Chemical treatment of surfaces is effective for some time, especially in combination with a strong vacuum cleaner, but does not stop aerosol formation. Chemical treatment against live mites is needed every few months to have a longer-lasting effect.

The exposure to allergenic material is reflected by the concentration and the production and distribution of allergen-containing aerosols. Sleeping does not appear to be a dust-disturbing activity, but the combination of high concentration in the bed and moving sheets working as a blowpipe towards the nose creates at certain moments a high exposure level. Aerosols of house dust mites are rather heavy and are deposited after disturbance of sources. This means that, during the night, the mattress and covers are the major source of inhaled particles and during the day moving around on carpets and sitting on soft material is likely to be the major source.

Given the dominant occupancy rate of 0,5–0,8 and no clear evidence of higher occupancy related to higher concentration, 'occupancy load' does not appear as robust indicator. The data show a small difference for single-fami-

Figure 7.7 Guanine concentration correlated with occupancy load per type of housing in the subdataset of house dust mite with analysed guanine



ly and multi-family houses. Multi-family houses are in general more airtight, resulting in lower air change rates (see Figure 7.7).

The age of the mattress supposedly is a strong parameter, because a relatively new mattress cannot contain a large concentration of house dust-mite allergen and it take months to years before a mattress is 'loaded' with allergen material. In addition, a foam mattress supposedly presents a higher risk on HDM allergy than a box-spring or pocket spring mattress that contains more air, less material and dries faster after someone slept on it.

Table 7.6 presents the source, emission and removal indicators and indicators of the resulting concentration.

Model of concentration of house dust mite allergen

The indicators that mark the resulting concentration are presented in Table 7.7. The exposure risk in bed is equivalent to the concentration. We consider the prediction of concentration in the bed as most relevant; the second route is the build-up in carpets and old sofas in the living room. For sensitisation, the peak exposure is considered important, not so much the period of exposure.

Indicators of exposure risk of house dust-mite allergen

The study of house dust-mite allergen concentration has resulted in new insights into the conditions that support growth. First, mattresses are a major source of allergenic material and dust is blown into the face of the person in bed and deposit under and around the bed. A secondary source is the 'soft' carpet, first because of deposition and second because of growth of mites in damp material with enough protein in the dust to feed on. The temperature in the carpet is important, with higher humidity and more material in thick carpets on a cold floor. The condition of mattresses supposedly is a robust indicator of exposure risk to house dust-mite allergen. Occupancy load is suggested as a proxy indicator (Ginkel, 2005a), but evaluating the dampness is prob-

Table 7.6 Indicators of house dust mite allergen concentration

Source indicators	Emission indicators	Removal indicators	Indicators of resulting concentration
Moisture from showers and laundry drying, from crawl space or foundation and effect on growth all over the house	Dust emission from mattress, sofa, flooring while using it	Partial removal of allergen material via intense washing/ cleaning, removal of airborne particles via ventilation	Dust load of places where people move around, access to nose and mouth area; proxy: occupancy load of the house
Accumulation of dead mites and faeces after months and years	Dust emission from mattress, sofa, flooring while using it	Partial removal of allergen material via intense washing/ cleaning, removal of airborne particles via ventilation	Number of people in bed and accumulation of allergens as mattress is older

Table 7.7 Indicators of exposure risk to house dust mite allergen and possible consequences of exposure

Source	Indicators of peaks in concentration	Indicators of exposure risk
Mattress	Sleeping on an old mattress (>5 years)	Low: sleeping on a new mattress Medium: sleeping on a mattress between 3 and 5 years old High: sleeping on an old mattress (>5 years, or >8 years with mite cover)
Soft damp or old flooring or soft old furniture	Strong disturbance of dusty floors or soft dusty furniture	Low: moving around on dusty floors, furniture, or vacuum cleaning somewhere in the house Medium: present in room while dusting or moving around on material with accumulated dust, short exposure period High: present during vacuum cleaning, or people moving around on carpet, old sofas with high allergen content
Possible consequences of exposure	Low exposure risk: considered harmful to people with allergy to house dust, risk score 2 Medium exposure risk: harm to people with respiratory problems, potential harm especially for children and people in a weak state of health, risk score 4 High exposure risk: harmful to asthmatics, irritation for people with respiratory problems, potential sensitisation for every person; risk score 8	

ably more relevant. The few data available suggest that age of the mattress is very important. All mattresses over five years of age (or 8 years with antimite cover) contain a high allergen concentration. Pet keeping is likely to promote the house dust mite allergen concentration, but we could not find statistical evidence for that.

7.2.3 Parameters of legionella

Ecology of legionella bacteria

Some 10% of the housing stock, in which occupants depend on collective services, have legionella risk management. Within the home, the occupants are responsible for safe drinking water. The question is whether domestic water creates risk and how the risk depends on technical services and use. Drinking water, even originating from well-protected sources, contains small concentrations of microbiological lifeforms which, under certain conditions, can explode into a health-threatening pollution. Water tanks, non-used parts of the piping system, water filters and showerheads are breeding grounds of bacteria and viruses including legionella bacteria. KIWA tested 400 houses and found 17 houses (4%) with increased legionella concentrations in the shower and the inspectors in the KIWA study followed the official protocol for sampling, but were also allowed to sample taps in the house that they considered to present the highest risk factors, because of a warm environment, low flow and frequency of use. In these samples, the concentration exceeded 100 colony forming units (CFUs) in 15% of all houses. This indicates that many houses contain a source of contamination.

Legionella bacteria prefer water with enough oxygen, sediment, some potassum, certain algae and protozoa. Biofilm and protozoa seem to play a major role. Hot water tanks provide a friendly ecology, especially in parts of the tank with biofilm or sediment. Rubber parts in the piping system and certain alloys like iron or zinc can induce growth of organisms. Copper is an antibacterial metal and has negative impact on growing conditions, but legionella bacteria will not be killed effectively in copper conduits, because of the protective biofilm and low concentration of copper ions. Chlorine will slow down growth, but a high concentration of chlorine will not kill all the bacteria. Little is known of circumstances that can trigger explosions, except for the temperature range. Keeping water at 25-50°C is creating a major risk factor. The optimum for growth of legionella is 37°C, which is the temperature of the human body. When the temperature and other conditions are favourable, the population of legionella bacteria will explode within a day. Legionellosis is acquired through breathing water vapour with a high concentration of bacteria, so the risk is associated with aerosols and the dominant place to acquire legionellosis is the shower or bathroom. Many documented cases indicate that the person who inhales the bacteria must have low resistance and sensitive lungs for legionella to cause serious risk, but we cannot account for susceptibility and must consider any person to be at risk when exposed to water with legionella bacteria. In addition, the supposed relationship between bacteria concentration and contamination is not useful, because even small concentrations with little chance of contamination could have a devastating effect.

Different measures for legionella removal have been tested: 'heat and flush', chlorination, ozone, treating with ultraviolet light and anode oxidation. Heat and flush is considered the most feasible measure: 90% of the legionella population dies at 60°C in 25 minutes and at 70°C in 10 minutes. Because it is a decimation process, not all bacteria are destroyed and precautions against regrowth are needed. Anode oxidation is relatively new in the market and was acknowledged in 1998 in Germany as a measure for the prevention and elimination of legionella. In the process the other bacteria will also be electrocuted.

Study of model parameters

For model construction, many studies were used that were presented after the first diagnosis in Philadelphia in 1978. The Bovenkarspel epidemic of 1999 and the diagnosis of other recent epidemics in other countries have created a large volume of scientific results. We selected literature on domestic situations. Alary (1991), Bailey (1990) and Bollin (1985), Lee (1988) and Stout (1987, 1992) were the first authors to discuss the exposure risk in homes, Euroforum (1999) organised a conference including a speaker on legal aspects, Gezondheidsraad (2003a) made of followup study of 1986, the Health and Safety Commission proposes revised regulations (1999), Hoebe (1999) documents cold water pipes as the source of contamination, ISSO publication no. 55.1 presents the Dutch new regulations on the prevention of legionellosis, Percival (2000) discusses the role of biofilm, Raw (2000) sampled more than 500 modern water heaters in the UK but did not find high levels of legionella, Tieffenbrunner (1993) tested installations applied in Germany, Schets (2004) presents the KIWA research project in 400 houses, and there are many other sources.

The main elements of the model are risk factors for explosive growth into a large population. This risk is high when growth conditions are favourable in combination with bacteria containing aerosols that occupants are exposed to. Aerosol production takes place in a shower, a bathroom, when spraying water around in the garden, around fountains, when opening the lid of an aquarium. Contaminated aerosols can be dispersed by air currents over hundreds of metres. The most frequent exposure indoors in houses is to aerosols in the shower. As water systems have cooler niches and legionella bacteria are protected within protozoa or cysts, the temperature of 60°C is not a complete guarantee against live bacteria. We analysed the conditions in the temperature range between 20 and 60°C. In the heating season, cold water pipes may be heated by floor heating or hot pipes in shafts. In some houses, cold and hot water conduits run next to one other in the floor slab and stagnant cold water reaches temperatures of 25°C or higher. Cold water pipes also get warm close to the heater, making cold water conduits the greatest risk factor for the presence of legionella contamination, but the total concentration is low, because water pipes contain little volume of water and most bacteria will be drained in a few seconds. The high concentration can develop in water buffers of more than 2.5 dm^3, when polluted water will run for more than 20-30 seconds up to many minutes when the buffer is larger. Good ventilation of the shower reduces the concentration of aerosols, but the peak concentration is still high and the risk level doesn't not change. With legionella we deal with low risk but extreme health effects.

Figure 7.8 Hot water systems in the 364 subset of water temperatures (sub-datset on water temperatures, n=364)

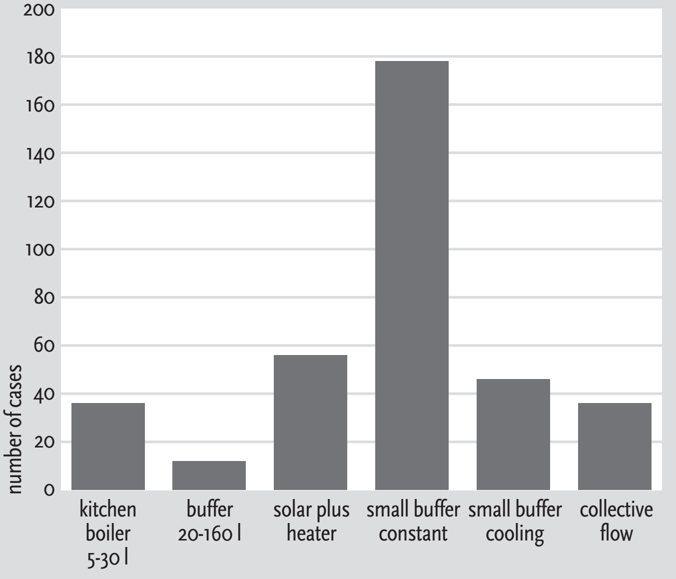
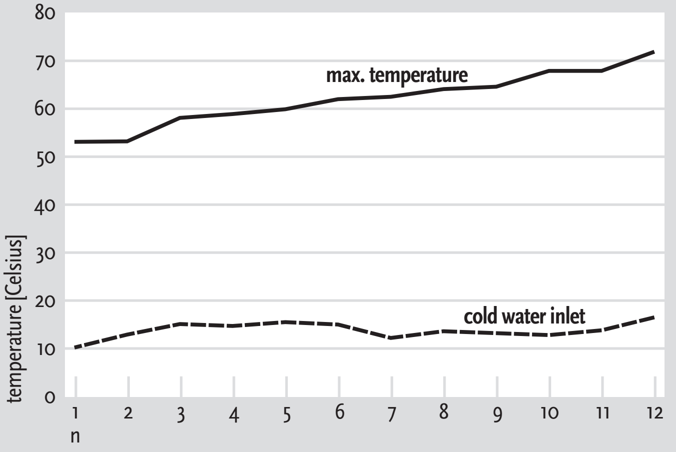


Figure 7.9 Hot water boilers combined with gas heaters (n=12)



Water temperatures

The technical properties and temperatures of 364 domestic water systems were inspected and analysed. Because the data was collected in May-July, the effect of the heating system on the temperatures of cold and hot water was not monitored. The flow and temperatures were measured at the kitchen tap: cold water for one minute and warm water for two minutes, at maximum flow. The maximum temperature is the highest monitored temperature for two minutes of running hot water. Two minutes equates to a total flow of about 11-15 dm^3.

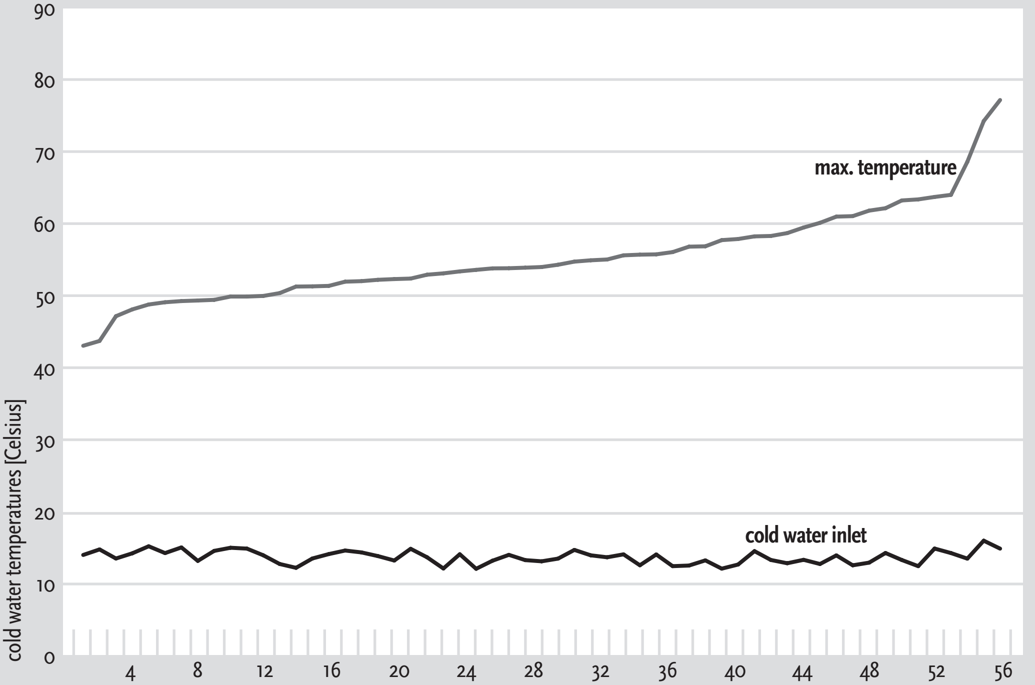
Hot water systems can be divided into two major types: buffer systems and flow-through systems. Buffer systems contain 5 to 160 dm^3 (sometimes more) of hot fresh water. Flow-through systems heat water directly from cold to hot conditions and only when used. The buffer systems need attention because of the potentially high population of bacteria. Most types of flow-through heaters and those with buffers up to 25 dm^3 are designed to heat to 60°C with a flow of 5.5 to 6 dm^3/min. Larger buffer systems may provide 8 to 12 (16) dm^3/min and can fill a bathtub much faster. Six types are studied (see Figure 7.8):

- kitchen boiler
- buffer type, 20-160 dm^3
- solar domestic hot water system
- small buffer types: constant warm or cooling down
- collective flow through systems.

Table 7.8 Performance of water tap in kitchen in the subdataset of water temperatures (n=364)

Overall results (n = 361)	Average	Median	Standard deviation	
1. Minimum temperature	15	15	2	°C
2. Maximum temperature	61	60	7	°C
3. Waiting time 51°C	46	41	39	sec
4. Hot water flow	7	7	2	dm³l/min
5. Temperature after 2 minutes	60	58	12	°C
6. Temperature at start of running cold water	19	19	2	°C
7. Cold water flow	9	9	3	l/min

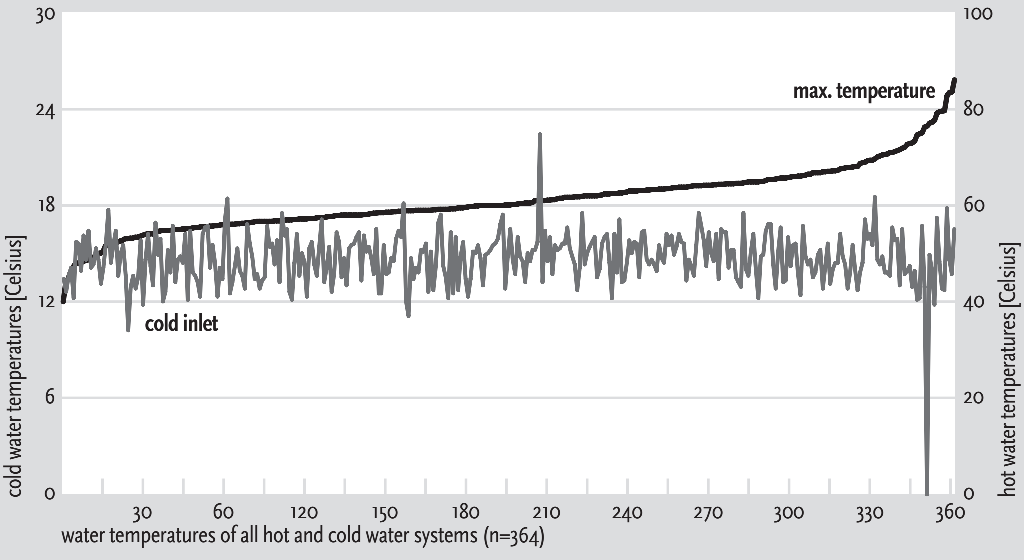
Figure 7.10 Buffers of solar domestic hot water systems and combined with auxiliary heater for conditions when the buffer is not hot enough (n=56) in the sub-dataset of water temperatures (n=364)



The overall results are presented in Table 7.8.

One third of hot water buffers do not reach 60°C in two minutes, but all buffers produce water of at least 52°C. The cold and hot water temperatures for two buffer systems are presented in Figure 7.9 and Figure 7.10. A number of buffer temperatures point at risk of legionella growth as indicated by temperatures at the kitchen tap being lower than 58°C. Flow-through heaters heat

Figure 7.11 Cold (left axis) and hot (right axis) water temperatures of the subset on domestic water systems (n=364)



cold water for instant use. Almost 50% of the temperatures in flow-through systems do not reach 60°C (see Figure 7.11), but there is no risk of high legionella concentration.

Parameters of legionella concentration

Many systems do not perform as required or as indicated by their manufacturer. One obvious reason is a higher water flow that does not allow for higher temperatures with the available capacity of the heater. The second reason is poor maintenance, causing deregulation of the gas flow or a dirty heat exchanger that insulates against the heat of the burner. The third reason is the long distance between the heater and the kitchen tap, but this effect would decrease in two minutes of running hot water, which does not happen in most cases, because the water temperature often reaches its peak temperature within two minutes.

Solar domestic hot water systems present a high risk of contamination (relative to other individual systems). For several months a year, the buffer temperature is in the range 30-45 °C. Heating the water up to 60 °C does not eliminate bacteria, because the period at high temperatures is only a few minutes (boiler) or seconds (flow-through heaters). A potential population of bacteria will remain viable until the sun shines long enough to reach high temperatures and kill all bacteria in the solar water buffer. This phenomenon could be the safeguard: periodic cleaning of the system through temperatures up to 70°C or higher may destroy the biofilm and any protozoa or cyst or bacteria, even in niches. Daily use of the buffer system does not allow high temperatures but flushes bacteria. During stagnancy the population could grow, assuming enough nutrition and oxygen is provided. So the risk situation arises after a stagnancy period in the winter: returning from a winter vacation

Table 7.9 Indicators of sources and resulting concentration of legionella bacteria

Source indicators	Emission indicators	Removal indicators	Indicators of resulting concentration
Water in buffer at 25-55°C	Aerosol producing shower-head or taps, period of showering, aquarium	Frequency and period of flushing, ventilation	Buffer size and stagnancy of a few days or more
Stagnant water in pipes, biofilm	Thermal shock, loose biofilm, aerosols production in bathroom	Frequency of flushing	

Table 7.10 Indicators of exposure risk of legionella bacteria and possible consequences of exposure

Source	Indicators of peaks in concentration	Indicators of exposure risk
Buffer of water, taking a shower	Temperature range 25-55°C	Low: regular flushing Medium: first use of shower after period of stagnancy High: showering not in own home (after stagnancy and with buffer system)
Possible consequences of exposure	Low exposure: risk score 2 Medium exposure: risk and potential serious effects if in poor condition, risk score 4 High exposure: high risk and potential serious health effects, risk score 8	

requires that the system be flushed completely before taking a shower: at 6 dm^3/min this procedure takes 10 to 25 minutes. Some buffer temperatures are below 50°C because the heater setpoint had been turned down, which increases the risk of legionella growth. Buffers of heat pumps operating at 45 to 50°C also present a risk: the auxiliary electric resistance heating element that brings the buffer to 60°C once a week is likely to be in the centre or top position of the buffer, while the bottom of the tank is not heated well enough. Experiments show that, after the heater stops, the temperature at the sensor drops to the range of 47 to 50°C within two minutes, indicating a large stratification of temperatures and legionella growth risk at the bottom of the buffer tank. The risk of sediment, stagnant flow and biofilm is highest at the bottom.

Aerosol formation has effect on contamination risk, but because aerosol formation is partly a dynamic process, inspection cannot reveal the aerosol forming properties. We focus on the source of bacteria.

Model of legionella

The indicators that point at sources, emission, removal and the resulting concentration is presented in Table 7.9. The indicator of exposure risk is presented in Table 7.10.

Indicators of legionella contamination

The source indicators of legionella are stagnant drinking water, buffer size and the age of the buffers. The source strength depends on the temperature in the buffer and pipes (growth peak around 37°C, growth possible in the range 25-55°C). Killing bacteria depends on the frequency and period >60°C. Flow-through systems at (or near) 60°C kill only a few bacteria and are a health hazard in combination with a solar system or heat pump with a buffer at 50°C or lower. Cleaning of polluted pipes and small buffers is possible through heat and flush, but not with buffers of 60 dm^3 or larger. The emission indicator is aerosol formation, mainly in the shower, and with lower aerosol formation also from taps, a fountain in the house or garden, or an aquarium with an aeration system. Contamination is possible at a large distance of more than 100 metres. The source indicator is dominant: buffer, temperature of buffer (at bottom) and stagnant periods. The concentration of legionella bacteria is considered low when the domestic hot water system does not include a buffer tank. Medium concentration can occur in a small buffer with relatively low temperature (50-55°C). High concentration is conceivable in large domestic hot water buffers at temperatures below 50°C.

7.3 Chemical hazards

7.3.1 Parameters of exposure to TVOC and other pollutant gases

We collected some data on renovation activities, but these data do not include information on chemical emissions. However, because the set of indicators that is used for tool development must cover the major health issues, we study parameters of chemical hazards, using field experience and literature. Validation of indicators is not possible.

VOCs emitted indoors are primarily from the materials used to construct, renovate and furnish the house: flooring materials, paints, adhesives and sealants, furniture, electronic equipment and textiles. PVC-based plastics can emit phthalates (plasticizers). Odorous alcohols are often released if excessive moisture in the environment reacts with the plasticizers. Solvents include a variety of commonly used VOCs. The most significant sources of formaldehyde are likely to be pressed wood products: particleboard, hardwood plywood panelling and medium-density fibreboard. We focus on the peak emission periods, mainly the period during and shortly after application. These emissions are likely substances with a short half life in the body (of minutes to half hours), with high peak emissions but with ongoing emissions in the period of months after application. Persistent chemical pollutants with a long half life in the body can only be indicated by the type of materials or appliances used in the house. The human senses may not warn against peak emmissions, so we need indicators to warn against exposure risk.

Selection of parameters

Boleij (1985) compiled an 'early' Dutch work on indoor air pollutants published by the Ministry of Housing, Spatial Planning and the Environment, Brunekreef (1987) studies the effect of NO_2 and tobacco smoke, Bouw- en Houtbond FNV (1992) and also Hoogendijk (1993) point out the chemicals that construction workers are exposed to (which apply to many do-it-yourself jobs as well), Cox (2000) and Offermann (2000) develop a method to predict emissions from vinyl flooring, Dijkstra (1988), Farrar (2000) and Flöckiger (2000) study NO_2 in kitchens (as many others do), Gaikema (2002) points out metals in washing powders, Horn (2000) investigates biocide emissions of 'mould-resistant' wall paint, Jaakkola (2000) and Lehmann (2005) and recently many others study the health effects of plastic interior materials on respiratory health, Joost (1992) edited a book on the effect of substances on the skin, Knudsen (2000) studies the effect of the chemically active ozone on the emissions from building materials, Pope (1995) edited a book on environmental medicine and included health effects of exposure to many chemicals, Raalte (2002) evaluates health risk for carpet layers, Raaij (2003) studies chronic health effects of exposure to chemicals, Säteri (2000) presents the target values for IAQ in Finland, Wijnen (1998) the exposure to chemicals in houses adjacent to chemical dry cleaners and print shops in Amsterdam.

The impression from litterature is that certain emissions and effects are well-documented (NO_2 in kitchens, effect of tobacco smoke, risk of plasticizers and early exposure to chemicals for children (unborn infants). Of many chemicals the effects are unknown. The persistent chemicals must be detected by (proxy) indicators, many chemicals with short half life can be identified via immediate sensory effects.

The model of concentration of chemical air pollutants

The indicators that lead to the evaluation of resulting concentration is presented in Table 7.11. The indicator of exposure risk is presented in Table 7.12.

Indicators

The indicators refer to peak conditions mainly: any hazardous chemical during periods of application, as long as the emission products can be smelled. If the health effect is unknown, precautionary measures are important. The indicators in this situation are sources with hazardous substances, accumulation in dust and also ventilation during emission periods.

Concentration indicators: low without sources, medium: sources generally outgassed, removed, and high: conceivable smell, recent application, large amounts, low ventilation.

Table 7.11 Indicators of concentration of chemical substances in indoor air

Parameter	Source indicators	Emission indicators	Removal indicators	Indicators of resulting concentration
TVOC	Garage, barber- or print-shop, drycleaners	Activity level, distance, wind	Indoor-outdoor ratio, ventilation	Airflows, source minus removal
	Construction materials containing VOCs	Amount of material, type of chemicals, emission characteristics	Ventilation, period since application, baking-out period	Period since application, air change rate
	Interior decorations containing VOCs, soft plastics			
	Cleaning materials containing VOCs			
NO_2, SO_2	Traffic, certain industry, power plants	Traffic intensity, distance, wind, rain	Indoor-outdoor ratio	Traffic intensity, industrial activity, wind, distance
	Atmospheric fuel-burning indoors	Capacity, period of use	Ventilation	Capacity of burner, air change rate
Heavy metals, toxic substances	Specific industrial activities, contaminated soil or water	Distance, wind direction, water level	Indoor-outdoor ratio	Dilution level, determined by distance
Lead, pesticides, toxic substances	Lead water pipes, lead-containing paint, indoor electronic appliances with flame retardents, pesticides	Amount of material, type of chemicals, emission characteristics	Flushing water pipes, ventilation	Cleanliness, air change rate

The baseline of most chemical hazards is proper ventilation. The concentrations that reach hazardous levels with low ventilation require priority attention to ventilation rather than to the emissions.

7.3.2 Parameters of exposure to aerosols

Selection of model parameters

Research results on aerosols including radon that are used for the model can be found in the following sources: Baron (2001), Cheong (1997), Graaf (1997), He (2003), Kunzli (2000), Lucht (1995 and 2003), Morawska (2000, 2002, 2003), Winter-Sorkina (2002), Yang (2001), Zijverden (2001).

An aerosol is defined by Baron as a particle that is airborne long enough to be studied (Baron, 2001). The behaviour of a particle or aerosol strongly depends on its aerodynamic size and mass. In normal distributions, there will be a magnitude of ultrafine and fine particles but a relatively small number of coarse particles. Aerosols change due to deposition, coagulation and chemical changes, including change from gas into the particle phase. Diffusion is the primary transport mechanism for particles <0.1 micrometres in smaller enclosures and is caused by Brownian motion, which is the random motion of particles due to collision with gas molecules. It causes particles or gas to move

Table 7.12 Indicators of exposure risk to chemicals and possible consequences of exposure

Source	Indicators of peaks in concentration	Indicators of exposure risk
TVOC	Airflows, period since application, air change rate, application of soft plastics	Low: low amount of materials, no harmful pollutants Medium: potential hazardous substances High: low ventilation rate, present during and shortly after application of material
NO_2, SO_2	Traffic or industrial activity, wind, distance. Capacity of burner, air change rate	Low: low concentration Medium: short periods with increased concentration High: outdoor level plus indoor activities, breathing rate for SO_2
Heavy metals, toxic substances, lead, pesticides	Use of persistent toxic materials (pesticides, flame retardents), lead pipes and lead-containing paint, air change rate during application, cleanliness	Low: slightly increased, compared to background level Medium: incidental exposure to higher levels High: long periods with increased concentration level
Possible consequences of exposure	Low exposure risk: short term effect, not intense, risk score 2 Medium exposure risk: irritative effects, dangerous substances, risk score 4 High exposure risk: long term health effects, risk score 8	

from a higher to a lower concentration. Deposition, bouncing and decomposition or re-entrainment can cause changes in the aerosol distribution. In air ducts with both laminar and turbulent flow characteristics, the air velocity defines the deposition process. Coagulation is the aerosol growth process resulting from the collision of aerosol particles with one other. Thermophoresis is the force that pushes particles away from warm to cold surfaces, resulting from differences in collision forces at different temperatures. The thermophoretic velocity exceeds the terminal settling velocity for particles smaller than 0.1 micrometres (Hinds, 1982). Electrophoresis is similar, but in this case is caused by charged particles in an electric field. The boundary layer is the region of flow near a bounding surface where the flow is determined by friction forces resulting in reduced flow velocity relative to the free stream and resulting in deposition (Baron, 2001). This process causes deposition in sections of ducts where flow speeds change, for instance near the edge of turbulent flows after joints or other barriers. The deposition increases on surfaces that are rough from deposited material.

Particles are deposited on all surfaces: Brownian movement causes deposition on ceilings as well as horizontal and vertical surfaces, while gravitational forces primarily result in deposition on horizontal or sloping surfaces. In ducted systems, the particles have a relatively high chance of settling, due to gravitational force and bouncing, caused by turbulence. Bioaerosol formation in the deposited particle layer in inlet ducts and re-entrainment of particles due to intermittent use of fans, vibrations in ducts and change in the physical properties of air causes periods of increased concentration, which are noticed by occupants and influence perceived air quality (Hasselaar, 2002d). A critical period is the beginning of the heating season, when the conditions in the ducts change dramatically. Complaints of residents about foul ducted inlet air are often reported in the period October-January and start one to three years after new installation, but are more widespread after five years. After 15 years, many residents (50%) will have made major changes to ducted inlet systems; the mechanical inlet function is often not used any more or with low volumes of fresh inlet air (Hasselaar, 2001a). The exhaust function is still used in these conditions.

Large particles are more likely to settle in ducts than smaller ones, due to gravitational forces. In bends, the centrifugal force is larger than the dynamic force of the airstream and large particles will hit the surface and be deposited. Oily residues from the manufacturing process bind dust particles on the surface (Pasanen, 1992, 2000). The Brownian motion of ultrafine particles also causes collision on duct surfaces. The chance of deposition increases when the particle spends a longer time interval within a duct (Baron, 2001). This means that more ultrafine particles will deposit at low flow rates.

Filters

The filtration effect is the result of diffusion, interception and inertial impaction mechanisms. Diffusion is the main collection mechanism for particle sizes <0.1 micrometres. Interception is important for particles >0.1 micrometres, and the effect increases with higher filter density or packing. Impaction is important for particles >1 micrometres. In the particle size range of approximately 0.1-1.0 micrometres, none of the mechanisms contribute much to deposition (Jamriska, 2001), which implies that filters have little effect on the number concentration of particles in the range of 0.1-1.0 micrometres and no effect in the range of 0.1-0.3 micrometres. Typical panel filters used in domestic air conditioning systems or heat recovery ventilation systems block insects and coarse particles that may damage fans and heat exchangers, but for PM2.5 aerosols the efficiency is as low as 10 to 20%. The filter efficiency and airflow resistance increase with filter loading, meaning that dirty filters perform better as filters, with side-effects like intermittent outbursts of clouds of dust. High-performance filters can filter as much as 99.97%, but for PM2.5 and PM1 the efficiency in the field ranges between 40-60% only.

Filters and deposited material in ducts can become a new source of aerosols (Bjorkroth, 1997, 2000; Bluyssen, 2000; Heide, 1997). Experiments with smell panels (Fanger, 2003) indicate that the air quality after clogged filters is perceived as worse than without a filter: occupants can smell the difference between a clean filter and a dirty one. It is likely that a change in perception is possible within a matter of weeks instead of months. In the Dutch maritime climate, filters in the inlet air system get wet in rainy or foggy weather, and these conditions are favourable for mould growth or the growth of other organisms (bacteria). The concern for ducted inlet air and deposition studies is influenced by the poor perceived air quality of these systems by occupants: we do not know what causes these sick-building-type complaints. The study of deposition is part of the search for better answers.

Experimental study of particle deposition in air ducts

A series of experiments conducted in the study of aerosols focus on the aerosol deposition in air ducts and on particle distribution in rooms. Other experiments with airflow patterns in furnished rooms indicate areas where the air is not moving, where particles accumulate and air becomes old or 'stale'. Experiments in the test chamber at the International Laboratory of Air Quality and Health (ILAQH) resulted in drawings of circulation patterns near walls and the ceiling and in the vertical cross-section of the chamber. The description of data, the data acquisition protocol, scenarios and some results are included in Appendix 2.

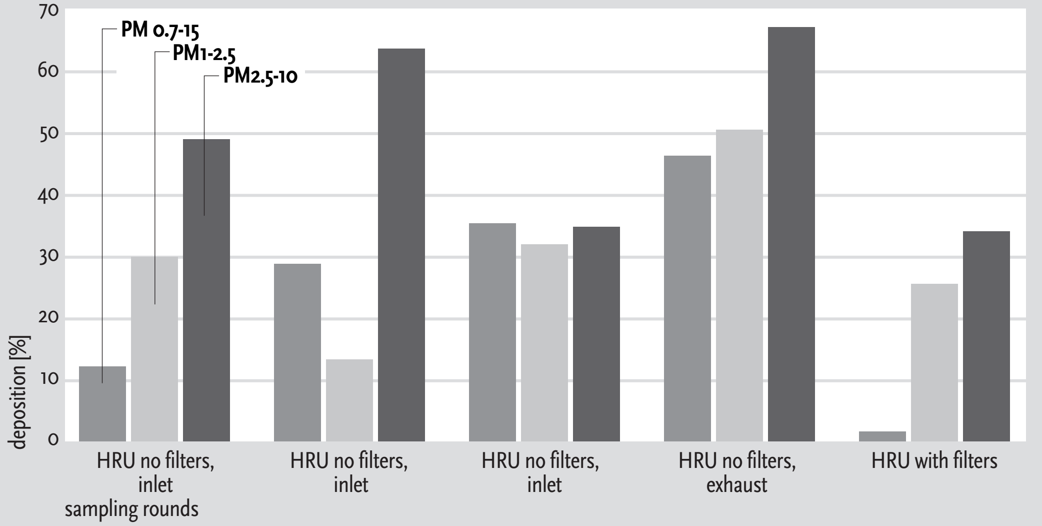
The objective of the experimental study is quantification of aerosol deposition within mechanical ventilation systems measured under usual operational conditions and with distinctive size ranges. The second objective is understanding the particle losses in main parts of the system: the air handling unit (HRU including fans, filters, heat exchanger) and the ducts between the HRU to the inlet point in the chamber. The third objective is understanding airflow patterns and particle distribution in rooms, caused by mechanical inlet or outlet through dampers or natural inlet through modern line-type inlet grates and outlet through the seam under the door.

The main instrument used in the experiments is an Aerodynamic Particle Sizer, providing particle number counts for different size ranges between 0.7 and 15 micrometres. Results are presented for the size ranges PM0.7-15; PM1.0-2.5; and PM1.0-10.

The readings with an optical photometer for PM2.5 mass concentration were not discriminative enough to provide results. These readings are used as a reference measure, to omit experiments with unexpected fluctuations in the ambient particle concentration (e.g. presence of a car near the ambient air inlet, workshop activities nearby). More than 90% of total number count refers to sub-micrometre particles, of which some 80% is ultra-fine (smaller than 0.1 micrometres). In this size range the accuracy of the aerodynamic particle sizer is low. An ultra-fine condensation particle counter (>0.02 mm) was added in later experiments to collect data in this range.

Sampling points were selected upstream and downstream of a tested component. Five consecutive measurements were conducted at each sampling point, starting from the most upstream location and progressing systematically downstream through all sampling points along the system. Some uncertainties remain: e.g. the curves in the flexible sampling tubes that connect the probe to the particle counter differ for the different sample points; moving around on the rooftop of the chamber may have caused release of deposited particles, thus affecting the readings obtained. The sample probes are designed for optimal sampling conditions for isokinetic sampling; however, due to different airflows, the probes are expected sub-optimal at some flow velocities. The effect of these sampling conditions was not evaluated.

