European project HOPE (Health Optimization Protocol for Energy-efficient Buildings)

Philomena M. Bluyssen,[a,*], Christian Cox[a], Marco Maroni[b], Nadia Boschi[c], Gary Raw[d], C.A. Roulet[e], Flavio Foradini[f]

[a]*TNO Building and Construction Research, Department of Healthy Buildings and Systems, Delft, The Netherlands;* [b]*University of Milan, Italy;* [c]*Virginia Polytechnic Institute and State University, USA;* [d]*BRE Environment, Watford, UK;* [e]*EPFL (Swiss Federal Institute of Technology, Lausanne, Switzerland;* [f]*E4Tech Ltd, Lausanne, Switzerland*

ABSTRACT
In January 2002, a new European project named HOPE (Health Optimization Protocol for Energy-efficient Buildings) started with 14 participants from nine European countries. The final goal of the project is to provide the means to increase the number of energy-efficient buildings, i.e. buildings that are at the same time healthy and low energy users. Reducing energy use by buildings also reduces CO_2 emissions from primary energy used for ventilation, heating and humidity control. The outcome of the project will comprise a methodology for assessing the performance of buildings according to a set of integrated health–energy criteria, to improve unhealthy or energy inefficient buildings. This paper presents the current status of this three-year European project, covering a provisional set of performance criteria, based on available knowledge and a description of tools used to test these criteria in a multidisciplinary study in 180 office buildings and multi-apartment buildings.

INDEX TERMS
Health and comfort; Performance criteria; Energy efficiency

INTRODUCTION
In principle, it is economically feasible to create buildings that are both energy-economic and healthy, and are therefore truly sustainable and energy-efficient. Nevertheless, the current health situation of people in buildings is far from ideal (Preller *et al.*, 1990; Bluyssen *et al.*, 1995; Jantunen *et al.*, 1999; Fisk, 2000; Sundell, 2000; Institute of Medicine, 2000) and the potential from improving the indoor environment is high as well as the potential for reduced energy in buildings.

It becomes clear that there may be a potential conflict between strategies to reduce energy use in buildings and to create healthy buildings. For example, a particular material/product might have a low embodied energy but cause unhealthy emissions, or the ventilation rate may be reduced to save energy but indoor pollutant concentrations may increase. While there is a strong logic to improving energy performance by attention to healthy indoor environments, more needs to be done to realize the potential. Action needs to be directed at both improving guidance on how to realise the potential, and making a convincing case for the building industry to make changes.

To provide the means to increase the number of energy efficient buildings that are at the same time healthy, the European project named HOPE (Health Optimization Protocol for Energy-efficient Buildings: Pre-normative and socio-economic research to create healthy and energy-efficient building: contract no. EUK6-CT-2001-00505) started in the beginning of 2002. The 14 participants from nine European countries have the challenge to answer the following questions in this 3-year project:

[*] Corresponding author. E-mail: p.bluyssen@bouw.tno.nl

– What is a healthy building and what is an energy-efficient building?
– What is an energy-efficient healthy building?
– Are buildings with energy saving measures energy-efficient? And what is the health status of buildings with energy saving measures as compared to buildings without energy saving measures?
– How can we assure that buildings are healthy and energy-efficient at the same time?

The project HOPE comprises a number of work packages as described in Bluyssen (2002) to meet the following objectives:

- Define a set of qualitative (prescriptive) and quantitative (measurable) performance criteria for healthy and energy-efficient buildings for Europe.
- Determine a protocol for testing and verifying these performance criteria in a number of buildings.
- Create a database of the health and energy efficiency status of buildings in Europe.
- Develop a protocol for improving a building that is unhealthy and/or energy inefficient.
- Create a Web-site for the public with the possibility to add data on ones own building into the database and compare these to the investigated buildings.

Halfway through the project, first results are available with regard to the performance criteria, the protocol for testing performance criteria and the database.

PERFORMANCE CRITERIA

For the purpose of this work, based on available knowledge and HOPE research scope, the definition of a 'Healthy and Energy Efficient Building' adopted here is as follows:

- Does not cause or aggravate illnesses in the building occupants.
- Assures a high level of comfort for the building's occupants with respect to the designated activities for which the building has been intended and designed.
- Minimizes the use of non-renewable energy taking into account available technology including life cycle energy costs.

From the above definition, it is clear that buildings with different uses may pose different requirements in terms of indoor environment quality. At the same time, as the 'occupant population' may vary in characteristic composition (age, gender), density of occupancy (high, low), health status (healthy or sick), genetic and biological predisposition to get ill (e.g. hypersensitive people, allergic people, etc.), it is virtually impossible to define an absolute set of criteria that would always meet the needs of all occupants in every building.

Table 1 outlines a possible development of the stakes of healthy and energy efficient buildings as defined above into criteria and factors (Roulet *et al.*, 2003). Note that every stake is represented by one criterion, itself evaluated by a family of factors, and that increasing the value of any one of the factors decreases the performance. However, the HOPE enquiry is more complete, and additional factors will be taken into account.

