Health performance of housing, indicators and tools
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Evert Hasselaar, OTB Research Institute for Housing, Urban and Mobility Studies, Delft University of Technology, the Netherlands

Corresponding email: e.hasselaar@tudelft.nl

Summary

Occupants and housing managers deal with several environmental problems in dwellings. To support the diagnosis of cause and effect and to promote good communication about health hazards, indicators of the relationship between physical properties, occupancy patterns and health risks are needed. The research project focussed on the selection of indicators that mark the relationships between physical parameters, user behaviour and health risk. Houses were inspected and occupants interviewed to study environmental conditions. Through modelling the relevance of parameters was evaluated. Performance evaluation in practice suggested the importance of communication and action oriented strategies. A tool was designed, used and evaluated after one year. The results ask for accessible information to support the assessment of performance and a simple action list to remediate major problems.

Keywords – Healthy Housing 2008, performance evaluation, indicators, occupant behaviour.

Introduction

Indoor air pollution, noise, radiation and un-safety are important health risk parameters of the home environment. The health impact does not only involve mortality or shorter life, but also changes the quality of life in a broader sense, for instance aggravating asthma, sleep disturbance, a reduced ability to concentrate, feelings of insecurity and poor health perception (Hollander 2004). How can housing managers and occupants evaluate the health risks in dwellings? How to make a distinction between the technical performance of the building and the problems caused by occupant behaviour? Indicators of health performance are needed, that show how technical aspects and occupant behaviour are related. The indicators are for strategic use: diagnosis of maintenance problems, good communication about health risk and data collection for setting out maintenance and renovation activities. The goal of health performance evaluation is to make a comprehensive analysis (diagnosis) of problems that are perceived by occupants. By supporting occupants in evaluating the quality of the home environment, they may develop better understanding of the impact of their user patterns and how to improve the environmental quality. This strategy implies the selection of indicators of housing quality, occupant behaviour and associated health hazards.

The research questions are:

1. Which are the main indicators of health hazards in dwellings?
2. Which tools can contribute to improvement of housing health performance?

Methods

First step: indicator selection, based on literature

Occupants of dwellings are exposed to many agents, often at a relatively low concentration, which makes it hard to establish a direct link with health of occupants. Certain indicators refer to phenomena that can be quantified, others to phenomena that can be observed (stimulation of senses) or are being perceived by the occupants, while the inspector tries to understand these perceptions on the basis of hazards and the physical and mental condition of the occupants. The selection of a preliminary list of indicators is based on literature. Scientific research tends to focus on single agents with a high concentration (Säteri 2003, Affset 2006). When these single variables mark a hazard condition, they can be used as indicator. Much research evidence is available about the impact of air pollutants on health. House dust mite has been recognised as a major indicator of respiratory problems (Bronswijk 1996, Boer 1997).
Recent studies on asthma point at the potential role of chemicals and especially plasticizers in surfacing materials and consumer goods. In general, chemical exposures supposedly play an important role in the development of children (Jaakola 2000, Sundell 2005), but effects of only a few chemicals are understood: formaldehyde, ozone, PAH’s, heavy metals, lead and pesticides. Fine dust is an emerging research topic and the evidence on the relationship with pulmonary and cardiac disease is well established, possibly even the relationship with cancer. The chemical content of dust and also the size distribution from ultrafine to coarse particles seems very important for the health impact. Traffic exhaust fumes, but also airborne dust from waste belts or forest fires and chimney stacks contribute to the health effects downwind. Flame retardants in domestic appliances are a concern. The use of pesticides indoors may have health effects (EPA 2003). Lead has been banned effectively from paint and gasoline, but exposure from polluted soil and dust in the house (EPA 2003) still is a potential risk.

