HOPE

HEALTH OPTIMISATION PROTOCOL FOR ENERGY-EFFICIENT BUILDINGS
ENK6-CT-2001-00505

FINAL REPORT

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TITLE:

Health Optimisation Protocol for Energy-efficient Buildings
Pre-normative and socio-economic research to create healthy and energy-efficient buildings

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Energy used in buildings represents more than 40% of the total primary energy used in Europe (500 Mtoe (millions of tonnes of oil equivalent) or 2x1010 GJ for energy use in buildings). Approximately 20-50% of the consumption is related to heating and cooling purposes, depending on climate and economical development of the different EU countries. Energy use to compensate for ventilation loss is about 30% of heating and cooling energy in buildings, and may reach 50% in modern, well-insulated buildings. Efficient energy recovery on ventilation loss may reduce this loss by 70%. In recent years, much effort has been put in the realisation of energy-efficient buildings. There may however be a conflict between strategies to reduce energy use and to create healthy buildings. An example is the reduction of the ventilation rate to save energy which leads to an increase of indoor pollutant concentrations that can have an adverse effect on health and comfort of the occupants. Action needs to be directed at both improving guidance on how to realise healthy energy-efficient buildings, and making a convincing case for the building industry to make changes.

The final goal of the project HOPE is to provide the means to increase the number of energy-efficient buildings that are at the same time healthy, thus decreasing the energy use by buildings and consequently resulting in a reduction of CO_2 emissions from primary energy used for ventilation, heating and humidity control. To reach this goal the following objectives have been set:

- To solve the conflict between strategies to reduce energy use and strategies to create healthy buildings
- To identify European agreed parameters to describe the health status of occupants and energy efficiency status of buildings
- To develop European agreed techniques to assess the health status of occupants and the energy efficiency of buildings
- To develop methods to relate the health status of occupants and energy efficiency status of buildings.

The following results have been achieved:

- A set of qualitative and quantitative performance criteria for healthy and energy-efficient buildings for Europe, available on the HOPE web-site: http://hope.epfl.ch/;
- A protocol for testing performance criteria for healthy and energy-efficient buildings, available on the HOPE web-site;
- Application of performance criteria and testing of a protocol in existing buildings by:
    - a multi-disciplinary study in 164 office and multi-apartment buildings of which approximately 75% are designed to be energy-efficient;
    - a detailed investigation of 29 of the above buildings;
- A database of the health and energy efficiency status of the 164 investigated buildings, with information on:
    - energy consumption and energy efficiency;
    - comfort and health status of the occupants;

  The database (HODA) is available on the HOPE web-site;
- Guidelines/recommendations for designing a healthy, comfortable, energy-efficient building and for improving a building that is unhealthy and/or not energy-efficient, available on the HOPE web-site;
- A public web-site with:
    - Progress and results of project

- Possibility for non-participants to add data on their own buildings into the database and characterise how healthy and energy-efficient their own building is as compared to the investigated buildings.

The results of the project show that it is possible to realise low-energy buildings with good indoor environment quality. The existence of buildings that are healthy, comfortable and have a good energy performance, as well as better comfort and health shown on the average by low energy buildings, shows that the apparent conflict between health and comfort on the one hand and energy use on the other hand need not, in fact, exist.

HOPE:
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1 Introduction

Energy used in buildings represents more than 40% of the total primary energy used in Europe (500 Mtoe (millions of tonnes of oil equivalent) or 2x1010 GJ for energy use in buildings). Approximately 20-50% of the consumption is related to heating and cooling purposes, depending on climate and economical development of the different EU countries. Energy use to compensate for ventilation loss is about 30% of heating and cooling energy in buildings, and may reach 50% in modern, well-insulated buildings. Efficient energy recovery on ventilation loss may reduce this loss by 70%. In recent years, much effort has been put in the realisation of energy-efficient buildings. There may however be a conflict between strategies to reduce energy use and to create healthy buildings. Action needs to be directed at both improving guidance on how to realise healthy energy-efficient buildings, and making a convincing case for the building industry to make changes.

The final goal of the project HOPE is to provide the means to increase the number of energy-efficient buildings that are at the same time healthy, thus decreasing the energy use by buildings and consequently resulting in a reduction of CO_2 emissions from primary energy used for ventilation, heating and humidity control.

