ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

2005-4

LESO-PB

Multi-criteria analysis of health, comfort and energy efficiency of buildings

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Indoor Air 2005 Conference, Beijing, China

2005, September 4-9

Proceedings: Indoor Air 2005

MULTI-CRITERIA ANALYSIS OF HEALTH, COMFORT AND ENERGY-EFFICIENCY OF BUILDINGS

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ABSTRACT
In order to cope with sustainable development policy, buildings should be at least healthy, comfortable and energy efficient. Criteria for assessing individually the occupant's perceived health, the provided thermal, visual, acoustical comfort, the indoor air quality and the energy efficiency are known. This paper proposes a methodology to perform a global evaluation of a building with regard to all these criteria. This methodology is applied to 97 apartment buildings and 64 office buildings audited within the HOPE European project to sort, out of these samples, a set of best buildings and a set of buildings that are not acceptable for comfort, perceived health and energy use. Some significant differences between these two groups of buildings are presented.

INDEX TERMS
Buildings, indoor environment, multicriteria analysis, energy

INTRODUCTION
According to the Rio agreement, sustainable buildings should take account of environmental, economical, and social stakes. This includes, among others, low energy use, good indoor environment quality (IEQ) and health. The three stakes have a similar importance: a building cannot be good if it fails in one of them.

RESEARCH METHOD
Collecting information
A multi-disciplinary study was performed in 164 buildings (98 apartment buildings and 66 office buildings) of which half of them can be characterised as having low energy use. This investigation has been carried out in nine European countries. Three kinds of screening methods were used *(Bluyssen et al., 2003)*:
(1) an inspection of each building, providing data on the building and its environment,
(2) interviews with building management, from which, among others, information on building energy performance was collected, and
(3) questionnaire surveys of occupants, providing information on how they feel and perceive their internal environment.

From the collected data, the following information was selected for the present analysis:

Delivered energy use, i.e the amount of all energywares delivered to the building, quantified by the net heating value and summed. A rough approximation of primary energy use, in which a weight 2.5 was allocated to electricity, a unity weight being kept for the other energywares was also calculated. This total delivered energy use, in kWh, is divided by the gross conditioned floor area to take account of the building size. Since heating and cooling was not metered separately from the other energy uses in most buildings, no correction is made for climate.

For **perceived comfort,** questions were asked to occupants in the questionnaire. The basic question was: *How would you describe typical working conditions in the office?* Then for each item, the occupant should cross one box, from 1 to 7. The same questions were asked for winter and summer seasons. The items and qualifications corresponding to extreme marks are given in **Table 1**. The results for a building are the average marks of all respondents for each question.

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For **perceived health**, the occupants were asked if they had two or more episodes of 8 symptoms, and if they feel better on days out of the office. A symptom that does disappear when out of the building is assumed to be building-related. The list of symptoms includes those commonly connected to the sick building syndrome, i.e., in office buildings: dryness of the eyes, itchy or watery eyes, blocked or stuffy nose, runny nose, dry throat, lethargy or tiredness, headaches, dry, itching or irritated skin. In homes, additional symptoms are sneezing and breathing difficulties. From these replies, a building symptom index (BSI) is calculated to get the average number of building-related symptoms per occupant.

Table 1. *Questions related to comfort*

	Item	Grade 1	Grade 7
Thermal comfort	Temperature	Comfortable	Uncomfortable
	Temperature*	Too hot	Too cold
	Temperature	Stable	Varies during the day
	Air movement*	Too still	Too draughty
Air quality	Air quality*	Dry	Humid
	Air quality	Fresh	Stuffy
	Air quality	Odourless	Smelly
	Air quality	Satisfactory	Unsatisfactory
Light	Natural light Glare from sun and sky Artificial light Glare from artificial light Light overall	Satisfactory	Unsatisfactory
Noise	Noise from outside Noise from building systems Other noise from within the building Noise overall Vibration in the building	Satisfactory	Unsatisfactory
Comfort	Comfort overall	Satisfactory	Unsatisfactory

* Items marked with an asterisk are two-sided: the best mark for them is 4, both 1 and 7 being not satisfactory.

Sorting buildings

One of the ways the collected data are interpreted is presented below.

The buildings are sorted basically into two classes, which are "poor", "not satisfactory" or "red" on one hand; and "good", "satisfactory", or "green" on the other hand. A "veto" class is added to take account of very poor level for a given criterion. If the position of the building is not clear, it is sorted in an intermediate, uncertain or yellow class.

For comfort, average marks below 2.5 on the 1-7 scale are considered as satisfactory, while average marks larger or equal than 4 are taken as unsatisfactory, more than 6 being considered as a "veto" mark. Bilateral scale was first transformed into a -3 0 +3 scale by subtracting 4 from the average mark. Marks between -0.75 and +0.75 are green, outside ± 1.5 are red, and outside ±2.5 are veto.