Second step: indicators based on field work
A Dutch list of indicators developed in the period 2002-2004 in preparation of new tools for the assessment of housing health performance (Bergs 2002, Broeke 2003, Versteeg 2003, Nieman 2004). The Ministry of Housing, Spatial Planning and the Environment promotes the use of this list, to facilitate comparison of results on the basis of different tools. Hasselaar (2006) took this list as the starting point for a re-evaluation of indicators. A new list was developed, with more focus on exposure to health risk rather than on concentrations of air pollutants and a few hazard conditions. Also, the distinction between technical conditions (the building) and occupancy and occupant behaviour was introduced. More than 500 houses were visited and occupants interviewed. The results of measurements, observations and interviews resulted in a database with 333 documented cases and 165 variables per case. This dataset allowed statistical explorations, to understand the relations between different parameters (variables) better. In addition to this database, experiments were done in four test houses in the Netherlands and in a test chamber in Brisbane, Australia. The parameters have a place in models that explain complex health risk conditions, not the actual health effects. The analysis of this data is presented in Hasselaar (2006).

Third step: instrumentation for housing health performance evaluation
The selection of indicators is placed in a practical context: dealing with complaints and problems and discussion with housing managers about problem solving. This involvement resulted in attention for process indicators: to improve communication and support action taking for remediation of problems and change of occupant behaviour. A theoretical framework was developed, to support this strategy of inspection, communication and improving the health performance of houses. It means that the focus is more than on a health assessment rating system, it includes the relationship between housing managers and occupants as well, while an owner occupant is supported in combining the role of manager and occupant.

Framework of housing health performance evaluation
The health effect of the indoor environment of a dwelling depends on a chain of events. For air pollutants there must be a source that emits into the indoor environment, the concentration must reach a hazardous level, occupants must be exposed to the hazard and finally the occupants must be vulnerable to the potential health effect. A simple chain of events is the Driving Force-Pressure-Effect-chain, which was transformed into the DPSEEA framework by WHO (2001): Driving Force-Pressure-State-Exposure-Effect-Action. Hasselaar (2006) included Risk Ranking, Monitoring and Prevention in the framework, to fit housing management policy into the framework and to stress the importance of communication and action taking, including precautionary action. It is difficult to collect data on the complete chain of a specific hazard condition, but it is possible to collect data on parts of the chain, which helps better understanding of the total chain, so the diagnosis will improve and the relative risk of being exposed to the hazard can be evaluated. See Table 1.
The purpose of the risk score is to decide how urgent it is to avoid the exposure to hazard conditions. The Risk Score in Table 1 has a flexible position in the framework and “floats” over the acronym SCEAM: the score is either primarily based on the concentration or condition, or based on information about exposure and effect or even based on the availability of actions. The R of risk score can be seen as a label for the hazard: high when dealing with carcinogenic pollutants, lower when dealing with agents that irritate the respiratory tract. Because health is not measured, but a risk is scored, the assessment represents a qualitative method. This qualitative method allows for more simplification, which is needed to make instrumentation user friendly and to allow focus on action taking, rather than on a “hazard label”.

**Performance evaluation strategy**

Many houses have similar sources of pollutants. The identification can be based on a list of potential pollutants and checking the items of the list during the inspection of the house. The emission level depends on the amount of material and the emission characteristics and this needs expertise on the material characteristics. For health effects the potential peak level and exposure period are important. Occupants can give information on how certain pollutants effect their perception of health: they can smell many emissions and will be alarmed by poor smell, but not all pollutants can be smelled. The removal mechanisms of pollutants are ventilation or removal of the sources. The ventilation quality can be checked on the basis of inlet and exhaust openings, type or size and controls. But information about the performance of ventilation systems is needed as well, because the effectiveness of ventilation systems is difficult to assess. The health effect of exposure to pollutants will depend on the condition of a person. The period and type of exposure depends on the use of different rooms, with the bedroom being very important. The risk score for a specific hazard must be connected with the health condition of the occupant(s): the score is higher for susceptible persons, for instance children and the elderly. Exposure and health conditions are occupant-related and indicated how important the interview is. The inspection and interview will be done in the day time, mostly on weekdays, and this moment will no reflect peak exposures. So the inspector must translate the conditions to the worst period of the year, which is the winter season for most hazards, but some hazards my prevail in the summer, or during storm, or when it is very