The questions to which answers have been sought within the framework of the HOPE project were:

- 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?

2 Definition and criteria for an energy-efficient healthy building

The first question has been answered in the project by:
- Developing definitions and criteria for a healthy building, an energy-efficient building and an energy-efficient healthy building.

  A building is defined "Healthy and Energy Efficient" if it does not cause or aggravate illnesses in the building occupants; it assures a high level of comfort for the building occupants; it minimises the use of energy used to achieve desired internal conditions, taking into account available state-of-the art technology and non-technical measures. The criteria include a set of measurable parameters related to indoor air pollutants or physical characteristics of the indoor environment. Compliance with this set is expected to assure, with a high degree of confidence, the provision of acceptable performance of buildings and zones within them. Target values of the selected parameters have been set taking as reference the WHO air quality guidelines [1], when available. An example for some chemical parameters is given in Table 1. The tables also provide a list of factors/ conditions that can be checked in a building for a preliminary, qualitative assessment of each parameter. Target values to assess the parameters are set according to full exposure (e.g., WHO guidelines, 24 hours all people [1]) or partial exposure (e.g., EPA guidelines, 8 hours average adult [2]). Generally, values for full exposure are more stringent. As for health protection, a Basic Target is a No Effect Level, while a Best Target is a further reduced value to account for uncertainty and individual human variation.

- Developing tools/techniques to assess the health status of occupants and the energy efficiency status.

Protocols to assess the performance of a building with regard to health, comfort and energy-efficiency have been developed. Due to the intrinsic structural differences and consequently to the need for a different approach, different tools for offices and multi-apartments building have been designed. The general structure of both protocols is identical. The protocol for office buildings is presented in Figure 1.

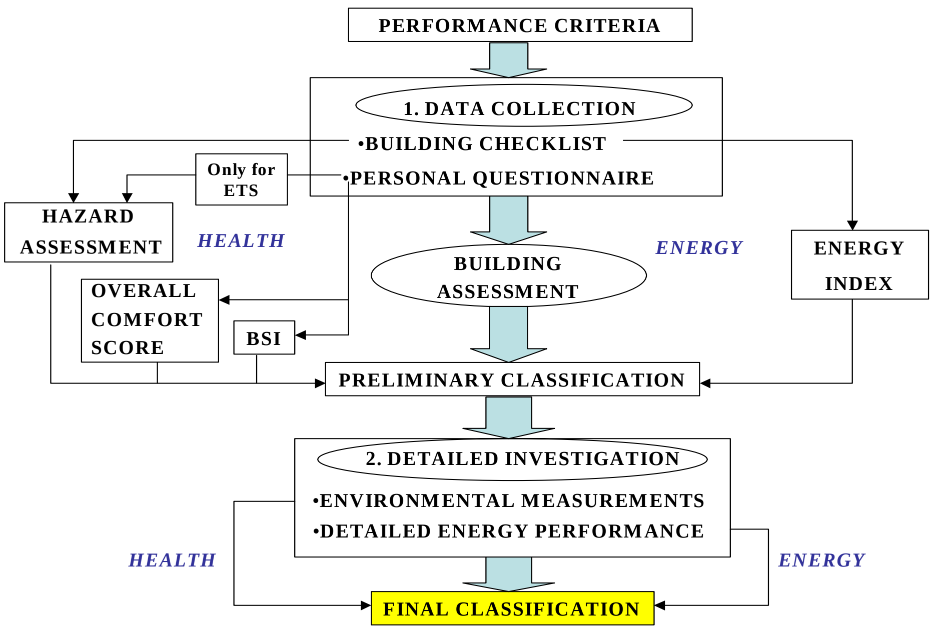


Figure 1. Structure of protocol for office buildings

Health classification of buildings is based on health risk analysis from checklist data (building characteristics, systems and use) and health- and comfort-related questionnaire data (first phase), if necessary integrated with measurements (second phase).

Health hazards have been divided into 3 groups and acute building-related symptoms are evaluated through the Building Symptom Index (BSI), a numeric indicator that considers the frequency of symptoms related to the Sick Building Syndrome (SBS) perceived by the occupants.

