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**Assessment of health risks in buildings using
health hazard algorithms**

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ASSESSMENT OF HEALTH RISKS IN BUILDINGS USING HEALTH HAZARD ALGORITHMS (HOPE PROJECT)

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ABSTRACT

The EU project HOPE (Health Optimisation Protocol for Energy-efficient buildings) seeks to characterise those buildings that achieve good performance in both energy efficiency and occupant health and comfort. This project involved two stages of fieldwork: assessment of buildings by checklist and occupant questionnaire in the first stage, more detailed physical measurements in a subset of buildings in the second stage.

In order to help with selection of buildings and measurement plans for the detailed measurements, a series of health hazard algorithms were designed, each based on an individual building health hazard (such as asbestos, carbon monoxide, fungi, etc). The criteria within the algorithms were based on the responses to the checklists and questionnaires, in order to highlight potential hazards.

This paper briefly describes the fieldwork methodology used in HOPE, and explains the derivation of the health hazard algorithms and their use in the evaluation of health risks in buildings.

INDEX TERMS

Questionnaire, Checklist, Occupant health, Building health assessment, Health hazards

INTRODUCTION

The HOPE project was set up to investigate the perceived conflict between healthy and comfortable environments and energy efficiency. The project entailed two stages of fieldwork.

The first stage involved over 160 buildings across Europe, office buildings and residential buildings. Information and characteristics of the buildings were collected by means of occupant questionnaires and building checklists.

The second stage of fieldwork involved detailed physical measurements of the environment in a subset of the buildings from the first stage.

A means of evaluating the information from the first stage of fieldwork was needed, in order to make a selection of buildings for the second stage, and in order to inform

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the creation of measurement plans. Measurement plans for the second stage of fieldwork were devised individually for each building. A series of health hazard algorithms was therefore derived, which identified information from the checklists and questionnaires that were relevant to each building health hazard, and combined the information to produce an assessment of whether each hazard was likely to be present in the building, possibly present in the building, or unlikely to be present in the building.

This paper describes the checklists and questionnaires used in the first stage of the fieldwork, describes the derivation of the health hazard algorithms, and describes their application to the selection of buildings, creation of measurement plans and their further use as a means of assessing building health.

RESEARCH METHODS

Building selection for first stage of fieldwork

Fieldwork buildings were selected with the aim that at least fifty occupant questionnaires would be returned. In addition, energy consumption and building description information should be available, the buildings should have been in their current state of operation and occupancy for at least one year, and there should be energy saving measures present in most of the buildings.

Occupant questionnaires

For office buildings, an Office Environment Survey was used, based on Raw (1995). This self-completion questionnaire covers the following factors.

- Location and orientation of working space
- Personal well-being (acute health symptoms)
- Personal well-being (existing conditions)
- Environmental comfort in winter and summer (Temperature, air movement, air quality, light, noise)
- Control of environmental factors
- Other factors (privacy, layout, décor, cleanliness, view)
- Response to requests for improvements to office
- Time worked in building, hours at VDU, etc
- Smoking behaviour

For homes, up to four questionnaires were used. A questionnaire was distributed to each occupant (one version for adults, one version for children) and covered the following factors.

- Years in apartment, hours per day in apartment
- Environmental comfort in summer and winter
- Personal well-being (incidence of acute symptoms)
- Personal well-being (chronic conditions)
- Opinions on heating and ventilation in the apartment
- Smoking behaviour
- Employment status
- Effect of environment on health, and on ability to carry out necessary work

A household questionnaire was also distributed, one per apartment.

- Ages of household, length and status of tenancy
- Window orientation

- Ventilation: natural, mechanical, fixed, adjustable
- Cooling fuel, cooker hoods, behaviour
- Use of appliances (esp. moisture-generating appliances)
- Window opening behaviour
- Smoking status
- Condensation and mould
- Pets and pests
- Energy use / bills

Finally, a supplementary household questionnaire was occasionally used, in buildings where systems or services varied between individual apartments, rather than being uniform through the building.

- Ages of household, length and status of tenancy
- Window orientation
- Ventilation: natural, mechanical, fixed, adjustable
- Cooling fuel, cooker hoods, behaviour
- Use of appliances (esp. moisture-generating appliances)
- Window opening behaviour
- Smoking status
- Condensation and mould
- Pets and pests
- Energy use / bills

Checklists

The building checklists were designed to collate information about the buildings in a standard format, for entry to a shared database, HODa. Some information could be completed by researchers from documentation or visual inspection. Other information required the help of facilities management staff or equivalent. The checklists were in three main sections.

The first section covered information on the description of the building, including information on the location and local environment, the building construction and design, solar shading, occupants and offices, air and water leakage, glare, décor, etc. The second section covered information on the building services (heating, cooling, ventilation, water supply, maintenance and cleaning, etc). The third section covered information on the use of the building, including activities, office machines, smoking policy, cleaning schedules, etc.

RESULTS

Evaluating the fieldwork results

In terms of health, the metrics used to compare buildings were as follows.

- Acute health symptoms (data from occupant questionnaires)
- Environmental comfort (data from occupant questionnaires)
- Building health risk factors (derived primarily from building checklists, but using some information from occupant questionnaires).

It was the third of these metrics for which the health hazard algorithms were derived.

Building Health Hazards

A list of the building health hazards considered is shown in Table 1.