<table>
<thead>
<tr>
<th>SCREAM-P framework of housing health performance evaluation</th>
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<tr>
<td><strong>Source</strong></td>
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<td>---------------------------------------------------------------</td>
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<tr>
<td><strong>Evaluation of agents</strong></td>
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<td>emission of agents in indoor air</td>
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<td><strong>Evaluation of conditions</strong></td>
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<td>physical effects and user effects</td>
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<td><strong>Types of indicators used in tools for housing health performance evaluation</strong></td>
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<td>sources and conditions</td>
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Table 1. The SCREAM-P framework and types of indicators (based on Hasselaar 2006)
damp and wet outside, for a long time. Also, the occupant must be invited to explain conditions and experiences during “worst” but common cases. These interpretations make performance evaluation a qualitative activity, while the risk score cannot be very specific. The importance is to agree on an action list that can reduce the diagnosed health risks. The occupant will be “empowered” by better feedback on behaviour, and the dwelling will be improved as a result of remediation.

Results
Analysis of the 333 dataset provides new insights in what causes hazards in dwellings. In the next paragraphs, only a few results are presented, based on each of the three methods applied: case studies (the 333 dataset), experiments and involvement in complaint handling processes.

Results of the 333 dataset
The exposure patterns indoors in the house differ between persons mainly at home and persons at work or in school. On average, the time spent at home is about 60%. Every person spends one third of a lifetime in bed and for persons with a job up to 60% of the time spent in the house is in the bedroom. The time spent in the living room and kitchen differs very much per individual.

House dust mite exposure
The exposure to allergen material is reflected by the concentration of allergen-containing aerosols. Moving around on the carpet or sofa, moving around in bed on the mattress and vacuum cleaning are major causes of aerosol production and inhalation. Thick carpets on a cold floor have high moisture level and high allergen concentration after some time. The combination of much allergen material in bed and the blowpipe effect of covers cause high exposure levels, while exposure increases when sleep is disturbed due to respiratory problems. The age of the mattress is considered a robust indicator for exposure to house dust mite allergen.

Ventilation
Occupants tend to overreact: the window is opened widely after sensation of bad smell, but closed again after a short while. Fear of draught or noise is a reason for keeping inlet openings closed. The large seam length of large windows and doors in two opposite façades in older houses provides relatively high infiltration. The living room for that reason tends to receive little attention regarding active ventilation, but does not present major indoor air problems either. Of the houses with mechanical exhaust ventilation (58% of n=324), 14% has turned the system off. Individual systems are at lowest set point most of the day, so the ventilation depends largely on the use of grates and windows. In the master bedroom 43% keep openings closed in the winter season while in 82% of master bedrooms two persons are sleeping. The air quality in tight buildings depends on active control of ventilation; the low set point and closed windows cause indoor air problems.

Exhaust systems show a reduced capacity, due to wear, dirt and maladjusted dampers: 38% of the mechanical exhaust boxes in the dataset were never cleaned and in 90% the fan capacity was never restored. The estimate is that 70% of all mechanical exhaust systems in the Netherlands have a capacity of only 50% of standard volume, and the low set point provides 15% of nominal capacity. Occupants tend to substitute low mechanical volumes with natural cross ventilation, but this is not always effective. Natural exhaust volumes are in the range of 40 - 60% of norm values in the kitchen (average weather conditions), which is higher than mechanical exhaust at low set point.