Table 1. Target values for several chemical pollutants

PARAMETER	TARGET VALUES (mg/m^3)	FACTORS TO BE CHECKED
CARBON DIOXIDE (CO_2)	Basic: 1800 Best: 900	Cooking in inadequate conditions (presence of local exhaust equipment) Combustion appliances (gas, kerosene, wood fuelled appliances) Tobacco smoking Density of occupants Exhaust from vehicles on nearby roads or in parking lots, or garages
CARBON MONOXIDE (CO)	Basic: 10 (8 hrs); 30 (1 hr); 60 (30 min); 100 (15 min) Optimal: 5 (8 hrs); 15 (1 hr); 30 (30 min); 50 (15 min)	Cooking in inadequate conditions (presence of local exhaust equipment) Combustion appliances (fireplace, gas cooking stoves) Tobacco smoking Exhaust from vehicles on nearby roads or in parking lots, or garages Presence of industrial furnaces nearby

PARAMETER	TARGET VALUES ($\mu g/m^3$)	FACTORS TO BE CHECKED
NITROGEN DIOXIDE (NO_2)	Basic: 200 (1 hr) Basic: 40 (1 year) Optimal: 100 (1 hr) 20 (1 year)	Cooking in inadequate conditions (presence of local exhaust equipment) Combustion appliances Exhaust from vehicles on nearby roads or in parking lots, or garages
OZONE	Basic: 120 (8 hr) Optimal: 60 (8 hr)	Laser printers Photocopiers Any equipment which uses high voltage or ultraviolet light Electronic air filters Equipment which uses ozone to purify air or water Exhaust from vehicles on nearby roads
PARTICULATE MATTER **PM10 *** **PM2.5 ***	Basic: 50 (24 hrs) Optimal: 25 Basic: 40 (long term) Optimal: 20	Cooking in inadequate conditions (presence of local exhaust equipment) Combustion appliances Tobacco smoking Dust from indoor demolition Airborne dust or dirt (e.g., circulated by sweeping and vacuuming) Paper in open shelves Exhaust from vehicles on nearby roads Dust from outdoor demolition Outdoor industrial emissions

* No guideline value without health effects recommended by [1].

The **Health and comfort hazards** (from performance criteria) have been classified in three classes, based on the level of health outcome:

- **Class 1 -** Hazards that represent a risk of causing death or an illness with a high probability of being fatal (e.g. lung cancer): asbestos, radon, carcinogenic volatile organic compounds (VOCs), Environmental Tobacco Smoke (ETS) and a high carbon monoxide concentration.
- **Class 2 -** Hazards that represent a risk of causing illness (principally respiratory illness): ozone, nitrogen oxide, particulate matter, infectious agents (from the building or from occupants), house dust mites (only for residential buildings), fungi, other allergens, non-carcinogenic VOCs, CO at low concentrations.
- **Class 3 -** Hazards that represent risk of minor diseases or causing discomfort: noise, lighting, too hot, too cold.

Health hazard assessment algorithms have been developed within the project and have been coded into the HOPE Database (HODA) to provide automatic evaluation of building characteristics.

A comparison of the hazard assessments with the assessments based on measurement results in 29 buildings shows that the hazard assessments lead to fair results.
False positive results, a judgement for a hazard being absent while measurements show hazard present are almost non-occurring (1 out of 165 comparisons). False negative results (hazard assessment indicating hazard present while measurements show hazard absent) are limited, less than 10% of the comparisons made fall into this category. False negative results are rare for the class 1 hazards (1 out of 49 comparisons).In the majority of cases (75%), the judgment of the hazard assessments is equal to or more stringent than the outcome based on the measurements. This result ensures that a building is not wrongfully categorised healthy.

Based on questionnaire results and results of the hazard assessment, a building is given a preliminary classification according to the health status in one of 3 classes: healthy, conditionally healthy or unhealthy. Following measurements, a final classification of the building can be made in one of two categories: healthy or unhealthy. For the classification scheme see Table 2.

Energy efficiency is evaluated by means of the energy index, i.e. the yearly delivered total energy per conditioned floor area, and the building is ranked accordingly. The energy assessment method is described in the draft standard ‘Energy performance of buildings - Assessment of energy use and definition of ratings’, in the clause related to operational rating.
Based on the energy evaluation, the buildings are classified as optimal, medium, or low:

Good : < 150 kWh /m² (540 MJ/m²): considered as low energy building.