Figure 7.12 Deposition in heat recovery unit in scenarios that represent one period of sampling, based on experiments in the International Labatory of Indoor Air Quality and Health



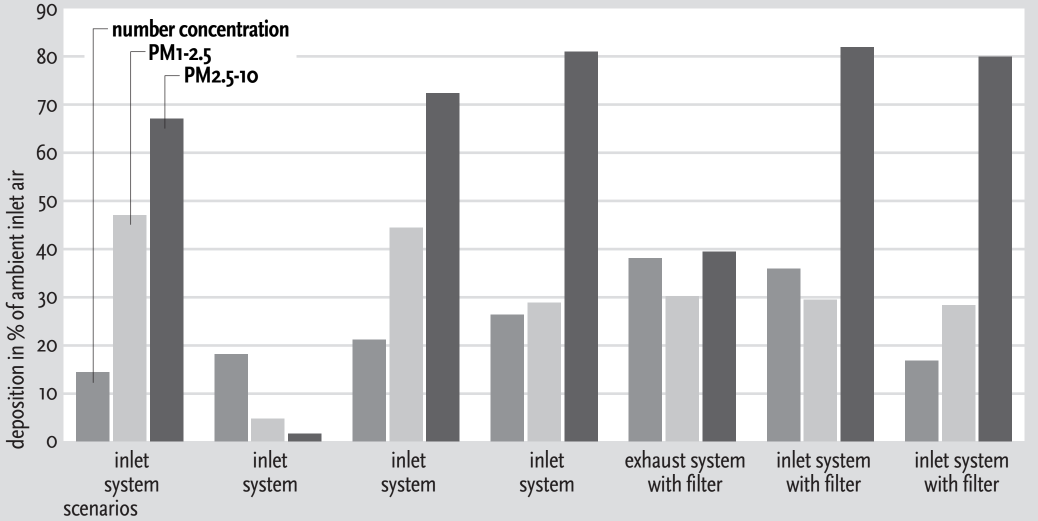
Source: Hasselaar (2004)

Figure 7.12 and 7.13 show the deposited fraction in the heat recovery unit and in the total system. The fraction is in the order of 10 to 45% for all sizes, and 35 to 65% for the larger particles with extremes of more than 80% deposition of PM2.5-10 in the total system. The HRU unit contributes to the filtering mechanism, which means that the HR unit will become clogged with dust particles. The filter efficiency of the unit (without filters) for larger particles is higher than for particles in smaller size ranges.

The PM0.7-15 concentration increases in the ducts (negative values of deposition, indicating a particle source). Larger particles are deposited, except for one scenario. This effect can be the outcome of two competing mechanisms: deposition and re-emission from locations with increased turbulence. Turbulent flow and large changes in air velocity over the duct section are believed to cause this effect. The acoustic units are porous and filled with mineral wool. Both the packing material and re-emission of already deposited particles can function as a particle source. Straight ducts and also circular bends show positive deposition effects. The particle concentration fluctuates in different parts of the ducted system, even with high concentrations at the end of the ducts. A lower concentration downstream indicates deposition; a higher concentration indicates presence of a particle source or 'trap'. Re-emission from the deposited layer and mineral wool in the sound attenuators can 'produce' particles. A trap can be a whirl in the airstream, where the concentration is high and change in airflow velocity or turbulence permits a cloud of particles to escape. The fluctuations in the measured concentration can be interpreted as instability of the deposition mechanisms. In ducts of residential houses, deposited material is found after sections with high velocity changes.

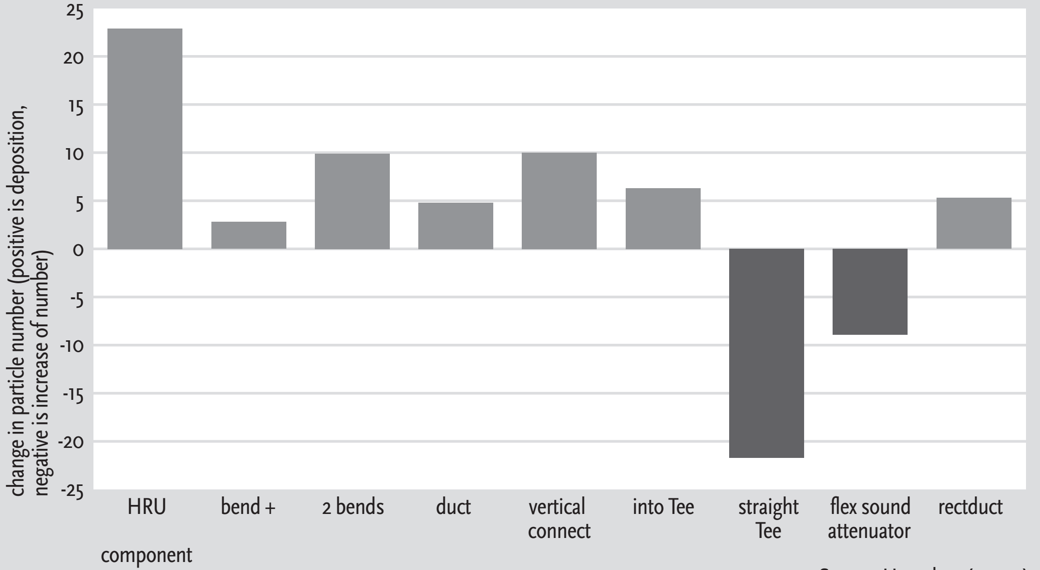
The negative bars in Figure 7.14 indicate increase in particle mass: in the rigid and flexible sound attenuator. The increase is at the end of the unit,

Figure 7.13 Deposition in the system, including HRU, based on experiments in the International Labatory of Indoor Air Quality and Health, Brisbane



Source: Hasselaar (2004)

Figure 7.14 Deposition of PM >2 in individual components, based on experiments in the International Labatory of Indoor Air Quality and Health, Brisbane

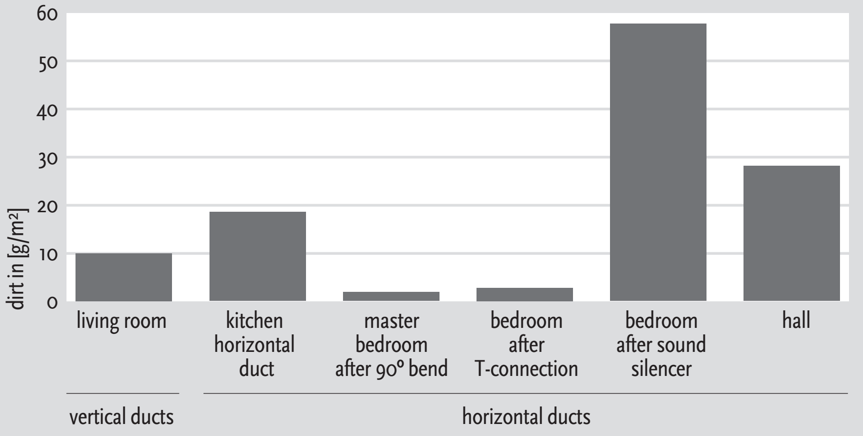


Source: Hasselaar (2004c)

probably at a location where turbulence creates a cloud of particles. This mechanism seems plausible but was not validated.

The study demonstrates that a ducted ventilation system acts as a fil-

Figure 7.15 Deposition mass in ducts of balanced flow ventilation systems after 16 years, based on the sub-dataset on dust sampling in Arnhem (n=19)



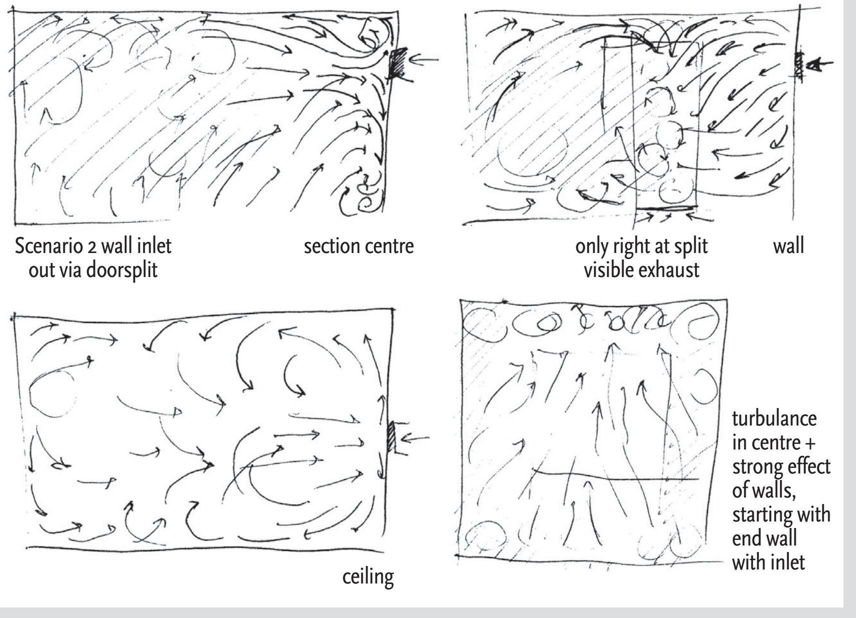
ter: particles are deposited not only in the applied (EU3 type) filters, but also in heat recovery units, in ducts, bends, T-sections and dampers. The overall deposited fraction for particles in the size range 0.7-15 micrometres varies between 10 to 45%, and for PM2.5-10 it amounts to more than 80%. Larger particles (diameter >2.5 micrometres) are primarily deposited in bends due to impaction. The sound attenuators show deposition of particles in the smallest size ranges, but they tend to 'produce' particles in the ranges from 1.5 micrometres upwards. This effect could be caused by coagulation of smaller particles in the turbulent areas near the surface of the sound attenuator. The effect of ducts is comparable to the effect of low-efficiency filters: high deposition in the larger particles size ranges, small to negligible in the ultrafine ranges. The 'fresh' air that the system delivers indoors has a smaller number of particles, but is not of a constant better quality. The particle concentration is not very stable: release of particles from turbulent air pockets and from the surface is thought to be the sources of polluted air from the ducted ventilation system. A solution to that problem is the application of more efficient filters at the inlet starting point of the ducted system, in combination with coarse to fine particle filters in the inlet damper at the side of the occupied space.

Deposition in ducts after many years of use

In a project in Arnhem, fresh air has been ducted into houses for 15-16 years. The latest maintenance visit at the time of the inspection occurred 1 year ago: dampers were controlled and the units cleaned, but the ducts were not cleaned, except in one house in which (due to a control problem) the fans worked at maximum capacity for these 16 years.

Deposited material was taken from the inlet ducts at different locations and the mass per surface area was determined. Five systems were sampled. Only one of the five systems functioned as designed and intended: the system in the house of a technical expert who understood and maintained the system properly. One of the systems was very clean and did not seem to have ever been used.

Figure 7.16 Air circulation patterns and particle movements in the test chamber at ILAQH, made visible by smoke: mechanical inlet from the wall and natural outlet via the door



Source: Hasselaar (2003)

The results in different houses have been interpreted for a scenario with normal use: 16 hours/day at nominal volume, 7 hours reduced and 1 hour at peak level. The deposited mass in horizontal ducts is, following a scenario of 'normal use' calculated and the results show a deposition of around 30 g/m^2 of duct over a period of 15 years. The rate is 2 g/m^2y, implying that, within two years, the standard of minimum cleanliness is surpassed (see Section 3.2.1.). The bottom of the duct has the highest deposition rate due to gravitational forces acting on the larger particles. The mass of 150-200 g/m^1 over a surface area of about 100 mm wide at the bottom of circular ducts with diameters of 150 and 125 mm is 20 g/m^2 average (see Figure 7.15). This result may explain why foul air could be perceived in a few months and complaints are expressed within one year (typically six months, from a handful of diagnosed complaints). The source of the dust is not certain: an unknown volume of settled dust may have entered the ducts during the construction process.

Particle distribution in rooms

In the test chamber at the International Laboratory of Air Quality and Health, smoke is injected to visualise airflow patterns in the test chamber. Drawings of the flow pattern in the vertical and horizontal sections of the chamber were created. A total of 14 scenarios were pictured and analysed. The experiments result in qualitative insight into how 'pockets' of high particle concentrations are formed. One scenario is presented in figure 7.16. Two other scenarios are included in Appendix 2.

Analysis of the flow patterns

Temperature differences between walls, openings in walls, heat sources in the chamber and also of inlet air have a major influence on airflow patterns. This means that a person sitting at a desk or at the table or lying in bed (50-100 watts heat source) will cause a stack of warm air, bringing 'new' air into the area around the nose and mouth. The mechanism has an important effect on the quality of the inhaled air, preventing a connection between exhaled (mouth) and inhaled air (nose). A very low ventilation rate and small temperature differences permit a sink effect, meaning that larger particles settle and the mass concentration is likely to decrease during quiet periods at night in a non-occupied room with closed inlet openings and without exhaust function. The scenario presented in Figure 7.16 is typical for bedrooms in houses with heat recovery ventilation, except for position of the inlet damper in practice, which is over the door.

The sun heats high-efficiency insulation glazing (U=1-2 W/m^{2}K) and the temperature of the glass surface inside the room shows a strong stack effect. This effect is similar to the stack effect of a heater under the window. The warm airflow mixes with cold inlet air and the mixed volume is warmer and uplifted to the ceiling, which brings the fresh airflow deeper and at higher level into the room, but during the experiments the distance between the window with the horizontal inlet slit and the downward cold air flow was not more than 150 cm from the facade and the distance being larger only when the heater was extremely hot (>70°C).

The inlet and exhaust volume of natural ventilation is determined by pressure differences and size of openings, while the temperature differences determine the flow pattern. Fresh air tends to be cooler than indoor air and falls from the window opening down to the floor until part of the air is uplifted near heat sources, or to exhaust points, while part of the air volume circulates back to the inlet area. This creates a good displacement efficiency, provided the exhaust point is near the ceiling. When the exhaust point is a seam under the door, the higher regions of the room do not mix well and the air gets 'older'. Inlet of air of near-room-temperature from a heat recuperation unit along the ceiling surface causes a flow along the ceiling, while air near the cold floor area gets 'older'. Mixing of fresh and stale air depends on the location and type of inlet more than on the exhaust. Induction-type inlet dampers influence the circulation patterns better than low velocity-type inlet dampers, but create more noise. Surfaces influence the transport and circulation pattern: the boundary layer provides a guiding mechanism for air.

The inlet volume through a grate is identical to the exhaust volume and a door with large seams (6 metres in length) can technically provide enough opening, but a hatch or opening above the door would be better for the quality of the displacement ventilation. The combination of mechanical exhaust and natural inlet supports displacement ventilation, provided the location of the exhaust opening is opposite the inlet opening. Experiments in the test chamber and also in the field show that low displacement efficiency can be expected in balanced-flow systems when not accounted for the following qualities:

- inlet dampers have a larger effect on the airflow patterns than exhaust dampers;
- the boundary effect influences the airflow in an area of 3 metres (or more, depending on the air velocity), which is positive for the effect along a ceiling, but negative if the air does not escape from the boundary walls in a corner and keeps circulating in a space of less than 10 m^3;
- collision with an obstacle or a wall changes the direction of the flow and this effect can be strong enough to limit and almost stop the circulation in other parts of the room.

Radon as aerosol

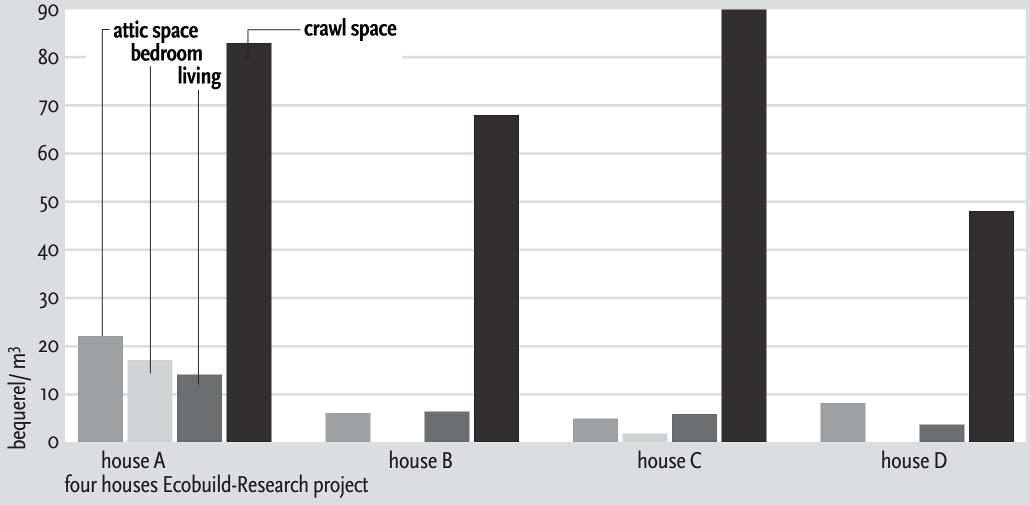
The naturally occurring element radium changes into the gas radon (isotope 222 Rn). Radon reduces within one day into the stable phase of lead and radiates energy in several stages of the decay stages. The smallest particle is most dangerous, because it penetrates deep into the lungs. The larger the particle it is attached to, the more likely it is that this particle including the radon nuclide will be caught in the mucous membranes and either be swallowed or blown out.

In addition to the effect of radon as inhaled aerosols, occupants are exposed to a constant level of ionizing radiation, directly from building materials, even in adjacent rooms. The radiation can penetrate walls, meaning that even material in other rooms or in neighbouring houses have influence, but stone or concrete walls with a certain density and thickness will isolate from radiation. A concrete wall is both a source and offers protection. The concentration of gas in the home environment depends on ventilation. The most important source of radon in Dutch houses are the building materials, with an average contribution of 70%. The other 30% comprised outside air and air from the crawl space in equal quantities. The radon concentration was found to be positively correlated with the radon concentration in the crawl spaces and the total area of concrete in the living room (Stoop, 1998). Excessive exposures are typically related to low ventilation, use of natural stone including concrete and/or high ambient concentration.

Radon concentration measurements

Figure 7.17 shows the radon concentrations measured over a period of three months in two periods in four unoccupied test houses in Petten. The differences between the concentrations can be attributed to differences in the materials used and in different ventilation efficiencies including infiltration. Since the materials used for houses A and B are almost identical (house A has 10% more concrete surfaces inside), the difference in radon concentra-

Figure 7.17 Radon concentration in indoor air in four test houses at Petten (2002 and 2005)



tion may be caused by the ventilation system: house A has natural ventilation, house B heat recovery ventilation.

The model of aerosols

The experiments in the test chamber lead to the following parameters of the aerosol model:

- there is evidence that deposited material releases from the filter and other segments with turbulent flow, creating clouds of aerosols that could be perceived by occupants: when fan speeds increase, when turbulence occurs and after vibrations from slamming doors, heavy vehicles passing, etc.;
- dust layers in certain sections are expected to deserve the label 'dirty' in less than five years;
- circulation patterns determine the age of air and pockets of old air in rooms;
- displacement efficiency depends on temperature difference between inlet, room and exhaust point;
- the location and type of exhaust damper have little impact on air circulation at low fan speed;
- the location and type of mechanical inlet damper have a major impact on the circulation pattern;
- the effect of temperature difference is missing with balanced-flow ventilation and (high efficiency) heat recuperation, meaning that flow velocity and damper type determine the circulation, with short-circuit patterns when air flows to corners of walls or wall/ceiling connections;
- a large distance between inlet and outlet opening per room improves the ventilation efficiency.

Model of concentration of and exposure to radon aerosols

Table 7.13 shows the indicators of sources, emission and removal that point at the resulting concentration. Table 7.14 shows the indicators of exposure risk.

Table 7.13 Indicators of sources and resulting concentration of aerosols indoors

Source indicators	Emission indicators	Removal indicators	Indicators of resulting concentration
Outdoor PM2.5 (traffic, industry)	Indoor-outdoor ratio 80-98%, activities	Deposition of larger particles	Outdoor concentration
Radon	Mass of concrete or stone, emission from crawl space	Ventilation	Surrounding mass of radon-containing material, ventilation rate
Indoor sources of fine particles	Smoking, baking, vacuum cleaning, fire place, candles, fragrances, pets	Ventilation and cleaning	Number of cigarettes, candles, type of pet, etc., air change rate, activities such as vacuum cleaning

Table 7.14 Indicators of exposure risk to some groups of aerosols and possible consequences of exposure

Source	Indicators of peaks in concentration	Indicators of exposure risk
Outdoor PM2.5 (traffic, industry)	Heavy traffic jams, wind direction, humidity (rain)	Low: large distance, low intensity Medium: urban level High: within 300 m of busy traffic and in urban area
Radon	Ventilation rate, type and amount of stone or concrete	Low: wood based construction, air change rate >0,7 Medium: stone/concrete structure and high constant air change rate High: concrete- or stone-based building structure, low air change rate
Tobacco smoke	Number of cigarettes smoked indoors	Low: incidental smoking Medium: up to 3-5 cigarettes per day High: more than 5 cigarettes per day in room in presence of others
Bioaerosols: pets (see also mould)	Pet size and number, cleanliness and locations of resting area indoors	Low: contact with other pets owners Medium: pet exclusively outdoors and minor contact High: pet inside the house
Possible consequences of exposure to aerosols	Low exposure: short periods of irritation for people with respiratory problems, risk score 2 Medium exposure: periods of irritation for people with respiratory problems, potential harm over a long period for children and people in a weak state of health, risk score 4 High exposure: increased irritation for people with respiratory problems, potential serious health effects over a long period (reproduction, lung cancer), risk score 8	
Possible consequences of radon exposure	Low exposure: no threshold level, potential harm after a long time period, risk score 2 Medium: some increased risk of lung cancer, small chance but high stakes: risk score 4 High: increased serious health risk, compared to effect of active smoking: risk score 8	

Selected indicators of aerosol concentration indoors

1. outdoor concentration level, given that most of PM2.5 enters the house;
2. indoor sources: abrasion of materials (concrete, fibres), tobacco smoke and burning of fossil fuels, baking, radon gas and radiation from materials, TVOC aerosols from hot or greasy surfaces;

3. indoor particle production by mould and house dust mites;
4. temporary release of aerosols from inlet ducts after turbulence, vibrations, change in air velocity;
5. turbulence and re-entrainment of deposited particles in indoor air, caused by moving around, vacuum cleaning, turbulence of air created by doors, fanned inlets and wind pressure differences.
6. pet allergen: the presence of a cat, dog or bird inside the house.

Definition of low, medium and high
The concentration of PM2.5 from outdoors is considered low in 'clean' rural areas, medium in urban and industrial areas and high when the European PM10 norm value is surpassed, or with heavy traffic nearby, or with smoking indoors (more than 1 cigarette a day).

The concentration of radon is considered low in houses with a wood-based construction and a sealed floor over the crawl space. Medium concentration: stone-based structure, ventilation with >0.5 ACH, sealed crawl space. High concentration: stone-based structure and low permanent ventilation rate.

The concentration of aerosols produced indoors is considered low when the activity level is low and pollution sources are effectively vented off. Medium concentration: with 'normal' activities, no smoking, ventilated during aerosol production. High: smoking, poor ventilation during cooking, cleaning or do-it-yourself work.

Ventilation quality is the priority parameter of aerosol concentration from sources indoors. Outdoor sources are not stopped from emission into the house with normal ventilation, except for inlet via ducted (or filtered) systems and for the coarse and larger particles >PM10, that are to a certain degree deposited in seams and insect grates etc.. Sealing and stopping ventilation only helps to reduce temporary peaks in aerosol distribution outdoors (traffic jam, calamities such as bush fires or fires of buildings). Reduced ventilation may reduce particle concentration but is no option in an integrative approach, as other hazards are likely to become more dominant.

7.4 Physical hazards

7.4.1 Parameters of noise

In the 333 dataset 191 cases have information on noise from outdoors: 30% live in a quiet neighbourhood and 70% in an urban area with constant background noise levels. Almost one third of the cases complain about noise from neighbours (of n=143) and from indoor services (n=137), but hardly ever at the same time. Noise has in 27% of cases effect on behaviour, for instance keeping the windows closed (of n=134, which is mostly related to noise outdoors. Ef-

Table 7.15 Parameters of noise level and indicators of noise

Parameter	Source indicators	Emission indicators	Indicators of protection	Indicators of resulting concentration
Ambient noise	Traffic, industrial, commercial, recreational	Distance, wind direction	Insulation and sealing of envelope, control functions of inlet openings	Distance to source (level on envelope), opening in envelope
Technical noise	Stairs, doors, drain, shaft, water pipes, fan, pump, elevator	Distance, noice level, frequency of nuisance	Insulation, buffers, control of indoor sources	Frequency, period of the day, type and level of noise
Social noise	Noise from neighbours, music/TV, talking, do-it-yourself work	Distance, noise level, frequency of nuisance	Insulation, buffers, control of openings	Frequency, social interaction, period of the day, type and level of noise

fect on stress and nuisance shows stronger correlation with noise from neighbours than with outdoor noise or noise from appliances indoors. Effect on behaviour is strongly correlated with noise from appliances (mechanical ventilation). Almost all negative scores come from people living in urban areas with background noise.

Building type and period and mechanical ventilation are indicators of noise; not so much the level of noise but the mental condition of the occupant determines the complaint level. We do not know how the noise has influenced the mental condition. Literature used in support of modelling include Bree (2002) and Franssen (2003 and 2004).

The model of noise

Table 7.15 presents the indicators that point at a resulting noise level, Table 7.16 shows the indicators of exposure risk.

The level of noise is considered low at background level and with few peaks. Medium level: constant noise, frequent experience of being disturbed. High: interruption of speech, difficulty listening, frequent peaks, constant levels, creating anxiety.

Possible health consequences are related to the mental condition of the person complaining about noise. It means that the perception of noise is the main indicator. Without mental effect the noise level is not (very) important. Experience of discomfort, loss of concentration indicates a medium level. The mental effect is considered high when noise causes sleep disturbance, stress, social conflict.

7.4.2 Parameters of thermal discomfort

Thermal discomfort is caused by extremely low or high temperatures, draughts around the neck and ankles, extremely high or low relative humidity, poor lighting, lack of daylight and a perception of a poor view (see Table 7.17). Comfort conditions are relatively important for the elderly, the people with poor health and small children. Protection against overheating is more difficult

Table 7.16 Indicators of exposure risk to noise levels and possible consequences of exposure

Source	Indicators of noise levels	Indicators of exposure risk
Ambient noise	Distance to source (level on envelope), opening in envelope	Low: in quiet urban neighbourhood, traffic for small neighbourhood, no industry Medium: traffic for larger neighbourhood, shops nearby, short peak traffic High: along road with heavy through-going traffic, or near dual carriage way, heavy vehicles, long peak periods
Technical noise	Frequency, period of the day, type and level of noise	Low: services dispensable and controllable Medium: periods with high noise levels, or low level of permanent noise High: noise from indispensable services, no control, high level during quiet periods
Social noise	Frequency, period of the day, type and level of noise	Low: non-frequent noise of communicative neighbours Medium: noise from public area: children playing, bar visitors, neighbours during quiet hours High: high noise level despite requests for turning down the level, disturbing noise at frequent intervals
Possible consequences of exposure	Low exposure: risk score 2 Medium exposure: risk and potential serious effects if in poor condition, risk score 4 High exposure: high risk and potential serious health effects, risk score 8	

than against low temperatures, daylight and view are important for the elderly. Draught and asymmetry of radiant temperatures is discomfort that can be solved to a great extent with proper clothing and does for that reason not result in selected indicators. Extreme outdoor high humidity does occur in the maritime Dutch climate and in combination with high temperatures and consequently high emissions of plasticizers, formaldehyde, ozone and a cocktail of chemical reaction products, etc., there are known health effects.

Daylight regulates cyclic body functions and is directly and indirectly associated with mental health. Exposure risk is according to this short appraisal limited to high temperatures and daylight exposure.

The comfort model

Table 7.17 presents the indicators that point at a resulting level of (dis)comfort, Table 7.18 shows the indicators of exposure risk. The level of discomfort depends on the periods of discomfort and whether discomfor can be avoided. The possible consequences depend on the perceived stress, more than on physiological effects.

7.4.3 Parameters of safety hazards

Falls and collision with objects are the dominant causes of injury in the Netherlands and one quarter of the emergency visits from these accidents involve broken bones (Lanting, 2005). Data from the Netherlands indicate that people over 60 years of age are at relatively high risk: 50% of fatal injuries in and around the house occur in this age group. Stairs, small obstacles, slippery floors, hot water and sharp and hot elements (kitchen) create high risk levels.

Table 7.17 Indicators of comfort level

Parameter	Condition indicators	Likelihood indicators	Indicators of resulting comfort level
Extreme temperature	Low ambient temperature	No heating, draught, large windows, poor insulation	Period <14°C during 8 hrs in the daytime
	Overheating	Large windows, no shading, no night-time flush ventilation	Period >26 (30)°C indoors during more than 8 hours
Radiant asymmetry	Temperature difference of 'view' surfaces	Single glazing, poor insulation	Large surface single glazing without compensating warm surface
Draught	Temperature differences, high air velocity	Poor airtightness and insulation, concentrated inlet	Low ambient temperatures, air velocity >0.2 m/sec., no control
Extreme relative humidity	Hot air or concentrated airflow of dry air	Flow of dry and warm air around head (low ambient temperature)	<20% relative humidity >80% relative humidity in combination with high temperature
Light and view	Poor daylight	Room without window, small window, closed curtains	Artificial light always needed
	Poor view	Small or high window, narrow angle of view, obstacles	No view of sky
Level of discomfort	Low: short periods of discomfort or discomfort can be avoided Medium: long periods of discomfort, no avoidance High: extreme discomfort limits use of spaces		
Possible consequences of exposure	Low: acceptable periods, level is accepted by occupants Medium: discomfort causes periods of (perceived) stress High: constant high level of discomfort creates (perceived) health problems		

Table 7.18 Indicators of exposure risk to discomfort and possible consequences of exposure

Source	Indicators of extreme conditions	Indicators of exposure risk
Extreme high temperatures	>26°C indoors for 8 hrs and peak temperatures >30°C	Low: <30 days at 26°C indoors for 8 hrs per year Medium: >30 days >26°C indoors 8 hrs High: >10 days >30°C indoors 8 hrs
Daylight	No direct view of the sky, low daylight level, artificial light needed	Low: daylight indirect, reduced view of sky Medium: enough daylight, not direct and no view of sky High: artificial lighting only
Possible consequences of exposure	Low exposure: risk score 1 Medium exposure: risk and potential effects if mostly indoors, risk score 2 High exposure: high risk and potential serious health effects, risk score 4	

Many physical parameters point out the risk of injury. Because of the mental stress involved, we include burglar proofing to the parameters:

1. Defective flues from exhaust pipes of solid-fuel appliances;
2. Poor step geometry and surface, inadequate guarding to stairs, landings or balconies;

3. Low internal windowsills;
4. Exposed hot water pipes;
5. Inappropriately located window catches (stretching, or reaching over cookers or other facilities);
6. Inappropriately located nonsafety glass;
7. Low door lintels or low headroom on stairs;
8. Unsafe kitchen layouts (risks of scalding or burns, flame may be blown out by open window);
9. Unsafe heaters presenting a risk of explosion or exhaust of CO;
10. Badly located doors, windows, cupboards or shelves presenting a risk of collision;
11. Obstructed circulation areas;
12. Slippery floors;
13. Sharp or protruding points and edges along circulation areas;
14. Electrical cables on the floor;
15. No provisions for child safety (storage of chemicals, hot surfaces, stairs, etc.;
16. Poor control over access to the dwellings, or low protection by hinges, locks and glass panes that increase the risk of burglary.

The model of safety

Table 7.19 presents the indicators that point at certain hazards occurring, Table 7.20 shows the indicators of exposure risk.

We consider the level to be safe when the layout of rooms has good ergonomic quality and when protective features prevent predictable events. Increased safety hazards are created while engaged in hazardous activities, for instance washing windows, exchange of a light bulb etc.). Unsafe conditions are associated with poor ergonomics, unexpected obstacles, risk of smoke or fire, toxic emissions. Children are at risk of scalding, suffocation and drowning. The elderly and mobility impaired are at risk of falling and scalding.

The risk score is based on three levels: acceptable risk of injury (risk score 2), injury likely when not attentive (risk score 4) and personal injury is likely to occur (risk score 8).

7.4.4 Parameters of social quality

The 333 dataset gives some information on how occupants perceive their neighbourhood: the intensity and quality of contacts, the opportunity for children to play outside and also having individual space outside, which can promote interaction with neighbours. Many occupants responded with having good contact with neighbours, but not frequent. Caretakers often have to take care for children at play, because playgrounds are not around the house and the street is not safe. We did not get indications of health impact of these

Table 7.19 Indicators of hazards

Parameter	Condition indicators	Likelihood indicators	Indicators of hazards occurring
Personal injury: falls, cuts, bruises	Different levels, slippery floors, thresholds, electric wires over the floor, loose rugs	Poor lighting, wet floor, small foot space, need for supports	Available bars, lighting, location of slippery rugs
	Sharp or protruding objects, use of sharp utensils	Lighting, overhead glazing, location in circulation area	Protection, signals, lighting
Scalds, burns	Hot surfaces or water	Temperature over 60°C, poor do-it-yourself work, poor maintenance	Unprotected oven, heater, fire, very hot water taps
Electric shock	Open leads		Poorly maintained (old) electric appliances and wiring
Drowning	Surface water in garden or near the house	Location near circulation or play areas	Surface water near circulation or play areas and poor lighting, poor view, poor control
Suffocation, poisoning	Storage of chemicals, pills, plastic bags, hazardous toy material	Control, locks, location of storage	Closed and separate storage facilities
Trespassing	Hinges, locks, single glazing, isolated area	Time needed to gain access, social or technical alarm	Open doors or windows, lack of control, no alarm

Table 7.20 Indicators of exposure risk to unsafe conditions and possible consequences of exposure

Source	Indicators of hazards	Indicators of exposure risk
Personal injury: falls, cuts, bruises	Available bars, signals, lighting, location of slippery rugs, loose wires	Low: ergonomic design, sustaining for mobility impaired Medium: 'normal' environment with steps, stairs, thresholds, slippery when wet High: uneven levels, slippery floors, poor lighting, no bars
Scalds, burns	Unprotected oven, heater, fire, very hot water taps	Low: surfaces no more than 50°C Medium: surfaces up to 100°C High: surfaces higher than 100°C
Electric shock	Poorly maintained (old) electric appliances and wiring	Low: well maintained connections Medium: long loose electric leads, poorly maintained High: visible open leads, loose connections
Drowning	Surface water near circulation or play areas and poor lighting, poor view, poor control	Low: no surface water, good view on children at play Medium: surface water nearby, poor view on children at play High: deep pond in private garden, poor view on children at play
Trespassing	Open doors or windows, lack of control, no alarm	Low: inlet openings well protected against burglary Medium: use of large inlet openings when at home High: poor locks and hinges, easy access while ventilating
Possible consequences of exposure	Low exposure: risk score 2 Medium exposure: risk and potential serious effects if in poor condition, risk score 4 High exposure: high risk and potential serious health effects, risk score 8	

Table 7.21 Indicators of privacy and care when in need of help and possible consequences of exposure

	Likelihood	Exposure risk
Privacy		
Access to outdoor (semi-)private space	No area for (semi-)private outdoor activities	No outdoor area for relaxation and socialising or for children to play
Care when in need of help		
Access with aids (when mobility impaired)	Limited space for use or parking of electric cart, for wheelchair and rollator	Barriers that limit the use of mobility aids
Emergency help	Visual contact, SOS-functions, both technological and in personal attention	Services for care and social interaction for those in need of contact and help
Possible consequences of exposure	Low exposure: risk score 1 Medium exposure: risk and potential serious effects if in poor condition, risk score 2 High exposure: high risk and potential serious health effects, risk score 4	

environmental conditions, except in rare occasions when feelings of unsafety or isolation were reported and when the semi public area was not suitable for use, being too small or not 'inviting' to be used. The second parameter is care when in need of help, with a broad interpretation: sustaining quality for a stretcher and a wheelchair, exchange of care for children at play, vigilance to improve security, contact to see how elderly are doing, if someone being sick needs help etc. Of special importance is the emergency warning when someone falls or is otherwise in problems: can a warning be exchanged, is emergency visit possible and how long will it take for someone to interact? We select privacy of the outdoor environment and care when in need of help as parameters of social quality.

The model of social quality
Table 7.21 shows indicators of (outdoor) privacy, of access with aids and of emergency help.

7.5 Conclusions

7.5.1 Conclusions of Chapter 7

The research question was: *Which indicators mark the relationship between housing, occupancy and health hazards?* The study on parameters that influence the concentration of agents and the likelihood of hazard conditions results in indicators of exposure risk to mould, house dust-mite allergen, aerosols and legionella and the physical conditions noise, comfort and safety. The potential concentration is compared with three exposure levels, equal to three relative risk scores. This score is a qualitative description of the exposure risk. In these models the scores have the weight 2, 4 and 8, except in models, where the risk is considered lower, with scores 1, 2 and 4. The descripion of the three levels is according to the weight, but the home inspector will have to make a personal judgment, relating the exposure risk to knowledge about agents or conditions and the potential health effect.

The indicators are rephrased, so they can be used as individual inspection items in performance evaluation protocols.

The set of indicators resulting from Chapter 7:

Mould

1. Visible mould at any location in the house that emits aerosols into the living room and bedrooms or other places with relatively long exposure periods.
2. Hidden mould from cavities, caused by leakage or condensation and identified on the basis of smell, and when exposed to aerosols from live and dead mould material.