Table 1. Building health hazards

Air pollutants		Other hazards
Radon	Allergens (e.g. pollen or from fungi, mites, pests or pets)	High temperature
Heavy metals (primarily lead) in the air	Total volatile organic compounds (TVOC)	Low temperature
Asbestos	Individual VOCs (e.g. benzene, formaldehyde)	High humidity
Synthetic vitreous fibres	Carbon monoxide	Low humidity
Other particulate matter	Oxides of nitrogen (NO _x)	Draughts
Ozone	Sulphur dioxide	Inadequate ventilation (may be indexed by CO ₂ concentration)
Infectious agents from the occupants (primarily bacteria)	Environmental tobacco smoke	Noise
Infectious agents from the building (primarily Legionella)		Poor lighting
		Heavy metals (primarily lead) in water

For each health hazard, a matrix was created of every checklist item or questionnaire response that was considered likely to contribute to the presence or otherwise of the hazard. Table 2 shows an example of the health hazard matrix, in this case the one built for assessment of ozone as a hazard.

Table 2. Extract from health hazard matrix for ozone

Mechanical ventilation (if applicable)		
Type of mechanical ventilation	Exhaust system only - toilets, bathroom, kitchen, other polluted rooms only - also other rooms; Supply system only; Balanced system; Balanced system with dual ducts; Other	Exhaust system only - toilets, bathroom, kitchen, other polluted rooms only - also other rooms; Supply system only; Balanced system<; Balanced system with dual ducts<; Other
What type of control system is there for mechanical ventilation?	Central - manual (on/off); Central - clock; Central - demand control (temperature, CO ₂ , other pollutant, RH); Local - manual (on/off); Local - clock; Local - demand control (temperature, CO ₂ , other pollutant, RH); Recirculation control	Central - manual (on/off); Central - clock; Central - demand control (temperature, CO ₂ , other pollutant, RH); Local - manual (on/off)<; Local - clock; Local - demand control (temperature, CO ₂ , other pollutant, RH); Recirculation control
Humidification	None; Spray; Evaporative; Steam; Ultrasonic; Infrasonic; Other	None>; Spray; Evaporative; Steam; Ultrasonic; Infrasonic; Other
Water purification	None; Ozone; Biocidal; High voltage; UV; Other	Ozone>; High voltage>
Outdoor air filter	Prefilter; Main filter	Prefilter<; Main filter<

The likely contribution of each relevant checklist and questionnaire item was described in the matrix, and the information was then combined into an algorithm based on logical statements. As an example, using the information contained in Table 2, below is a short extract from the algorithm for ozone, provided to give an example of the format of the algorithm.

Hazard possibly present if:
 Potential indoor source
 <“Water purification” = “Ozone” or “High voltage”>
 OR
 <{Potential outdoor source
 “Where is the building situated?” = “City centre, densely packed housing”}
 AND
 {[Ventilation is by openable windows
 “Are there openable windows in the apartment?” = “Yes” OR “Yes, some”
 AND/OR
 “How is the building ventilated?” = “Openable windows”]
 OR
 [(MV with supply air
 “Type of mechanical ventilation” = “Supply system only” OR “Balanced system” OR
 “Balanced system with dual ducts”)
 AND
 etc

With the checklist and questionnaire data for each building already contained within the HOPE database in a standard format, the algorithms were then coded into the database to enable calculation of the hazards for each fieldwork building. This resulted in a method for using the collated building information and obtaining an output saying whether a hazard was considered likely to be present, possibly present, or unlikely to be present.

For each building, a measurement plan was then derived to ensure that hazards that were likely to be present or possibly present were measured, in order to confirm their presence or absence. For some of the most serious hazards, measurement was recommended regardless of the algorithm outcome. For many of the other serious hazards, measurement was recommended if the hazard was likely or possible. For the least serious health hazards (e.g. lighting) measurement was recommended if the hazard was likely, suggested if the hazard was possible, unnecessary if the hazard was unlikely. In practice, some measurements were carried out even when they might have been unnecessary, in order to provide better comparison between buildings for the purpose of the study.

Evaluation of health hazard algorithms

At the end of the fieldwork, the measurement results were compared to the health hazard algorithm assessments, to examine how well the algorithms had predicted hazards within a building.

A comparison of the hazard assessment predictions with the results based on measurement in the building showed that the hazard assessments provided reasonable predictions of building health hazards.

Over all the measurements were made in all the buildings, only one case occurred where a hazard was predicted as absent, but found to be present. A prediction of the hazard being present and a measurement show the hazard to be absent occurred in fewer than 10% of cases, and in only one case for the most serious class of hazard.

In the majority of cases (75%), the prediction of the hazard assessment algorithms was equal to the outcome of the measurement, or more stringent than the measurement (e.g. prediction of "possibly present", measurement showing "absent"). This balance of results, erring on the side of caution, helps to ensure that a building is not wrongfully categorised as healthy.

Health hazard algorithms as a tool for building evaluation

The successful results of the predictions based on checklist and questionnaire data enabled the project team to consider using the algorithms as a building evaluation tool for general use, in particular to direct building investigators to recommended measurements.

As a result of the results obtained from the fieldwork buildings, the outcomes of the health hazard algorithms were considered. In some cases, the algorithms did not show sufficient discrimination between buildings to be useful: sometimes this was because the algorithm itself needed revision, and other times because missing pieces of information on the checklist led to clusters of default outcomes.

A review process was therefore undertaken, refining the algorithms themselves, and making the appropriate changes or additions to the supporting building checklists and occupant questionnaires.

CONCLUSIONS AND IMPLICATIONS

Within the HOPE project, a set of tools has been developed to evaluate the health status of a building.

This includes building checklists and occupant questionnaires, and a series of health hazard algorithms based on the data obtained from the checklists and questionnaires. When compared to results of measurements in buildings, the predictions were found to be good in the majority of cases.

These algorithms are coded into the HOPE database at <http://www.hope.epfl.ch/>. From this database, results can be viewed and the building evaluation tools can be downloaded.

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