Air change rates
Based on measurements in 38 houses (Hasselaar 2006), using CO₂ data logging over 1-10 days, estimates are given for the effect of inlet openings on the air change rates in bedrooms with typical surface areas of 8-12 m² and opening in one façade. See air change rates in Table 2. The results show that a window must be wide open to allow enough exchange of air for two people sleeping in a bedroom: 1.4 ACH to keep the CO₂ concentration below 1000 ppm. This analysis leads to the following indicators: exhaust fan older than 5 years has low exhaust volume and does not contribute to air change, performance depends on façade openings and cross flow; and bedroom ventilation requires large openings during sleep.
### Table 2. Air change rates and openings

<table>
<thead>
<tr>
<th>Opening</th>
<th>Air change rate per hour (ACH)</th>
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<tbody>
<tr>
<td>all closed</td>
<td>0.1 - 0.3</td>
</tr>
<tr>
<td>door open</td>
<td>0.5 - 0.7</td>
</tr>
<tr>
<td>window open, door closed</td>
<td>0.5 - 0.7</td>
</tr>
<tr>
<td>window and door open</td>
<td>0.7 &gt; 1.2</td>
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### Results of experiments

Moisture is a major maintenance topic in Dutch housing. Health effects of moisture are mould growth and high reproduction potential of house dust mites.

Showering, laundry drying and other moisture sources

Drying the skin of an adult loads a towel with about 100 cm³ of water. The wet surfaces in the shower cubicle represent 200-300 cm³ of water and without cubicle the amount of water left behind to evaporate may result in up to 500 cm³ of water per shower. The amount of water in the warm and humid air in the bathroom is only 100-130 cm³. The absorbed water content in surface materials is quite low, when layers of paint have been applied. In the Netherlands the number of showers per day equals the number of people over the age of about 9-12 years. In one third of the cases the bathroom becomes wet from three or more showers a day. In half of the bathrooms laundry drying adds to moisture production. It takes several hours before the moisture effect of a shower has disappeared completely. Three or more showers a day may result in a long “time of wetness” of materials, which is the key to the germination of spores and mould growth (Sedlbauer 2003). Stripping the water from tiles after a shower drains 100-200 cm³ into the sewer. Drying the tiles in the shower with the towel instead, and hanging the towel to dry outside, reduces the moisture load with 200-300 cm³, including the moisture from the skin.

The frequency of the washing cycle is related to lifestyle and the age of children. Each kg of wet laundry releases 500-700 cm³ of moisture, depending on the size and speed of the spinner applied. A full load produces 2.3 to 3 litres of moisture. About one quarter of the households dries laundry outside or in a dryer connected to an exhaust system. One quart uses the attic or a separate room, 18% uses the bathroom for drying on racks or in the condensing dryer and 32% dries the laundry in the living room or stairwell (n=254). Worst scenario: one machine load equals three to four showers.

Cooking, plants and an aquarium contribute little to the moisture production. Humans and large pets do matter: 800 – 1500 cm³ of moisture per 24 hours, of which one third in the bedroom (and half of the emission into the bed).

This analysis leads to one indicator: mould is visible. The other parameters indicate mould growth, but this is not relevant as long as mould is not visible, maybe because it was wiped off.

### Results of process involvement

A conflict between the housing association and a tenant or neighbourhood committee is often caused by poor communication. “Empowerment” has positive impact on self awareness and contributes to better quality of life. Complaints and consequently the inspection and interview provide a chance for communication and a process that restores trust. Empowerment can stimulate tenants for instance to talk to neighbours first, instead of calling the police.

### Selected indicators

The indicators are per room, which makes the inspection protocol simple. The list includes background information that explains the inspector or owner occupant to what hazard the indicated condition refers and how to assess for instance poor ventilation or emission from the crawlspace.

#### 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
4. emission of moisture, radon and pollutants from the crawlspace via chinks in the floor;
5. over-occupancy and peak emissions from people and inherent activities;
6. tobacco smoke and fine dust from carpets and sofa’s.

Kitchen
7. emission from gas heaters without exhaust system, aerosol production from grilling and baking;
8. mould from the bio-container and from the kitchen closet (crawlspace);
9. safety hazards from using knives, hot pans, steam, fire.

Bathroom
10. safety hazards of falling on slippery wet floor;
11. legionella from shower, in combination with low temperature in buffer tank and stagnancy;
12. large mouldy surfaces.