The relationship between dampness, bacteria, mould and other emissions is not clear. Following the precautionary principle, we consider dampness to be a proxy indicator and add to the list:

3. Dampness in the bedroom because of three or more people sleeping in the room or two or more people and low capacity of permanent ventilation with fresh outdoor air.
4. Dampness in the living room, indicates by long periods of foggy windows or condensation under carpets, or because of capillary moisture or high emission from a damp crawl space (wooden floors) in combination with low capacity of permanent ventilation with fresh outdoor air.

For hidden mould, the following proxy indicators support the risk evaluation:

5. Mechanical ventilation system older than 5 years without maintenance and no fresh air inlet.
6. Moisture under carpets or behind cupboards on cold surfaces (surface temperature 5°C lower than indoor temperatures plus outdoor condition below 6°C average over 24 hours).
7. More than 3 showers/day or more than 2 showers/day plus wet laundry on a rack in the bathroom.
8. Open connection to the crawl space plus poor ventilation of the space above the crawl space.

House dust mite allergen

1. Mattresses older than 5 years (or older than 8 years with mite protective covers).
2. Thick carpets or rugs on cool floors, flooring older than three years;
3. Dampness in the house.
4. Peak concentration during vacume cleaning.

Legionella

1. Stagnant buffer of hot water lower than 55°C in the lower part of the buffer

for more than 3 days, with exposure to risk in bathrooms during or after using a showerhead.
2. Showering not in own individual house, in combination with buffer system with parts below 55°C.

Chemical agents
1. Activites involving TVOC: painting, cleaning with solvents.
2. Large surfaces or close contact with small surfaces of soft plastics with (certain) plasticizers.
3. Any room with high indoor temperatures in combination with poor ventilation.
4. Exposure to outdoor air near heavy traffic or industry with exhaust of SO_2, NO_x, Ozone.
5. Indoor exposure to fuel burning exhaust gas or smoke.
6. Appliances with flame retardents (bromium, chromium), lead water pipes, lead containing paint.
7. Ventilation volume and efficiency, low and efficient in removing airborne particles and gases.
8. Cleaning efficiency, to remove grease and pollutant containing dust.

Aerosols
1. Radon exposure in stone based houses in combination with low ventilation rate (larger opening that minimum requirement permanently open).
2. Tobacco smoking indoors in the presence of non-smokers.
3. Pets with hairs or feathers, cockroaches and mice in the house with someone allergic to dust.
4. Cleanliness of filters and ducts in inlet air systems and of surfaces including bed, sofas etc.
5. Outdoor aerosol concentration level, given that 60-98% of PM2.5 enters the house.
6. Abrasion of materials (concrete, fibres), burning in wood stove or fireplace, baking and temporary release of aerosols from inlet ducts after turbulence, vibrations, changes in air velocity.

The following indicators cover more hazards and are mentioned under different headings:

7. Ventilation volume and efficiency, to remove airborne particles and gases.
8. Cleaning efficiency, to remove grease and pollutant containing dust.
9. Indoor particle production created by mould and house dust mites.
10. Re-entrainment of deposited particles in indoor air, caused by moving around, vacuum cleaning, turbulence of air created by doors, fanned inlets, wind pressure differences.

Noise

1. In area with heavy traffic or other noise producing activities (industry, planes, trains).
2. Noise from indispensable services, not controllable and producing a high level during quiet periods.
3. High noise level despite requests for turning down the level.
4. Noise that is perceived as unacceptable by the occupant, for any reason.

Comfort

1. Extreme high temperatures during more than 10 days a year, or more than 4-5 days in a row.
2. No direct view of the sky or artificial lighting only, in occupied spaces (except bedroom).

Safety

1. Risk of falling because of uneven levels, slippery floors, poor lighting, no bars.
2. Risk of burning or scalding because of hot surfaces in circulation area or hot water from taps.
3. Risk of electric shock from open electrical leads (or from exposure of children to wall sockets).
4. Risk of drowning with a pond in the garden or near the house and poor control over children at play.
5. Poor burglar safety, both by technical means and by social control in areas with risk of trespassing.

7.5.2 Conclusions of Part B

Part B: Practice, presents field data and shows the practical orientation of the research: dealing with complaints, health hazards, physical aspects. The scale is the house and individual rooms and specific features such as ventilation systems, domestic hot water, the sealing of the floor over a crawl space, etc. The observations of occupants behaviour has resulted in better understanding of occupants' reaction to comfort and to the control of ventilation and heating etc.. This understanding leads to lending occupants a key position in healthy housing: to provide good control over the building and to support adaptive behaviour. The most crucial function for healthy housing is ventilation: with poor ventilation the exposure risk of biological and chemical emissions is higher than necessary. In the occupancy pattern of houses, the priority is to check how ventilation services work and how occupants can use them, next comes the focus on polluting agents and hazardous conditions. Chapter 6 on physical housing conditions shows how much the research is situated in the discipline of building technology. Expert knowledge developed in the field and resulted in insight in relationships that facilitate risk identification, for instance in the section on building physiology, moisture balance and analysis of ventilation systems. For noise and discomfort the perceptions of the occupants are relevant. Noise and comfort have great influence on behaviour. The parameter study of Chapter 7 results in prioritization of indicators on the bases of qualitative risk scores. For the parameters of indoor air quality much field data was available and this parameter study resulted in some new indicators, with a certain degree of validation. Data on aerosols and legionella cover only few aspects, but new insights were used to select indicators.

Part C
Synthesis

8 Results

8.1 Introduction

8.1.1 Introduction to Part C

After Part A on Theory and Part B on Practice, this third part contains a synthesis of theory and practice. Synthesis is the integrative conceptualisation of separate results. Integrative conceptualisation enters the field from different viewpoints: health performance in each room of the house, the final set of indicators and recommendations for different actors involved in housing. This part on synthesis gives the results of the research project. During the research the discussions with other researchers and consultants have revealed what is conceived as important, what is understood or not recognised. In this sense, synthesis is also the result of 'fieldwork': communication about preliminary results.

All research questions are revisited, to review what has been accomplished and to answer to the research questions. The theoretical framework is reconsidered in Chapter 9: does the framework support the research, does it support the quality of tool design? What is the resulting set of indicators, and how relevant or reliable is the selection? The final Chapter 10 gives a short conclusion and also recommendations for different actors in the field of housing: housing managers and housing associations, occupants, the central and local government, environmental and medical consultants and researchers.

8.1.2 Introduction to Chapter 8

Chapter 8 reviews the results per research question and gives an integrative description of the health performance of the living room, the bedroom, kitchen, bathroom, circulation and storage areas. However, it is the bedroom that receives the most attention. Per research question the following results are presented:

1. What is the state-of-the-art knowledge about housing and health?
   The research does not contribute to new scientific knowledge on housing and health, because health effects were not studied. The latest developments since the start of the research, based on the AFSSET conference on environmental epidemiology and exposure, in September 2006, is reviewed.
2. How can we evaluate housing health performance?
   The Healthy Housing Checklist is interwoven with the research but is not part of the thesis. The design and implementation is evaluated, to see what the experience adds to indicators and strategy of performance evaluation.
3. How do occupants use the house?
   The study of occupancy is a first exploration into this field, but contributes to insights in the conflict between occupant capacities and perceptions and the technical services in the house.

4. Which physical housing conditions are associated with health?
   Some new information is added to the knowledge about the effect of housing conditions on emissions and hazards. Certain hazard conditions are very widespread: increased pollutant concentration because of low ventilation efficiency, dampness and related problems of mould and house dust-mite, noise and fine dust.
5. Which indicators mark the health hazards of housing?
   A new list of indicators is presented in Chapter 8.

Table 1.4 highlights the position of this chapter.

8.2 Results for each research question

8.2.1 What is the state-of-the-art knowledge about housing and health?

The relation between housing and health is complex. Much data on health from occupational environments is transformed and applied in the home environment. In Chapter 3 the major known exposure values were linked to potential health effects. Other chapters do not deal with health, but focus on the housing conditions and occupancy patterns and behaviour that cause increased health risk: increase of the concentration of and exposure to those agents or to those conditions that are linked to health, according to Chapter 3. The research contributes to understanding of complaints and housing needs. A qualitative risk ranking on a 4-point-scale is applied, to serve priority-setting. By promoting the role of communication, the problem of risk ranking is put on the table of the negotiating parties, who can act according to their understanding of the risk level.

There is much scientific information on the relation between the environment and health in general and housing and health in particular. On the International Conference on Environment, Epidemiology and Exposure (AFSSET 2006) the state-of-the-art knowledge was presented. The latest findings on asthma point at the potential role of chemicals and especially plasticizers in surfacing materials and many consumer goods. New attention is to the potential role of bacteria in connection with mould as a trigger for respiratory effects. House dust mite is a major marker and the focus is more on the study of remediation than on sensitisation. Many remediation measure have a minor effect, even when concentrations are effectively reduced in specific items of consideration. Either the exposure sources are abundant or the bodily responses are selective, so reduction of allergen concentration is not in proportion with reduction in health effect.

In general, chemical exposures supposedly play an important role in the development of children, of which only very few is understood. Obesity, ADHD and many birth defects receive attention. Many researchers focus on formaldehyde, ozone, PAHs, plasticizers, heavy metals, lead and pesticides. Fine dust is the dominant topic nowadays and the evidence on the relationship with pulmonary disease, cardiac disease is well established, and the relationship with cancer is suspected. The chemical content of dust and also the size distribution from ultrafine to coarse particles seems very important. Traffic exhaust fumes is of great concern, but also airborne dust that travels over hundreds of kilometres, from waste belts, polluted areas or from chimney stacks with trace metals such as zinc and cadmium. Flame retardents in domestic appliances are of concern. Nowadays the use of pesticides in households is much larger than in agriculture and the concentration can be very high even after cleaning the house, with potential serious effects on the development of children and the condition of adults. Lead has been banned effectively, but still with potential exposure from polluted soil and dust in the house (AFSSET 2006).

The research project does not contribute to new knowledge on the relation between housing and health, because this is not an epidemiological research. Health complaints have resulted in inspected cases and the self reported health condition has pointed at certain performances in houses, but this type of information has no scientific value for strengthening the insight in the relation between housing and health. Insight was used to diagnose housing problems that are related to certain health effects, not to study the direct dose-effect response.

The role of indicators

Indicators simplify inspection, because they point more precisely at the parameters that create hazards. Indicators used for the Healthy Housing Checklist support a process of self-learning, and feedback shows that applying the Checklist stimulates change in behaviour to correct the worst conflicts with healthy performance. The set of indicators integrates occupancy and occupant behaviour and this choice for involving occupancy leads to a change in the state-of-the-art indicators in the Netherlands.

The impact of the research on awareness of health related performance of housing

Public discussion has contributed to sharper formulation of problems with poor ventilation, of user problems with heat recovery ventilation systems, of the poor quality of the bedroom environment and of different approaches to mould problems in the bathroom. Both the user unfriendliness of ventilation systems and the noise level of mechanical systems have received attention. The slogan ‘ventilate natural as long as possible and mechanical as soon as necessary’, presented for the first time in 1999, was adapted by others as useful ventilation strategy. A neglected topic in public debate is the legionella risk in individual systems with the need for better control of buffer temperatures. The radon issue is recognised by a few, but neglected in the field of housing design and maintenance. The feedback by product developers show that health performance has impact on products and processes, but market conditions pose a restriction on health oriented innovations. Health performance evaluation hardly was adopted in housing policy and it will take many years before a health performance label becomes reality. At turnover of houses, more opportunities could be used to find a good match between health related housing needs and performance. In order to promote matching, information about the performance of a large number of houses is required.

8.2.2 How can we evaluate housing health performance?

Chapter 6 deals in a prominent way with this research question.

Three decisions have contributed to better insight into the relationship between housing and health: the first decision was to make a distinction between the empty dwelling and occupancy. This decision makes it possible to discuss occupant behaviour as distinct from the quality of the building. The second decision was to see the house as a system of microclimates and to evaluate each room as a separate system. It highlighted the bedroom as a place of concern, a result that differs from the mainstream discourse about comfort in the living room and mould problems in the bathroom. The third decision is to focus on communication between the housing manager and the occupant. This decision is the consequence of dealing with occupant behaviour. Cooperation on risk reduction of the major hazardous environmental conditions that are a shared responsibility of the home owner (to improve the technical quality) and the occupant (to adapt behaviour to requirements of healthy housing) is essential for action taking. Communication serves the goal of creating awareness of the health performance problems, which is considered essential in change of behaviour and pro-activity to prevent problems. This is a moral choice that has great impact on the design strategy of tools for performance evaluation. The steps in the protocol of evaluation are:

1. occupant or home owner: identify problems, using a checklist;
2. owner and tenant: learn about health risk by using the tool, discuss and take action;
3. home owner: provide the means (money, capacity, planning) to solve the problems;
4. home owner: make a relation between technical remediation and adaptation of behaviour.

The last point refers to the multiplier effect of action: if the house is improved, the occupants adapt their behaviour, and vice versa. Involvement, learning to take control and change in physical conditions are believed to contribute to a better perception of health (see Figure 2.5).

The need for problem identification is well-recognised by housing associations and occupants, but conflicts of interest lead to eagerness to jump to conclusions (even if wrong), while in some situations the lack of knowledge leads to the wrong diagnosis. In many housing associations, the 'front office' deals with complaints, while the 'back office' must solve the problems. The link between the front- and back offices influences the link between problem identification and problem solving and the relation may not be strong enough (Gruis, 2005). For a number of institutional home owners, environmental problems and especially indoor air problems are primarily the responsibility of the occupants. One housing manager reported: "When we appear in court because of serious complaints about dampness and mould, our solicitor is told to blame it on poor ventilation behaviour, disregarding other conditions" (interview with head of technical department, 2004).

The main model of relations has contributed to a better balance in the attention given to different topics in performance evaluation.

The strategy of performance evaluation, the list of indicators and the Healthy Housing Checklist show how we can evaluate housing health performance and answer the research question.

8.2.3 How do occupants use the house?

Chapter 5 presents the results of explorations into the field of occupant behaviour.

Not many occupants perceive housing health risks, even when exposed to these risks; an example is smoking in the house. A smoker complaining about dampness or traffic exhaust presents a dilemma for the housing manager. The fact that occupants are not fully aware of the hazards involved is not only an individual responsibility, but also a collective issue that demands for strategies to improve awareness and control over risk. Some groups are aware of risks but have no means to control them. Self-help performance evaluation can create awareness of relevant risks and how to deal with them. Because perception can make a person ill, learning via self-help evaluation protocols is a way to change perception: this process is part of adaptation and personal healing and can lead to change of behaviour. Awareness of many kinds of environmental problems is created by the senses: smell, hearing, feeling, observation. Conditions that create health risk while senses do not give a warning signal must be identified on the basis of indicators. This result leads to simplification of certain indicators: e.g. focusing on visible mould, not on a risk that mould could grow; or: a given noise level is a hazard not on the basis of measured dB(A), but because occupants are aware of stress caused by noise, etc. Comfort problems receive attention for similar reasons: because

Table 8.1 Dilemmas between immediate comfort and long-term health

Dilemmas	Comfort *actual use, influenced by the senses, immediate effect wanted*	Health *rational use, awareness of long-term effect, adaptation*
Inlet closed or draught	sealing envelope, low inlet volume	permanent inlet flow
Low setpoint or noise of fan	no noise: system low or off	>6 hours/day standard volume
Fine setpoints or large interventions	no attention, alarmed by smell	permanent basic ventilation
Noise or better air quality	sealing against traffic noise	ventilation when away + control
Night-time flushing or overheating	flushing not feasible, trespassing	bars and locks to allow flushing
Open window or risk of burglary	no provisions, windows closed	bars and locks to allow ventilation
Soft flooring or smooth cold flooring	soft and warm carpet with mites	smooth and clean surface
Laundry drying outside or indoors	drying indoors is safe and easy	drying outdoors or exhaust dryer
Removal of mould or filing complaint	do nothing	clean and file a complaint
Safety precautions or taking chances	risk is part of everyday life	risk prevention behaviour/action

the occupant perceives discomfort or even stress. Problems that occupants sense require a good diagnosis before action is taken.

Occupant behaviour expresses the identity of different types of households, different steps in the housing career, culture, condition and comfort needs. Comfort has great influence on behaviour: comfort optimising is an important motivation for ventilation, heating, cleaning habits, etc. Comfort optimising can conflict with healthy housing, for instance when fear of draughts limit the use of air inlet openings. Table 8.1 presents some dilemmas between immediate comfort and long-term health that are mentioned in previous chapters. These dilemmas reveal conflicts with the user interface of technical services. Because it is hard to influence behaviour, the user-friendliness of building services is the key to solving these dilemmas.

Occupancy-related hazards deal with pollutant production, lack of ventilation, and poor control over the physical and social environment. Occupant-related pollution sources are:

- the use of gas ovens (or other fuels that emit into indoor environment);
- chemical emissions from decoration materials;
- emissions from cleaning materials, pesticides, fragrances, candles, etc.;
- biological emissions, based on the age of the mattress, the type and humidity and cleanliness of surface (flooring) materials and other dust pockets and soft decorations;
- excessive moisture production without activities to remove moisture;
- leaving visible mould as it is;
- pet keeping (animals with hairs or feathers);
- smoking in the house with other people present.

Occupancy rate points at a multitude of emissions and reduced air volume per person. Long exposure periods, special activities and individual health condition or medication result in priority setting of indicators (risk weight) that is specific for the occupant involved.

The chapter on occupancy and occupant behaviour provides results that support the main model of the relationship between performance, occupancy and health hazards: the model shows how to deal with occupants. The research question leads to the strategy to support proactive behaviour as a means of taking control over health risks.

8.2.4 Which physical housing conditions are associated with health?

Health hazards give structure to Chapter 6 on physical housing conditions. The main physical properties related to air pollution are: emissions from crawl spaces, condensation and mould incidence, moisture and house dust mites, emissions from fuel-burning appliances, emissions from construction materials and ventilation services and the physical hazards caused by noise, extreme discomfort and personal injury. The building location, the construction, openings in the envelope and the technical services have a strong relationship with both technical and social noise and exposure to ambient air pollution. Many complaints point at physical conditions: discomfort is caused by extreme temperature differences, draughts, extreme low or high humidity, lack of daylight and lack of contact with the ambient environment. Some building parameters influence the perception of the social quality: trespassing, social control and privacy of outdoor space.

Construction methods and materials have developed step by step, and information about the building period indicates specific materials and construction details that, when recognised, make the identification of hazards easier. Of special interest is housing from the period 1960-1980 that is now under reconstruction and being renovated. In this building period, many small multifamily houses were created that do not meet the increased thermal and acoustic insulation standards any more. The poor sealing and thermal performance of the ground floor and inherent emissions from the crawl space still apply to a large number of houses. Condensation and mould occurrence is a major concern and is related to insulation quality.

Vapour transport from the wet bathroom or the living/kitchen requires optimal bedroom ventilation, which is a major problem: many occupants do not ventilate enough, the ventilation capacity is too low for two or more people. Natural ventilation, including cross-ventilation, is an indispensable feature in older houses. Infiltration supplements the ventilation and prevents different kinds of indoor air problems, especially in the living room. Problems occur in airtight houses with insufficient ventilation capacity.

The chimney-tied atmospheric central heat sources in the living room and flueless domestic water heaters create serious health hazards. Emissions from construction materials are likely to be low, due to strict source control requirements in building regulations except for radon. The emissions from occupancy-related materials are high, mainly during and shortly after application (decoration, renovation, cleaning). The acoustic quality represents a complex phenomenon, technical solutions are often possible, but are expensive and the contribution to solving complaints is low. Extreme humidity levels are not a comfort or health issue and 'dry air' is often a misperception of polluted air in combination with emission peaks caused by high temperatures. Daylight and view are hardly a health issue in the housing stock, but they influence satisfaction with the house.

Safety is an important topic for the elderly. Except for stress, we know little of the health effects of privacy and trespassing.

The research topic has provided many results that can be applied in remediation and renovation practice and in evaluation tools.

8.2.5 Which indicators mark the health hazards of housing?

The criteria for selection of indicators are summarised in one quality: robustness. Robust means: focused, in line, easy to use, easy to evaluate, resulting in better insight into the major health risks. Three versions of the list of indicators are presented in this study:

- the list representing the state-of-the-art in 2005 in the Netherlands is the starting point and was completed to add social qualities (see Section 3.3);
- the indicators used in the Healthy Housing Checklist (see www.toetslijstgezondwonen.nl);
- a final list (see Section 8.5), which can be used in new tools for health performance evaluation.

Performance evaluation focuses on exposure risk. Many exposure situations in houses are standard and do not need evaluation. Indicators of sources and (safety) conditions are important.

The 10 major health risk sources and conditions are:

1. fine particles from outdoors and from indoor sources, such as from smoking, frying, the fireplace;
2. house dust mites, depending on moisture balance, age of mattresses or cleanliness of pet areas;
3. ergonomic quality being the cause of falls from slips and trips, burning, scalding, cutting;
4. the overall air quality in all individual rooms occupied for several hours per day with poor ventilation, typically below 4 l/s per person;
5. visible mould on surfaces, from biodegradable waste disposal and poor construction details;
6. legionella from stagnant water buffers <55°C;
7. radon in concrete-based buildings and houses with a low effective air change rate;

8. Technical and social noise that cannot be controlled and causes stress and, for instance, poor use of ventilation appliances;
9. TVOC during and days after application, including emissions from a geyser or wood-burning stove;
10. all other conditions that can be very specific for housing conditions and likely to cause stress, for instance lack of control of the indoor climate, trespassing or burglary, lack of privacy, perception of non-specific air pollution, poor access and circulation when physically handicapped.

Each room has a separate microclimate and requires specific control functions. Central functions are in some ways in conflict with the functional needs in specific room. In older houses, the individual control of rooms is often facilitated by local heaters and handcontrolled inlet openings; in modern houses, central inlet and exhaust via balanced-flow ventilation is in conflict with individual ventilation needs in each room. The behaviour and the needs of occupants are different for winter and summer conditions, for day or night, for periods alone or with guests, for healthy periods and periods of illness and disability. By looking at individual rooms and their occupants, it is easier to understand complaints and conflicts between occupant needs and the housing conditions. The bedroom is a critical place in many houses. Some households desire large closed kitchens. The answer to this question shows that a variety of ventilation services, flexibility, more space than functionally required and good means of control to adapt to many different conditions are needed.

8.3 Selected indicators

8.3.1 Indicators per room

The living room must be evaluated for occupants with specific needs. For the elderly, or a person being sick and in bed the exposure period is long. The positive health potential comes from active daily use, with heating, permanent ventilation, sunshine entering through large windows, cross-ventilation, regular cleaning.

The indicators of the kitchen are the type of kitchen (closed large >10 m², closed small 6-10 m², semi-open, open), the cooker system (electrical, gas plus electrical oven, gas incl. gas oven) and cooking hours per week and also the condensation on windows during/after cooking.

Many bedrooms are full of allergen material. Despite little data available for validation, the age of the mattress is supposedly an important indicator of the allergen concentration. The resulting indicators of allergen concentration are: the number of people sleeping in bedrooms and the number of occupants compared to number of rooms. Indicators that support the analysis of growth conditions and concentration of allergenic dust are: the use of mite-protective covers, the type of mattress: springs/pockets, foam or water bed, and ventilation of the mattress and covers. Dust removal by cleaning and ventilation during sleep reduce allergen concentrations. The circulation of air depends highly on cross-ventilation. With poor ventilation, all kinds of pollutants will build up and the exposure to allergen-containing dust will increase.

The indicators of the bathroom are its location (enclosed, façade with window, in bedroom) and the number of showers and other moisture production: laundry drying, wet towels, leakage. The surface materials of walls above tiles and on ceilings influence mould exposure. Slippery surfaces and the temperature of hot water influence safety hazards, including legionella risk (temperature and size of hot water buffer).

The indicators of circulation areas point at safety conditions: type of steps on stairs, available handles and railings, obstacles and lighting, smoothness of floors.

8.3.2 Indicators of agents and conditions

Indicators of ventilation quality (see also Table 8.2)
Ventilation involves technical features and use by occupants. The required ventilation volume for a healthy indoor climate depends in the first place on the number of occupants in each room, not only because of the bioeffluents, but (maybe more important) because of a multitude of other emissions related to clothing, washing, cooking, pets, smoking, etc. The second variable is the emission from all sources in the house not directly related to occupants: construction and surface materials, including emissions from shafts, the crawl space, furniture and decorations. The required ventilation volume during pollution peaks is often higher than can be established, meaning that high pollution peaks will occur. The smallest capacity of the chain inlet-overflow-exhaust determines the ventilation level. The performance does not differ much between ventilation systems, but the parameters that influence the performance differ. The 'natural performance' includes infiltration, including the stack effect of a stairwell in combination with exhaust openings (chinks, window, open chimney-tied heater) at a high point in the stack. In many houses with mechanical ventilation the infiltration contributes much to the total air change rate. Modern houses are more air tight and require inlet and exhaust functions with user friendly control functions and a secure positioning in the room and here is where problems start. These ventilation problems are more evident in airtight buildings with heat recovery ventilation, because these systems depend most on performance and user friendliness. Complaints of occupants are related to the quality of services during a variety of conditions: in the summer and winter, at day and at night. Cross-venti-

Table 8.2 Indicators of ventilation quality, depending on capacity and user friendliness

Ventilation		Capacity	User friendliness	Indicators of ventilation quality
Inlet	Line grate	Cleanliness, dimensions	Ambient noise, more than one inlet opening in each room	Simultaneous use of more inlet services, capacity and period of use
	Sash, large window	Dimensions and location	Ambient noise, draught, setpoints in (almost) closed position, burglarproofing open position	Period of use, size of opening
	Mechanical inlet	Maintenance, volume per room	Fan noise, draught, setpoints, peak volume, fan noise	Capacity and user period of (high) setpoint
Circulation and overflow	Obstacles	Temperature, overflow	Position of large pieces of furniture	Compensation with extra inlet
	Via door to other area	Chink under door >1 cm, door ajar, sash window or grate in wall	Open door in conflict with privacy	Chinks under and around the door, period of open position
	Flow across	Dimensions of chain of openings	Ambient noise, draught, opening under doors and in next façade	Increase size of smallest opening(s)
Exhaust	Mechanical exhaust	Maintenance, volume	Fan noise, peak volume, control in bathroom	User period of high setpoint
	Stack effect stairwell	Size, opening in roof, obstructions	Control	Allowing air to move into stairwell and out at the top of the stack
	Natural capacity of duct	Maintenance, dimensions, length and roughness	Backward flow in bathroom, peak and volume control	Capacity of inlet, selection of opening against wind direction
Infiltration	Location of chinks	Construction quality, type of house (height)	Control during windy weather, risk of draught	weather condition dependent
Flushing	Window, door	Dimensions	Rain protection, burglarproofing	Period and moment of use

Score	Physical quality of the ventilation services	Overall ventilation quality, including use of services
(NB. low is poor quality, high is good quality)	Low: services not working properly or not user friendly, low contribution of infiltration or stack effect, barrier in the sequence inlet-overflow-exhaust Medium: limited capacity when not at home or in certain rooms High: controllable air change rate per room without restraint in use and as much as needed	Low: no services available or not permanently used and in combination with low infiltration rates Medium: only proper ventilation when at home, poor circulation quality, not all levels can be controlled per room High: permanent basic level per room, increased level during occupancy per room and extra during peak pollution periods, good circulation

lation is also in modern houses an important function. For better understanding of complaints about indoor conditions it is relevant to include the evaluation of ‘natural’ functions. In airtight rooms (primarily bedrooms with one façade opening and also closed-in bathrooms) the combination of (large) inlet and exhaust openings is essential for reaching sufficient ventilation volume. The location and user-friendly control of openings for flushing are essential in rooms with peak type pollution levels, primarily the kitchen and bathroom. Because an enclosed bathroom cannot be flushed, permanent ventilation with indoor air is required to reduce the effect of moisture on other rooms. In bedrooms constant ventilation with outside fresh air remove more moisture and pollutants than with indoor air.

The robust indicator of ventilation is the quality of services in each individual room in relation to the specific pollution sources in this room and in combination with occupant exposure period. Permanent basic inlet of fresh air in each room is essential. Closed inlets while asleep indicate insufficient ventilation.

Indicators of exposure to mould (see also Table 8.3)
There is evidence of the relationship between dampness, mould and health, but it is not possible to identify the specific hazard conditions. Therefore the precautionary principle is applied: mould is avoided. When mould grows somewhere, mould material is everywhere in the house and with concentration peaks when moving around, during windy periods or cleaning). Viable mould and dead mould material may have similar health effect, however, growing and potential spore forming presents relatively higher concentration and exposure levels.

Indicators are visible mould at any location in the house that causes aerosols to diffuse into places where occupants are exposed. Indicators also point out hidden mould aerosols from cavities likely to be wet from leakage, from condensation (in the winter, but certainly also in the summer, for instance in the crawl space) and vapour transport in combination with mouldy smell and air leakage from these cavities in windy weather. Visible mould can be wiped off and then the risk is under control. Ventilation reduces the concentration of mould aerosols produced indoors, but to which degree is unknown. By improving the airtightness of cavities (including crawl space) in which mould can grow, the emission is lower, but to an unknown level.

Despite the lack of clear evidence two robust indicators are proposed: visible mould and prediction of hidden mould, based on suspected environmental conditions in closed (but leaky) cavities.

Indicators of exposure to house dust mites (see also Table 8.3)
It is not clear which concentration causes sensitivity to allergen or asthma attacks or respiratory problems, but levels starting at 2 µg/g dust are in the 'danger' zone. This danger zone is easily achieved in the warm and humid Dutch houses and especially in bedrooms. Of the population with allergy problems (range of 10% of adults and 20% of children) 70% are allergic to house dust mite allergen, and this means that in one of every four to five houses the allergen concentration is likely to cause health effects. The relationship between house dust mites and allergy problems is well-established.

Table 8.3 Indicators of mould and house dust mite allergen and possible consequences of exposure

Mould	**Indicators of peaks in concentration**	**Indicators of exposure risk**
Visible mould	Mould surface area, viability (=spore forming) and release of dry material	Low: with mould any place in the house Medium: large surface any place elsewhere in the house or short exposure period in space with visible mould High: peak exposure in space with visible mould or long period of exposure in house with large area(s) of mould
Invisible mould	Cavities in construction, water leakage and pressure differences (wind) over cavities, mouldy smell via chinks	Low: mouldy smell any place in the house Medium: mouldy smell any place during strong wind or short period of exposure in space with mouldy smell High: in area with source of mouldy smell or long period of exposure in house with hidden mould
Possible consequences of exposure	Low exposure risk: considered harmful to people in a weak state of health, risk value 1 Medium exposure risk: potential harm to every person, especially children or in a weak state of health, risk value 2 High exposure risk: considered harmful to every person, risk value 4	
House dust mite allergen	**Indicators of peaks in the concentration**	**Indicators of exposure risk**
Mattress (>5 years)	Sleeping on an old mattress	Low: sleeping on a new mattress Medium: sleeping on a mattress between 3 and 5 years old High: sleeping on an old mattress (>5 years, or >8 years with mite cover)
Soft, damp or old flooring or soft old furniture	Strong disturbance of dusty floors or soft dusty furniture	Low: moving around on dusty floors, furniture, or vacuum cleaning somewhere in the house Medium: present in room while dusting or moving around on material with accumulated dust, short exposure period High: present during vacuum cleaning, or people moving around on carpet, old sofas with high allergen content
Possible consequences of exposure	Low exposure risk: considered harmful to people with allergy to house dust, risk score 2 Medium exposure risk: harm to people with respiratory problems, potential harm especially for children and people in a weak state of health, risk score 4 High exposure risk: harmful to asthmatics, irritation for people with respiratory problems, potential sensitisation of every person; risk score 8	

The mattress is the major source. A mite cover can slow down the emission rate, but the mattress will still become a source. Secondary sources are: soft flooring, soft furniture, pet sleeping areas, closets. The emission depends on growth conditions and accumulation of allergen material: local humidity level in the winter, abundance of food (number of humans, pets). Accumulation occurs, meaning that mattress, flooring, bedding material of pets are filled with a high concentration after a period of a few years. Emission depends on aerosol formation, caused by disturbance of the source, which means that locations where people or pets move around are important: bed, sofa, flooring material. Aerosols deposit and can be (partly) removed by cleaning (washing, vacuuming) or by replacing the mattresses, carpets and sofas. Airborne aerosols can be ventilated away. The effect of cleaning and ventilation is evident, but evidence on the effect on respiratory problems is not clear. The bed is the major exposure location.

A proxy indicator refers to occupancy load and indirectly to dampness: three or more people sleeping in a bedroom and an average of one or more people in each room.

A mattress is probably full with allergen material when older than five years, or older than 8 years with mite covers around the mattress. Already at the age of a few months the allergen concentration can be relatively high, but after some years (especially summer periods) in the Dutch maritime climate, the level is almost certain very high. The type of material of the mattress and the bedroom climate makes a difference in the accumulation process, but this is not decisive in exposure to allergen.

Exposure to pet and pest allergen (see also Table 8.4)
The relationship between pet allergen and health effects is well-established. Pet allergen stays airborne for a long time. The sources are a cat or dog or birds, but also mice and insects such as cockroaches. Exposure is anywhere in the house.

The robust indicator is the presence of a cat or dog, or of (many) mice and cockroaches.

Indicators of exposure to other aerosols (see also Table 8.4)
The health impact of PM2.5 is strong enough to follow the precautionary principle. Indicators of PM2.5 are related to traffic and industry outdoors and abrasion of materials (concrete, asbestos, other fibres) tobacco smoke and burning of fossil fuels, baking, radon nuclides and radiation from within materials indoors. This means that aerosols are present in every house. The concentrations and the exposures differ. Peak concentrations are often related to normal use of the house: cooking, cleaning, maintenance like painting, moving around and even sleeping.

Robust indicators are the outdoor concentration of PM2.5, indoor materials with radon emission (concrete, natural stone) and indoor activities (tobacco smoking, decorating, cleaning).

Indicators of potential exposure to legionella (see also Table 8.5)
The indicators are selected on the basis of growth conditions, using evidence that in 5-15% of houses these bacteria are present. We do not know when health threatening species develop. The precautionary principle applies. Emission is via aerosol formation, generally in the shower, but also potentially from taps, a fountain, from the tropical aquarium.

Indicators are: stagnant buffer of hot water lower than 55°C in the low-

Table 8.4 Indicators of aerosols and possible consequences of exposure

Aerosols	Indicators of peaks in concentration	Indicators of exposure risk
Outdoor PM2.5 (traffic, industry)	Traffic jams, wind direction, humidity (rain)	Low: large distance, low intensity Medium: urban level High: within 300 m of busy traffic and in urban area
Radon	Ventilation rate, type and amount of stone, concrete	Low: wood-based construction, air change rate >0,7 Medium: stone/concrete structure and high constant air change rate High: concrete structure, low air change rate
Tobacco smoke	Number of cigarettes smoked indoors	Low: incidental smoking Medium: up to 3-5 cigarettes per day High: more than 5 cigarettes per day in room in presence of others
Bio-aerosols: pets (see also mould)	Pet size and number, cleanliness and locations of resting area indoors	Low: contact with others who have pets Medium: pet exclusively outdoors and minor contact High: pet inside the house
Possible consequences of exposure to aerosols	Low exposure: short periods of irritation for people with respiratory problems, risk score 1 Medium exposure: periods of irritation for people with respiratory problems, potential harm over a long period for children and people in a weak state of health, risk score 2 High exposure: increased irritation for people with respiratory problems, potential serious health effects over a long period (reproduction, lung cancer), risk score 4	
Possible consequences of radon exposure	Low exposure: no threshold level, potential harm after a long time period, risk score 2 Medium: some increased risk of lung cancer, small chance but high stakes: risk score 4 High: increased serious health risk, compared to effect of active smoking: risk score 8	

er part of the buffer for more than three days, with exposure to risk in the bathroom during or after using a showerhead. Stagnancy means that regular flushing reduces the risk. The source indicator is dominant: buffer type, water temperature and stagnant periods. Taking a shower after having been away for a few days creates a major hazard situation.

Indicators of exposure to chemical air pollution (see also Table 8.5)
Several chemicals have health effects, but of many chemicals the effects are unknown. The precautionary principle applies in general. Outdoor sources and sources in adjacent spaces can be important, when the house is located above or next to a garage, a dry cleaners shop, a print shop or a restaurant kitchen.

Indoor sources are likely to show higher concentrations including peak levels: fresh paint, new surface decorations on the wall and floor, new furnishings, use of washing and cleaning detergents, use of open fuel-burning appliances (geyser), baking, frying and grilling and combinations of conditions (e.g. vinyl on fresh concrete). Chemicals can be absorbed or react with other materials, and may re-emit later. Chemicals in the form of aerosols will deposit and re-entrain when disturbed, for instance children playing on the floor, vacuum cleaning, wind pressure. All possible sources of chemical pollution including volatile organic compounds must be checked.