Medium : > 250 kWh/m²: (900 MJ/m²): this building has a significant energy saving potential, a further study is recommended

Low : > 500 kWh/m² (1800 MJ/m²): urgent energy retrofit measures are needed

These outcomes of the project (criteria and protocol for assessment of buildings) can be used by e.g. designers, consultants and facility managers for the evaluation of existing building. The data in the HOPE database (HODA), based on the field investigations carried out in 164 office and apartment buildings, can be used as a benchmark. Tools (checklists, questionnaires and guidelines on process and sample selection) are available on the HOPE web-site (http:/hope.epfl.ch). A downloadable version of HODA allows an external user to compare the results/outcomes of his building to statistics from the HOPE buildings sample. This includes the risk analysis rules developed within the project.

The methodology for expressing energy performance was elaborated in co-ordination with CEN/TC89/WG4, in charge of drafting standards on energy performance of buildings within the framework of the Directive on Energy Performance of buildings [3]. The criteria and tools for health and comfort are suited for evaluating these aspects in buildings within the framework of the Directive, in which is stated that "*The measures further to improve the energy performance of buildings should take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. They should not contravene other essential requirements concerning buildings such as accessibility, prudence and the intended use of the building*." The EU Directive 89/106 [4] includes good "hygiene, health and environment" as well as "energy economy and heat retention" as essential requirements. Energy savings should clearly not be achieved to the expense of poor indoor environment, since this is not only at the opposite of the purpose of buildings, but would also result in a bad perception, and may generate unexpected waste.

3 Are buildings with energy saving measures energy-efficient?

A multi-criteria analysis of health, comfort and energy use in 67 office buildings and 97 apartment buildings in nine European countries has been carried out within the framework of the HOPE project.
Approximately 75% of the buildings audited were chosen for having energy saving measures in order to have a good energy performance. The annual total delivered energy use divided by the gross conditioned floor was used as an indicator of the energy performance. Other indicators such as final energy use per conditioned floor area, per person, per building volume, etc. could be used. The conclusions will not change much by using these other indicators.

Annual energy consumption in residential buildings in OECD[1] countries averages 150-230 kWh/m². In eastern and central Europe energy consumption for heating purposes is in the order of 250-400 kWh/m² annually, often averaging about 2-3 times higher than that of similar buildings in western Europe [5]. In the IAQ Audit project [6], an average energy use of 278 kWh/m² was found for 56 office buildings in nine European countries.

The median values for energy use in the HOPE database are 140 kWh/m² for the apartment buildings and 200 kWh/m² for the office buildings (see figure 2 for more details). Energy consumption varies strongly from building to building. In practice, it depends more on planning, construction, and management than on climate, building type or HVAC systems.

Using a target value for the yearly energy use lower than 150 kWh/m^2 for a low-energy building, it can be concluded that this value is superseded by respectively 44% of the apartment buildings and 79% of the office buildings in the HOPE sample.
Obviously, including energy saving measures does not necessarily lead to an energy-efficient building.

[1] Organisation for Economic Co-operation and Development, consisting of 30 member states, including the nine countries represented in the HOPE project.

Table 2. ***Scheme of the health and comfort based (preliminary) classification***

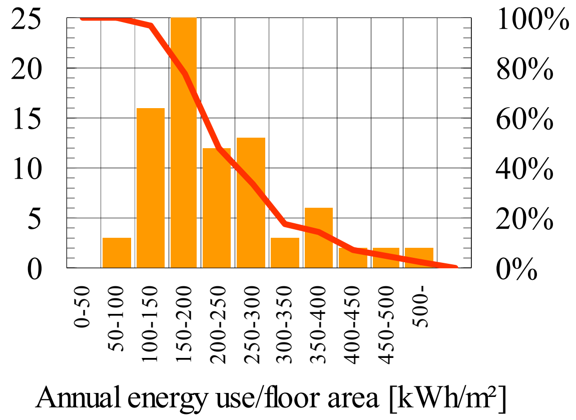
	Health and comfort risk factors								Symptoms BSI ***
	Hazards class 1		Hazard class 2		Hazard class 3* Check-list		Hazard class 3* Questionnaire and Overall Comfort Score**		
Category 1 Healthy Building	absent	AND	absent	AND	absent	OR	≤ 2,5	AND	BSI ≤ 1 AND No single symptom > 40%
Category 2 Conditionally Healthy Building	≥ 1 possibly present	OR	≥ 1 possibly present	OR	≥ 1 possibly present	OR	> 2,5 and ≤ 4	OR	BSI > 1 and ≤ 2 OR one symptom > 40 %
Category 3 Unhealthy Building	≥ 1 present	OR	≥ 1 present	OR	≥ 1 present	OR	> 4	OR	BSI > 2 OR more than one symptom > 40 %