Studio: place for hobby and home work
13. chemical emissions from activities, toys, office machines, in combination with poor ventilation;
14. poor ergonomic layout and work position;

Circulation areas
15. steep stairs with narrow foot space, slippery steps and inconvenient supports;
16. risk of falling because of obstacles and poor lighting;
17. poor sustaining design, limiting the use when disabled (sick, elderly, mobility impaired).

Anywhere in the house
18. during and after application of paint, etc, pesticides or refurbishing or decoration activities;
19. vacuum cleaning in the presence of children or people with respiratory sensitivity;
20. high occupancy rate including large pets, as average per room.

Outdoors
21. poor outdoor air quality: fine dust, chemical pollution;
22. high noise level, causing frequent sleep disturbance;
23. perception of insecurity or social intimidation, lack of social support and lack of privacy.

Process indicators
24. quality of communication about the environment
25. involvement in maintenance and renovation;
26. learning about the indoor environment, by information, control and feedback.

The allocation of indicators to separate rooms makes the bedroom for two people the room that requires attention for the mattress and for ventilation. 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 bathroom is relevant for mould growth and as a source of dampness that influences the moisture balance in other rooms, mainly bedrooms. The living room shows a mixture of relatively low pollutant concentrations.

Evaluation of the Checklist Healthy Housing
A tool was developed and made available through the internet (www.toetslijstgezondwonen.nl). The tool was evaluated one year after publication. An electronic questionnaire was sent to 1350 persons who had requested to use the Checklist. The response through email was 20,5%. See Figure 1.
The users have a positive opinion about the familiarity, simplicity, attractiveness and educative aspects of the Checklist. The opinion about the dwelling changes to some extent and is more negative, indicating a more critical perception of the health performance of the dwelling. Only few persons have taken action towards the housing manager, several users have changed ventilation behaviour.

**Discussion**

The study relies on literature on the health impact of pollutant agents and hazard conditions. It means that a direct link is not studied and that health performance evaluation focuses solely on the environmental conditions in dwellings and not on health. Because of the focus on health risk we can speak of housing health performance or even of healthy housing, but we cannot speak about the health effects of remediation measures or designs.

The selected indicators support a quick evaluation of the qualities of a house. The indicators that point at sources of pollutants and hazard conditions are relevant and easy to handle. Exposure was simplified to a few scenarios, with the bedroom as most important location. Through modelling, inspections in the field and allocating the risk parameters to different rooms, many potential indicators disappeared, creating a short and more robust list. This selection process is the result of deductive reasoning, without loosing the complexity of environmental cause and effects. For example: the complexity of mould risk disappears with the selected robust indicator: mould is a risk when you see mould. And when you do not see mould, it creates a risk when you smell it. This study of mould parameters resulted in a different solution for mould in the bathroom: not by improving the ventilation but by applying surface layers from which mould can be wiped off: tiles up to the ceiling and a smooth ceiling are alternatives for the costly changes of the ventilation system.

The list of 26 indicators may not cover specific conditions in certain dwellings: it is a short list with open end. The Checklist Healthy Housing differs from the Housing Health and Safety Rating System in the UK (Ormandy 2003): it is not a labelling system and the suggestion of objectivity is not given, it leads to an action list instead. However, there is a function for different assessment methods: from quantitative and objective to qualitative and action oriented.

**Conclusion**

The selection process of indicators of health performance follows a stepwise strategy: from a longlist via data collection and model studies to a shortlist of priority indicators. The indicators support diagnosis of problems caused by the building parameters and by occupancy and behaviour,
and support communication and action taking. The instrumentation used for performance evaluation that was based on these indicators is user friendly, but has low impact on action taking. Also, much information is needed, to support a learning process. The conclusion from the evaluation of the Checklist Healthy Housing is that for the learning process, more information is needed, while for action taking a short action list will be enough. The promotion of awareness about the health hazards of housing is supported by highlighting “new” indicators. Dealing with conflict situation has resulted in better awareness and communication about improvement of systems. Do-it-yourself performance evaluation on the basis of the indicators highlights the need for user friendly appliances and systems in dwellings.

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