Indicators of exposure are the amount of materials and period since appli-

Table 8.5 Indicators of legionella and chemicals and possible consequences of exposure

Legionella	Indicators of peaks in concentration	Indicators of exposure risk
Buffer of water, taking a shower	Temperature 25-55°C	Low: regular flushing of taps Medium: first use of shower after period of stagnancy High: showering not in own home (after stagnancy and with buffer system)
Possible consequences of exposure	Low exposure: risk score 2 Medium exposure: risk and potential serious effects if in poor condition, risk score 4 High exposure: high risk and potential serious health effects, risk score 8	
Chemicals	**Indicators of peaks in the concentration**	**Indicators of exposure risk**
TVOC	All sources including soft plastics during and shortly after application, and during high temperature	Low: low amount of material, no harmful pollutants Medium: potential hazardous substances High: low ventilation rate, present during and shortly after application of material
NO_2, SO_2	Traffic or industrial activity, coal and oil burner, smoking, indoor combustion, capacity of burner, air change rate	Low: low concentration Medium: short periods with increased concentration High: long periods of exposure to outdoor level plus indoor emissions, breathing rate for SO_2
Heavy metals, lead, pesticides, toxic substances	Toxic substances: use of persistent toxic materials (pesticides, flame retardents), lead pipes and lead containing paint, air change rate during application	Low: slightly increased compared to background level Medium: incidental exposure to higher levels High: long periods with increased concentration
Possible consequences of exposure	Low exposure risk: short term effect, not intense, risk score 2 Medium exposure risk: irritating effects, dangerous substances, risk score 4 High exposure risk: long term health effects, risk score 8	

cation. Of secondary importance are other peak conditions such as temperature and humidity in a period of days to months after application. A hot period helps to 'bake out' the emissions, meaning that after a warm period this delayed emission is likely to be over. Extreme ventilation volume is needed to reduce peak concentrations during application. Emission of potentially toxic pollutants at very low level can accumulate in dust layers and produce high levels, even when the concentration in the air is hardly measurable. Each component and appliance with persistent chemicals is an indicator of a hazard. For the constant emissions at room temperature a permanent basis ventilation volume is required: in many houses infiltration provides this basis volume, but in more airtight houses a permanent use of both inlet and exhaust functions is required, and for each room. Especially infants and pregnant women are vulnerable to health effects from exposure to contact or inhalation with pollutants, even in trace concentrations of dangerous substances (solvents, smoking).

Table 8.6 Indicators of noise and possible consequences of exposure

Noise	Indicators of noise levels	Indicators of exposure risk
Ambient noise	Distance to source (level on envelope), opening in envelope	Low: in quiet urban neighbourhood, traffic for small neighbourhood, no industry Medium: traffic for larger neighbourhood, shops nearby, short peak traffic High: along road with heavy throughgoing traffic, or near dual carriageway, heavy vehicles, long peak periods
Technical noise	Frequency, period of the day, type and level of noise	Low: services dispensable and controllable Medium: periods with high noise levels, or low level of permanent noise High: noise from indispensable services, no control, high level during quiet periods
Social noise	Social interaction, frequency, period of the day, type and level of noise	Low: non-frequent noise of communicative neighbours Medium: noise from public area: children playing, bar visitors, neighbours during quiet hours High: High noise level despite requests for turning down the level, disturbing noise at frequent intervals
Possible consequences of exposure	Low exposure: risk score 2 Medium exposure: risk and potential serious effects if in poor condition, risk score 4 High exposure: high risk and potential serious health effects, risk score 8	

The robust indicator is: exposure in any furnished room during high indoor temperatures and poor ventilation. Other indicators: exposure to any polluting source during and shortly after application.

Indicators of stress from extreme comfort conditions (see also Table 8.6)
The relationship between comfort and stress is evident. The relationship between overheating and being exposed to low indoor temperatures is related to health effects that are likely to be indirect.

Robust indicators are the experience of stress from overheating, and from draught when it influences ventilation behaviour.

Indicators of stress from noise (see also Table 8.7)
Indicators refer to all conditions that cause stress: technical noise that cannot be controlled and social noise in connection with poor relations with neighbours. Ambient levels depend on the indoor-outdoor ratio, but inlet acoustic insulation has low effect when windows or grates are open. Noise during the night time is likely to have more impact on stress than in the daytime. Occupants define the acceptable noise level. The perception of the occupant is a robust indicator of health effect from noise. Indicators that mark nuisance for many people are the traffic intensity and distance to the house and noise from fans of mechanical ventilation with poor compensation by natural services.

Indicators of safety (see also Table 8.7)
Poor safety, causing personal injury represents a performance quality with immediate and serious health effect. The relationship between safety and health is evident. Exposure is influenced by personal condition: attention-span, experience, use of medication and drugs or alcohol. Aggravating con-

Table 8.7 Indicators of comfort and safety and possible consequences of exposure

Comfort	Indicators of extreme conditions	Indicators of exposure risk
Extreme high temperatures	>26°C indoors for 8 hrs and peak temperatures >30°C	Low: <30 days at 26°C indoors for 8 hrs per year Medium: >30 days >26°C indoors 8 hrs High: >10 days >30°C indoors 8 hrs
Daylight	No direct view of the sky, low daylight level, artificial light needed	Low: indirect daylight, reduced view of sky Medium: enough daylight, not direct and no view of sky High: artificial lighting only
Possible consequences of exposure	Low exposure: risk score 1 Medium exposure: risk and potential effects if mostly indoors, risk score 2 High exposure: high risk and potential serious health effects, risk score 4	
Safety	**Indicators of hazards**	**Indicators of exposure risk**
Personal injury: falls, cuts, bruises	Available bars, signals, lighting, location of slippery rugs	Low: ergonomic design, sustaining for mobility impaired Medium: steps, stairs, thresholds, slippery when wet High: uneven levels, slippery floors, poor lighting, no bars
Scalds, burns	Unprotected oven, heater, fire, very hot water taps	Low: surfaces no more than 50°C Medium: surfaces up to 100°C High: surfaces higher than 100°C
Electric shock	Poorly maintained (old) electric appliances and wiring	Low: well maintained connections Medium: long loose electric leads, poorly maintained High: visible open leads, loose connections
Drowning	Surface water and poor lighting, poor view, poor control	Low: no surface water, good view on children at play Medium: surface water nearby, poor view on children at play High: deep pond in private garden, poor view on children at play
Trespassing	Open doors or windows, lack of control, no alarm	Low: inlet openings well protected against burglary Medium: use of large inlet openings when at home High: poor locks and hinges, easy access while ventilating
Possible consequences of exposure	Low exposure: risk score 2 Medium exposure: risk and potential serious effects if in poor condition, risk score 4 High exposure: high risk and potential serious health effects, risk score 8	

ditions are poor lighting, poor layout, obstacles. Dependency on other people pushes disabled people to help themselves, which increases the risk level. Each hazard condition is an indicator.

Robust indicators refer to those hazards with high likelihood, serious consequences and high exposure: unsafe stairs, slippery floors, uneven levels, poorly visible obstacles, poor kitchen ergonomics, very hot water, hot surfaces, flames and use of chemicals. Falls represent the major occurrence with serious health effect.

Indicators of social quality (see also Table 8.8)

The relationship between social quality and health effect is not clear. The relationship between SES and health has been established, but the relationship

Table 8.8 Indicators of privacy and social care and possible consequences of exposure

Privacy	Indicators of likelihood	Indicators of exposure risk
Access to outdoor (semi-) private space	Availability of area for (semi-)private outdoor activities	Low: in certain periods it is not possible to use outdoor area Medium: poor use of outdoor area, disturbance, unsafe for children High: no outdoor area for relaxation, socializing or for children to play
Care when in need of help	**Indicators of likelihood**	**Indicators of exposure risk**
Access with aids (when mobility impaired)	Limited space for use or parking of electric cart, for wheelchair and rollator	Low: increased risk of hazards because of obstacles Medium: barriers that limit the use of mobility aids High: living independently is hardly possible for people with impaired mobility
Emergency help	Visual contact, SOS-functions, both technological and in personal attention	Low: help needs to be organised but is available Medium: mainly professional help, not from neighbours High: no SOS services available and poor social interaction for those in need of contact and help
Possible consequences of exposure	Low exposure: risk score 1 Medium exposure: risk and potential serious effects if in poor condition, risk score 2 High exposure: high risk and potential serious health effects, risk score 4	

is never direct, meaning that SES is a poor indicator. Trespassing and burglary/robbery causes stress, but the health consequences cannot be scored. Social isolation is an effect of the social environment. The perception of occupants defines the quality of the social relationships, which is the result of both active involvement and getting support from others. Social isolation creates health effects when not being in control to organise help when help is needed. The following indicators are selected: access and circulation possibilities with wheelchair and rollator, access with emergency stretcher and parking place for electric cart, perceived stress by different reasons related to housing and the neighbourhood: intrusion of privacy, trespassing, assault, discrimination, including stress from fear of these hazards. We add social alarm: signal response in three minutes and help within 15 minutes represents good quality.

Process indicators

Processes to improve problem identification and problem solving processes focus on the cooperation between tenants and home owners. Process indicators are:

- information about maintenance policy, procedures, planning and quality requirements and how to reach the proper people or organisation;
- advisory function of tenant representatives and support in developing alternative proposals;
- a protocol for interaction between the tenants and managers;
- a decision-making protocol on renovation projects, with time schedules that applies to all parties.

When renovation plans are being prepared, the interaction can be described in the design brief.

8.4 Conclusion

The main results per research questions were reviewed in brief. The ten major hazards were presented. The major result is the list of indicators. The list is compiled on the basis of the parameter study in Chapter 7 and takes three aspects of the models in this chapter as indicators:
1. the Source (Driving force of agents or physical condition);
2. the Concentration (State of agent concentration or hazard condition);
3. the Exposure risk.

In the exposure risk the main aspects of source, emission, removal or protection are combined. The indicators point at three different levels of exposure risks: mainly with a weight score of 2, 4 and 8, meaning (see Section 2.5): warning for susceptible people (2), alert for susceptible and warning for healthy people (4) and warning for all people (8). For a few indicators the weight is 1: this low risk does not require attention, but still the hazard could be removed or avoided. This weight is not the burden for society, but the risk for individual persons in their own house, when exposed to a high risk level.

House dust mite allergen, exposure to chemicals, legionella, aerosols, radon, noise and safety are the parameters that score the highest weight. Noise is certainly among these parameters, but the weight is a matter of qualitative scoring for exposure by individuals. After some deliberation mould was awarded a lower weight, meaning that an alert for susceptible and a warning for healthy people is given, no alert for healthy people. Comfort and the social environment have received a lower weight in this order of priorities.

The priority indicators relate to house dust mite allergen, exposure to chemicals, legionella, noise and safety.

Ventilation is scored in low, medium and high quality of services and also of the final ventilation quality (air change rate, effectiveness, according to needs and ventilation behaviour of occupants). For these scores many different parameters of ventilation have to be evaluated.

9 Discussion

9.1 Introduction

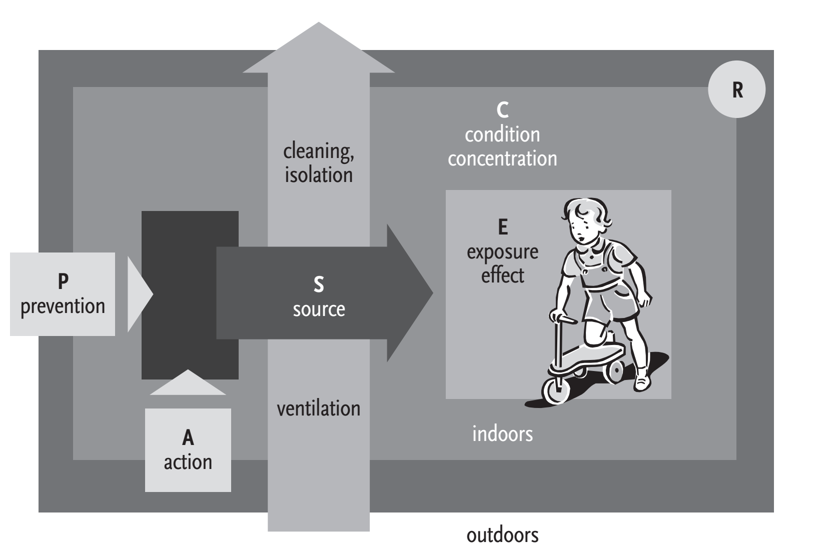
The research question for this Chapter is: What is the (new) state-of-the-art knowledge about housing and health? We will discuss the framework, the 'integrated' performance of each room, the optimal performance quality, the selected indicators and finally the home inspection strategy. Discussion means that we elaborate on results of previous chapters, make a synthesis and look at what is achieved, in an integrative way. Also, we present the hypothesis that are the result of abductive reasoning. We will discuss to what extent the framework can be used and how we will value the parameters and the models of chapter 7. This Chapter 9 is an aspect of the learning process: what new information is added since the start of the research, what is added to existing knowledge? The position of Chapter 9 is highlighted in Table 1.4.

9.2 The framework

The framework of DPSEEA, ITOO, LEDO and CIA have been useful in providing a vocabulary and tools in support of the selection of strategies and indicators. In the process of this study, we have simplified the framework. The DSEEA framework was simplified to DPSE, the ITOO framework to ITO. Learning-by-doing is used more as a moral value than as a theoretical framework. In the selection process of indicators, we still miss the process indicators, despite the attention given to pro-activity and awareness of hazards. In an improve framework Driving Force and Pressure are combined into Source. State is explained in terms of Concentrations and Conditions. Exposure and Effect are a pair as well and can be combined into Effect. This Effect is not the measured health effect, but the risk ranking (R), so Effect and Risk Ranking are synonyms. Action is still a clearly defined single step. We then add Monitoring, indicating that the action needs evaluation and feedback and that the sequence of steps starts over again, turning the framework into a process. We propose the acronym SCREAM for this new framework (see Figure 9.1). This framework is not complete: it focuses too much on problems and we can improve the framework by adding Prevention as part of the output, which in Figure 9.1 is the beginning of the sequence: new problems occur only when prevention is not successful.

The resulting acronym is SCREAM-P. In this framework communication has no specific place. Also we would like to add a guarantee that a certain quality is achieved, for instance control or guidance by a team that stimulates the quality of home inspectors (quality of professionals), or of inspection protocols (quality of the process), or of health performance reports (quality of the product). This aspect of the framework is the trade-mark, the certification or registration, by a branch organisation, or normalisation institute etc. We

Figure 9.1 The proposed SC^{R}EAM-P P framework



change the R into ^{R} and the acronym becomes SC^{R}EAM-P.

This acronym was presented at a meeting of researchers involved in INTARESE, a EU project with the goal of solving methodological and information problems on integrative risk assessment (INTARESE, September 1, 2006, Paris). At the end of that group discussion SC^{R}EAM-P emerged as a proper summary of needs expressed in addition to the DPSIR or DPSEEA frameworks.

9.3 Health performance of each room

9.3.1 Living room

A living room used for a long time every day will have many pollutant sources, but also someone present who is aware of bad smells, condensation, dust in the air and dirty surfaces: an active person who is aware of these conditions will do whatever is needed to prevent or remove pollutants. A household that uses the house mainly for sleeping, has all the sources of pollution, the same number of showers, laundry cycles, cooking, but without the care for the indoor environment in the daytime. If ventilation is at the low setpoint and the heater is off, then moisture and other pollutants are likely to build up. The total number of occupants in the house is most likely the number of occupants in the living room. Temporary visitors will not take a shower or bath, nor do they sleep or produce laundry.

Hazard conditions in the living room are caused by smoking tobacco, pets sleeping in the room, open connections with the kitchen area, large cold or wet floor areas with soft carpets, heating with open-type heaters using fossil fuels, potential pollution sources such as air fresheners, cleaning detergents, mouldy pot plants, soft foams, glued carpets, electronic equipment, etc.

Houses, located at the head of a block, may have hazards arising from thermal bridges of floor support, causing cold floor surfaces with higher moisture level and better ecology for house dust mites. Many single-family houses have the living room above a crawl space, sometimes a garage or storage area. Openings in the floor can become sources of mould, moisture, radon and other pollutants.

9.3.2 Bedrooms

We spend 30-40% in the bedroom, which is roughly one third of our lives. In the bedroom, we sleep on soft mattresses, in a single daily time block and housed in secured and solidly walled spaces. During the night, our bodies take a rest from the physical and psychic stresses of the day, we digest and emit metabolic waste and go through many other processes essential for long-term health. A healthy bedroom is one that allows us to rest free from environmental stresses. Undisturbed relaxation is the basis for health and vitality, two of the most important aspects of quality of life. When we suffer from lack of sleep and sleep disturbance, the bedroom and the bed do not support a period free from stress. Noise can disturb sleep. Poor indoor air quality in the bedroom can influence health. A low air change rate will increase the radon level, and create a higher risk of lung cancer. Poor ventilation will not remove allergenic airborne dust particles (house dust mites and mould) and may weaken the condition of people with respiratory problems. The airways of allergic people also have a lower resistance to chemical pollutants, meaning they are more susceptible to toxic substances and bacteria. TVOC sources are likely to be found in the bedroom, creating health risks, for instance a higher risk of asthma in infants (Lehmann, 2005). In the Netherlands, 9% of health loss is supposedly due to environmental factors, including accidents. Almost half of this loss (2-5%) is directly related to the physical environment (Kamp, 2002). Looking at the estimates for lung cancer, inflammation of the lungs, respiratory problems and accidents, an estimated 0.3–0.5% of the total burden of disease in the Netherlands is related to the bedroom (estimates by author). Better bedroom conditions can prevent 20-35% of this estimated burden of disease attributed to the bedroom.

Bedroom conditions

Daytime ventilation of the bedroom will slowly remove absorbed moisture from the mattress, pillows, bedcovers, wallpaper, floorings, etc. Night-time ventilation is often quite low (air change rate of 0.2–0.5 ACH) when occupants keep large inlet openings closed for different reasons.

In rented social housing in the Netherlands, we find many master bedrooms with a volume of 25-35 m^3. A general consideration of air volumes to keep concentrations of pollutants caused by humans at a steady level is 25 m³/person-hour, which would require an air change rate of about 1.5/hour in the bedroom for two adults. A large inlet opening not obstructed by curtains, or an inlet opening plus an open door to facilitate cross-ventilation, provide this air change rate. In bedrooms, the heavy curtains or blinds (or combinations) are closed to block the light, but certain curtain positions also block part of the inlet of fresh air. If the inlet grates have a large surface or the window is wide open, a good influx of fresh air is possible, moved in and out by pressure differences on the façade, caused by the wind. The cool inlet air will fall down behind the curtain and spread over the floor. The warmth of people in bed causes an upflow draft of air, which secures the circulation of fresh air near the nose. When the upward flow is not removed by exhaust openings, the air gets 'older' and the pollutant concentration increases, which can affect the quality of sleep.

Mattresses and house dust mites

Mattresses are the major source of house dust-mite allergen in bedrooms and are expected to be the largest source in many houses. The area under and around the bed has a high concentration of dust from the bed. Part of this dust will become airborne, for instance when someone walks on the floor or when the room is cleaned. Moving around in bed causes emissions of allergenic aerosols from the mattress. The covers function as a blowpipe of allergenic material towards the nose. A new mattress does not contain mite allergens. When mites infest the new mattress and multiply, it takes months to some years before the allergen concentration reaches levels that may cause airway irritation. As mattresses grow older, dust builds up and may reach high levels. Even if the dust mites stop multiplying after some years, the allergen stays active in the mattress, only slowly broken down by mould and removed by biological processes. The allergen can stay active for years. Very fine woven dust covers prevent live mites from entering the mattress, but the covers do not block fine dust particles. Live mites under the cover will have plenty of food and growth of the population seems to have only minor limitations.

The type of bed influences the humidity and the cleaning efficiency. A mattress with springs has a lot of open space and the moisture and aerosols are vented away. Foam mattresses tend to hold more moisture and create a better habitat for house dust mites. A closed-in bed bottom can block the air circulation under the mattress.

Heated waterbeds may have quite damp covers at the end of the night, because the layer near the plastic cover cannot ventilate. Stains on the plastic refer to transpiration. Permanent heating of the water bed or the use of hot wire blankets on other types of beds give a good protection against mites: the high temperature causes better evaporation and the mites are not very active in these dry conditions, limiting their food intake and reproduction rate (Boer, 1998).

Potentially dangerous environmental conditions are those where exhaled air is not carried clear of the face by the stream of air issuing from the mouth or nose and especially of small infants that cannot move well. Environmental aspects which affect the accumulation of exhaled air at the face include air pollution, temperature, humidity, bedding arrangement, sleeping position, interaction between the infant and the environment. Physiological mechanisms can be identified that provide explanation for sudden infant death as a result of prolonged exposure to a hypercarbon dioxide atmosphere. Other pollutants are also important. Conventional mattresses contain many chemicals from glues, foams, pesticides, or chemical flame retardant treatments. Permanent-press bedding is treated with formaldehyde that does not wash out of the fabric. Many bedroom materials may be outgassing for years after we purchase them. As we sleep, we may absorb these chemicals through the skin from our sheets, pillowcases and sleepwear.

Moisture in the bedroom

In an average non-ventilated room and disregarding absorption and condensation, the moisture production by a person asleep would create 100% relative humidity of the bedroom air within one hour. Part of the water vapour is being absorbed into the mattress, furniture and all surface materials in the bedroom, the rest is vented away. In a double bed, the amount of moisture in the mattress is expected to be 250 grammes per night, which diffuses into the mattress due to temperature differences. After we get out of bed, the temperature drops to room temperature, creating a high humidity level that allows house dust mites to regenerate the water content of their body. After the mattress has dried or after the mattress has cooled down to a temperature below 15°C, house dust mites are not very active, do not eat much, do not reproduce well, and it takes longer for their eggs to hatch. A dry environment and low temperatures are considered the best conditions for preventing high dust-mite populations and the associated high allergen levels.

Ventilation with enough fresh outdoor air will remove more moisture than is produced, even with two adults sleeping. This may not be possible when the room is ventilated with warm and damp indoor air.

9.3.3 Kitchen

Frying, grilling, stove use, toasting, cooking pizza elevate the indoor particle number concentration by several times. The indoor PM2.5 concentrations could be close to 90 times, 30 times and three times higher during grilling, frying and smoking respectively, than the background levels (He, 2003). The main hazards are:

- open gas fires (flueless gas-fired water heaters, gas cookers and gas ovens): NO_2, CO, moisture;

- production of organic aerosols by baking, grilling and boiling;
- mould and chemical emissions from kitchen cabinets and storage of cleaning agents;
- risk of fire, cuts, scalding, falls on slippery floors (water, vegetable peels, grease, etc.).

Open connections with a drain shaft or crawl space under the sink often contribute to the pollution level. The kitchen closet contains all kinds of chemicals, for instance aggressive and perfumed cleaning fluids. A mouldy waste storage may emit allergenic material or mycotoxins.

The transport of pollutants to the living room and other rooms depends on the location and separation of the kitchen, maximum concentrations and ventilation possibilities (inlet openings, peak exhaust). The cooker system indicates emissions from combustion of gas or other fuels. NO_2 and CO present the main risks. The evaluation of the cooking method, the ventilation, the type of sources and the transport mechanisms define the concentration. The quality of the combustion process determines the concentration of CO. Visible yellow gas flames indicate a toxic combustion process. Condensation on windows during and after cooking is a simple marker of the total moisture load, which is of course related to outside temperature and type of glazing. No condensation during cooking is an indicator of a dry indoor climate, especially when windows in the kitchen are single-glazed. Open kitchens (which include the living room) mostly have two walls with large seams along windows and openings that permit cross-ventilation. The kitchen air quality depends on this cross-ventilation and on mechanical peak exhaust. Quality is related to a large opening for flushing cross-ventilation and a highly efficient kitchen hood and mechanical exhaust at normal and peak capacity.

9.3.4 Bathroom

The bathroom is used for personal care and doing laundry. Bathrooms have only been regulated since the 1950s in the Netherlands, meaning that in older houses a bathroom was installed in one of the small bedrooms, often without an exhaust duct, but with inlet openings in the façade. Bathrooms in these bedrooms are large enough to provide room for a toilet, bathtub and shower, washbasin and Laundromat including a tumble dryer. The required exhaust volume is 14 dm^3/sec. The inlet is from under the door, sometimes through a grate in the door, typically with a 140 cm^2 opening. Since the 1960s, bathrooms have tended to move to the central area of the house, not connected to the façade any more, and are ventilated with warm air from other rooms.

Many bathrooms show mould problems, while other damp bathrooms may not show any sign of mould. The number of showers that most bathrooms can handle without a risk of mould growth or a foul smell is limited to somewhere between 14 and 21 showers a week, roughly around a maximum of three showers a day (where two showers within a short period count as one shower). One shower creates so much water on surfaces and in towels that it takes two to three hours (or longer in the summer) before the water is evaporated and wet walls start to dry. The bathroom may have other sources of moisture production: washing lines, emissions from certain types of condensing laundry dryers and leakage from outside or from the bathroom into the wall and floor.

Mechanical exhaust does not prevent mould growth, because the exhaust volume is too low to increase the evaporation process in a substantial way. Small fans running during the lighting period plus some minutes extra have a negative effect: they block the (natural) exhaust ducts and prevent exhaust of damp air after the fan is switched off. Permanent ventilation with fresh air and a warm bathroom are the most effective measures against high moisture levels and mould growth.

Fresh ambient air can absorb more water than warm humid indoor air: on average twice as much, and bathrooms with a façade opening can be vented effectively to prevent mould growth above the tiles.

A large window with chinks and a sunny location may provide just enough heat to prevent mould growth. Seams in windows or an inlet grate can perform better than a large opening (for airing), because the bathroom will not cool down too much.

The large surfaces with tiles or smooth and water-repellent paint allow effective rinsing and cleaning of all types of dirt, including mould. The strategy of applying large surfaces of absorptive material that reduce the moisture peak can buffer a large amount of 'free' water with three or more showers and supports mould growth. High absorption can, however, reduce the free water content, as long as the moisture balance is not disturbed. The use of untreated wood (in saunas) shows how effective buffering is at preventing mould. Absorptive properties are lost with a layer of paint. Therefore the suggested strategy is to apply water-repellent surfaces that are easy to clean. Some mouldy spots on seams between tiles and in joints will not create a health risk when cleaned regularly.

Because of transport of moisture to other rooms, the concentration of house dust mites will increase with more showers or extra moisture sources, e.g. laundry drying. Exposure to legionella occurs primarily in the bathroom. The bacterial source is the buffer with warm instead of hot water. Scalding or hot water is a risk especially for small children and seniors. Flow-through hot water system or buffer >60°C are safe against legionella. The wet bathroom floor causes many fall injuries. Handrails and rough flooring, on surfaces that get wet, can prevent fall accidents.

9.3.5 Circulation and storage

Other areas than the living, kitchen, bedrooms and the bathroom are spaces, used for storage, work and play, a guest room or circulation areas. Storage rooms can be a cellar, an attic space, a shed connected to the house or a (small) room.

The ventilation efficiency and the sources of pollutants determine the exposure to health risks, while poor ergonomic quality increases the risk of injuries, often in hobby-rooms and circulation areas.

People with impaired mobility may use an electric scooter or other mobility aids. A parking place with connection to electricity is required. Work/office areas require good ergonomics. Printers, computers and copiers may increase the pollution concentration in the air. Workspaces with valuable equipment need curtains, etc., to block the view, and other burglar protection measures.

A spare room can function as a guest room for someone who is available for help during day and night. The circulation areas need attention because of obstructions, lighting, security when opening the door for strangers, and communication between people outside and inside.

9.4 Optimal quality of healthy housing

The Healthy Housing Checklist required the description of optimal quality levels for the inspector: the level expected to cause no health risk, or even being supportive of good health. The optimal quality marks the 'distance-to-target', as a measure of quality. The qualities look separately at the physical building and the qualities of occupancy. The optimal quality illustrates the best available and also practically feasible health performance of housing. The quality descriptions are clustered around allergens, chemicals, acoustics, comfort, safety and social quality. The descriptive qualities are based on a variety of literature sources and work experience of the author.

Free of biological agents

Allergy-free means 'free of biological agents': minor exposure to mould, biowaste, house dust mites, pollen, bioeffluents and smells. Under optimal conditions, the envelope of the house is free from nesting birds (like pigeons) and plagues of pests that produce allergens. The house has a separated and ventilated kitchen annex or storage room for 'smelly' cooking and cleaning jobs. The occupied spaces are well-sealed from the crawl space, collective shafts and sewers. The heater, a stove, a fireplace does not emit exhaust gases into the indoor air. The house is completely free of mould, and also free from hidden mould in leaky cavities. Cold floors have a smooth surface layer that can be cleaned easily.

The ventilation system allows for three controllable functions: basic air exchange for fresh air during a period not spent at home, comfortable permanent ventilation while at home and peak exhaust or flushing during cooking, bathing and other extreme conditions. Each room can be flushed, regardless of the type of ventilation system and each room allows a high individual air change rate of 2 or more. The use of permanent ventilation services is at minimum standard capacity not limited by noise levels from outside or from fans and dampers. All wet or greasy surface layers in the bathroom and the kitchen can be dry-stripped or cleaned of mould and dirt (based on Weterings, 1999).

The allergy-free qualities of occupancy

The house is smoke-free, without air fresheners, perfumed candles or a wood-burning stove, a fireplace or a heater without connection to a flue-gas exhaust pipe. In the house, no pets with hairs and feathers are allowed and no excreta of other pets are found. Laundry is dried outside or with exhaust of damp air directly into the ambient environment and never into the house. The services for permanent ventilation are used at the norm capacity, with flushing during peak pollution periods. The flooring is hard, with washable carpets only. Interior decorations are kept dust-free and free of irritating emissions. The airway-sensitive person sleeps in a well-ventilated and large bedroom on the sunlit side. Mould is removed and surfaces cleaned regularly and as soon as mould is visible. Bed and soft furnishings are dried and sunlit regularly, especially during very cold dry winter weather. Mattresses are newer than 5 years (or, with dust mite cover, newer than 8 years) and replaced when older to get rid of the accumulated house dust-mite allergen (Hasselaar, 2004; Oosting, 2002).

Free of irritating chemical emissions

The reference quality for emission-free houses are quite similar to allergen-free housing. It is difficult to free the house from all chemical emission sources. The best way to reduce exposure is to ventilate well and keep temperatures low to reduce the emission rate. Certain chemicals can cause problems for everyone, including people who are allergic to biological agents.

The house is not located in a large urban area or a large city, where the concentration of fine dust and chemicals such as ozone, SO_2 and NO_2 is often high. This means that chemically sensitive people including airway-sensitive people will suffer in any house located in large cities or connected urban regions (most of the Dutch Randstad area, Utrecht, Eindhoven, Maastricht etc). The optimal location is far away from roads with heavy traffic and from polluting industrial chimneys. The ambient area has clean air that provides the opportunity for physical activity and work on a better health condition.

An annex space of the house is available for polluting activities such as frying and laundry drying. A water heater, stove, furnace, fireplace or room heater without exhaust of flue gas is not available or infrequently used. Construction materials and surface layers do not emit hazardous gases. Smell or dust cannot emit from chinks and seams connected to cavities in the construction. Lead water conduits have been replaced. The rooms have large inlet openings that are used permanently, even when not at home. The rooms have a door or large window used for flushing during polluting activities and whenever flushing is not in conflict with energy consumption or comfort problems, and especially for cooling the house on hot or sunny days, in order to prevent the 'baking out' process while being exposed to these emissions. The indoor spaces are comfortable with a temperature below 20 ^{0}C to reduce emission of chemicals with a low 'boiling' temperature. Mechanical ventilation is well-maintained by cleaning the fans and dampers and by adjusting the capacity. The maintenance cycle of mechanical ventilation systems including ducted inlet air systems is less than 5 years.

The low emission qualities of occupancy
Smoking is not allowed inside the low-chemicals house. Air fresheners, incense and perfumed candles are banned. Laundry is dried outside or in a machine with exhaust to ambient air. Baking, grilling is done in an annex space or outside. Inlet and exhaust of ventilation air is used permanently and flushing is practiced during peaks and whenever flushing does not increase energy consumption or discomfort from draught or low temperatures (level depending on the condition and activity level of occupants but ranging between about 15-20°C). The interior is decorated with low-emission products and other emission sources have been or can be removed. All surfaces are easy to clean and actually kept clean (Snijders, 2001), while cleaning products have been selected with lowest possible emissions of solvents or fragrances. Do-it-yourself construction and decoration jobs involving chemicals are not done in a period when a sensitive person, child or pregnant woman is at home: the house is then open to flush continuously for at least a week and is baked out by heating while away.

Optimal acoustic quality
The noise-free house can be located in a quiet environment, or has good acoustic insulation in a noisy location The qualities in this location relate to the perception of the occupants, not so much to the dB(A) levels. Noise levels from outdoors and neighbours are acceptable when they do not cause nuisance (talking, music, slamming doors). Mechanical ventilation does not cause nuisance when using the setpoint meant for occupation periods, and sleep is not disturbed by noise of the permanent ventilation, of pumps, motorised valves and pipes. The house has at least one 'silent room', with optimal acoustic insulation quality. Noise-sensitive functions of the house are situated at the quiet side of the house. Interior decorations absorb noise. Social contact with neighbours allows for agreement on noisy or quiet periods.

Optimal comfort conditions
Comfort relates to conditions and control of extreme temperatures, radiant asymmetry, draught, sufficient day light and view of the sky and the surrounding area. Control over the personal environment is essential in reaching a high level of comfort. The comfortable house is well-insulated, with nice view from large windows with the lowest possible U-value. Fresh air is cool but does not cause draught problems. The control functions of temperature, ventilation and lighting are accurate and easy to use. The layout is flexible and allows different functions and adaptation to specific needs, especially when ill or disabled.

Qualities for the living room are: privacy, direct access to semi private outdoor area and visual contact with outside world, a place to socialise, enjoy music and TV and a safe playground for small children. The house has at least one flexible space that can be changed and adapted to personal needs, to provide identity and to feel at home.

Optimal safety conditions
Safety criteria require the prevention of personal injury such as falls, cuts, bruises, scalds, burns, electrical shock, poisoning and suffocation. Safety focuses on people with reduced mobility, sight, balance (for instance the elderly), or with low experience in the particular environment (children, visitors).

Ergonomic qualities of the empty house
The distance from the sidewalk or car parking to the main entrance door can easily be covered with a wheelchair. Steps or a ramp and other obstacles to get indoors have a supporting bar. The main entrance door can be controlled and opened by remote control, so a handicapped person does not need to walk to the door. The vehicle of people with reduced mobility can be parked near the main entrance of the building or the house. Staircases indoors are not steep or with open steps and have supporting bars. The bathroom is on the floor of the living or can be reached with elevator or stairlift. Good day lighting, especially in circulation areas, prevents falling over obstacles or from stairs, but artificial lighting is also important, especially in areas without daylight that need extra luminance from lighting in the day time. The kitchen and bathroom allow use in a wheelchair (a circle of 150 cm or l and w >220 cm is available). The toilet level is high and bars support getting up and down. The bathroom or kitchen floor does not get slippery when wet. A fall accident cannot lead to serious cuts from breaking glass or pointed obstacles. The appropriate numbers of smoke alarm are present and working and within hearing distance. An emergency exit is easily accessible. Ventilation, heating and lighting can be controlled from the position of a wheelchair (Siekkinen, 2002; Slangen-de Kort, 1999).

Ergonomic qualities of occupancy
It is easy to clean the house by 'strangers' and by someone with impaired mobility. Obstacles and smooth rugs that may cause fall accidents have been removed. The bed allows access from both sides. The cooking system is without flames and cooking utensils are not located over or behind hot pans. Hot water taps in the bathroom have a thermostat to prevent scalding. Work tables are well-lit, large and easy to access. The stairs are safe for children. Storage of chemicals, is well-locked and electrical plugs are safe for children (Wijk, 1996, 1998, 2001).

Optimal quality of the social environment: privacy and personal safety
Social quality is a perception and works on neighbourhood level in the first place. Indicators point out change in conditions rather than absolute conditions (deducted from Anderson, 2003), for instance:
- the process of reduction of segregation of ethnic groups or income groups;
- reduction of the number of accidents and injuries, of assaults;
- reduction of mental stress (social isolation, loneliness) and also:
- quality of and proximity of schools and health services;
- renovation processes have a positive effect on the value of houses in the neighbourhood.

These qualities will not effect the list of indicators, except for what can be influenced on the level of the individual house: good maintenance of the house, positive interaction with neighbours etc.

The socially secure quality supports people who need care and attention. This quality allows these people to live longer in their house. The social environment provides safe opportunities for children to play and children playing outside can be seen from the house. All is done to prevent trespassing or burglary. The home protects against visual and acoustic interference of the public. The main entrance door can be controlled from the living room. The neighbourhood atmosphere is likely to give protection against intimidation by youngsters or aggressive people. Social alarm is available for people who need daily attention (contact within three minutes, help within fifteen minutes). A peep lens or window in the main entrance door permits a view on callers at the door. It is possible to sit outside with enough privacy to welcome visitors.

9.5 Evaluation of health performance evaluation framework

The design of the tool required choices between complexity and simplicity. Despite several pilot versions that were steps in the simplification process, the tool still is complex and only accessible for motivated persons, but at the same time the tool is understandable and user friendly for lay people.

Consumers who are interested in healthy housing have used the tool without any problem. Also, interested lay persons are open minded and are willing to follow the sequence of questions. They understand often why a certain output is positive or negative. Some even indicated that they discussed their ventilation behaviour and started applying better ventilation of the bedroom.

The strategy to support pro-activity, to promote action taking via filing of complaints worked with the Ventilation Checklist, but it is not clear how it works for the Healthy Housing Checklist. A questionnaire was distributed to collect experiences, but results could not be included.

Professionals are experienced in dealing with complaints and have developed a workable protocol. The Healthy Housing Checklist for professionals changes this protocol and leads to more discussion with the tenant and more (difficult) questions on the performance quality. The tool is not aligned with daily procedures and applying the tool is beyond the core activities of managers. Pilots have indicated that it is hard to deal with the health topics involved. Information on what the managers learn about environmental health and how they apply this knowledge is not available.