Table 1 Criteria for comfortable, healthy and energy efficient buildings

Stakes	Criteria		Factors
Low energy use	Energy index per heated floor area		Total energy index Heating energy index
Not cause or aggravate illness	Prevalence of typical sick building symptoms		Dry, itching or irritated skin Blocked or stuffy nose; runny nose Dry throat; chest tightness, flu-like symptoms Dryness of the eyes; itchy or watery eyes Lethargy or tiredness; headaches
High level of comfort for the building's occupants	Indoor environment quality	Indoor air quality	IAQ dissatisfaction Air stuffiness or dryness; air odour
		Thermal comfort	Thermal discomfort in general Too cold or too hot; draughts
		Acoustical comfort	Noise dissatisfaction Noise from ventilation and other noise
		Visual comfort	Lighting dissatisfaction Glare and light flickering

A framework for performance criteria for healthy and energy-efficient buildings was developed within the context of two European funded Projects: PeBBu and HOPE (Bluyssen and Loomans, 2003). 'Stakeholders', 'building phases' and 'building objects' are regarded as important components. Interrelations between the building phase and the type of stakeholder are obvious, as is the case for building objects and building phases. Each specific performance criterion therefore can be related to the individual contexts. These contexts can be presented on axes in a three-dimensional format. In this framework, it is possible to represent all the information that defines the required performance for the given stakeholder, building phase and building object. It contains the specific performance/target values and gives a method for evaluating the performance, all in an unambiguous way.

As a first approach, the framework seemed rather wide to cope with in the project HOPE. Therefore, it was decided to deal with the situation in which: building phase = use and stakeholder = user. Thus, two dimensions of the framework are predefined and the axis 'building object' is omitted (for this axis, performance criteria will be translated to environmental attributes, target values/demands and evaluation procedures). For a more detailed description see Bluyssen and Loomans (2003).

A comprehensive table of health parameters and related target values and associated factors/building objects has been drafted (Maroni *et al.*, 2003). Target values are based on generally accepted guidelines (WHO, EU), standards or best currently available data (e.g. for TVOC reference values from Seifert 1990 are used). For some parameters target values are questionable (e.g. radon, because it is a natural gas, but is carcinogenic). Instead the ALARA-principle (As Low As Reasonable Achievable) should be strived for.

PROTOCOL

In nine countries, 20 buildings per country are to be investigated, using a common methodology. For the selection of buildings to be included in the multidisciplinary study, the following criteria have been agreed upon:

- 50+ occupants;
- Energy consumption over last 12 months available;
- Building description information available;
- In current state of operation for at least 12 months;
- Energy saving measures present (for 75% of the sample).

The following instruments were agreed upon:

Questionnaires

- Office Environment Survey: containing questions about symptoms, environmental comfort, productivity, sick leave and personal factors as sex, job type, personal health status etc. based on (Raw, 1995).
- Household questionnaire: containing for example questions about use of the apartment, heating and ventilation systems, problems like moulds, pests.
- Household supplementary questionnaire: containing questions about features of a specific apartment, like type of glazing; to be used where any or all of the features discussed vary between apartments or where such features are not centrally controlled.
- Home personal (adult) questionnaire: containing questions about symptoms, environmental comfort, personal factors as sex, job type, personal health status etc.
- Home personal (child) questionnaire: containing questions about symptoms.

Building checklists

These are used to collect information about the buildings like dimensions, building materials, HVAC system, lighting, use of the building etc. There are three checklists, for offices, homes (whole apartment block) and individual apartments.

Items from the checklists and questionnaires will be used to rank buildings for health status, the three types of metric being:

- Acute building-related symptoms (from the questionnaires);
- Environmental comfort responses (from the questionnaires);
- Building health risk factors (mainly from the checklists but some data also from questionnaires).

Building health risk factors means those characteristics of the building or the environment that may, directly or indirectly, have an impact on the health of the occupants. These will be used to identify the presence (or likelihood of presence) of specified hazards, as listed in Table 2.

The questionnaires also collected data on illnesses but this was intended primarily to control for effects of pre-existing illness, not to provide a health metric for judging the building.

Table 2 Hazards to be considered in HOPE

Air pollutants		Other hazards
Radon Heavy metals (primarily lead) in the air Asbestos Synthetic vitreous fibres Other particulate matter Ozone Infectious agents from the occupants (primarily bacteria) Infectious agents from the building (primarily Legionella)	Allergens (e.g. pollen or from fungi, mites, pests or pets) Total volatile organic compounds (TVOC) Individual VOCs (e.g. benzene, formaldehyde) Carbon monoxide Oxides of nitrogen (NO_x) Sulfur dioxide Environmental tobacco smoke	High temperature Low temperature High humidity Low humidity Draughts Inadequate ventilation (may be indexed by CO_2 concentration) Noise Poor lighting Heavy metals (primarily lead) in water

The health risk metric is potentially the most demanding to derive, because it will depend much more on expert judgement and less on application of statistical analysis. The main elements of this approach are to:

- Identify the hazards that are to be considered (see Table 2);
- Identify the building or environmental characteristics that might contribute to the risk for each hazard;
- Make quantitative judgements about the relationship between building/environment characteristics and also (a) the likelihood of harm occurring and (b) the severity of harm.