* Two alternative possibilities for Hazard class 3 evaluation:
    - Presence of hazard evaluated by Check-list or
    - Presence of discomfort (expressed by Overall Comfort Score, average of summer and winter) from questionnaire survey

** If both evaluations are available, questionnaire evaluation is predominant if questionnaire response rate is ≥ 70%

*** Building Symptom Index (BSI), a numeric indicator that considers the frequency of symptoms related to the Sick Building Syndrome (SBS) perceived by the occupants

In Office Buildings: BSI_5; 5 symptoms (dry eyes, blocked/stuffy nose, dry throat, headache and tiredness/lethargy) used to calculate index of SBS
In apartment buildings: BSI_{10}: 10 symptoms (additionally itching or watering eyes, runny nose, flu-like symptoms, difficulty breathing and chest tightness included) used to calculate index of SBS.



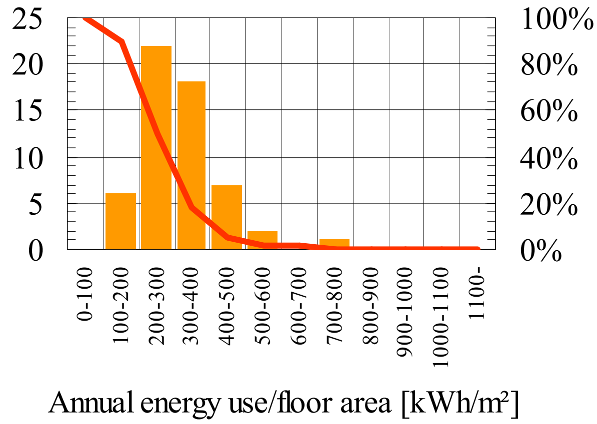


Figure 2 **Annual energy use per floor area (energy index) of apartment buildings (left) and office (right) buildings in the HOPE sample.**

It should be noted that the values are not representative of the European building stock, since the sample is biased by the selection of low energy buildings for 75% of them.

4 What is the health status of buildings with energy saving measures as compared to buildings without energy saving measures?

On the average, low energy buildings in the HOPE sample are perceived as more comfortable than buildings with high energy use, as illustrated by the following table:

Characteristics	Mean values for "low" energy	"high" energy	P[2]
Mean number of SBS symptoms per person in apartment buildings	0.98	0.86	16%
Mean number of SBS symptoms per person in office buildings	1.95	2.11	2%
Comfort overall in offices in Summer (scale from 1=satisfactory to 7=unsatisfactory)	3.21	3.47	2%
Comfort overall in offices in winter (scale from 1=satisfactory to 7=unsatisfactory)	3.08	3.26	6%
How comfortable is your home? (scale from 1=satisfactory to 7=unsatisfactory)	2.97	3.22	0.2%

Also low energy office buildings are perceived healthier than high energy ones (lower number of perceived symptoms). The same difference is not observed for apartment buildings, where

[2] P is the probability that the correlation is due to chance

there are slightly more symptoms in low energy buildings. This difference is however not significant (see Figure 3).

There are of course healthy and comfortable buildings that use much energy, and also low energy buildings that are neither healthy nor comfortable. However, there are, within the HOPE building sample, several low energy buildings that are also perceived as healthy and comfortable.