A scan for quick-and-dirty evaluation of major risks may have potential for use. However, simplicity must still result in policy relevant results. More insight is needed in the chances for information transfer, in the questions that can be resolved by using short checklists or tips. Complaint handling has the potential to create a market of professional users. The aspect of social quality is not recognised by housing managers as a relevant quality issue.

The exploration of the landscape of tools indicates that the impact and use of most tools is low. Health performance evaluation has low priority for housing associations. Not so much the quality of the tools but the time and money involved, the voluntary character and low added value (in the eyes of housing managers) are reasons for the low interest in health performance evaluation. In most tools, the aspect of risk identification is not well-developed, except in the Housing Health and Safety Rating System in the UK (Ormandy, 2005). This evidence-based protocol looks at conditions for vulnerable occupants and has a legal basis for (certified) inspection and risk rating. In the final stage of the legislation process in the UK the HHSRS was not made obligatory but a voluntary action.

Table 9.1 presents the link between the newly proposed SC^{R}EAM-P framework, the steps in the performance evaluation process, the object for which indicators are selected and the instruments and activities that are suggested as elements of the health performance evaluation protocol.

Certain actions that result from using the Healthy Housing Checklist have the potential to be picked up by housing managers:

- correction of the capacity of ventilation systems by performing maintenance activities;

Table 9.1 The relation between the SC^{R}EAM-P framework and the performance evaluation protocol

Source	Concentration	Risk	Effect	Action	Monitoring	Prevention
Framework of performance evaluation						
Driving force and Pressure	State	Exposure	Effect	Action		
Air quality						
emission of agents in indoor air	effect of air change rate and cleaning	dose in relation to condition	possible consequences	communication about quality, remediation	feedback	personal guidance
Physical hazards						
use of building	hazard conditions	likelihood	type of use, vulnerability	remediation	cyclic labelling	communication about hazards
Performance evaluation						
Indicators						
indicators of sources and conditions	indicators of emissions and ventilation or cleaning	indicators of exposure and likelihood of hazards	risk score based on low, medium, high exposure risk	indicators of complaint handling and communication	indicators of registration and feedback	indicators of maintenance and housing distribution policy
Inspection, interview and evaluation						
checklist of agents and hazard conditions	inspection of emissions and likelihood	interview of occupants: needs and behaviour	default exposure type (period)	risk scoring and presentation of report	feedback action	information, interaction and guidance
Instrumentation						
Checklist	Inspection, interview protocol	Diagnosis and risk scores	Communication	Remediation	Healthy housing policy	Pro-activity, involvement

- improving ventilation of the bedrooms by burglar safe controls and larger openings under the door;
- solving mould problems in bathrooms by smooth surface layers and not by ventilation;
- solving indoor air problems in houses with HRV by improving natural inlet services;
- cleaning inlet air ducts more frequently;
- seal the floor over crawl spaces;
- provide ‘hard’ and easy to dry and clean shower cabins;
- select legionella safe individual hot water appliances;
- deal more effectively with noise problems;
- communicate more about conditions that require remediation and adaptation from both parties;
- improve safety prevention measures and information.

Topics with the potential to change occupant behaviour are:
- replacement of mattress and application of ‘new’ mite control measures;
- flush water pipes and buffer tanks after a period of stagnancy;

- better ventilation, especially at night and when heating is not needed or only at low capacity;
- pro-active behaviour to take control over the quality of the environment.

9.6 Conclusion

Chapter 9 presents the integrative synthesis of the research and more specific of housing health performance. The framework was useful in structuring the research but it can be improved to include monitoring, quality control of the process and also to emphasize prevention of hazards. A new framework was proposed: SCREAM-P (Source/Concentration/Risk Score/Exposure/Action/Monitoring-Prevention). The acronym SCREAM suggests how important communication about hazard conditions is. To position the acronym in the field, we could add Environmental Health, so the framework can be pronounced as SCREAM-PEH.

Part of the discussion on results was included in previous chapters: the scoring of risk levels in Chapter 7 is part of the Discussion and the Conclusions of Chapter 8 include a selection of the major parameters of healthy housing, that is part of the Discussion as well.

10 Conclusion and recommendations

10.1 Introduction

Chapter 10 looks back on the main results, starting with the problem definition and the central research question: *What physical parameters and which occupancy patterns and behaviour result in exposure to health risk and how can exposure to health risk be evaluated and reduced?*

Recommendations are presented for further research, for product innovation, new regulations and other actions in maintenance, renovation and allocation of houses.

The three parts of the research are marked by a specific output: in the part on Theory the main result is the theoretical framework and the model of the relationship between housing, occupants and health, including the strategies for the development of instrumentation for performance evaluation. The part on Practice results in parameters and indicators that mark the relationship between housing and health. The synthesis is the integration of results and the application to individual rooms. The selected topics are biological and chemical hazards that primarily relate to air quality and physical hazards such as acoustics and safety. Table 1.4 highlights the position of this chapter.

The health effect of the physical environment is complex. Both objective causes and perceived conditions cause effects and the conditions are often not very extreme, making it hard to prove relationships between housing and health. The precautionary principle is followed for many hazards. The general perception that Dutch housing is of good quality does not prevent the negative effects of poor ventilation, noise or legionella exposure. A major problem is that not all information about the health performance of houses is collected or used by professionals. Occupants seem very interested in health issues and like to learn more about healthy housing.

The research focus is on identifying exposure risk, in order to solve problems for the occupants. Even if a problem occurs in only 5% of the houses, it is considered a major health issue. The research goal is to reveal how occupied houses function and what hazards occur.

The study provides physical parameters and occupancy patterns and behaviour that cause health risk and also how these risks can be identified or evaluated. We did not include measures for reduction of these hazards, but the indicators that mark the hazards lead directly to these measures. The thesis provides answers for the central research question.

10.2 Conclusion

Overall results

The study a) does not include medical expertise and results, b) all results apply to Dutch housing conditions and c) the focus is on diagnosis of exposure to health risk conditions. The study is integrative and explorative in the field of exposure to health risk in Dutch housing. The main activity is the selection of indicators that mark the relationship between performance, occupancy and hazards. The indicators are based on the literature and analysis of inspection results and interviews with occupants. Inspections provide data on the physical aspects of houses, parameters of the indoor environment, occupancy and occupant behaviour, and not on the health perception and condition of occupants. The goal of indicator selection is to contribute to user-friendly evaluation of health risk conditions. The indicators are used in a tool to evaluate the health performance of housing. The strategies for this tool result from practical experience with tools such as the Ventilation Checklist, the EPA+Health tool and the consumer version of the Healthy Housing Checklist. This experience is analysed on the basis of criteria derived from the theoretical framework, in which housing, health and occupancy are combined with problem identification and problem solving, with behaviour and communication (see Figure 2.1).

No house is free from health hazards. The outdoor environment is important for the indoor environment; it is hard tor isolate aerosols and noise from traffic, poor smell or avoid trespassing.

The interaction between technical services and occupants is rather poor, causing all kinds of hazards. Poor matching between health needs and the performance of houses causes conflicts, for instance for occupants with respiratory problems and the elderly and children. Many occupants are not aware of risk and do not perform inspections or do not improve the hazard conditions.

Moisture and mould is often caused by constructions that are sensitive to condensation even with normal moisture production. Surface layers define how easy it is to remove mould and grease and how much pollutants will emit. With smooth materials that are easy to clean, any bathroom can be free of mould. House dust mites grow in all houses and a high concentration of allergenic material supposedly is correlated with the age of furniture, including mattresses, cleanliness and possibly with pet keeping. The research result is that allergenic material accumulates and that the focus is not the reduction of live mites but the eradication of accumulated dust pockets, for instance by cyclic replacement of mattresses in the beds of people with an allergic response to house dust.

Exposure to noise point out poor insulation levels of the envelope, but primarily high noise levels of outdoor and indoor sources. The requirements for the noise level are quite low for existing houses and do not provide a guideline for solving problems. Noise caused by appliances in the house is not regulated.

Most comfort problems are caused by a combination of behaviour and physical factors: draught and overheating in the summer.

The risk of injury is a normal consequence of using the house, but part of the hazards can be avoided by better lighting, interior layout, supports and handles. Awareness of hazards is important and a simple safety inspection can reveal important hazards.

Ventilation is poorly understood by occupants and the technical services are not user-friendly. Often, the ventilation services cannot be used for fear of burglary or nuisance from a high noise level. The control functions of fine setpoints are often poor. Many occupants apply flushing for 30 minutes per room per day in the heating season, next to low permanent ventilation volume except what infiltration causes. Small inlet openings, especially line grates, are used for longer periods than large openings like sash windows or one-sided hinged windows: grates allow fine setpoints, are burglarproof, stop rain and the inlet has relatively low risk of draught, etc. Many individual mechanical systems are used at lowest setpoint whenever possible. The combination of low setpoint and reduced capacity brings the exhaust volume to around 9-15 dm^3/sec instead of the norm value of 42-63 dm^3/sec, but this low volume is supplemented by infiltration or natural ventilation, except in houses where these 'natural' conditions are not available. Without compensation for reduced exhaust flow tenants are likely to have complaints about indoor air quality. Natural ventilation is better appreciated by many occupants than mechanical conditions. Occupants prefer to use a flush opening during cooking in combination with whatever ventilation system is installed.

Priorities

The study gives better insight into why certain technical features cause complaints and health hazards. The study on separate rooms makes the bedroom for two people the room with the highest health performance requirements. The kitchen is second in health risk, due to hazards that cause acute problems and peaks in pollutant concentrations (chemical, aerosols). Occupants are exposed to flue gases, hot steam and hot surfaces, sharp utensils and even smoke or fire. The aerosol concentration can reach high peaks. The bathroom is relevant for legionella exposure and emission of dampness.

A new comprehensive set of indicators was developed. A short priority list is deducted from this list and also presented in this chapter on conclusions. The list of indicators can be used as a basis for tool designs, in support of performance evaluation by different user groups: architects, project developers, construction companies, indoor environmental consultants, advocacy planners and occupant groups.

The major parameters of healthy housing that emerge from the study are house dust mite allergen, exposure to chemicals, legionella, noise and safety. Noise is certainly among these parameters, but the weight is a matter of qualitative scoring for exposure by individuals. After some deliberation mould was not awarded as major parameter. Radon and aerosols still are major parame-

Table 10.1 Inventory of the 10 major health issues

Condition (in order of priority)	Indicators of concentration or condition	Indicators of exposure risk
1. Poor ventilation (per room)	Services not working properly or not user friendly, low contribution by infiltration, barrier in the sequence inlet-overflow-exhaust	No services available or not permanently used and in combination with low infiltration rates
2. House dust mite and other biological allergens	Old mattress (>5 years, or >8 years with mite cover), pet with hairs or feathers, pests in the house	Present during vacuum cleaning, or moving around on carpet, old sofas with high allergen content, sleeping on old mattress, contact with pets
3. Chemical pollutants (from the building, decorations and housekeeping products)	TVOC: all sources including soft plastics, when new or in period of and shortly after application, or with high temperature	Low ventilation rate, present during and shortly after application of material and in hot periods, flueless gas fired appliances, leaky chimney
	CO, NO_2, SO_2: traffic or industrial activity, coal and oil burner, smoke, indoor combustion, geyser without exhaust duct	Outdoor level plus indoor activities, breathing rate for SO_2, tobacco smoking, long periods of use of geyser (showering)
	Heavy metals, toxic substances, lead, pesticides: use of persistent toxic materials (pesticides, flame retardants), lead pipes, air change rate during application	Low ventilation rate, being present during and shortly after application of material, disturbance of dust pockets, vacuum cleaning
4. Safety	Falls: available bars, signals, lighting, location of slippery rugs, loose wires Shock: visible open leads, loose connections Burns: surfaces >60°C Trespassing: lack of control, no alarm	Uneven levels, slippery floors, poor lighting, no bars Use of electrical appliances Hot surfaces not protected, use of hot water Poor locks and hinges, easy entrance route
5. Legionella	Water temperature range 25-55°C, buffer size and stagnancy of a few days or more	Taking a shower after stagnancy (especially not in own house)
6. Noise	Technical and social noise: distance to source opening in envelope, frequency, period of the day, type and level of noise	Being annoyed by noise, along road with heavy through going traffic, noise from indispensable appliances and without control, high level during quiet periods, high level from neighbours despite requests for turning down the level, disturbance at frequent intervals
7. Mould	Visible mould, hidden mould in cavities	Size and location of mouldy surfaces (bedroom, living room)
8. Particulate matter and radon	PM2.5 (traffic, industry): heavy traffic, wind direction, humidity (rain), keeping pets, tobacco smoke, radon (type and amount of stone, concrete, chinks in floor)	Within 300 m of busy traffic, in urban area, smoking indoors, pets indoors, concrete based building structure, low air change rate
9. Sustaining design	User-friendly for wheelchair and rollator, extra space for supporting equipment and helpers	Small dimensions of rooms and circulation areas, obstacles, no private outdoor area, not suitable for wheelchair, no visual contact through windows or 3 minute SOS service
10. Lack of control	Control of indoor climate in each room, control over privacy, safety and over proper maintenance	Stress, non-use of essential climate systems(ventilation), poor or missing control functions, no feedback on complaints, anxiety about suspected hazards

ters. Comfort and the social environment received a lower weight in this order of priorities.

The major health risk sources and conditions are placed in order of priority for which indicators are selected (see Table 10.1).

- The ventilation performance emerges as important indicator of healthy housing. Individual conditions and needs can cause high sensitivity, or vulnerability to physical conditions, or mental problems that need special care, so for the individual person certain topics can become very important. A personal approach is essential in healthy housing. A tool for health performance evaluation requires for that reason that healthy and susceptible people can identify risk and diagnose the cause of complaints in relation to their housing needs.
- For house dust-mite allergen exposure the source indicator is dominant: the age of the mattress. For pet allergen the source indicator is dominant: presence of a cat or dog.
- For chemical pollution all sources must be checked. The period since application of chemicals is important, the focus is on period shortly after application. Extreme levels of ventilation are needed to reduce exposure to a peak concentration. For the constant emissions at room temperature a basis ventilation volume is required.
- Dominant indicators of safety come from the hazard condition (uneven levels, slippery floors, activities involving hazardous tools) and the personal condition (attention-span, experience).
- The complex phenomenon of exposure to noise must be simplified in order to deal with noise. Simplifications are: ambient noise enters through open inlets, so ambient sources present dominant indicators.
- For legionella the source indicator is dominant: buffer type and stagnant periods.
- The dominant indicators of mould are visible mould and likelihood of hidden mould.
- The dominant indicator of aerosols are outdoor and indoor sources of PM 2.5, with tobacco smoke, and materials with radon emission (concrete, natural stone) as important indicator.
- Dominant indicators of discomfort are perception of overheating and draught. Draught influences behaviour, with impact on use of essential services such as inlet openings and exhaust fans.
- The indicators of social interaction refer to individual health needs that are not met and that increase disability and mental problems.

Three priority indicators per room

Bedroom

1. poor permanent ventilation during sleep, caused by weakest part in chain inlet/overflow/exhaust;

2. old mattress (>5 years) with accumulated allergen material, or even mould;
3. mould or cold hidden places (bed, behind or in cupboard).

Living room
1. emission of moisture, radon and pollutants from the crawl space via chinks in the floor, around window systems, around pipes through the floor and in combination with moist soil;
2. over-occupancy and peak emissions from people and inherent activities;
3. tobacco smoke in the presence of non-smokers and emission of fine dust from outside.

Kitchen
1. emission from flueless gas heater, aerosol production from grilling and baking;
2. mould material from the bio-container and from the kitchen closet (opening to crawl space);
3. safety hazards from using knives, hot pans, steam, fire.

Bathroom
1. safety hazards of falling on slippery wet floor;
2. legionella from showerhead and in combination with buffer tank and low temperatures or stagnancy;
3. mouldy surfaces.

Studio
1. chemical emissions from hobby activities, toys, office machines in combination with poor ventilation;
2. poor ergonomic layout and work position;
3. extreme conditions: too hot or cold, disturbance by noise.

Circulation
1. steep stairs with narrow footspace, slippery steps and inconvenient supports;
2. risk of falling because of obstacles and poor lighting;
3. poor sustaining design, limiting the use when disabled.

Health performance evaluation tool

A tool for use by occupants/tenants has been developed, tested and implemented.

Pilots show a way out of the design choice dilemmas. 'Rational limited' automatic calculation of a score by a personal computer is preferred by users, because automated scoring works more simple than scoring on the basis of insights of the inspector (who can be the occupant). Integrative scoring is likely to promote learning by doing better than automated scoring, but especially the professionals take little time for health inspections. Practical experience shows that health performance evaluation tools will have low market potential and therefore low impact. A more action-oriented approach is welcome, for instance in the form of short action lists. This is a reason why the research focuses on 'explaining' how hazards work and how the house functions, rather than on quantifying risk levels. Also, a recommended next step is to find ways of 'creating chances' and to apply best practices in the design and implementation of housing and renovation policies and projects.

Health perception is a paradox: some people always feel healthy, even in unhealthy conditions, while the hypochondriac suffers from anxiety and many ailments. The first strategy is to consider perception as a serious phenomenon and look for the underlying health risk conditions, the second is the notion that perception can be changed, that people can create 'health awareness' by self-learning and by education. In the study of housing health this aspect is placed in the context of communication.

On the basis of experience with the implementation of the tool, a new framework for health performance evaluation was developed (see figure 9.1). The first step is prevention of pollutants or hazards. When this is not effective and hazards occur, the evaluation then starts: sources are identified, the emission is evaluated in connection with removal functions (the main are ventilation and cleaning) and the resulting concentration is diagnosed per room. The exposure differs per room and type of activity, also per type of pollutant or condition. Exposure determines the dose and this determines the effect, depending on the condition and perception of the occupant. This framework is called SCREAM-PEH, meaning: Source/Concentration (or condition)/Risk score/Exposure/Action/Monitoring. The addition PEH is Prevention in the field of Environmental Health.

10.3 Recommendations

The recommendations are clustered per party involved in housing and research: researchers and consultants, housing managers and product manufacturers, occupants and policymakers at the national and local level.

Recommendations for research

a. Further development of the research field of healthy housing
- establish cooperation between housing managers and medical specialists and between researchers in the field of housing, maintenance and renovation with researchers in the field of environmental medicine, to create results that can be used in different professional fields;
- make environmental health a study topic at universities of technology;

- study the user-technique interaction of equipment in the house that requires control by occupants;
- study housing needs of the elderly, including mental aspects such as loneliness and self-neglect.

b. Validation of indicators
- create a dataset of monitored houses, with input from and access for other researchers;
- continue the study of indicators: collect field data on the relation between housing and health;
- develop process indicators for identification of problems and problem solving and that support healthy housing policies.

c. Perform studies on the perception of environmental quality
- how people perceive different chemical and physical conditions of air;
- the indoor concentration and inhalation rate of fine particles and their health effects;
- how to promote positive perceptions and the impact on health;
- how occupants adapt their behaviour to given conditions;
- the relevance of comfort for behavioural patterns and the relationship of comfort with health;

d. International housing
- establish exchange of health and housing research with other countries, to reduce health inequalities in European countries and in developing countries;
- create international housing associations to improve housing conditions where needed.

Recommendations for indoor environmentalists
- develop measures for risk ranking of housing health risk;
- integrate the health measure in a tool for evaluation of sustainable performance.

Recommendations for architects
- develop design processes and solutions for renovation;
- design for vulnerable people in general;
- redesign existing houses to meet the needs of the elderly with mobility impairment;
- design architecturally integrated hybrid ventilation solutions;
- apply ventilation openings in indoor dividing walls;
- redesign the bathroom to make the bathroom free of mould and safe against falling.

Recommendations for housing managers

- develop a labelling system for the performance quality of houses that includes health performance;
- develop sets of requirements (the brief) for concepts for healthy renovation and maintenance plans that meet specific general health needs: allergy-free, free of chemical pollutants, silent, safe and sustaining for those in need of care;
- develop the policy issue of matching of needs and performance at turnover and selling of houses;
- develop a policy to solve over-occupancy;
- apply smooth and easy to clean materials in bathrooms.

Recommendations for product manufacturers

- design burglar-, rain- and weatherproof and insect protecting large natural inlet openings for summer conditions and flush ventilation (climatic façade design);
- develop mechanical exhaust dampers with disposable and cheap fine dust filters;
- develop hybrid ventilation systems that can be applied in existing houses;
- develop ventilation systems with controllable inlet plus exhaust in each room;
- find simple solutions for clean air inlet in air polluted regions;
- develop a compact and health supporting appliance for nighttime rest (the sleeping machine) that contributes to reducing the pollution related to over-occupancy;
- set up a leasing system of mattresses (including bedding), to accelerate turnover of mite dust-infested bedding.

Recommendations for occupants

- test the health performance of the houses, remediate to prevent conflict or find a different house that supports the health needs;
- perform a safety check of the construction, the appliances and services of the house;
- replace mattresses and pillows of people with allergy to house dust mites;
- take an active role in filing complaints, in demanding for improvements and in communicating about the maintenance of the house by the owner or housing manager, or take action when home-owner;
- ventilate bedrooms during sleep at high volume and without heating the bedroom.

Recommendations for policymakers at the local level

- provide expertise and capacity to diagnose health related problems of housing and urban planning;

- enforce quality requirements by active control and interventions when standards are not met;
- take an active role in health performance evaluation of the housing stock;
- promote suitable housing for independent living elderly people.

Recommendations for the Ministry of Housing, Spatial Planning and Environment

- set standards for minimum ventilation on the basis of occupancy in bedrooms;
- regulate cross-ventilation;
- promote the enforcement of requirements, especially the performance of ventilation systems;
- provide better intervention capacity and knowledge for regional inspectors;
- create an organisation for troubleshooting on indoor environmental problems (free consults);
- set standards for noise level of essential technical installations indoors;
- reduce the maximum steepness of stairs;
- increase the quality standards for health performance of existing houses: acoustics, ventilation, safe water systems, thermal performance, draught free inlet and air circulation, standards for overheating, safety of stairs, surface materials in bathrooms;
- define a legal basis for labelling the health performance of houses (example: HHSRS in the UK), including penalties in the case of substandard conditions;
- develop demonstration projects: renovation for healthy housing and special needs;
- develop a policy for support of independent living elderly (boost activities);
- promote attention to over-occupancy.

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Summary

Health performance of housing: Indicators and tools

Human health is a condition influenced by many aspects: genetic predisposition, food and water, lifestyle, age and the physical and social environment. Outdoor hazards penetrate the house and add to the indoor hazards. The physical housing conditions and also occupant behaviour create health hazards. In maintenance policy and renovation projects, the opportunities to reduce health risks and adapt houses to the health needs of households are not used to their full potential. Health criteria were until recently poorly integrated into sustainable building, and some technical innovations to save energy are associated with health related complaints. Good diagnosis of environmental problems is often a bottleneck for home owners and housing managers. Better insight into health performance qualities and a clear framework and common language can improve health performance. The major question of the project is: What physical parameters and which type of occupancy and behaviour result in exposure to health risk and how can this risk be evaluated and reduced?

Background
The study is motivated by 1) improving the understanding of the relationship between housing, occupancy and health; 2) the development of instrumentation that will support occupants and housing managers in identifying health hazards and selecting the proper remediation measures; 3) the promotion of health-conscious maintenance and renovation; 4) the generation of ideas for user-friendly products, services and for integrated concepts for sustainable healthy housing and renovation and finally 5) to contribute to better matching of health-related housing needs and housing quality, by using information on housing health performance in the allocation of houses, both in the rented and in the owner occupied sector. These goals have shaped activities in the recent years that have contributed to results, but the thesis is shaped by more specific questions.

Research questions
The study deals with five research questions.

1. *What is the state-of-the-art knowledge about housing and health?*
Because the relationship between housing and health is complex and poorly understood, we will try to find more evidence in scientific literature and in field projects on this issue.

2. *How can we evaluate housing health performance?*
Making an inventory of indicators and of examples of health performance evaluation tools supports the development and implementation of performance evaluation tools.

3. How do occupants use the house?
The occupants' use of the house is in many ways in conflict with housing performance. By studying user behaviour, we can understand when the occupants' use is poorly adapted to the physical parameters and which conditions of the house are in conflict with the needs of the occupants.

4. Which physical housing conditions are associated with health?
The house has thousands of components, physical properties and user interfaces. It is important to know which features create health hazards. The main focus is on those components for which the housing manager/owner is responsible, because these components are part of the 'public' arena. The decorations and furnishings supplied by the occupant are part of individual lifestyles, but general interior elements like sofas and mattresses will be included in the study.

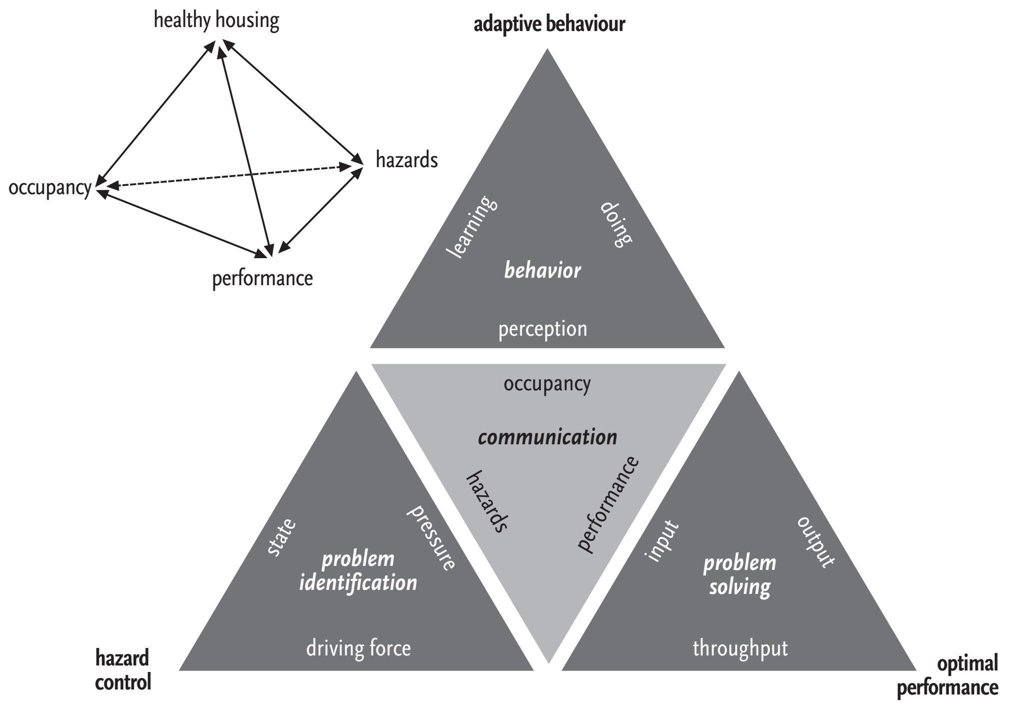
5. Which indicators mark the health hazards of housing?
The selection of simple and robust indicators is the major challenge of the research. A comprehensive set of indicators will facilitate health performance evaluation. Many research activities and chapters add indicators to the list.

The research project
The study is explorative and by no means epidemiological. The discipline is architecture, the main direction is building technology and with attention to occupancy. The research is an integrative explorative study of housing health hazards, with focus on the physical properties.

For the research a large amount of 'historical' data is used: reports and case descriptions collected in a period of many years. The study of houses, occupants and their health involves three fields: hazard identification, occupancy and performance quality, all in support of healthy housing. Communication about the performance quality and the roles and responsibilities of managers and occupants is important. The major research activity is the selection of indicators that mark the relationship between performance, occupancy and exposure to health hazards. The scientific claim is the selection of robust indicators that allow easy and fast evaluation of health risk conditions. These indicators are used in instrumentation for health performance evaluation. A tool was developed, tested and implemented during the research project and the experience is used to select a design strategy and to understand the strength and weaknesses of health performance evaluation in the context of technical housing management. The occupant has an important role in the research.

Framework
A framework of relations is constructed. The fields, the connections between the corners of Figure 1 and the dividing lines between the fields represent the

Figure 1 The main model of the relationships between occupancy, performance and hazards



three research topics: occupancy, housing performance and health hazards. Also, the steps from problem identification to problem solving, via behaviour and with communication to link the steps, represent the strategy used in the development of tools for performance evaluation.

Research methods

The research took a 'workbook' on the health performance of the Dutch housing stock in 2001 (How healthy is Dutch housing?) as the starting point for the PhD thesis. The book presents literature reviews and practical problems and ideas on the relationship between housing and health.

The research methods are 1) desk research, 2) field research and 3) laboratory experiments.

Statistical analysis leads to correlations between variables which are used to construct models of these relationships, models which in turn are used to make a qualitative selection of health performance indicators. The research follows both methods of explorative statistical analysis and qualitative methods of integrative descriptive analysis. Observations and interviews are the major methods used in the field. A balance between practical application and scientific research is typical for the methods used. Different projects have resulted in data on about 2,750 houses, with subsets of data used for the selection of indicators. 600 houses were visited, 500 of them were inspected per room while interviewing an occupant and 333 are put in a database with 165 variables used for data analysis. Other datasets were collected as well, in a range of different projects that together form the background of inspections results, observations and experience in problem solving and design processes.

Results

The results are presented per research question.

1. What is the state-of-the-art knowledge about housing and health?

Only one chapter (3) deals with personal health: the major known exposure values were linked to potential health effects. Other chapters focus on the housing conditions and occupancy patterns and behaviour that cause increased health risk: increase of the concentration of and exposure to those agents or to those conditions that are linked with health. There is much evidence on the relation between the environment and health in general and housing and health in particular. On the International Conference on Environment, Epidemiology and Exposure (AFSSET 2006) the state-of-the-art knowledge was presented. The latest findings on asthma point at the potential role of chemicals and especially plasticizers in surfacing materials and many consumer goods. New attention is to the potential role of bacteria in connection with mould as a trigger for respiratory effects. House dust mite is an established major marker and the focus is more on the study of remediation than on sensitisation. Many remediation measures have a minor effect, even when concentrations are effectively reduced in specific items of consideration. Either the exposure sources are abundant or the bodily responses are selective, so reduction of allergen dose is not in proportion with reduction in health effect.

In general, chemical exposures supposedly play an important role in the development of children, of which only very little is understood. Obesity, ADHD and many birth defects receive attention. Many researchers focus on formaldehyde, ozone, PAHs, plasticizers, heavy metals, lead and pesticides. Fine dust is the dominant topic nowadays and the evidence on the relationship with pulmonary disease, cardiac disease is well established, possibly even the relationship with cancer. The chemical content of dust and also the size distribution from ultra fine to coarse particles seems very important. Traffic exhaust fumes is of great concern, but also airborne dust that travels over hundreds of kilometres, from waste belts, polluted areas or from chimney stacks with trace metals such as zinc and cadmium. Flame retardants in domestic appliances are a concern. Nowadays the use of pesticides in households is much larger than in agriculture and the concentration can be high, even after cleaning the house, with potential serious effects on the development of children and the condition of adults. Lead has been banned effectively, but still with potential exposure from polluted soil and dust in the house (AFSSET 2006).

The research project does not contribute to new knowledge on the relation between housing and health, because this is not an epidemiological research.

Health complaints have resulted in inspected cases and the self reported health condition has pointed at certain performances in houses, but this type of information has no scientific value for strengthening the insight in the relation between housing and health. Insight was used to diagnose housing problems that can create hazards (that are related to certain health effects), not to study the direct dose-effect response.

2. How can we evaluate housing health performance?
Three decisions have influenced the development of performance evaluation strategies: the first decision was to make a distinction between the empty dwelling and occupancy. This decision makes it possible to discuss occupant behaviour as distinct from the quality of the building. The second decision was to see the house as a system of microclimates and to evaluate each room as a separate system. It highlighted the bedroom as a place of concern, a result that differs from the mainstream discourse about comfort in the living room and mould problems in the bathroom. The third decision is to focus on communication between the housing manager and the occupant. This decision is the consequence of dealing with occupant behaviour. Cooperation on risk reduction of the major hazardous environmental conditions that are a shared responsibility of the home owner (to improve the technical quality) and the occupant (to adapt behaviour to requirements of healthy housing) is essential for action taking. Communication serves the goal of creating awareness of the health performance problems, which is considered essential in change of behaviour and pro-activity to prevent problems.

The strategy of performance evaluation, the list of indicators and the Healthy Housing Checklist show how we can evaluate housing health performance and answer the research question.

3. How do occupants use the house?
Few occupants will perceive housing health risks, even when exposed to these risks. Some occupant categories are aware of risks but have no means to control them. Awareness of many kinds of environmental problems is created by the senses: smell, hearing, feeling, observation. Conditions that create health risk while senses do not give a warning signal must be identified on the basis of indicators. This result leads to simplification of certain indicators: e.g. focusing on existing mould, not on a risk that mould could grow; or: a given noise level is a hazard not on the basis of measured dB(A), but because occupants are aware of stress caused by noise, etc. Occupant behaviour expresses the identity of different types of households, different steps in the housing career, culture, condition and comfort needs. Comfort has great influence on behaviour: comfort optimising is an important motivation for ventilation, heating, cleaning habits, etc. Comfort optimising can conflict with healthy housing, for instance when fear of draughts limit the use of air inlet openings.

These dilemmas reveal conflicts with the user interface of technical services. Because it is hard to influence behaviour, the user-friendliness of building services is the key to solving these dilemmas.

Occupancy-related hazards deal with pollutant production, lack of ventilation, and poor control over the physical and social environment. Occupant-related pollution sources are:

- the use of gas ovens (or other fuels that emit into indoor environment);
- chemical emissions from decoration materials;
- emissions from cleaning materials, pesticides, fragrances, candles, incense, etc.;
- biological emissions, based on the age of the mattress, the type and humidity and cleanliness of surface (flooring) materials and other dust pockets and soft decorations;
- excessive moisture production without action to remove moisture;
- leaving visible mould as it is;
- pet keeping (animals with hairs or feathers);
- smoking in the house with other people present.

4. Which physical housing conditions are associated with health?

The physical properties related to air pollution are: emissions from crawl spaces, condensation and mould incidence, moisture balance and house dust mites, emissions from fuel-burning appliances, emissions from construction materials and ventilation services and the physical hazards caused by noise, extreme discomfort and personal injury. The building location, the construction, openings in the envelope and the technical services have a strong relationship to both technical and social noise and exposure to ambient air pollution. Many complaints point at physical conditions: discomfort from extreme temperature differences, draughts, extremely low or high humidity, lack of daylight and lack of contact with the outdoor environment. Some building parameters influence the perception of the social quality: trespassing, social control and privacy of outdoor space.

Construction methods and materials have developed step by step over the past one hundred years, and information about the building period indicates specific materials and construction details that, when recognised, make the identification of hazards easier. Of special interest is housing from the period 1960-1980 that is now under reconstruction and being renovated. In this building period, many small multifamily houses were created that do not meet the increased thermal and acoustic insulation standards any more. The poor sealing and thermal performance of the ground floor and inherent emissions from the crawl space still apply to a large number of houses. Condensation and mould occurrence is a major concern and is related to insulation quality.

Vapour transport from the wet bathroom or the living/kitchen requires optimal bedroom ventilation, which is a major problem: many occupants do not

Table 1 Inventory of the 10 major health issues

Condition (in order of priority)	Indicators of concentration or condition	Indicators of exposure risk
1. Poor ventilation (per room)	Services not working properly or not user friendly, low contribution by infiltration, barrier in the sequence inlet-overflow-exhaust	No services available or not permanently used and in combination with low infiltration rates
2. House dust mite and other biological allergens	Old mattress (>5 years, or >8 years with mite cover), pet with hairs or feathers, pests in the house	Present during vacuum cleaning, or moving around on carpet, old sofas with high allergen content, sleeping on old mattress, contact with pets
3. Chemical pollutants (from the building, decorations and housekeeping products)	TVOC: all sources including soft plastics, when new or in period of and shortly after application, or with high temperature	Low ventilation rate, present during and shortly after application of material and in hot periods, flueless gas fired appliances, leaky chimney
	CO, NO_2, SO_2: traffic or industrial activity, coal and oil burner, smoke, indoor combustion, geyser without exhaust duct	Outdoor level plus indoor activities, breathing rate for SO_2, tobacco smoking, long periods of use of geyser (showering)
	Heavy metals, toxic substances, lead, pesticides: use of persistent toxic materials (pesticides, flame retardants), lead pipes, air change rate during application	Low ventilation rate, being present during and shortly after application of material, disturbance of dust pockets, vacuum cleaning
4. Safety	Falls: available bars, signals, lighting, location of slippery rugs, loose wires Shock: visible open leads, loose connections Burns: surfaces >60°C Trespassing: lack of control, no alarm	Uneven levels, slippery floors, poor lighting, no bars Use of electrical appliances Hot surfaces not protected, use of hot water Poor locks and hinges, easy entrance route
5. Legionella	Water temperature range 25-55°C, buffer size and stagnancy of a few days or more	Taking a shower after stagnancy (especially not in own house)
6. Noise	Technical and social noise: distance to source opening in envelope, frequency, period of the day, type and level of noise	Being annoyed by noise, along road with heavy through going traffic, noise from indispensable appliances and without control, high level during quiet periods, high level from neighbours despite requests for turning down the level, disturbance at frequent intervals
7. Mould	Visible mould, hidden mould in cavities	Size and location of mouldy surfaces (bedroom, living room)
8. Particulate matter and radon	PM2.5 (traffic, industry): heavy traffic, wind direction, humidity (rain), keeping pets, tobacco smoke, radon (type and amount of stone, concrete, chinks in floor)	Within 300 m of busy traffic, in urban area, smoking indoors, pets indoors, concrete based building structure, low air change rate
9. Sustaining design	User-friendly for wheelchair and rollator, extra space for supporting equipment and helpers	Small dimensions of rooms and circulation areas, obstacles, no private outdoor area, not suitable for wheelchair, no visual contact through windows or 3 minute SOS service
10. Lack of control	Control of indoor climate in each room, control over privacy, safety and over proper maintenance	Stress, non-use of essential climate systems(ventilation), poor or missing control functions, no feedback on complaints, anxiety about suspected hazards

ventilate enough, the ventilation capacity is too low for two or more people. Natural ventilation, including cross-ventilation, is an indispensable feature in older houses. Infiltration supplements the ventilation and prevents different kinds of indoor air problems, especially in the living room. Problems occur in airtight houses with insufficient ventilation capacity.