The third stage entails a series of judgements on the likelihood of death, the likelihood of very serious harm, the likelihood of serious harm, etc. These judgements can be combined into an overall risk index for each hazard, and these risk indices can be added to provide an overall risk for the building.

The ranking procedure should not be the same for office and apartment buildings (see Table 3). Offices do not have real hazards in comparison to homes. In offices, there is generally more strict regulations. Symptom scores for homes are less useful because of differences in living. Therefore, for offices, the health and comfort ratings may be the priority. For homes, the building health risk factors may be the priority.

Table 3 Metrics and indices for offices and apartments

Metric	Offices	Apartments
Acute building-related symptoms	Building Symptom Index (BSI) (Raw, 1995)	BSI based on all adults and children, if enough questionnaires returned
Environmental comfort responses	Similar approach as BSI resulting in one overall comfort index	Similar as BSI, but based only on adults
Building health risk factors	Five hazards have been defined that would be a basis for excluding a building from the “healthy” category: “other” particulate matter, infectious agents from occupants, carbon monoxide, heavy metals (primary lead) in air and in water	Three levels of health outcome are considered per potential hazard: - Death or an illness with a high probability of being fatal (e.g. lung cancer) - Illness (divisible into serious and minor illness) - Serious discomfort

VERIFICATION

Halfway through the project, approximately 150 buildings have been audited resulting in a promising dataset. Building recruitment for the multidisciplinary study proved more difficult than anticipated, due in part to survey fatigue of residents of energy-efficient buildings.

Especially in apartment buildings, there was a low response on the questionnaires. Reasons why will be compiled as much as possible. A bias may be introduced by the fact that owners from ‘unhealthy’ buildings (with known health problems) did not approve an audit of their building.

The data of the multidisciplinary study will be introduced in a database called HODA (Hope Database). Using the database, the different metrics for ranking the buildings according to health and energy efficiency will be determined. Via a multi-criteria analysis implemented in HODA (Roulet, 2003), the buildings will be ranked and 32 buildings will be selected for detailed investigations. These detailed investigations will take place in 2004.

The database will be incorporated in the web site of the project (http://hope.epfl.ch), giving the possibility for non-participants of the project to submit their own data and make their own multi-criteria analysis of how healthy and energy-efficient their building is, as compared to the investigated buildings.

ACKNOWLEDGMENTS

HOPE is partly sponsored by the European Union in the JOULE programme (DGXII) under the management of Dr. G. Deschamps. The co-ordination is done by Dr. Philomena M. Bluyssen from TNO Building and Construction Research in The Netherlands. Other participants are: Weerdenburg Huisvesting Consultants and Technische Universiteit Eindhoven (TU/e) (The Netherlands); University of Porto (Portugal); Danish Building and Urban Research (Denmark); Technical University of Berlin (Germany); Helsinki University of Technology and Technical Research Centre of Finland (VTT) (Finland); University of Milano (Italy); BRE (United Kingdom); Charles University of Prague (Czech Republic); Swiss Federal Institute of Technology Lausanne (EPFL), E4Tech Sarl and Vaud State University Hospital Centre (Switzerland).

REFERENCES

Bluyssen, P.M. *et al.* (1995). European audit project to optimise indoor air quality and energy consumption in office buildings, final report, contract JOU2-CT92-002, March, Delft, The Netherlands.

Bluyssen, P.M. and Loomans, M.G.L.C. (2003), A framework for performance criteria of healthy and energy-efficient buildings, *Healthy Buildings 2003*, Singapore.

Fisk, W.J. (2000), Review of health and productivity gains from better IEQ, *Healthy Buildings 2000*, Helsinki, Finland, August, Vol. 4, pp. 22–34.

Institute of Medicine (2000). *Cleaning the Air, Asthma and Indoor Exposures.* Washington, DC: National Academy Press, 438 pages.

Jantunen, M. *et al.* (1999). Air pollution exposure distribution of adult urban populations in Europe (EXPOLIS), Final report, Environment & Climate Research Programme (1994-1998).

Maroni *et al.* (2003). Performance criteria for healthy buildings. *Healthy Buildings 2003*, Singapore.

Preller, L. et al. (1990) Gezondheidsklachten en klachten over het binnenklimaat in kantoorgebouwen, Directoraat Generaal van de Arbeid van het Ministerie van Sociale zaken en Werkgelegenheid, S83, Voorburg, mei.

Raw, G.J. 1995 The Office Environment Survey. London, CRC Ltd.

Roulet, C.-A., Johner, N., Flourentzou, F. and Greuter, G. (2003). Multi-criteria analysis methodology of health, IEQ and energy use for sustainable buildings. *Healthy Buildings 2003*, Singapore.

Sundell, J. (2000). Building related factors and health, Increased asthma and allergies. *Healthy Buildings 2000*, Helsinki, Finland, August, Vol.1, pp. 22–34.

Seifert, B. (1990). Regulating indoor air. *Indoor Air '90*, Toronto, pp. 35–49.

WHO (2001). Air quality guidelines for Europe 2000—2nd edn. WHO Regional Publications, European Series, N. 91, Regional Office for Europe.