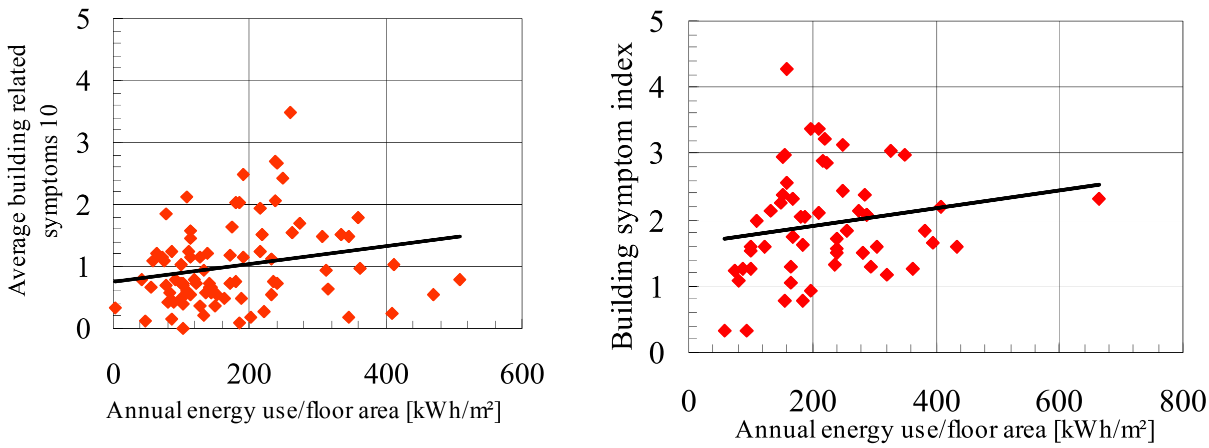


Figure 3. Average number of buildings related symptoms versus energy index for apartment buildings (left) and for office buildings (right)

It should also be noticed that perceived health does not give a full insight in the "healthiness" of a building. Some building characteristics (presence of asbestos or radon, VOC, etc) could be dangerous for health but not lead to acute symptoms. Using the health hazard assessment developed within the HOPE project, a first evaluation of these health hazards can be made (hazard is present, possibly present or absent).

Furthermore, measurements showed, particularly for apartment buildings, no relation between Buildings Symptom Index and the presence of class 1 and class 2 hazards. Common problems frequently found both in healthy and unhealthy apartment buildings are ETS, high concentrations of fungi and particulate matter (PM), too low ventilation and overheating. Perceived occupant health and comfort was clearly based on more than the physical environmental parameters.

For the office buildings, perceived health by the occupants is correlated with indoor environment quality, expressed by a lower number of hazards present in the buildings perceived healthy. It should be noted that the results of the occupants surveys in the office buildings provided more reliable results (compared to the apartment buildings) due to high response rates. Main problems in the investigated office buildings perceived unhealthy were too low ventilation, too high temperatures (too hot) and high concentrations particulate matter. The latter have been attributed to high outdoor levels, e.g. due to a nearby busy road.

5 How can we assure that buildings are healthy and energy-efficient at the same time?

Recommendations for improving the performance of new and existing buildings based on the results of the project are drafted, organised according to main issues such as indoor air quality, thermal comfort, etc. They are written in a positive, performance based way to address designers, architects, and decision makers.

The intentions of the building owner and of the designer have the greatest influence on the quality of the building: most of the best performing buildings investigated within the HOPE project were designed to be High Quality (HQ) buildings. Good design is essential to achieve a HQ building. If planning, construction, and management are performed by energy and indoor environment conscious persons, the result will be a building with low energy consumption and a good indoor environment quality. However, one single bad step (e.g. poor management or poor planning) may destroy the qualities of a building or the effects of a conscious management.
Low-energy use building are often characterised by the implementation and/or combinations of relatively new techniques. Essential for a good performance in situations like this, is proper functioning of these systems and fine-tuning, especially after handing over of building and systems. This requires monitoring of the functioning of the building and its systems, e.g. using Building Management Systems often present in office buildings. It is envisaged that proper commissioning of buildings and their systems could increase the number of buildings with low energy use and good indoor environment.

Two important design principles for HQ buildings are emphasised: to prefer, as far as possible, passive (architectural) to active (technological) ways to ensure comfort in buildings and design for the building user. In particular, the user should be able to adapt his indoor environment to his needs. With regard to the latter, special care should be given to occupants' well-being in open-plan offices.