The chimney-tied atmospheric central heat sources in the living room and flueless domestic water heaters are serious health hazards. Emissions from construction materials are likely to be low, due to strict source control requirements in building regulations except for radon. The emissions from occupancy-related materials are high, mainly during and shortly after application (decoration, renovation, cleaning). The acoustic quality represents a complex phenomenon. Technical solutions are often possible, but are expensive and the contribution to solving complaints is low. Extreme humidity levels are not a comfort or health issue and 'dry air' is often a misperception of polluted air in combination with emission peaks caused by high temperatures. Daylight and view are hardly a health issue in the housing stock, but they influence satisfaction with the house.

Safety is an important topic for the elderly. Except for stress, we know little of the health effects of privacy and trespassing.

Providing an answer to this research question has provided many results that can be applied in remediation and renovation practice and in evaluation tools.

5. *Which indicators mark the health hazards of housing?*
Three versions of the list of indicators are presented in this study:
- the list representing the state-of-the-art in 2005 in the Netherlands is the starting point and was completed to add social qualities (see Section 3.3);
- the indicators used in the Healthy Housing Checklist (see www.toetslijstgezondwonen.nl);
- a final list (see Subsection 8.3.3), which can be used in new tools for health performance evaluation.

A new list of indicators is developed, which can be used as a basis for tool designs, in support of performance evaluation by professionals and occupants. The major indicators of sources, conditions and exposure to hazards are summarized in Table 1.

Three priority indicators per room

Bedroom

1. poor permanent ventilation during sleep, caused by weakest part in chain inlet/overflow/exhaust;
2. old mattress (>5 years) with accumulated allergen material, or even mould;
3. mould at cold hidden places (bed, behind or in cupboard).

Living room
1. emission of moisture, radon and pollutants from the crawl space via chinks in the floor, around window systems, around pipes crossing the floor and in combination with moist soil;
2. over-occupancy and peak emissions from people and inherent activities;
3. tobacco smoke in the presence of non-smokers and infiltration of fine dust from outside.

Kitchen
1. emission from flueless gas heater, aerosol production from grilling and baking;
2. mould material from the bio-container and from the kitchen closet (opening to crawl space);
3. safety hazards from using knives, hot pans, steam, fire.

Bathroom
1. safety hazards of falling on slippery wet floor;
2. legionella from showerhead and in combination with buffer tank and low temperatures or stagnancy;
3. large mouldy surfaces.

Studio
1. chemical emissions from hobby activities, toys, office machines and with poor ventilation;
2. poor ergonomic layout and work position;
3. extreme conditions: too hot or cold, disturbance by noise.

Circulation
1. steep stairs with narrow foot space, slippery steps and inconvenient supports;
2. risk of falling because of obstacles and poor lighting;
3. poor sustaining design, limiting the use when disabled.

The research gives insight in how individual rooms function as a micro-climate and how these micro-climates are related. Specific construction details and surface materials are highlighted as building components that mark practical problems and associated health risks. Most indoor environmental problems are caused by a combination of technical failures and poor performance that limit the proper use of services, primarily ventilation. Moisture and mould are often caused by constructions sensitive to condensation even with 'normal' moisture production by occupants. Exposure to noise is an indication of poor insulation of the envelope and high noise levels from outdoor and indoor sources. The risk of injury is a normal consequence of using the house.

The study highlights safety topics that deserve better attention in building regulations: stairs and circulation spaces, kitchen layout and smooth surfaces, legionella explosions. Safety is an important topic, mainly for the young and for the elderly, for pregnant women and people doing non-routine do-it-yourself activities. Awareness of hazards is important, and a simple safety inspection can reveal important hazards. Surface layers and decoration materials define how easy it is to remove mould and bacteria and how much pollutants are emitted from these materials. With smooth and easy to clean materials used, any bathroom can be free from mould. House dust mite allergens can be found in any house and more where allergens accumulate, mainly in older mattresses.

Ventilation is poorly understood by occupants, and the technical services are not user-friendly, not burglar-proof or have a high noise level, while control functions of fine set points are often poor. Small inlet openings, especially line grates, are used for longer periods than large openings like sash windows or one-sided hinged windows. Individual mechanical systems are poorly used. The combination of use of low set point and reduced capacity brings the exhaust volume to 20-30% of the norm value, meaning that tenants must take active control to open windows or grates, which many do not take. Bedroom ventilation is a problem: more than 40% of occupants of inspected houses keep inlet openings closed in the winter, 20% in the summer.

Emission of moisture, mould fragments and radon from the crawl space still applies to a large number of houses. Emissions from fuel-burning appliances disappear when open atmospheric systems are replaced by closed balanced combustion-type systems. Many chimney-tied atmospheric central heat sources placed in the living room and flueless domestic water heaters in the kitchen create health hazards. Emissions from construction materials are likely to be low, due to strict source control requirements in building regulations, except for radon and radiation from stone-based materials. The emission from occupancy-related materials tends to be high in peak periods, for instance during painting, application of new carpets, surface decorations, furniture and use of new electronic appliances. Toxic and allergenic dust accumulates in carpets.

Overheating is a growing problem, especially in houses with heat recovery ventilation without 100% bypass in combination with poor flushing and cross-ventilation services. Draught problems can often be solved. Extreme humidity levels are no comfort or health issue and 'dry air' is likely to be polluted air that causes irritations, sometimes in combination with emission peaks caused by high temperatures.

The study on separate rooms makes the bedroom for two people the room that requires good health performance, because we spend one third of our lives in this room, with relatively little perception of the air quality we breathe while asleep. The bedroom is a favourable habitat for house dust mites and presents the hazard of chemical pollution. The kitchen comes second in terms of health risks, due to hazards that cause acute problems and peaks in pollutant concentrations. Occupants are exposed to flue gases, hot steam and hot surfaces, sharp utensils and even smoke or fire. The exposure to aerosols can reach high peaks. The bathroom is relevant for mould growth and as a source of dampness that influences the moisture balance in other rooms, mainly cooler bedrooms. A bathroom used for three or more showers a day is likely to develop mould problems and requires smooth surfaces from which mould can be wiped off. More ventilation and better heating are not effective against mould and above a certain number of showers a large absorption surface does not prevent mould growth. Laundry drying inside the house is a moisture source that equals the moisture production of showering. The living room shows quite a mixture of relatively low pollutant concentrations. Other functions of healthy housing tend to be overlooked: privacy, security, flexibility when disabled, etc.

The output of the research is a set of indicators to support the identification of health risks and the design of health performance evaluation tools.

Samenvatting

Gezondheidstoetsing van woningen: indicatoren en toetslijsten

Achtergrond
Kun je ziek worden van je woning? Hoe zit de relatie tussen wonen, bewoners en hun gezondheid in elkaar en kun je die relatie in je eigen woning vaststellen? Je kunt inderdaad ziek worden van je woning, maar de invloeden zijn vaak niet één op één, omdat allerlei omgevingskenmerken van invloed kunnen zijn. De invloeden komen door blootstelling op alle plaatsen in de omgeving, op school, kantoor en in de bus of trein, op de sportschool en sauna, en ook thuis. Bovendien is gezondheid ook afhankelijk van aanleg, voedsel en gedrag. We besteden gemiddeld wel de meeste tijd thuis en bovendien ondernemen we thuis een grote variatie aan activiteiten die risico geven op persoonlijke ongevallen, op blootstelling aan gevaarlijke stoffen en aan hinder. De risico's kunnen door fysieke omgevingskenmerken worden veroorzaakt of verhevigd. De kans dat er iets gebeurt hangt ook van de bewoners af: hoe voorzichtig deze zijn, hoe ze de woning gebruiken, of ze voldoende ventileren en schoonmaken en ook of ze medicijnen of alcohol en verdovende middelen gebruiken.

Onderzoeksvragen
Het onderzoek naar gezond wonen heeft als doel om de relatie tussen de woning, de bewoning en gezondheid beter te begrijpen en om instrumenten te ontwikkelen die bij woningbeheer en renovatie ingezet kunnen worden, waarbij kansen worden benut om gezond wonen te bevorderen. De centrale onderzoeksvraag is: Welke technische woningkenmerken en kenmerken van bewoning en bewonersgedrag veroorzaken blootstelling aan gezondheidsrisico en hoe kan die blootsteling aan risico worden getoetst? Het onderzoek is gericht op het beantwoorden van vijf onderzoeksvragen:

1. Wat is de stand van zaken betreffende kennis over de relaties tussen wonen en gezondheid?
Omdat de relatie tussen wonen en gezondheid complex is, wordt de wetenschappelijke literatuur bestudeerd om bestaande kennis te verzamelen.

2. Hoe kan de gezondheidsprestatie van het wonen getoetst worden?
Door indicatoren en voorbeelden van toetsen te verzamelen kan een goed beeld worden gevormd van de positionering van een nieuw instrumentarium.

3. Hoe gebruiken bewoners de woning?
Bewonersgedrag strookt vaak niet met de woningkenmerken. Door bewonersgedrag te bestuderen hopen we te begrijpen wanneer het gedrag in conflict is met de woningkenmerken en andersom, welke woningkenmerken niet voldoen aan de behoeften van de bewoners.

4. Welke technische woningkenmerken wijzen op verhoogd gezondheidsrisico?
De woning bestaat uit duizenden componenten en eigenschappen en ge-

bruiksaspecten, die worden getoetst op het veroorzaken van gezondheidsrisico. De nadruk ligt op dat deel waarvoor een eigenaar verantwoordelijk is, iets minder nadruk wordt gelegd op inrichting en meubilering, maar algemene kenmerken van de inrichting worden wel meegenomen.

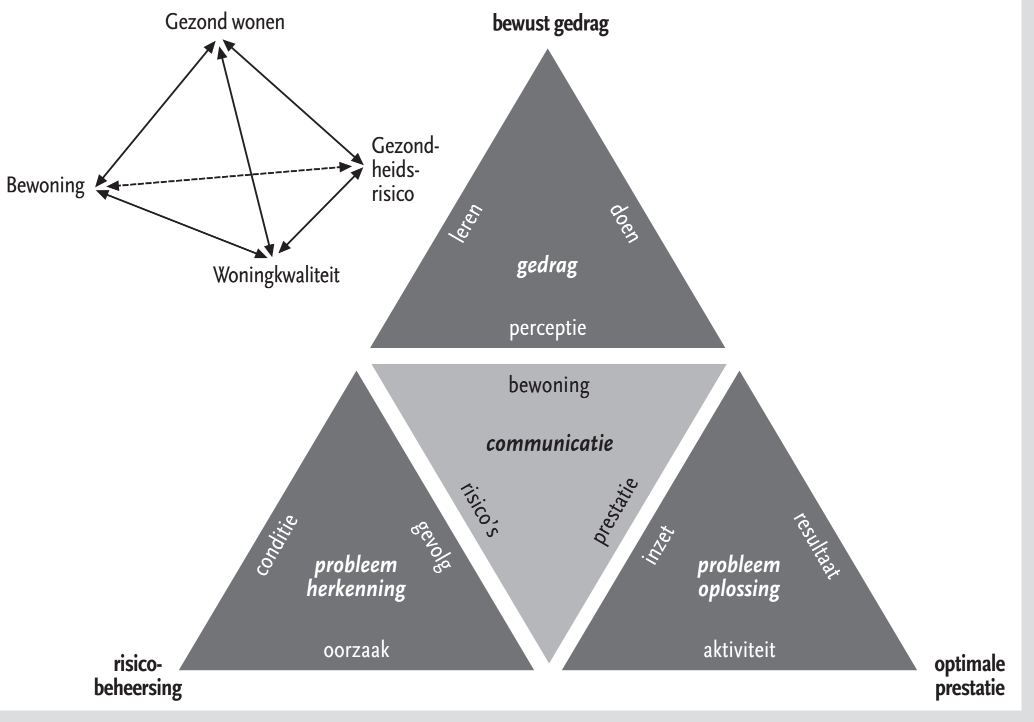
5. *Welke indicatoren markeren de gezondheidsrisico's?*
Een lijst van indicatoren wordt opgesteld om de invloed van woning- en gedragskenmerken op gezondheidsrisico snel te kunnen beoordelen.

Het onderzoeksproject
Het onderzoek is explorerend van karakter en geenszins een epidemiologische studie. Het wordt ondernomen binnen het vakgebied bouwkunde en daarin vooral de bouwtechniek en geeft aandacht aan bewoningsaspecten. Het onderzoek integreert en verkent allerlei oorzaken van gezondheidsrisico, bezien vanuit technische gebouwkenmerken. Een grote hoeveelheid gegevens werd gebruikt: adviesrapporten en woningopnamen die over een periode van meer dan 10 jaar werden opgesteld of uitgevoerd. De analyse richt zich op drie thema's: risicoverkenning, bewoning en prestatie in relatie tot gezond wonen. De communicatie over de woningkwaliteit en over de taken en verantwoordelijkheden van de eigenaars en van de bewoners speelt een belangrijke rol. De uitdaging van het onderzoeksproject is het kiezen van robuuste indicatoren. Er wordt een lijst ontwikkeld die compleet is, om alle belangrijke gezondheidsaspecten in een toets te kunnen verwerken. Allerlei onderzoeksactiviteiten en bijna ieder hoofdstuk levert extra indicatoren op. Er is een gezondheidstoets ontwikkeld, getest en toegepast en de ervaringen zijn gebruikt om een strategie voor dergelijke toetsen te ontwerpen en om de sterke en zwakke kanten van gezondheidstoetsing in het kader van technisch woningbeheer te leren begrijpen.

Raamwerk
De relaties van de belangrijkste onderwerpen in het onderzoek zijn in een relatieschema geplaatst (zie figuur 1). De linkerfiguur geeft de hoeken van de piramide weer, de rechterfiguur de verbindingslijnen (relaties). De velden gedrag en probleemherkenning en probleemoplossing raken aan elkaar, met communicatie tussen deze velden als basis.

Onderzoeksmethoden
Startpunt was het werkboek *Hoe gezond is de Nederlandse woning*, dat in 2001 werd uitgegeven. Dit boek geeft een literatuurverkenning en praktijkproblemen en ideeën over de relatie tussen wonen en gezondheid. De onderzoeksmethoden in het proefschrifttraject zijn literatuuronderzoek, veldwerk en laboratoriumexperimenten. Bij de analyse van gegeven is statistiek gebruikt om verbanden tussen variabelen te zoeken, waarmee relatiemodellen zijn ge-

Figuur 1 Raamwerk van relaties tussen bewoning, woningkwaliteit en gezondheidsrisico



bouwd, die hielpen bij het kiezen van bruikbare indicatoren. Het onderzoek combineert kwantitatieve statistische methoden met kwalitatieve integrale beschrijvende methoden, omdat die combinatie het best past bij de specialistische kennis die is opgedaan in de vele jaren van werkzaamheden in de praktijk van woningbeheer en probleemoplossing rond bouwfysische-, onderhouds- en binnenmilieuproblemen. Evenwicht tussen theorie en praktijk kenmerkt de studie. Veldwerk omvat technische woningopnamen en interviews met bewoners en er zijn gegevens beschikbaar van ongeveer 2.750 woningen, waarbij door de auteur 600 woningen werden bezocht en daarvan 500 per kamer, samen met de bewoner, zijn geïnspecteerd. De opnamerapporten zijn niet allemaal per woning uitgewerkt, omdat sommige bezoeken dat niet vereisten, maar 333 woningen zijn in een gegevensbestand verwerkt, met daarin gegevens over maximaal 165 variabelen per woning (maar meestal minder). Verschillende andere onderzoeksprojecten leverden ook bruikbare gegevens op: de gegevensbestanden vormen samen met de ervaringen dankzij observaties en conflictbemiddeling en advieswerk bij renovatieprojecten een schat aan gegevens op. Deze opgebouwde deskundigheid verklaart de keuze voor integraal verkennend onderzoek.

Resultaten

1. Wat is de stand van zaken betreffende kennis over de relaties tussen wonen en gezondheid?

Alleen hoofdstuk 3 behandelt gezondheidsaspecten, andere hoofdstukken leggen de nadruk op technische - en bewoningskenmerken die invloed hebben op gezondheid, zonder gezondheid van bewoners te onderzoeken. Hoofdstuk 3 verkent bestaande literatuur over wat is aangetoond betreffende de relatie wonen en gezondheid. Er zijn veel gegevens beschikbaar. Het meest actuele overzicht is ontleend aan een congres in september 2006 in Parijs over omgeving, epidemiologie en blootstelling (AFSSET 2006). De laatste inzichten over astma wijzen op mogelijke relatie met blootstelling aan bepaalde weekmakers in plastics: die komen in heel veel producten voor, ook in behang en vloerbedekking en speelgoed en zelfs in de inhalator die een astmapatiënt gebruikt. Er is aandacht voor de rol van bacteriën in relatie tot allergie, bijvoorbeeld door de gecombineerde effecten van schimmel en bacteriën. Huisstofmijten blijven de onderzoekers bezig houden, waarbij tal van onderzoekers pogen om het effect van saneringsmaatregelen te valideren, omdat hierover verwarrende berichten naar buiten komen. Afname van de allergeenconcentratie is niet evenredig met afname van luchtwegklachten. Chemische stoffen spelen naar verwachting een belangrijke rol in de ontwikkeling van kinderen naar volwassenheid, en van slechts zeer weinig stoffen is iets over de invloed bekend. Onderzoekers proberen de ontwikkeling van zwaarlijvigheid, van ADHD en allerlei geboorteafwijkingen in verband te brengen met chemische verontreinigingen. Formaldehyde, ozon, polycyclische aromatische koolwaterstoffen (PAK's) waaronder weekmakers, zware metalen, lood, insectenverdelgers genieten volop aandacht van onderzoekers. Fijn stof staat in het middelpunt van de belangstelling en de bewijslast over de invloed op hart- en vaatziekten, op longziekten en mogelijk kanker stapelen zich op. De chemische samenstelling van het stof en ook de grootteverdeling van de deeltjes lijken van belang te zijn. Uitlaatgassen van auto's veroorzaken gezondheidseffecten, maar ook luchtvervuiling die over vele kilometers wordt verspreid, bijvoorbeeld nikkelstof of cadmiumstof uit hoge schoorstenen en rook van grote bosbranden. Loodconcentraties in het milieu nemen af, maar kunnen in het lichaam van onderzochte personen nog steeds toenemen. Veel stof dat zich in woningen genesteld heeft bevat allerlei verontreinigingen die gevaar voor de gezondheid kunnen opleveren. Tot zover de stand van zaken op de conferentie (AFSSET 2006).

Het proefschrift draagt niet verder bij aan kennis over gezondheid, omdat gezondheidsinformatie nauwelijks verwerkt is: de nadruk ligt op de woning zelf en op de bewoning, niet op de bestudering van het effect van blootstellingen op de gezondheid.

2. Hoe kan de gezondheidsprestatie van het wonen getoetst worden?

Drie keuzes zijn van grote invloed geweest op de resultaten van het onderzoek. De eerste keuze betrof het onderscheiden van de 'lege' woning en bewoning. Deze keuze leidde tot beter onderscheid naar de invloed van woningkenmerken, respectievelijk van bewonersgedrag op problemen met het binnenmilieu. De tweede keuze was om de woning te zien als een verzameling binnenklimaten voor iedere ruimte afzonderlijk. Dit heeft in combinatie met de blootstelling per kamer een nieuw kijk gegeven op de woning, met meer aandacht voor de slaapkamer ten opzichte van de badkamer en de woonkamer. De derde keuze was om de bewoners centraal te stellen en problemen niet alleen te zien als technische problemen, maar mede als problemen die voorkomen uit (gebrek aan) communicatie: het ontkennen van problemen, het niet willen toegeven aan terechte klachten, het voeren van strijd om maatregelen af te dwingen en tevens het aanpakken van woongedrag dat door verhuurders verantwoordelijk wordt gehouden voor problemen. Communicatie en van daaruit overleg en onderhandeling over verbeteringen, is de essentie van een beheerproces dat (mede) gericht is op gezond wonen.

Vanuit het principe dat (eigenaar-)bewoners en verhuurders leren door te doen, dat inzicht actie stimuleert en dat beter overleg over klachten of risico's bijdraagt aan de juiste keuze van maatregelen, is onderzoek gedaan naar instrumenten om de gezondheidsprestatie van individuele woningen te evalueren. De eisen waaraan zo'n 'gezondheidstoets' zou moeten voldoen zijn geformuleerd en tal van voorbeelden zijn onderzocht naar opzet, methode en nut voor de praktijk. Ook is dankbaar gebruik gemaakt van een drietal toetsen die in het kader van dit onderzoek samen met anderen zijn ontwikkeld: de Toetslijst Ventilatie met de Woonbond, de EPA-plus-gezondheidstoets samen met TU Eindhoven en de Woonbond en vervolgens de Toetslijst Gezond en Veilig Wonen samen met SBR en de Woonbond. In de Toetslijst Gezond en Veilig Wonen zijn de belangrijkste resultaten van het onderzoek naar gezond wonen verwerkt. De toets is uitgebracht (in september 2005, via www.toetslijstgezondwonen.nl) in een versie voor consumenten en in oktober 2006 in een versie voor professionals (uitgave SBR). De ervaringen die zijn opgedaan in de testfasen met deze toetslijsten hebben geholpen om de lijst van indicatoren te verscherpen, te verkorten en gebruiksvriendelijker te maken.

Gezond en veilig wonen is ingedeeld in thema's, die ieder een kwaliteit van de woning laten zien. Niet alle kwaliteiten zijn belangrijk voor iedereen. Iemand die niet allergisch is, kan zonder problemen in een stoffig huis wonen. Iemand die overgevoelig is voor geluid stelt hoge eisen aan de omgeving en aan geluidsisolatie. Zorg betekent voor een jonge dynamische bewoner met een sportblessure iets anders dan voor een eenzame oudere met chronische mobiliteitsbeperking. De thema's zijn luchtkwaliteit met daarin allergenen, chemische stoffen, luchtverversing, dan het thermisch comfort, geluid en veiligheid.

De ontwikkelde strategie voor gezondheidstoetsing, de lijst met indicatoren en de Toetslijst Gezond en Veilig Wonen vormen samen antwoorden op de onderzoeksvraag.

3. Hoe gebruiken bewoners de woning?

Veel bewoners zijn zich niet bewust van de gezondheidsaspecten van hun woning en woongedrag. Maar als een bewoner wel vragen heeft, dan is de kans om in te grijpen vaak gering. De zintuigen spelen een belangrijke rol: zien, horen, ruiken en voelen. Stank geeft via de neus een waarschuwing voor mogelijke gevaren. Kenmerken die niet door zintuigen worden opgemerkt moeten via informatie, dus via indicatoren bewust worden. De zintuigen maken gezondheidstoetsing gemakkelijker: zo hoeft niet het risico op schimmelvorming door een koudebrug te worden beoordeeld, maar gaat het meer om zichtbare schimmel. Ook is het niveau van geluidsisolatie pas van belang als iemand hinder heeft en doet die informatie niet ter zaken voor iemand die geen buren heeft en in een stille omgeving woont. Bij bewoning is het nuttig om onderscheid te maken naar de grootte en samenstelling van het huishouden, de fase in de wooncarrière, de culturele achtergrond, de gezondheidsconditie en comfortbehoeften. Gezondheidstoetsing begint bij de bewoner. Comfortoptimalisatie heeft veel invloed op bewonersgedrag: soms ventileert een bewoner te weinig vanwege tochtgevoel, of omdat het dan te koud wordt, om omdat er dan lawaai van buiten binnendringt. Daarom worden apparaten of systemen stelselmatig verkeerd gebruikt: de mechanische ventilatie blijft op de laagstand vanwege lawaai, het raam blijft dicht vanwege inbraakrisico, de douche wordt nat achtergelaten omdat het strippen van de natte tegels moeite kost.

Bewoning is vanzelfsprekend met gezondheidsrisico verbonden, bijvoorbeeld door vervuilende activiteiten, denk aan:

- het gebruik van een gasoven of open haard of houtkachel;
- de emissie van vinyl behang of zeil op de vloer, of uit chemisch gereinigde en gesteven gordijnen;
- allergenen bevattend stof uit het matras, kussens, de vloerbedekking;
- vochtproductie door douchen en het drogen van de was binnenshuis;
- schimmels laten zitten en vette lagen niet tijdig schoonmaken;
- het houden van huisdieren;
- roken.

Soms klampen bewoners zich vast aan een bepaalde verklaring van oorzaak en gevolg en worden letterlijk ziek als men aan de 'oorzaak'-omstandigheid wordt blootgesteld. Chemische overgevoeligheid past in die categorie, maar ook geuren die hoofdpijn veroorzaken, tabaksrook die de keel snoert, of tocht die angst voor spierpijn veroorzaakt. Vaak zijn effecten (nog) niet voldoende bewezen en de opvatting is dat ook perceptie een gevoel van ziek zijn kan veroorzaken.

4. Welke technische woningkenmerken wijzen op verhoogd gezondheidsrisico?
De meeste woningen passen over het algemeen goed bij de dagelijkse behoeften van de bewoners, maar er zijn omstandigheden, bijvoorbeeld bij ziekte of een handicap, dat bepaalde woningkenmerken het ongemak vergroten. Voor kinderen zijn speciale veiligheidsmaatregelen nodig, voor alleen wonende ou-

deren, die vaak meerdere gebreken ontwikkelen, zijn voorzieningen nodig die het bewegen ondersteunen of die hulpverlening mogelijk maken. Een woning kan in zekere mate aangepast worden aan de behoeften die bewoners vanwege hun gezondheidstoestand hebben. We kunnen dan denken aan mensen die luchtweggevoelig zijn en een woning nodig hebben met een goede luchtkwaliteit, aan mensen die slecht tegen geluidhinder kunnen en een stille omgeving verlangen, aan teveel mensen in kleine woningen zonder privacy, aan mensen die slecht ter been zijn en gelijkvloers op de begane grond moeten wonen, of in een woning die geschikt is voor rolstoelgebruik. Hier ligt de eerste belangrijke relatie tussen wonen en gezondheid: individuele behoeften van bewoners verwijzen naar specifieke eisen aan de woonomstandigheden en als die eisen niet worden gehonoreerd dan is van gezond wonen geen sprake.

De tweede belangrijke relatie tussen wonen en gezondheid wordt gevormd door omstandigheden die het woongenot schaden en verantwoordelijk kunnen zijn voor het ontstaan van ziekte. Acute effecten komen door ongevallen: uitglijden over een gladde vloer, van een trap vallen, met de vingers bekneld raken tussen een deur, branden aan heet water, etc. Ongevallen kunnen het gevolg zijn van risico's die we dagelijks gewend zijn te nemen, maar waarbij het risico wel samenhangt met woningkenmerken. Vaak nemen de risico's toe bij het ouder worden of als goed zicht op obstakels ontbreekt. Andere acute effecten noemen we calamiteiten, waarvan de effecten vaak onherroepelijk zijn: schade aan organen of dood door koolmonoxide vergiftiging, legionellabesmetting, verstikking door rook, verbranding, elektrocutie, maar ook allergisch worden of chronische vermoeidheid ontwikkelen. In de meeste gevallen is er echter sprake van minder ernstige effecten, waarbij bewoners geen acute klachten hebben of deze niet toeschrijven aan het wonen. Koolmonoxide kan bij langdurige lage blootstelling vage klachten geven: minder fit, hoofdpijn en op langere termijn een zwakkere gezondheid. Als een legionellabesmetting minder ernstig is en Pontiackoorts veroorzaakt, wordt vaak gesproken van een zomergriepje. Een beetje rooklucht van de open haard of de barbecue is juist lekker en bijna niemand denkt na over de giftige stoffen die men inademt.

Er zijn honderden vervuilende stoffen en vormen van hinder, waarbij de gezondheidseffecten alleen vermoed worden, en waarbij een voorzorgprincipe gehanteerd wordt. Soms duiden overgevoelige personen, die wel duizend maal gevoeliger zijn dan een gezond iemand, op onvermoede kenmerken, zoals het geval is bij overgevoeligheid voor formaldehyde of voor elektromagnetische straling.

5. *Welke indicatoren markeren de gezondheidsrisico's?*

Het onderzoek neemt de indicatoren die anno 2004 in Nederland als 'standaard' werden gehanteerd als uitgangspunt. Daarna volgde de lijst die voor de Toetslijst Gezond en Veilig Wonen werd geselecteerd en waaraan veel verkennend onderzoek vooraf ging. Vervolgens is literatuur bestudeerd en zijn meet-gegevens van woningen geanalyseerd. Op basis hiervan zijn parameters gekozen en zijn modellen ontwikkeld, die de complexe relatie tussen vervuilingsbronnen en gevaren, tussen ventilatie en schoonmaken en blootstelling, etc. weergeven. De modellen laten zien dat sommige indicatoren in vergelijking tot andere indicatoren soms als dominant en soms als minder belangrijk naar voren komen; soms moeten indicatoren ter plaatse beoordeeld worden, terwijl andere indicatoren verwijzen naar kenmerken die in bijna iedere woning voorkomen en dus als vast gegeven kunnen worden meegenomen. Modellen zijn opgesteld voor blootstelling aan schimmels, huisstofmijtallergeen, legionella, fijn stof en vluchtige organische verbindingen, allergenen van huisdieren en ook voor blootstelling aan geluidshinder, comfortproblemen, onveiligheid en sociaal isolement. Deze modelvorming leidt tot een vernieuwde lijst van indicatoren. Vooral de modellen die met luchtkwaliteit te maken hebben zijn verdiept via statistische analyse van het gegevensbestand van 333 woningen en via proefnemingen. Ten slotte zijn de indicatoren geplaatst in de specifieke omstandigheden per kamer, omdat sommige risico's verbonden zijn aan de specifieke activiteiten, bronnen en de blootstelling in specifieke ruimten. De set van indicatoren is ingekort, omdat een korte lijst die snel tot resultaten leidt, naar verwachting beter toegankelijk is. De belangrijkste indicatoren zijn in het volgende schema samengevat. Daarna zijn belangrijkste drie indicatoren per kamer weergegeven.

Top-drie van indicatoren per kamer

Slaapkamer

1. geringe permanente ventilatie tijdens het slapen door zwakste schakel: luchttoevoer en luchtafvoer;
2. oud matras (ouder dan 5 jaar) met daarin veel opgehoopte allergenen van de huisstofmijt;
3. schimmel door permanent hoge vochtigheid op de relatief koudste plaatsen.

Woonkamer

1. emissie van vocht, radon en vervuilde lucht uit de kruipruimte via kieren in de vloer en rondom kozijnen, met name bij houten vloeren op houten balklaag, met verwarmingsleidingen in de kruipruimte en op een vochtig bodempakket;
2. overbezetting met piekvervuiling ten gevolge van mensen en daarmee verbonden woonactiviteiten;
3. tabaksrook of bij niet-roken: fijn stof van buiten in combinatie met fijn stof van binnen.

Keuken

1. emissies van afvoerloze geiser, maar ook de verspreiding van aerosolen door het braden, bakken en frituren en van vuile oppervlakken;

Tabel 2 Toptien van blootstellingrisico's aan luchtvervuiling en gevaren binnenshuis

Conditie	Indicatoren van concentratie of prestatie	Indicatoren van verhoogd blootstellingrisico
1. Geringe ventilatie (per kamer)	Voorzieningen hebben onvoldoende capaciteit of zijn niet goed bruikbaar, weinig correctie door infiltratie of in de reeks toevoer/overstroom/afvoer is een knelpunt aanwezig	Geen ventilatiemogelijkheid aanwezig, of niet permanent in gebruik in combinatie met kierdichting
2. Stof van huismijt, huisdieren en ongedierte	Oud matras, huisdieren of ongedierte aanwezig	Aanwezigheid tijdens stofzuigen, opdwarrelend stof in bed, door lopen en zitten, contact met huisdieren, veel ongedierte (muizen, kakkerlakken)
3. Chemische verontreiniging (van het gebouw, de inrichting en huishoudelijke artikelen)	Totaal aan vluchtige organische verbindingen: alle mogelijke bronnen inclusief verf, zacht plastic of schuim, in de periode kort na verwerking of aanschaf, en tijdens hoge omgevingstemperatuur CO, NO_2, SO_2: verkeer, industrie, verbrandingsproducten, tabaksrook, afvoerloze geiser, ventilatie tijdens gebruik Toxische stoffen inclusief zware metalen, lood en verdelgingsmiddelen: lood, brandvertragers, permanent ventilatievoud	Hoge concentratie bij laag ventilatievoud en hoge blootstelling bij aanwezigheid tijdens en in dagen (soms weken) na de verwerking van emissiebronnen, afvoerloze apparaten of lekkage schoorsteen of rookgasafvoer Buitenlucht plus bijdrage van binnenmilieu, activiteitenpatroon (hinder van SO_2 bij intensief bewegen), roken, gebruik geiser voor douchen Laag ventilatievoud, aanwezigheid gedurende verwerking, verstoring van stofnesten, stofzuigen, blootstelling in babykamer
4. Veiligheid	Vallen: handgrepen, waarschuwing, verlichtingsniveau, losse kleedjes, losliggende snoeren Schok: open elektriciteitspunten verbranden aan hete vlakken en water Inbraak: geen beveiliging, toegankelijk	Hoogteverschillen, gladde vloeren, slecht zicht op obstakels, geen leuningen Gebruik van slecht onderhouden elektrische apparaten Niet afgeschermde kachel, erg heet water Slecht hang- en sluitwerk, geen zicht
5. Legionella	Voorraadvat met temperatuur <55 °C en geen gebruik gedurende minstens drie dagen	Douchen, vooral in andermans huis
6. Geluidsoverlast	Technische en sociaal lawaai: afstand, noodzaak om via gevel te ventileren, tijdstip, type en duur van de geluidsoverlast	Bewoner ervaart hinder, bij druk verkeer, last van apparaten die niet uit kunnen, overlast 's nachts of op rustige dagen, burenlawaai waartegen niks te doen is, vaak overlast
7. Schimmel	Zichtbare schimmel en onzichtbare, maar voorspelbare schimmel (stank)	Plek en grootte van levend en dood schimmelmateriaal
8. Fijn stof en radon	Verkeer, industrie, steenachtige bouwmaterialen, tabaksrook	Hoge verkeersdrukte vlakbij, in rook van industrie, steenachtige bouw en geringe permanente ventilatie, roken in huis, huisdieren
9. Aangepast bouwen	Gebruiksgemak voor rolstoel, rollator, scootmobiel, bewegingsruimte in slaap- en badkamer bij bedlegerigheid	Geringe afmetingen van verkeersruimte en kamers, obstakels, geen private buitenruimte, geen SOS-hulpfunctie of oogcontact via raam
10. Individuele controle	Regelbaarheid binnenklimaat, afsluitbaarheid vanwege privacy, veilige afsluitbaarheid en invloed op onderhoudskwaliteit	Geen invloed op klimaatinstallatie, gebrekkige ventilatieregeling, geen gehoor bij klachten over beheer, ongevalrisico of onbekende vervuilingsbronnen

2. schimmels uit de biobak en via de keukenkastjes en openingen in de vloer uit de kruipruimte;
3. ongevalrisico van snijden, branden, vallen.

Badkamer
1. uitglijden en vallen op gladde vloer;
2. legionella uit de douchekop en in naar gelang de warmwater buffervoorraad groter is;
3. levende of dode schimmels op wanden en plafond.

Werkkamer of hobbykamer
1. chemische emissies (het totaal aan vluchtige organische verbindingen) door kluswerk, hobby, speelgoed, apparatuur in combinatie met slechte ventilatie;
2. lichamelijke problemen door slechte ergonomie met kans op ongevallen;
3. stress en concentratieproblemen door comfortproblemen: te koud of te warm, tocht en door verstoring (geluid, privacy).

Verkeersruimten
1. steile trappen met weinig voetruimte en weinig ondersteuning;
2. hinder van obstakels in loopruimten bij slechte verlichting;
3. ontoegankelijkheid bij verminderde mobiliteit, in combinatie met te weinig aanpassingen door middel van hellingbanen, leuningen of handgrepen.

Schimmel komt nog vrij algemeen voor en veroorzaakt naar verwachting gezondheidsrisico, hoewel over de omstandigheden van blootstelling en gezondheidsschade weinig bekend is. Huisstofmijtallergenen en daardoor luchtwegirritaties komen waarschijnlijk in een kwart van alle woningen voor. Het matras is de bron en tevens de sleutel tot vermindering van de blootstelling, maar zachte vloerbedekking, zitelementen en bekleding zijn mede oorzaak van opdwarrelend stof met daarin allergenen. Stofzuigen geeft een blootstellingpiek, zich omdraaien in bed ook. Schadelijke organische verbindingen komen in pieken vrij bij schilderwerk, schoonmaken en in een periode na gebruik van nieuwe inrichtingsmaterialen. De babykamer dient daarom bij voorkeur enkele maanden voor de geboorte heringericht te worden, met permanent veel ventilatie. Radon kan als een permanente vervuiling beschouwd worden. Legionella is ondanks het verlies van aandacht nog steeds een groot risico, ook in individuele woningen met een voorraad warm water, als de temperatuur in delen van het vat of tijdelijk niet warm genoeg is (beneden 55°C). Het risico is groot bij douchen na een vakantie vanaf een paar dagen. Geluid is vooral een comfortprobleem dat het gedrag beïnvloedt en mede daardoor een te lage (mechanische) ventilatie veroorzaakt, als er te weinig goede natuurlijke ventilatiemogelijkheden zijn. Het risico van persoonlijke ongevallen blijft hoog, ondanks veiligheidsadviezen. Hulpmiddelen zoals beugels kunnen de veiligheid verhogen, met name voor ouderen. Voor ieder die gezond wonen wil optimaliseren is het advies: toets de woning en onderneem actie om de kwaliteit te verbeteren.

Het onderzoeksproject is uitgevoerd binnen het Centre for Sustainable Urban Areas (SUA) van de TUDelft. Vanuit het Onderzoeksprogramma Innovatief Ruimtegebruik, waarin samen met Stichting Habiforum wordt geparticipeerd, kwam een belangrijke financiële bijdrage. In 2003 werd het onderzoek opgenomen in het samenwerkingsverband Corpovenista, waarin 8 grote woningcorporaties, Aedes en de Universiteit van Utrecht en Amsterdam participeren. Er ontstond een directe relatie tussen theorie en praktijk, doordat voor SBR en Habiforum vakgerichte publicaties en toetslijsten werden opgesteld, terwijl de wetenschappelijke verdieping zich richtte op de selectie van indicatoren van de relaties tussen wonen, bewoning en gezondheidsrisico.

Appendix 1 Inspection of variables and interview protocol (abridged)

Name, address:

Year of inspection:

Month of inspection:

Items	Observations 1	2	3	4	5
Outdoors, occupants, general information about the house					
location of house	lively urban	quiet neighbourhood	rural	other	
traffic, number of cars in 200 m circle	busy, throughtraffic	busy neighbourhood	quiet, no throughtraffic	other	
commercial, agricultural activities	irritant smell	sometimes smell	no effects	other	
commercial under or next to house	no	cleaners, print shop	garage, gas station	snackbar, restaurant	other
connection to garage	no	connected to house	under house	other	
birds' nests (pigeons)	nuisance of birds	no birds	other		
smell, location of sources	surrounding area	neighbours	own house	no smell	other
smell, effect on health	head ache, nausea	irritation	bearable effect	no effect	other
power lines, electric trains	<25 m distance	between 25-50 m	between 50-200 m	none, larger distance	
powerful communication antennas	<25 m distance	between 25-50 m	between 50-200 m	none, larger distance	
soil type	sand, peat	clay	rock	other	
soil pollution	yes, limited use	considered safe	none	other	
water level under the house	humid crawl space	dry crawl space	no crawl space	no information	other
treatment of soil in crawl space	foil on soil	floating insulation	foam concrete, shells	none, not functioning	other
occupants average day/night	number				
adults, age group >12	number				
children <12	number				
pets	heary, feather	other type of pets	none		
number of pets	number				
location of bedding/sleeping place	outdoors	living area	sleeping area	all over house	other
years since moving into this house	number of years				
laundry including handwash/week	number				
laundry drying indoors	lines living areas	lines bathroom	condensating dryer	dryer exh, attic	other
number of cigarettes smoked indoors/day	number per day				
person with airway problems	yes	no			
housing needs, medical advice	yes, see description	no			
health-related renovations/decorations	smooth surfaces	yes, mattress covers	yes, mob. /stair lift	other	none
renovation type performed	comfort, minor	comfort and health	comfort and energy	maintenance	none
renovation, how many weeks ago	going on	<4 weeks	5-12 weeks	>12 weeks	other
renovation, location	living room	bedroom used	several rooms inside	not indoors	other
building period (year)	number				
building type	single-family	multifamily low	multifamily high-rise	other	

Items	Observations 1	2	3	4	5
Outdoors, occupants, general information about the house					
number of rooms (occupied spaces)	number				
location of dwelling	free	half free/head block	in between	base, roof	other
building sector	rental	owner			
type of construction: main floor area	stone	wood	other/combination		
type of construction: dividing walls	concrete	stone elements	wood	other	
type of construction: inner façade	concrete	stone elements	wood	other	
type of construction: roof	stone	wood/light materials	other/combination	not under roof	
asbestos	none	small isolated area	large area or risk	unknown, other	none
openness, stack effect of stairwell	open 2 floors	open >2 floors	closed stairway	none	other
ventilation system	natural	mechanical exhaust, natural inlet	balanced		
ventilation system, exhaust locations	kitchen, bath, toilet	kitchen, bath, toilet, storage	two exhausts	no exhaust	other
age of fan box	number of years				
frequency of maintenance fan box	never	every >5 years	every 1-5 years	every year	other
last maintenance fan box	<one year	1-5 years	5-15 years	never	other
heating system	local heating	central heating			
heating source, open or closed	open no exhaust	open exhaust	closed balanced	collective	
heating system, location of source	living area	storage area inside	outside envelope	other	
main heating surfaces	hot conv/radiant	low temperature surface	air	combi/other	
heating system, usability	individual cost monitoring	collective, individual cost control	collective, cost distribution	other	
age of heater	number of years				
frequency maintenance visits heater	never	>5 years	every 1-5 years	every year	other
circulation pipes in crawl space	uninsulated	insulated or <2 m	not in crawl space	other	
extra heating appliances	fireplace	wood-burning stove	portable heater kerosene/gas	other	none
use of extra heater per year	never or <20 hours	from 20-100 hours	>100 hours	other	
hot water system	buffer individual	flow individual	collective	other	
hot water system, open or closed	open no exhaust	open exhaust	closed balanced	collective	
hot water system, buffer type	heatpump/solar dhw	boiler >5 liters	boiler 1-15 liters	boiler <1 l. flow-through	
hot water system, location	living area	storage area inside	outside envelope	other	
control of temperature	no control >60°C	control >60°C	control <60°C	no control <60°C	other
age of hot water system	number of years				
temperature of cold water	always cold	sometimes >25°C	warm spot	other	
temperature of hot water	always very hot	sometimes <50°C	not warm <50°C	other	
lead pipes	less than 3 m	more than 3 m	none	unknown	other
traffic situation in street of dwelling	>80% throughtraffic	exit neighbourhood	quiet street/yard	other	
noise from outdoors	traffic	general city noise	recreational, bars	other	
noise from neighbouring houses	doors, stairways	talking, music	appliances, lifts	no noise	other
noise from indoors	ventilation	heating	washing machine	visitors	none
effect of noise on health	sleeplessness	irritation, conflict	some nuisance	no nuisance	other
effect of noise on behaviour	turn appliance off	close window	social intervention	no effect	other
private space outdoors	balcony	patio	garden	none	

Items	Observations 1	2	3	4	5
Outdoors, occupants, general information about the house					
playing area for small children	possible and safe	supervised only	none	other	
design feature: balcony, walkway	long heat barrier	point heat barrier	isolated/no thermal bridge	other	
overhanging roof, protecting the wall	overhang >25-30 cm	overhang <20-25 cm	none	other	
type of roof (main roof area)	flat roof	under sloping roof	combination	not under roof	other
intrusion of privacy, burglary,	fear, isolation, danger	real risk intrusion	low risk, mostly private	private and safe	other
effect of intrusion on user behaviour	no window open	closed out/sleep	some extra attention	no effect	other
satisfaction with the home	very satisfied	reasonably satisfied	rather unsatisfied	very unsatisfied	other
satisfaction with indoor climate	very satisfied	reasonably satisfied	rather unsatisfied	very unsatisfied	other
satisfaction with maintenance, involvement	very satisfied	reasonably satisfied	rather unsatisfied	very unsatisfied	other
satisfaction with neighbourhood	very satisfied	reasonably satisfied	rather unsatisfied	very unsatisfied	other
heating level	all rooms warm	only living, rest unheated	low temperatures	short heating period	other
type of stairs	spiral	quarter	straight	steep	none
steepness to first or second floor	very steep	steep	normal	not steep	other
accidents in the house, cause	falling	cutting	bruising	smoke, burning	none
Living room					
overall number of people present	number				
average weekday use of the room	<5 hours	5-12 hours	>12 hours	other	
surface including open kitchen	m^2				
ceiling height	<250 cm	250 to 275 cm	>275 cm		
proportion of glazed openings	<25% small	25 to 50%	>50% large		
orientation of main façade (sun)	south	east/west	north		
window glazing type	single	double	HR++	other	
sun shade	indoors	outdoors	none	other	
glass panes in occupied area	glass door	low window frame	overhead glass	none	other
airtightness, lengths of connections	tight <6 m	open >6 m	other		
airtightness, seams in openings	double seams	single seams	no seams, draught	other	
ventilation, type of inlet	air-opening	small grate	large grate, cantilever	damper	other
height above floor level	<80 cm	>80 cm			
use of small inlet grate	mostly closed	airing <30 min/day	mostly/long open	always open	other
use of large inlet grate or cantilever	mostly closed	airing <30 min/day	mostly/long open	always open	other
hinging, top/side, sliding/sash	mostly closed	airing <30 min/day	mostly/long open	always open	other
cross-ventilation	inlet one façade	inlet two façades	one façade + overflow	other	
overflow opening to other space	<70 cm^2	70-140 cm^2	>140 cm^2	open door	
obstruction inlet of fresh air	large reduction	minor reduction	no reduction	other	
ventilation control	open/close	fine setpoints small	no control	other	
temperature setting daytime	Celsius				
temperature setting evening/weekend	Celsius				
temperature setting night or away	Celsius				
materials walls interior	stone	other			
materials inside part of façade	stone	other			
surface material walls	paper	plaster, open paint	paint, smooth	vinyl	other
surface materials ceiling	plaster/paper/wood	concrete, open paint	paint, smooth	vinyl	other
floor surface major area	smooth and coated	wood, smooth rugs	carpet short hair	carpet long hair	other

Items	Observations 1	2	3	4	5
Information per room					
opening to crawl space	none	small chinks, other	long connections	other	
floor connection on foundation	heat barrier	thermal bridge	humid, seams crawl space	insulated connection	other
uneven floors, steps, slippery rugs	slippery and rugs	threshold/uneven	rough	even	other
hot surfaces	hot unprotected	low temperature/ protected	other		
insulation level façade/outside	>4 cm insulation	<4 cm insulation	no insulation	massive stone	other
insulation level floor	>4 cm insulation	<4 cm insulation	no insulation	massive stone	other
heat barriers/thermal bridges	supporting beam	wall/ceiling	column/floor edge	none	other
condensation on windows	never	early morning	peak conditions	often	
visible live mould, size of area	<50 cm²	50-2,500 cm²	>2,500 cm²	none	
old mould material, size	<50 cm²	50-2,500 cm²	>2,500 cm²	none	
location of mould	skirting board	under flooring	behind furniture/closet	ceiling, corner	other
type of furniture	soft fabrics	smooth, hard	other		
how much furniture (dust collectors)	packed	empty	other		
plants	few, small size	many or large	none	other	
cleaning	easy cleaning	with residue	hard to clean	other	
general cleanliness	clean	little dust/dirt	dirty	other	
cleanliness insect screens, dampers	clean	little dust/dirt	dirty	other	
smell in room	no smell/fresh	cooking, perfume	mouldy/rotten	pets, humans	other
recent remodelling, work/hobby	painting	new fabric, soft flooring	new soft plastics	not recent	other
Master bedroom					
location	living floor	bedroom floor	attic	other	
number of people sleeping in room	number				
period of daily use of the room	<5 hours	5-12 hours	>12 hours	other	
surface area	m²				
ceiling height	<250 cm	250-275 cm	>275 cm		
inside wall proportion glazed	<25% small	25-50%	>50% large		
orientation of main façade (sun)	south	east/west	north		
window glazing type	single	double	HR++	other	
sun shade	indoors	outdoors	none	other	
glass panes in traffic area	glass door	window frame low	overhead glass	none	other
airtightness, lengths of connections	tight <6 m, stripping	open >6 m, no strips	other		
ventilation, type of inlet	air-opening only	small grate, flushing	large grate, cantilever	mechanical damper	other
type of curtains	roller blinds	clean grate, open	curtains, heavy	none	other
obstruction of inlet opening	reduction 30-50%	reduction 10-30%	no reduction or <10%	other	
height above floor level	<180 cm	>180 cm			
use of small inlet grate	mostly closed	airing <30 min./day	mostly/long open day	long open night	other
use of large inlet grate or cantilever	mostly closed	airing <30 min./day	mostly/long open day	long open night	other
hinging, top/side-hinged, sliding/sash	mostly closed	airing <30 min./day	mostly/long open day	long open night	other
cross-ventilation	inlet one façade	inlet two façades	one façade + overflow	door open	other
overflow opening to other space	<70 cm²	70-140 cm²	>140 cm²	open door	
ventilation control	open/close	fine setpoints small	no control	other	
heating daytime	yes, warm	yes, some heating	no heating	other	

Items	Observations 1	2	3	4	5
Master bedroom					
heating at night	yes, warm	yes, some heating	no heating	other	
age of mattress	<1 year	1-3 years	>3 years	other	
use of dust prevention mattress covers	none	yes mattress	yes pillow	other	
type of mattress	foam	springs, pockets	natural fibre	water bed	other
type of bed, ventilation under bed	open under bed	blanket near floor	no circulation	other	
materials walls interior	stone	other			
materials façade, indoor side	stone	other			
surface material walls and ceiling	plaster/paper/wood	paint, paper on concrete	paint, smooth	vinyl	other
floor surface	smooth	smooth and rugs	carpet short hair	carpet long hair	other
opening to crawl space	none	small chinks, other	long connections	other	
uneven floors, steps, slippery rugs	slippery and rugs	thresholds, uneven	even floors	rough floor	other
hot surfaces	hot unprotected	low temperature/ protected	other		
insulation level façade/roof of room	>4 cm insulation	<4 cm insulation	no insulation	massive stone	other
insulation level floor	>4 cm insulation	<4 cm insulation	no insulation	massive stone	other
heat barriers	supporting beam	wall/ceiling	column/floor edges	none	other
condensation on windows	almost never	early morning	peak conditions	often	
visible live mould, size of area	<50 cm^2	50-2,500 cm^2	>2,500 cm^2	none	
old mould material, size	<50 cm^3	50-2,500 cm^3	>2,500 cm^3	none	
location of mould	skirting board	under flooring	behind furniture/ closet	ceiling, corner	other
plants	few, small size	many or large	none	other	
cleaning	easy cleaning	only small residue	hard to clean	other	
general cleanliness	clean	little dust/dirt	dirty	other	
cleanliness insect screens, dampers	clean	little dust/dirt	dirty	other	
smell during inspection	no smell/fresh	cooking, perfume	mouldy/rotten	other	
recent: remodelling, work/hobby	painting	new fabrics, PVC	new soft plastics	not recent	other
Second and third bedroom	(see first bedroom)				
Room for hobby, work, play	(presentation of extra variables only, compared to bedroom)				
type of use	bedroom	work/hobby	storage/laundry	other	
overall number of people present	1	2	>2	other	
airtightness, seams in openings	double seams	single seams	no seams, draught	other	
heater present	yes	no	other		
temperature	always warm	only daytime	only night time	sometimes	other
appliances	tv/monitor	copier/printer	tv/monitor/copier/printer	artificial sun	other
type of furniture	soft fabrics/dust	smooth, hard	other		
type of furniture, number of items	packed	empty	other		
type of emission sources	biological/damp	chemical/VOCs	aerosols	noise	other
Kitchen					
type of kitchen	open kitchen	semi-open	closed large>10 m^2	closed <10 m^2	other
cooker system	electrical	gas + electrical oven	gas including gas oven	other	
age of gas cooker and/or oven	<3 years old	3-10 years old	10-20 years old	>20 years old	
surface area	m^2				
ceiling height	<250 cm	250-275 cm	>275 cm		

Items	Observations				
	1	2	3	4	5
Kitchen					
cooking, hours/week	hours				
condensation during/after cooking	never	early morning	peak conditions	often	
glass panes in traffic area	glass door	window frame low	overhead glass	none	other
ventilation control if mechanical ventilation	three setpoints on	two setpoints and off	on, clock	open/close	other
number of exhaust dampers	number				
exhaust system out	hours per 24 hours				
exhaust system low	hours per 24 hours				
exhaust system high	hours per 24 hours				
extra exhaust system	mechanical hood kitchen	window fan	passive cooker hood	none	other
use of extra exhaust system	cooking period	longer than cooking	shorter than cooking	other	
airtightness, lengths of connections	tight <6 m	open >6 m	other		
airtightness, seams in openings	double seams	single seams	no seams, draught	other	
ventilation, type of inlet	air opening	small grate	large grate, cantilever	damper	other
height above floor level	<180 cm	>180 cm			
use of small inlet grate	mostly closed	airing <30 min./day	mostly/long open	always open	other
use of large inlet grate or cantilever	mostly closed	airing <30 min./day	mostly/long open	always open	other
hinging, top/side-hinged, sliding/sash	mostly closed	airing <30 min./day	mostly/long open	always open	other
cross-ventilation	inlet one façade	inlet two façades	one façade, small	open/ overflow	other
temperature daytime	18°C or warmer	some heating 15-17°C	no heating	other	
temperature evening or weekend	yes, warm	yes, some heating	no heating	other	
materials walls interior	stone	other			
materials inside part of façade	stone	other			
surface material walls and ceiling	plaster/paper/wood	concrete + open materials	paint, smooth	vinyl	other
floor surface	slippery coated	wood+ smooth/rugs	carpet short hair	carpet long hair	other
opening to crawl space	none	small chinks, other	long connections	other	
hot surfaces	hot unprotected	low temp./protected	other		
insulation level façade/separation	>4 cm insulation	<4 cm insulation	no insulation	massive stone	other
insulation level floor	>4 cm insulation	<4 cm insulation	no insulation	massive stone	other
heat barriers	supporting beam	wall/ceiling	column, floor edges	none	other
visible live mould, size of area	<50 cm²	50-2,500 cm²	>2,500 cm²	none	
old mould material, size	<50 cm²	50-2,500 cm²	>2,500 cm²	none	
location of mould	skirting board	under flooring	behind furniture/closet	ceiling, corner	other
type of furniture	soft fabrics	smooth, hard	other		
type of furniture, number of items	packed	empty	other		
cleaning	easy cleaning	with residue	hard to clean	other	
general cleanliness	clean	little dust/dirt	dirty	other	
cleanliness insect screens, dampers	clean	little dust/dirt	dirty	other	
smell during inspection	no smell/fresh	cooking, perfume	mouldy/rotten	other	
recent activities: remodelling, work/hobby	painting	new fabrics, soft floor	new soft plastics	not recent	other
Bathroom					
location of bathroom	enclosed	façade without opening	window opening	in other room	other
number of showers	per week				

Items	Observations				
	1	2	3	4	5
Bathroom					
other moisture production	condensating dryer	washing lines	leakage	other	
surface area	m^2				
glazed opening in wall	up to 600 cm^2	600-2,500 cm^2	0.25-1 m^2	>1 m^2	none
orientation of window towards the sun	south	east/west	north		
glass panes in traffic area	glass door	glass shower frame	overhead glass	none	other
airtightness, lengths of connections	none	tight <6 m	open >6 m	other	
airtightness, seams in opening	double seams	single seams	no seams, draught	other	
ventilation, type of inlet fresh air	air opening	air opening, small	large grate, cantilever	damper	other
use of small inlet grate	mostly closed	airing <30 min./day	mostly/long open	always open	
use of large inlet grate or cantilever	mostly closed	airing <30 min./day	mostly/long open	always open	
use of hinging or top/side-hinged, etc	mostly closed	airing <30 min./day	mostly/long open	always open	
circulation between inlet and exhaust	no inlet or exhaust	short cut, obstruction	large circulation	other	
overflow opening	<70 cm^2	70-140 cm^2	>140 cm^2	door/cantilever	other
humid air into occupied spaces	large emission	minor emission	depends wind direction	no effect	other
use of exhaust	central control	on light switch	barrier in airflow, limit	none	other
temperature daytime	yes, warm	yes, some heating	no heating	other	
temperature night	yes, warm	yes, some heating	no heating	other	
materials above tiles and on ceiling	stone absorption	wood absorption	smooth water repellent	other	
handrails	none	in shower	in bath	other	
floor surface	slippery coated	smooth and rug	non-slip tiles	carpet	other
opening to crawl space	none	small chinks, other	long connections	other	
uneven floors, steps, slippery rugs	slippery when wet	rough	uneven floors	other	
insulation level façade/ceiling	>4 cm insulation	<4 cm insulation	no insulation	massive stone	
cold surfaces, heat barriers	supporting beam	wall/ceiling	column	none	other
condensation on windows	never	early morning	peak conditions	often	
visible live mould, size of area	<50 cm^2	50-2,500 cm^2	>2,500 cm^2	none	
old mould material, size	<50 cm^2	50-2,500 cm^2	>2,500 cm^2	none	
location of mould	in shower cubicle	on plastic sealants	behind appliances	ceiling, corner	other
cleaning	easy cleaning	with residue	hard to clean	other	
general cleanliness	clean	little dust/dirt	dirty	other	
cleanliness insect screens, dampers	clean	little dust/dirt	dirty	other	
smell during inspection visit	no smell/fresh	washing, perfume	mouldy/rotten	other	
Measurements					
inlet capacity all points	T in living room in heating season		dust sample 1, location		
inlet wk 1 and/or 1+2 damper	T in bedrooms (only sleeping)		dust sample 2, location		
inlet S1	T in bedrooms (hobby and sleep)		HDM dust sample 1		
inlet S2	T of water buffers		HDM dust sample 2		
inlet rest of dampers	T of hot water tap				
exhaust capacity kitchen	T of cold water tap		mould CFU location 1		
exhaust capacity bathroom	RV of air living room		mould CFU location 2		
exhaust capacity toilet	RV of air critical bedroom		mould CFU location 3		
blower door test, resulting Qv10	bacteria CFU location 1		bacteria CFU location 1		
ACH living room, bedroom	T in crawl space				
CO_2 concentration 1	sound level location 1		radon location 1 and 2		
CO_2 concentration 2	sound level location 2				

Items	Observations				
	1	2	3	4	5
Measurements					
air velocity at location 1	aerosols, number, size, distribution				
air velocity at location 2	water sample , location and contents				
air samples and analysis	legionella concentration tap 1				

Appendix 2 Description of sets of field data

Building periods

Figure A2.1 shows the sources of the dataset. The distributions of the dwellings in the 333 dataset does not represent the Dutch housing stock. Compared to the results of a recent national survey (Ministerie van VROM, 2003) the dataset contains 10% more dwellings of less than 30 years of age and approximately 20% more dwellings in the category of multifamily houses (49% in our survey versus 30% in the national survey). The number of occupants per dwelling was also significantly larger compared to the national survey. Houses of the period 1966-1980 are under-represented and houses of the period 1945-1965 and 1991-1992 are over-represented in the dataset compared to the housing stock (Ministerie van VROM, 2003) (see Figure A2.2).

The period 1966-1980 includes many high-rise buildings and inspection of problems focused often on collective services of heating and ventilation and the visits of these estates resulted in fewer individual case descriptions than visits of single family houses did.

The over-representation of houses in the period 1945-1965 is partly the effect of piloting the EPA+Health tool, and the quality of buildings in this period is often evaluated in the context of strategic decisions about the estates (renovation or removal). The over-representation of houses of the period 1981-1992 is caused by a few specific projects that added many cases to the data-

Figure A2.1 Clusters of cases in the 333-dataset

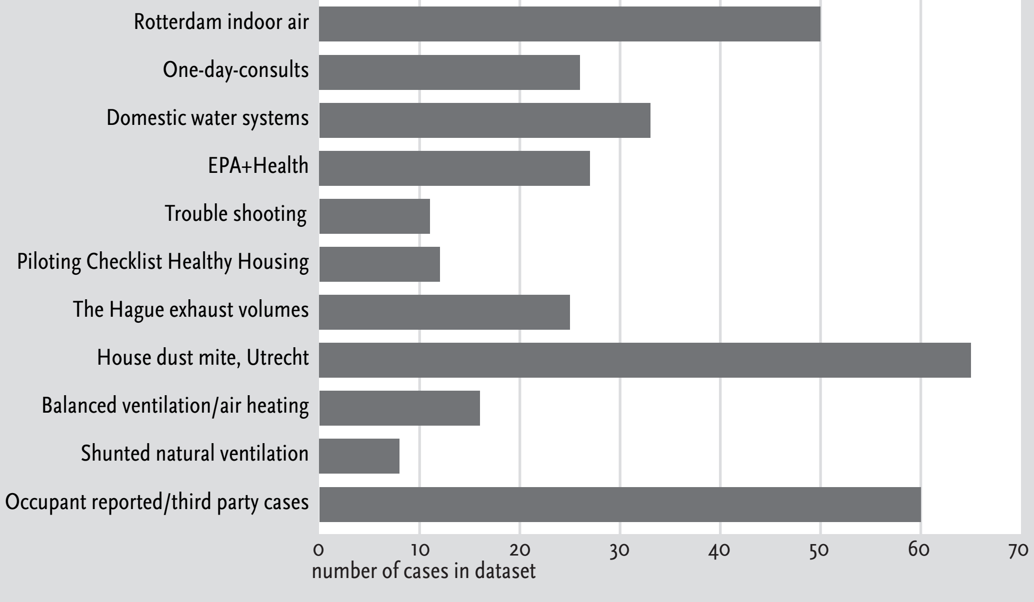
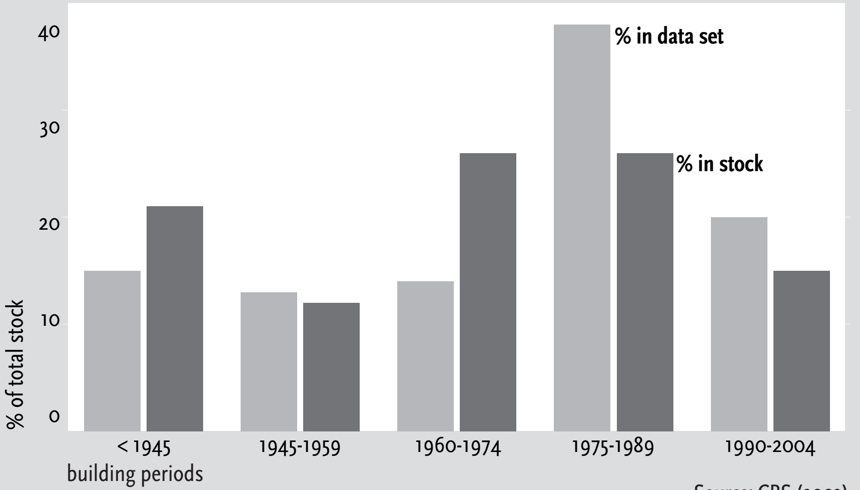


Figure A2.2 Building periods represented in the dataset and in the Dutch housing stock



Source: CBS (2003)

set: the Rotterdam Spangen project (houses were 6-7 years old), the domestic water project (houses in the age group 2-13 years) and the ventilation project in the Hague (with ventilation systems delivered 1-11 years ago, meaning that many houses have this age). The Rotterdam estate was constructed in the beginning of the 20th century and was stripped to the bare wall construction and new houses were fitted in between these walls.

Sector

The cases (n=261) with information about the sector show 71% rented sector and 29% owner occupied houses, compared with 48 and 52% in the Dutch housing stock. The average occupancy in the rented sector is 3.1 people and in the owner occupied houses is 2.9 people. The average room number is 4 in the rented and 4.5 rooms in owner occupied houses, while these rooms tend to be larger in surface area and volume (see Table A2.1). The owner occupied houses of the dataset have 20% more rooms. When we add these rooms and the larger space and compare the occupancy rate, than the owners in the dataset have on average 35-40% more volume per person than tenants have.

Location

In the 333 case dataset, about one quarter is located in relatively quiet neighbourhoods with mainly housing, while three quarters are located in crowded urban areas. Half of the houses in the dataset are located in three of the largest cities of Holland: Utrecht, Rotterdam and The Hague. To prevent bias, we focus on physiology, not on numbers and not on representation of the housing stock.

Data on mould and moisture

The model of mould is studied on the basis of visible mould. Of 308 dwellings data on mould is scored and 43% of these cases actually have mould some-

Table A2.1 Volume of space per person in two housing sectors in the 333 dataset (n= 261)

	Rooms	Surface area	Volume	Volume/person
Occupancy in the rented sector (n= 186)				
3.13	4.0	85 m^2	212.5 m^3	68 m^3
Owner-occupied sector (n=75)				
2.94	4.5	110 m^2	275 m^3	93 m^3

where in the house. Mould is better documented for rented houses than for owner occupied houses. The correlation between different variables is studied both for situations with and without mould occurrence. The relationship between housing characteristics and mould growth was investigated by means of correlation and regression analysis.

For the moisture production we reconstructed daily patterns of moisture production and removal in a single-family house. Experimental data was collected on the moisture production of cooking, washing and bathing and laundry drying. The results are based on experiments in 4 houses. Some calculations on the moisture emission from damp crawl spaces, capillary moisture transport from wet walls and data about the absorption of moisture in surface layers are made and used.

More occupants and more rooms (= more occupants) are correlated with more mould occurrence.

Data on ventilation

Ventilation volumes

A large dataset of exhaust volumes monitored at delivery of new and renovated houses by official inspectors of the municipality of The Hague is available. From the archives 384 cases with monitored mechanical exhaust volumes in kitchen, bathroom, toilet and sometimes also in a storage room were analysed. Many other delivery reports produced by installation contractors are available, but these are considered not reliable enough and are not used in the research project.

Exhaust volumes after years of use of systems

Exhaust volumes of different ventilation systems were monitored. A compensating air volume meter (ACIN Flowfinder) was used to measure volumes in 84 houses.

A model of capacity reduction of exhaust ventilation was validated on the basis of data from a specially designed project in The Hague. A selection of 60 cases (from n= 384 with known exhaust volumes at delivery) was made. These cases were remonitored by the same people and following the same protocol as years earlier, at delivery of the house. This project resulted in a subset of 51 cases with data on exhaust volumes and of these 51 cases 25 cases are in the 333 dataset. The subset of 25 houses is on average about 6 years old and the occupant number and room number is rather small.

Air change rate per hour (ACH)
The ACH is measured by using the CO_2 produced by humans and pets as a tracer gas. If CO_2 is continuously monitored then it is possible to calculate the air change rate by considering the rates of growth and decay in concentration as the occupancy level varies. The CO_2 concentration is measured over a period of 24 hours. The occupants write in a diary how many people are present, the opening of grates, windows and doors and at what moments changes occur, etc.

The CO_2 monitor is based on non-dispersive infrared detection which makes use of the property of a gas to absorb energy from an infrared light source. The resultant heat generated is detected as a volumetric change. The monitor has a resolution of typically +/- 50 ppm and suffers from drift caused by dust on optics and a gradual deterioration in lamp performance. The air change rate per hour is measured on the basis of the dilution rate after a peak concentration and after everybody has left the room.

The equation is: $$ACH = \frac{L_n(C_s) - L_n(C_t)}{T}$$

ACH = air change rate of the volume of a room per hour
$Ln\ (C_s)$ = n-logarithm of the tracer gas concentration at start time
$Ln\ (C_t)$ = n-logarithm of the tracer gas concentration at time t
T = elapsed time between start time and time t in hours

The ACH was determined for different ventilation scenarios and in different rooms. Data of 38 houses and n = 156 samples of the living room and bedrooms with known dimensions are used (see Table A2.2). Mainly three projects provide data: a project with well-sealed windows and without grates, a project with leaky aluminium window frames and small grates and a project with wooden window frames including grates and sash windows and average sealing quality.

Data on house dust mite allergen
220 dust samples were taken from 160 houses, of which 131 are cases in the 333 dataset (Table A2.3). Many samples are from the city of Utrecht, in houses of all types, sectors and age groups, but with relatively many houses from the period 1945-1965 and houses with children. Dust samples in other cities are often taken from houses newer than 14 years. Qualitative data is collected from 23 Acarex tests of mattresses, flooring materials in the living room, bedrooms and from sofas. The Acarex test measures the guanine concentration via a solution that changes the colour of reactive material. Most executed tests showed a high concentration, which indicates that the test is not very

Table A2.2 The number of ACH measurements

Living room	33
Living room incl. open kitchen	56
Master bedroom	39
Bedroom	28
Total	**156**

Table A2.3 Number of samples of house dust mite allergen

n	Type of analysis
64	Der p1 mattress
37	Der p1 floor of living room
24	Der p1 sofa
4	Guanine mattress
41	Guanine flooring of bedroom
34	Guanine flooring of living room
16	Various other surfaces either for guanine or Der p1 analysis

specific for concentrations higher than 3-4 microgrammes of guanine per gramme of house dust.

A total of 125 samples were analysed in the laboratory for Der p1 and 95 for guanine.

The house dust mite model is validated on the basis of dust samples collected in many different types of houses. Data is collected on the house and the occupancy. Samples are analysed in a laboratory for Der p1 or guanine. The guanine concentration of 94 samples was used to construct the house dust mite model. The Der p1 concentration of 135 samples was used to validate a model for the prediction of house dust mite concentration. For modelling, the sample collection was split into two halves. Correlations were calculated between collected data in the house and the measured concentration. On the basis of the best performing indicators, the model was redesigned and validated using the second half of the samples with known Der p1.

The concentration of Der p1 was determined through the method of monoclonal enzyme immunoassay (Bronswijk, 1986). The concentration of guanine was determined through High-Performance Liquid Chromatography (HPLC), following a protocol of preparing samples ready for HPLC as described by Lynden-Van Nes (1999). Guanine is one of the five nitrogenous bases (cytose, guanine, adenine, thymine and uracil) that helps make up the code in DNA and RNA. The guanine level is (non-linearly) correlated to the allergen Der p1.

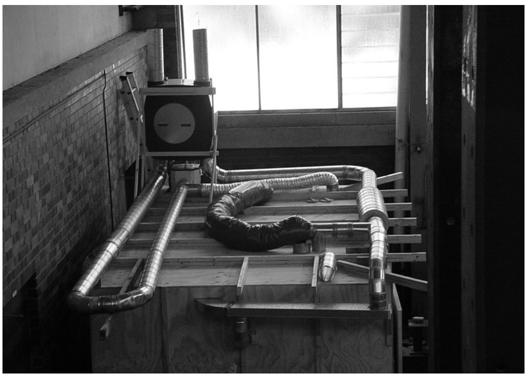
The methods of dust collection and preparing samples for analysis are not very accurate. Repeated sampling of dust on one spot shows a high variance. When the resulting allergen concentrations are not accurate, validation is a problem. Still, the validation was useful in the selection of indicators.

Data on particulate matter

Data on particulate matter are collected in a test chamber and in houses with heat recovery ventilation systems in Arnhem and Petten. Sampling in Arnhem was used to define the deposited mass in inlet air ducts. Sampling in Petten was used to compare the particle mass in indoor air in combination with different ventilation scenarios. Radon samples are collected in the test houses in Petten and in the project in Rotterdam. The test houses in Petten are not in the 333 dataset, because the houses are not occupied.

Data on particulate matter are collected at the International Laboratory of Air Quality and Health (ILAQH) at the Queensland University of Technology in

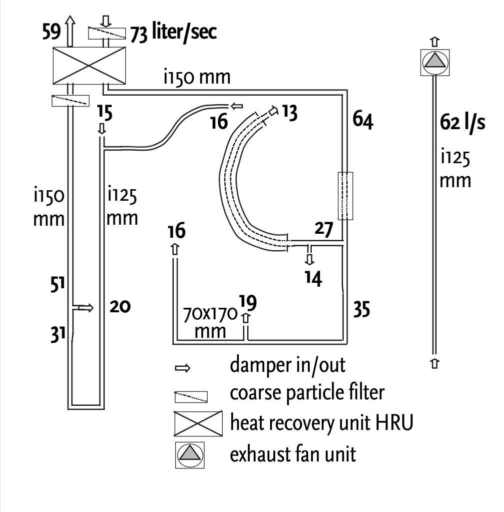
Test chamber at ILAQH in Brisbane, Australia

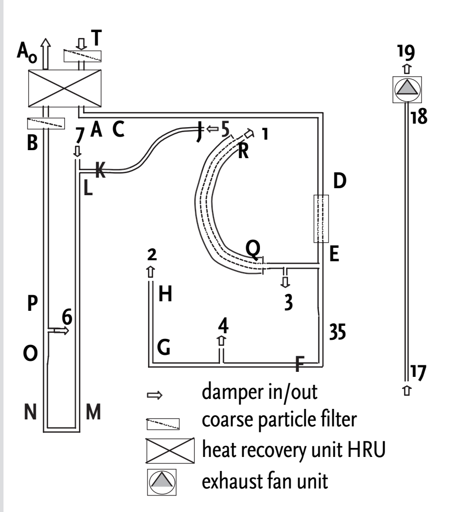


Brisbane, Australia. Experiments were conducted in a full-size test chamber.