Openable windows and absence of restrictions to open the windows (noise, pollution, security) have a positive effect on the performance of a building. In apartment buildings, mechanical ventilation should be preferred in kitchens.

Buildings with proper design and maintenance of HVAC systems, according to the recommendations derived from the former Airless project [7], show better performance than buildings where those recommendations are not or only partly met.

When looking at the differences between good and poor performing buildings, it is reassuring to see that recently built buildings perform better than older ones. The increasing rate of renovation of buildings can lead to a significant increase of good performing buildings.

Economic advantages of HQ office buildings are lower energy costs, but also economic gains from a higher productivity of the occupants of a building. It was shown in the HOPE sample of office buildings that too high temperatures (too hot) in summer decrease the perceived productivity. In good performing office buildings, absence rates were lower (see Figure 4).

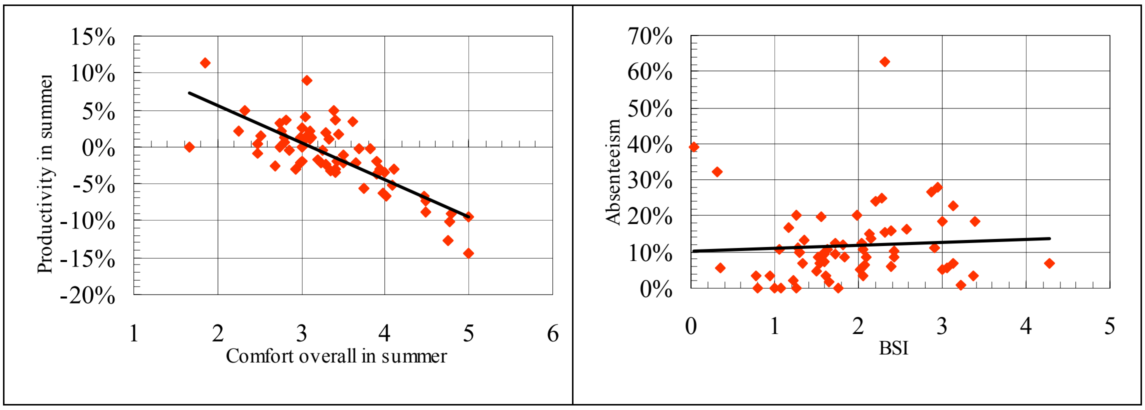


Figure 4. Self-estimated effect of summer comfort on productivity (left) and self-reported absenteeism as function of BSI (right) in office buildings.

The HOPE project has been focussing on the apparent conflict between strategies to reduce energy use and strategies to create healthy buildings. The results of the project show that it is possible to produce low-energy buildings with good indoor environment quality.
Healthy and comfortable buildings thus do not necessarily require much energy, and can have a limited impact on the environment. Smart managers, architects and engineers can construct and operate buildings in a way that both good indoor environment and low energy consumption can be achieved. Examples of such buildings are presented in the guidelines derived from the project, available at the web-site of the project. By contrast, expensive measures to improve the indoor environment are sometimes counterproductive: even when technical requirements (temperature, air flow rates, etc.) are met, occupants do not feel well, e.g. because they lack control on the system.

The existence of buildings that are healthy, comfortable and have a good energy performance, as well as better comfort and health shown on the average by low energy buildings, shows that the apparent conflict between health and comfort on the one hand and energy use on the other hand need not, in fact, exist.

6 Results

On the public web-site of the project (http://hope.epfl.ch/), besides a description of the project, the following results can be found:

- A set of qualitative and quantitative performance criteria for healthy and energy-efficient buildings for Europe;
- A protocol for testing performance criteria for healthy and energy-efficient buildings;
- A database of the health and energy efficiency status of the 164 buildings, with information on:
  - energy consumption and energy efficiency;
  - comfort and health status of the occupants;

  The database offers the possibility for non-participants to add data on their own buildings into the database and characterise how healthy and energy-efficient their own building is as compared to the investigated buildings;
- Guidelines/recommendations for designing a healthy, comfortable, energy-efficient building and for improving a building that is unhealthy and/or not energy-efficient.

7 References

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