The chamber was built for the purpose of experimenting with a heat recovery ventilation system and with mechanical exhaust in combination with natural inlet. The objective of the experimental study is quantification of aerosol losses within mechanical ventilation systems, of air circulation patterns and of particle distribution in the chamber. Figure A2.3 shows the layout of the balanced airflow ventilation system on the roof of the test chamber: the graph on the right shows the location of sampling points; on the left are typical airflows (l/sec) used in the experiments. Airflows were measured with a heat-wire anemometer at about 10 points in the circular cross-section of the ducts and the average air velocity was chosen on the basis of this pattern of velocities. The ducted system covers an area of 2,400 x 4,000 mm. The chamber (volume 20 m^3; dimensions 2,400/3,600/2,400 mm L/W/H) is constructed of plywood panels. With a door, a window and a heater the chamber shows air circulation patterns that reflect patterns in real size houses. The chamber is located in

Figure A2.3 Layout and typical air velocities [l/s] in the figure on the left and sample points of the experimental design in the figure on the right





Legend

1, 2, 3 and 4	inlet dampers
5, 6, 7	exhaust dampers
A_0/A/BT	heat recovery unit with inlet fan plus exhaust fan and two filters
A/C/D	duct diameter 150 mm and 2 bends of 90 degrees
D/E	sound silencer net diameter 150 mm, perforated steel and glass wool, lining
E/Q	2 straight T-sections, diameter 125 mm
Q/R	flexible plastic foil sound silencer, double lining filled with glass wool
E/G/H	90 degree connection of duct diameter 125 to flat duct 70x 170 mm, dampers
J/K	flexible ribbed aluminium duct diameter 125 mm
L/M/N/O/P/B	duct diameter 125 mm with bends and straight T-sections and one damper

a large hall in downtown Brisbane, at approximately 200 m from a freeway with a vehicle flow rate of about 25,000/24 hours. The vehicle emissions influence the particle concentration inside and around the building, especially in the submicrometre size range. Ambient air is used for the experiments, both from outside or from the large hall. The concentration of aerosols fluctuates, depending mainly on wind speed and directions and traffic flow. The activity level in the hall is low, with occasional use of welding equipment (high particle concentration) and wood and metal cutting tools (coarse particles).

On the right side of the figures is an exhaust fan box connected to a straight duct and one exhaust damper. See also the description in Table A2.4 with the length of ducts and the typical air velocities.

The test chamber is equipped with ventilation equipment in a design that reflects building practices: Dutch brand and on the market in 2003 (and still in 2006), a representative number of bends, T-sections, dampers, but with shorter ducts than in average applications. The balanced airflow ventilation system has a heat recovery unit (HRU) with a mechanical inlet fan, an exhaust fan, two filters, and a flat plate counter-flow type heat exchanger. The thermal efficiency of the heat exchanger is >90%, producing inlet air at near-room

Table A2.4 Ventilation components of ducted ventilation systems

Component	Dimensions (mm)	Airflow (m/s)	Comments
Balanced flow unit A°-T	450 x 750 x 850	1.9 - 4.8	2 fans, 2 filters, heat exchanger
Exhaust fan unit 18-19	300 x 300 x 300	1.2 - 3.0	1 fan in box
Round spiral sheet metal	Diameter 150	1.6 - 4.0	Typical length >1,000 mm
Round spiral sheet metal	Diameter 125	0.8 - 2.0	Typical length >1,000 mm
Rectangular sheet metal FGH	70 x 170	1.2 - 3.0	Typical length >1,000 mm
Straight T-section E	Diameter 150/150/125	0.8 - 4.0	
Straight T-section KL, PO	Diameter 125/125/125	0.8 - 2.0	
Bend 90 degrees A	Diameter 150	1.6 - 4.0	Radius 1.5 x D
Bend 90 degrees M. N	Diameter 125	0.8 - 2.0	Radius 1.5 x D
Bend 90 degrees G	Rectangular 70 x 170	1.2 - 3.0	Radius 1.5 x 170
Perforated duct DE	Diameter 150	1.6 - 4.0	Sound attenuator, glass wool fill
Flexible duct JK	Diameter 125	0.8 - 2.0	Aluminium
Flexible duct QR	Diameter 150	0.3 - 4.0	Sound attenuator, glass wool

temperature. The HRU volume control is proportional. The system with the mechanical exhaust fan and natural inlet openings has three hand-controlled fan speeds. The inlet openings are hand-controlled slit-type openings in the building envelope. The chamber can be heated by an oil-filled radiator, which creates a temperature difference of 10-15 K with ambient conditions during certain experiments.

For the measurement of particulate mass a single laser beam counter is used, with a cyclone that filters the particles larger than PM2.5. Number count is transferred into particle mass by volume. This instrument is also used to monitor the aerosol mass near the bed of a person asleep. Evaluation of the quality of indoor air requires number counts plus information about size distribution and for this purpose a double laser beam counter is used, that detects the aerodynamic size and number of particles in the range of PM0.7-PM15. A condensation particle counter was used for the particle range, where the double laser beam counter is not accurate enough: below PM1. To reach the best possible isokinetic flow, two identical air sampling probes for simultaneous sampling at two points were used. The tubes connecting the probes with the data acquisition system are of the same length (2,250 mm) and material. Because we use the relative aerosol particle distribution for successive data points in the system, the deposition in the tubes does not require correction factors for the final results. The results are used to compare values. We focus on particle count in the ultrafine size range. Monitoring PM10 mass instead of number counts provides less relevant information about potential health risk than particle count in the range below PM2.5.

Particle generator

The experiments also include the production of artificially produced aerosols: salt crystals and white smoke. A small smoke generator made air flow patterns visible, so they could be documented. Smoke is generated with very low added heat, on the basis of a chemical reaction in a tube and smoke distribut-

Table A2.5 Mass of dust collected after 16 years of use of inlet air ducts (sampled in Arnhem, 2004)

Case	total volume	living room, vertical duct	kitchen horizontal	main bedroom, main horizontal duct	bedroom after T-section	bedroom horizontal straight	bedroom >silencer	hall
	dm^3/s	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
1	– *		35.92	2.02	1.18			
2	43.3		15.02	1.34	2.15			28.14
3	0		4.7	2.27	1.52			
4	37.5	11.92				4.28	57.78	
5	39	7.96				4.5		

* temporarily out of function

ed by pressing a rubber ball connected to the smoke source. Experiments with a 'theatre' type smoke generator did not provide results because of the temperature of the smoke that influenced the flow patterns.

Deposition in ducts after many years of use

In houses in Arnhem a number of balanced-flow ventilation systems were renewed, which gave the opportunity to collect dust samples in existing ducts before the renovation started. Fresh air had been ducted into these houses for 15-16 years. The latest maintenance visit at the time of the inspection occurred 1 year ago: dampers were controlled and the units cleaned, but the ducts were not cleaned, except in one house.

In five houses and at about five points in the duct system per house a specific surface of the circular ducts (length of approximately 10 cm) was cleaned (with a solvent and cloth) and the mass of the collected dirt was measured. A few samples were polluted with sealant. Cleaning the surface of perforated sound silencers was not very effective. The cleaning efficiency is roughly estimated to be 90-95% of smooth surfaces and no more than 80% of rough surfaces of the sound silencer. The mass was determined at identical temperature and humidity conditions. The results are used for model construction of deposition of dust in ducts, in combination with the results from the test chamber. Results are presented in Table A2.5.

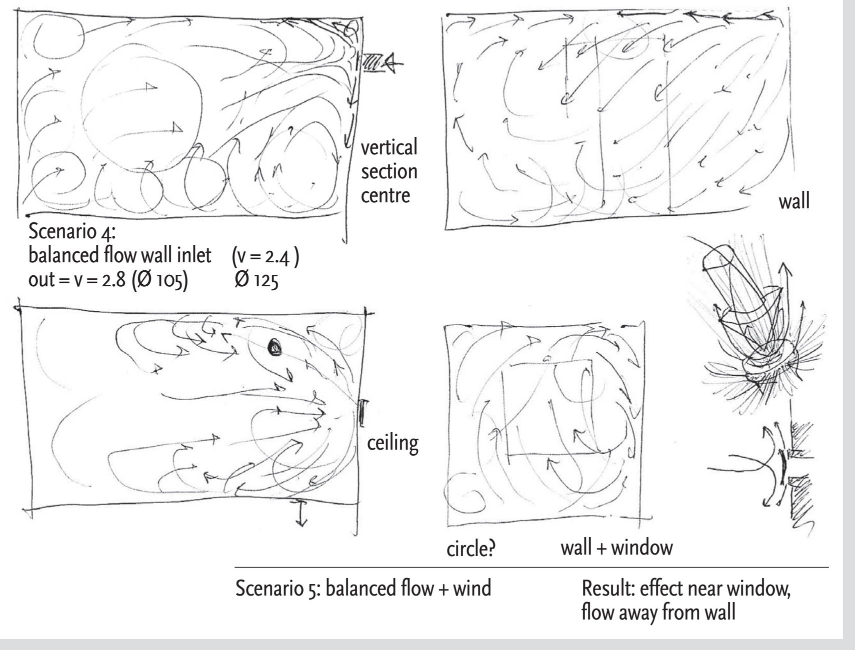
Dust collection in test houses in Petten

A cyclone, set at air velocity to measure PM8.5, collected dust on a filter over a few days. The mass of the collected dust was compared to analyse the difference in particle concentration in indoor air for different inlet systems and volumes. The results of this experiment are useful for modelling, not for validation.

Data analysis of particle distribution in rooms

In the test chamber at the International Laboratory of Air Quality and Health, smoke is injected to visualise airflow patterns in the test chamber. Drawings of the flow pattern in the vertical and horizontal sections of the chamber

Figure A2.4 Air circulation patterns and particle movements in the test chamber at ILAQH, made visible by smoke: mechanical inlet and mechanical exhaust



were created. A total of 14 scenarios were pictured and analysed. The experiments result in qualitative insight into how 'pockets' of high particle concentrations are formed. Two scenarios are presented in the Figures A2.4 en A2.5.

Flow patterns

The drawings shows one scenario: the first (top left) is the vertical cross section in the middle of the room, the top right shows the pattern near the wall with the entrance door (in the long side), the bottom left drawing shows the pattern near the ceiling and bottom right the pattern on the short wall with the window, including an inlet grate and a heater (used in different ways).

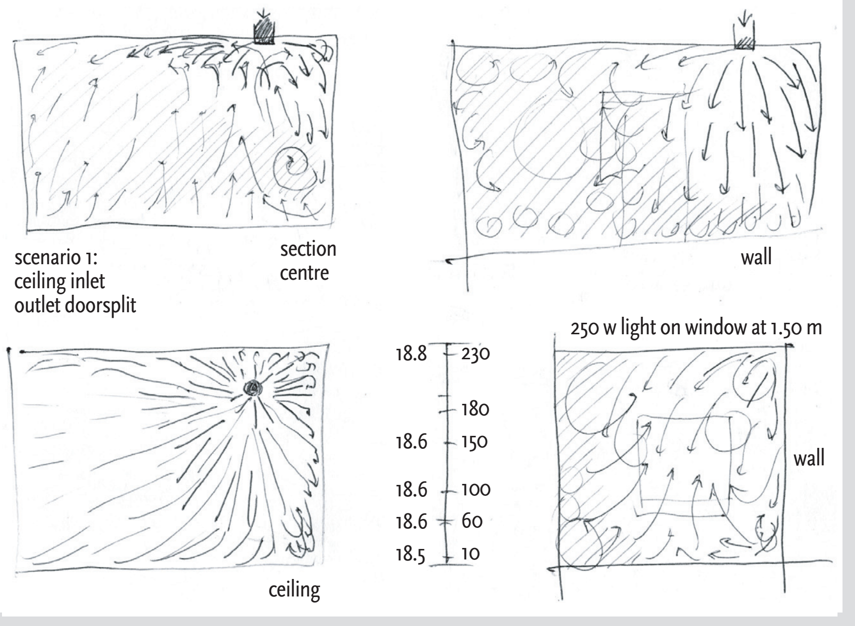
Data on radon

A total of 28 radon samples were collected in seven houses: three houses in the Spangen project and four test houses in Petten. In three test houses two repeated measurements were done, with different ventilation scenarios and systems (see Table A2.6). The sensors are passive samplers, provided and analysed by KVI Groningen. The sampling period is between one and four months.

Data on legionella

Legionella samples were taken from four test houses in Petten, and the temperatures and flows were monitored. Due to poor water quality in the test houses the analysis could not be performed according to the standard protocol of NEN 6265. It is not possible to validate the exposure risk model on the

Figure A2.5 Air circulation patterns and particle movements in the test chamber at ILAQH, made visible by smoke: mechanical inlet from ceiling and out via doorsplit



basis of legionella test results.

In a project on domestic hot water appliances 364 houses were visited to monitor temperatures of cold and hot water, to inspect domestic water heating systems and interview occupants on use and comfort. The dataset is used to analyse the temperature of water buffers. Together with reviews on the ecology of legionella the exposure risk in individual houses is scored.

An instrument based on a container with two temperature sensors and a clock was used to make a two minute flow diagram of water running from the kitchen tap. An electronic data logger was set at intervals of 0.5 sec., with thermocouples type J and twisted instead of soldered connections to limit the response time. The water flow of cold and hot running water is defined by the period it takes to fill the container with 7.2 litres of water (see Figure A2.6). The data collected about the domestic water heater include type and brand of heater, buffer size, type of heat exchange, pilot flame function, location of heater in the house and length of the piping system. The occupants are interviewed about occupancy and use of auxiliary water heaters.

All houses are privately owned and are 2-13 years old: the average of 33 cases of n=365 is 6.8 years, so it was expected that the heater systems were still on the market and that the results apply to actual market products. The houses in this subset have 4.1 rooms on average (all 4 and 5 rooms, except one with 6 rooms and four with three rooms) and 3.1 occupants average.

On the x-axis the time in seconds is represented. The cold temperature was measured between the time interval of 23-78 seconds, the hot water temperature between 150 and 280 seconds approximately. In this case the cold-

Table A2.6 Measured radon concentration and ventilation volume-based on the subdataset on radon, monitored in the Ecobuild-Research (2002-2004) and Spangen project (1995)

Ecobuild-Research project						Spangen project		
House	Location of radon detector	Period I Bq/m³	Period II Bq/m³	Period II mSV/y	Period II Ventilation m³/h	House	Location of radon detector	Bq/m³
A	attic on monitor	13.1	17	0.43	180	1	crawl space	40
	attic space		22	0.55				
	bedroom		17	0.43				
	living room	10.4	17	0.43				
	crawl space	82	84	2.10				
B	attic space	6.3	5.4	0.14	152	2	bedroom	25
	bedroom		4	0.10				
	living room	6.8	5.7	0.14				
	crawl space	56	80	2.00				
C	attic space	7.2	2.4	0.06	260	3	meter closet	24
	bedroom		1.7	0.04				
	living room	7.2	4.4	0.11				
	crawl space	115	64	1.60				
D	attic space	8.1						
	living room	3.6						
	crawl space	48						

est temperature is about 13 °C, the highest temperature 54 °C. The temperature of the hot water flow collapses after 30 seconds. The temperature may be restored after 3 to 4 minutes, but as the protocol included one minute of cold water and two minutes of running hot water at highest available flow and in the kitchen, this effect was not studied.

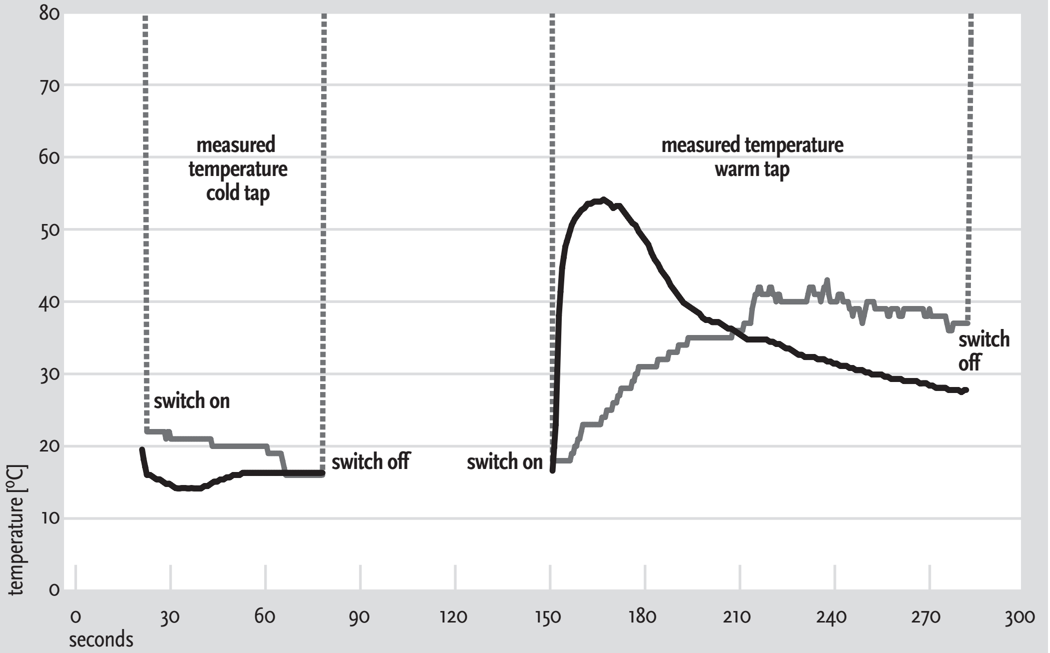
Data on comfort parameters, chemicals, bacteria and mould

Many inspections included the use of handheld instruments for monitoring of temperatures, relative humidity, or gases, using chemically reactive test tubes. In two projects NO_2 has been monitored, with typical sampling periods of one to two weeks. In three projects bacteria and mould spores have been sampled, with results that are hard to interpret, because of the small number of samples and the relatively low reliability or relevance of the laboratory results. The samples were used to signal specific problems, and further technical inspection was undertaken to find answers, but only when relatively high concentrations would occur (in a few cases).

Data was collected on:

- air and radiant temperatures and surface temperatures in rooms, using thermocouples;
- Relative Humidity, logged for 1 minute during inspections or for 1-10 days, using Sulphonate Polystyrene sensors;
- NO_2 sampling for 10-14 days using Palmes passive diffusion tubes;
- VOCs, CO, natural gas and formaldehyde with ad-hoc measurements using chemical reaction tubes;

Figure A2.6 Typical representation of the measured water temperatures in the 364 sub-dataset on domestic cold and hot water



- CO_2 reaction tubes to detect leakage in gas exhaust systems;
- heat wire anemometer to measure air velocities;
- sampling bacteria and fungi, using a fan controlled air sampler and strips with two types of agar, having the agar cultured and analysed in the laboratory;
- smoke tests in crawl spaces and in heaters to find leaks;
- smoke tests to visualise airflow patterns and for qualitative analysis of air circulation.

In the Petten test houses, CO_2 was injected from a CO_2 pressurised gas bottle, with control of inlet volume via exhaust valves in each room, to simulate the presence of people.

The results of sampling are used in both a quantitative and qualitative way, knowing that the sampling period was short, that sampling does not reveal peak concentrations, that the moment of sampling probably is a poor reflection of the real conditions and that the sampling and laboratory conditions differ considerably, so statistical analysis is not possible. The results from these measurements add to general understanding of indoor pollutants, and contribute to model construction. The monitored results however do not contribute to validation of models, for different reasons:

- temperature measurements do not contribute to indicator selection, except when showing extreme conditions and as an illustration of the reason for condensation, etc.;
- RH conditions outdoors and RH of crawl spaces contribute little to under-

standing of indoor moisture problems and are not used to diagnose individual problems;

- NO_2 sampling has shown outdoor influences, with weak relationships to indoor sources in the sampled houses;
- formaldehyde measurements are useful in identifying sources of irritant effects; but the sampling conditions do not match the official requirements for comparisons with limit values;
- sampling of bacteria and fungi did not contribute to solving indoor air problems: increased concentrations cannot be related to complaints and do not point out specific indicators: we do not use this type of sample results in this study.

Appendix 3 Moisture balance scenarios

Moisture removal

Ventilation is the dominant function for removal of moisture from the shower surfaces that is not drained away into the sewer. The rate of moisture removal can be estimated from the air exchange rate and the differences in relative humidity between the indoor and outdoor air. In the scenario we use as an example, the outdoor temperature was set to 6°C at 85% RH. This represents an average outdoor condition in the Netherlands. The indoor temperature varies between 14 and 22°C, whereas the indoor RH was calculated from the moisture balance. The air exchange rate was approximated from the infiltration rate and the rate of mechanical exhaust. The mechanical exhaust rate was estimated using the rates prescribed by Dutch building regulations and data on ventilation behaviour of the occupants obtained during the field study: the lowest capacity over 23 hours and the highest over 1 hour. At the lowest level the ventilation rate is nearly 40% of the level prescribed by the Dutch Building Code. The infiltration rate is approximately equal to 0.56 m^3/h per square metre of floor area. Since infiltration and mechanical ventilation rates depend on the dimensions of the building, we used a standard Dutch single-family house with a garden-facing living room to model these rates (Table A3.1). The exhaust rate φ is then given by:

$$\varphi = [23\sqrt{(\varphi_i^2+(0.4\varphi_{mv})^2)}+\sqrt{(\varphi_i^2+\varphi_{mv}^2)}]/24 \qquad (1)$$

in which φ_i is the infiltration rate and φ_{mv} is the mechanical ventilation rate.

Calculations

It was assumed that an equilibrium between moisture production and removal by ventilation was reached instantaneously. Then, the equilibrium concentration C_E [kg/m³] of water vapour can be calculated by:

$$C_E = C_O + \frac{Q}{\varphi} \qquad (2)$$

in which C_o [kg/m³] is the outdoor vapour concentration and Q [kg/s] is the moisture production rate. Subsequently, the rate of moisture removal was calculated by:

$$\varphi_V = \varphi \times (C_E - C_o) \qquad (3)$$

Equations 2 and 3 only hold if the saturated vapour density is not exceeded. This saturated vapour density C_S depends on temperature and was calculated by the formula given by [4]. If C_E was greater than C_S, C_E was set to C_S. Then:

$$\varphi_V = \varphi \times (C_S - C_o) \qquad (4)$$

Table A3.1 Room dimensions, infiltration and ventilation rates (m^3/h) in standard Dutch single-family house (November 1991)

Space	Floor area (m^2)	Height (m)	φ_i	φ_{mv} low	φ_{mv} high	φ
Living room	26.1	2.5	15	37	151	45
Kitchen	7.3	2.5	4	30	76	32
Bedroom	11.4	2.4	6	16	41	19
Bathroom	4.8	2.4	3	20	50	22

Table A3.2 Moisture absorption by the mattress in cm^3 per person per night (estimates by author)

Transpiration	from skin to mattress and cover	180-220
Respiration	from breathing to pillow	20-50
	total estimated absorption	200-270
	estimated absorption in mattress	125 (250 for two people)

and the moisture removal rate was smaller than the production rate. The excess moisture was supposed to condense and be removed by ventilation afterwards when the vapour density became unsaturated primarily due to a lower moisture production rate.

Scenarios

Two scenarios for indoor temperature are used: a warm and a moderate indoor temperature profile. In one scenario, the input air was obtained from outdoors, whereas in the other scenario the input air consisted of indoor air. The latter reflects the situation in which windows and ventilation grids were closed due to fear of cold draughts or risk of burglary.

In general, houses built before 1980 have a moderate indoor temperature regime, whereas in modern houses a warmer indoor climate prevails. Figure A3.1 shows the effect of these two temperature scenarios on the relative humidity in the living room. In both temperature regimes, the living room is ventilated with fresh outdoor air (T=6°C; RH=85%). As expected, higher indoor temperatures result in lower relative humidity.

When the production exceeds the removal, the RH is 100% and condensation occurs. This can be observed in the bathroom with the scenario of ventilation with indoor air. Then condensation occurs in the time span in which showers were taken. Ventilation with indoor air results in higher RH levels which prevail over a longer period compared to ventilation with outdoor air.

The Figures A3.1, A3.2, A3.3 and A3.4 show the effects in the livingroom, kitchen, bathroom and bedroom.

Moisture in the bedroom

The moisture production from exhalation and transpiration depends on body

Figure A3.1 Relative humidity RH and temperature T in the living room over 24 hours for low and high temperature regimes, calculated on the basis of the moisture production in Figure 4.2 of Subsection 4.3.2

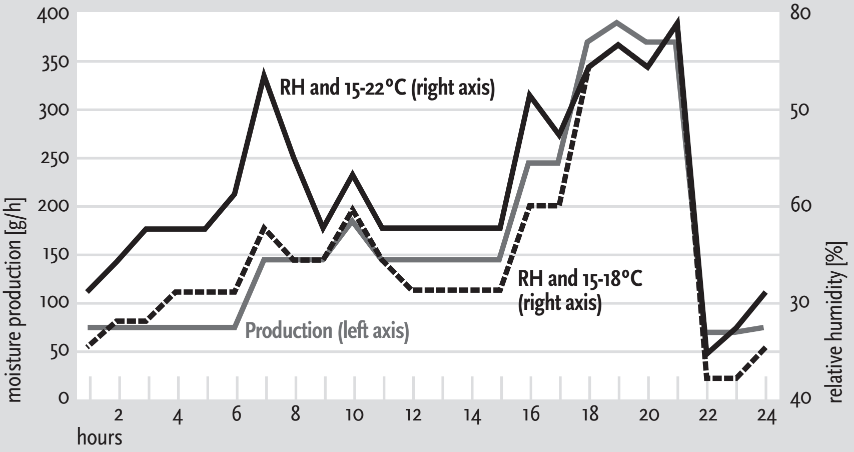
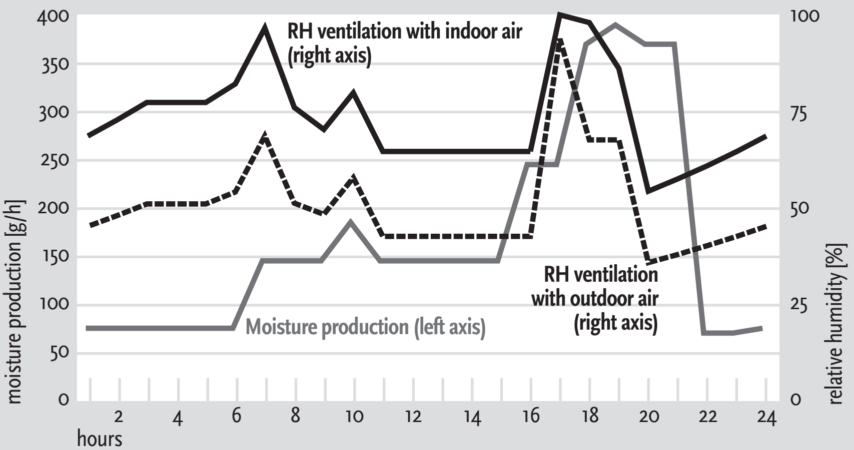


Figure A3.2 Moisture production and relative humidity RH in the kitchen, ventilation with outdoor and indoor air, calculated on the basis of the moisture production in Figure 4.2 of Subsection 4.3.2



mass and temperature and sleep level, but is roughly 40 g/hour average for an adult person. Part of this moisture is vented off directly. In Table A3.2 the effect on moisture absorption of a person in bed is presented.

Figure A3.5 shows the balance between production and removal of moisture in three bedrooms over a 24 hour period. The balance is the sum of theoretical production and removal volumes; the values below the 0-axis show more removal than production, while in reality the balance will stop on the 0-axis (based on experimental data and estimates by author, see Subsection 4.3.2).

The master bedroom of this case study is well-ventilated with dry air from

Figure A3.3 Moisture production and relative humidity RH in the bedroom, ventilation with outdoor and indoor air, calculated on the basis of the moisture production in Figure 4.2 of Subsection 4.3.2

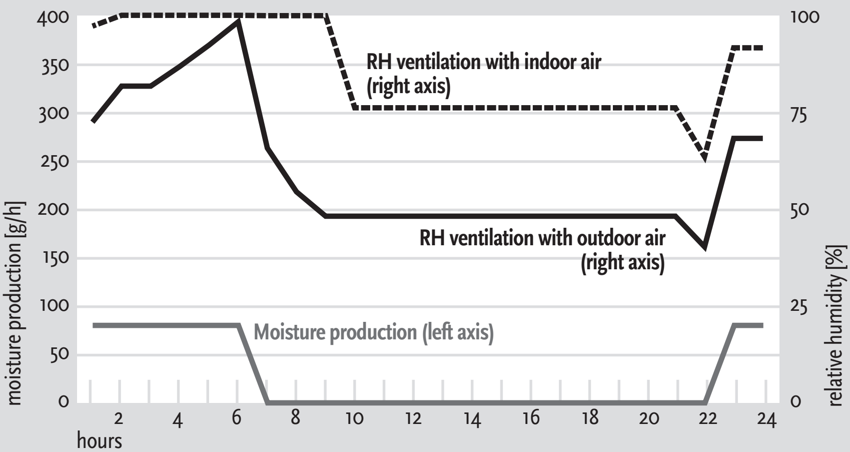
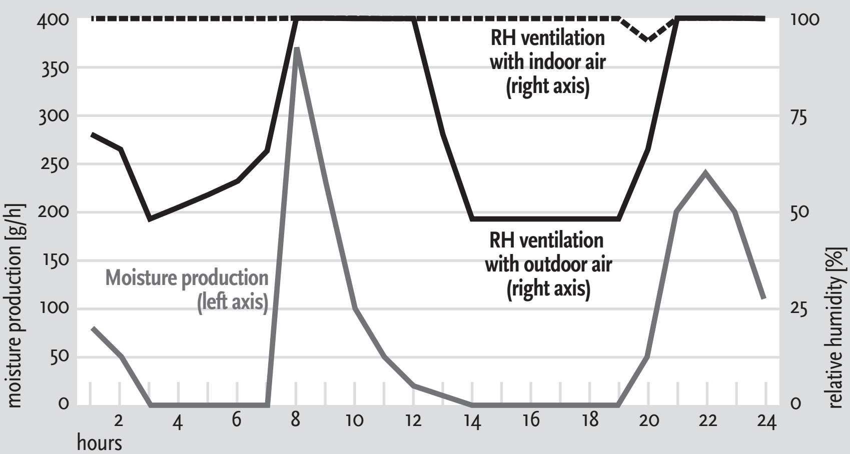
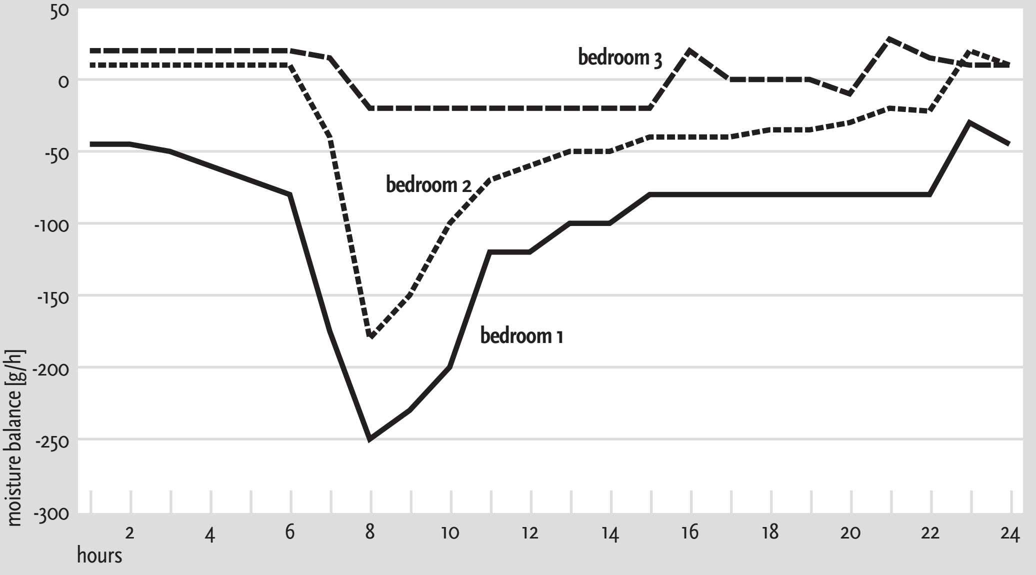


Figure A3.4 Moisture production and relative humidity RH in the bathroom, ventilation with outdoor and indoor air, calculated on the basis of the moisture production in Figure 4.2 of Subsection 4.3.2



outside. Ventilation removes more moisture than is produced, even with two adults sleeping. The bedroom for the two children has a poor balance with high moisture level. This room is ventilated with warm and damp indoor air.

Figure A3.5 Moisture balance over 24 hours in bedrooms, based on experimental data and estimates by author (See Subsection 4.3.2)



Curriculum vitae

Evert Hasselaar werd als vierde kind in een boerenfamilie geboren in 1947 in Veenendaal. Zelfstandig op een eigen akkertje werken is met de paplepel ingegoten. Na de Mulo en vervolgens de HBS-B werd in 1965 gekozen voor de studie Bouwkunde aan de TU Delft. Deze studie werd tweemaal voor een jaar onderbroken: in 1967 voor een studie sociologie, engelse taal en beeldhouwen aan het Pomona College for Liberal Arts in de Verenigde Staten en in 1969 vanwege werk voor bewoners van het Westerkwartier in Delft, toen een vervallen stadswijk. Het afstuderen was gericht op woningbeheer en woningverbetering en op de rol van bewoners en woningcorporaties. Met vijf anderen werd in de afstudeerperiode de groep Inspraakleerpakketten binnen de Stichting Werkgroep 2000 opgericht en werkte hij tot 1979 aan het organiseren van inspraakprocedures rond ruimtelijke plannen, waaronder woningverbetering. De behoefte aan meer techniek kreeg gestalte door de oprichting van Stichting Woon-Energie (het latere WE-adviseurs duurzaam bouwen). In de tien jaar daaropvolgend was duurzaam bouwen en daarbinnen vooral energiebesparing het thema. In 1985 werd met drie collega's Klimaat-Bouw BV opgericht, dat in 1989 door Evert Hasselaar werd voortgezet en nog steeds een (kleine) thuisbasis is voor ontwerpwerk en bouwkundige adviezen. In 1992-1993 leidde onderzoek naar het onderhoud van verwarmingsketels tot een tijdelijk dienstverband met het NCIV, een koepel van woningcorporaties. Een jaar later leidde het uitvoeren van het isolatieconvenant voor de Nederlandse Woonbond tot een half time dienstverband, dat 4,5 jaar zou duren en de ogen opende voor de positie van huurders en de kwaliteit van de woningvoorraad. In 1998 werd gekozen voor onderzoek bij het Onderzoeksinstituut OTB, onderdeel van de TU Delft, om problemen in kaart te brengen en oplossingen te zoeken voor gezond wonen. Dit betekende in verschillende opzichten het rondmaken van de cirkel: thuiskomen na 25 jaar op de TU, bij Hugo Priemus, die in 1973 hoofdmentor was bij het afstuderen, en nu promotor is bij het proefschrifttraject over gezond wonen.

In 1947 Evert Hasselaar was the fourth child to be born into a farming family at Veenendaal. He was brought up to embrace the idea that an ability to work independently in one's own field was particularly important in life. Having completed his secondary education in 1965 he then opted to study architecture at TU Delft. This study was interrupted twice for one year: in 1967 to study sociology and sculpture at Pomona College, a liberal-arts institution in the USA, and in 1969 to work on community development and advocacy planning for the Westerkwartier: a dilapidated district of the city of Delft. He followed his interest in urban renewal issues and consumer/occupancy matters. In 1973, in his graduation year, he teamed up with five others to start 'Learning-by-doing' participation projects within the 'Werkgroep 2000' foundation. In 1979 he returned to building technology and set up the Woon-Energie Foundation (later to become 'WE consultants'). Over the next ten years he focussed on sustainable building in general and energy conservation in particular. In 1985 Klimaatbouw BV was set up and it still offers (small-scale) consultancy services on building-related problems, product design and renovation plans. In 1992-1993 Evert was employed by an umbrella organisation of housing associations to conduct research into the maintenance of central heating appliances. One year later the implementation of the 'National Insulation Covenant' resulted in half-time employment with the Dutch National Tenants' Association (Woonbond). This involvement lasted four and a half years and meant that Evert came across the many different kinds of problems that tenants have with their homes and housing managers, including exposure to health hazards. In 1998 Evert took up a research position with the OTB Research Institute at TU Delft, for research on sustainable and healthy building. In many respects this meant that the circle closed some 25 years after graduating at TU Delft, when Hugo Priemus was his first mentor, who was then later to become the supervisor for Evert's PhD study on healthy housing - a study that has resulted in 2006 in this present thesis.

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Occupants in air-tight houses and with poorly maintained mechanical ventilation systems have stimulated the study of health hazards of housing. Five hundred houses were inspected, to diagnose the relation between lay-out, construction, technical services and interior decoration with potential indoor air pollution and problems with noise and safety. The occupants were interviewed about ventilation behaviour and activities that produce pollutants or hazards. These interviews provided data for an analysis of the relations between technical performances of houses, occupant behaviour and exposure to health risk. The result is a list of indicators that mark these relations and in particular the exposure to house dust mite, mould, legionella pneumophila bacteria, fine dust, noise, extreme discomfort and safety hazards. Tools for the evaluation of health performances were developed and tested. The strategy and the indicators presented in this thesis are the basis for the Checklist Healthy Housing, available in versions for households and professional users. This last group will find this book an informative source on healthy housing.

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