Well-being is assessed by the Building Symptom Index (BSI). A BSI lower than that of the best 35% of the audited buildings is considered as acceptable or green. A BSI larger or equal than that of 70 % of the buildings is not acceptable, and the veto level is placed at two standard deviations above the average BSI of all buildings. Therefore, thresholds for office buildings are not the same than those of apartment buildings.

The annual total energy delivered to the building divided by the net conditioned floor area is used to assess the building energy performance. This performance is judged satisfactory below 150 kWh/m², not satisfactory above 250 kWh/m² and unacceptable above 500 kWh/m².

Aggregation

Using a multicriteria sorting method based on democracy rules called Hermione, (Flourentzou and Roulet, 2002; Roulet et al., 2003), the evaluations for each criterion are aggregated to sort buildings in the two classes. The following rules were used:

- The building is "satisfactory" or "green" if there is a majority (more than 50%) of criteria with "green" marks and no veto among the criteria.
- It is unsatisfactory if there are more than 50 % criteria with "red" marks or less than 50% "green" marks and more than 33 "red" marks, or at least one veto.
- If the percentage of criteria with "veto" marks is larger than 33%, the building is marked "black".
- It is "yellow", or not sorted, otherwise.

In order to give the same weight to comfort, energy and health, questions related to each type of comfort are first aggregated to get comfort classes for temperature, light, noise and air quality. Then these four evaluations are aggregated into one for comfort. This procedure is used once more to aggregate the evaluations according the basic three criteria mentioned above: comfort, well-being and energy. Note that this sorting does not assess the risk of health hazards mentioned by (Maroni et al., 2005)

RESULTS

Introduction

Among the 97 apartment buildings and 64 office buildings for which enough information was available, 24 apartment buildings and 8 office buildings are found acceptable for all criteria (named "green" buildings below) while 34 apartment buildings and 15 office buildings are found not acceptable (the "red" buildings).
Some significant differences between these two groups, i.e. those for which the probability to get the difference by pure chance less than 5%, are summarised below. Differences in energy use, perceived comfort and symptoms of the sick building syndrome are of course very significant, since the groups are selected for these characteristics. For example, green office building use on average, per square meter floor area, half the delivered energy and less than half the primary energy than red ones. For apartment buildings, the ratio is 1:3.

Homes

There are no significant differences between green and red apartment buildings about population in each age class, presence of air pollution and noise sources, type and distance to sources of electromagnetic radiation such as power lines or cellular telephone antenna, number of storeys, density of nearby obstruction, height of surrounding buildings, and heating fuel. Cleaning schedules, painting, decorating or other renovation during the last 12 months are similar. The use of appliances such as microwave ovens, refrigerators, freezers, humidifiers and dehumidifiers do not differ significantly either. For all these criteria, the probability is 20% or more to get the apparent difference by pure chance.

Some more significant differences are shown in **Table 2**, others are listed below.

Table 2*: Some significant (P< 5%) differences of average values between "green" and "red" apartment buildings.*

Artificial light	Green	Reds	P
Number of buildings	24	34	
Year completed	1989	1978	3.E-03
Delivered energy use/floor area [kWh/m²]	114	285	3.E-17
"Primary" energy use/floor area [kWh/m²]	147	332	3.E-15
Degree days during the heating season	2548	3278	2.E-06
Building-related symptom index	0.52	1.56	2.E-13
How comfortable is your home (1-7 scale)	2.26	3.32	3.E-11
Percent females	44%	38%	3.E-04
Percent recent smokers	23%	27%	5.E-02
Average apartment area [m²]	85.3	59.4	1.E-05
Smallest apartment [m²]	61.6	39.1	2.E-06
Floor area per person	38.4	29.0	4.E-03
Condensation in the flat: scale 1 to 7	1.89	2.56	6.E-05
Heaters below windows	39%	67%	6.E-02
Mechanical ventilation in the kitchen: cooker hood	49%	28%	1.E-04
Request for improvements to heating, ventilation	11%	17%	3.E-03
View from the windows	2.59	3.65	1.E-08
Heating on the flat satisfactory	2.25	3.00	6.E-08
Environment inside the flat affects the health	2.37	3.52	7.E-20
Environment inside the flat affects the ability to carry out work or necessary tasks	2.41	3.52	3.E-16

- Kitchens are more often equipped with cooker hood. Therefore, mechanical ventilation is often used in "green" kitchen, while windows are more often open in "red" kitchens.
- Windows of the majority of the green buildings are never closed in winter for noise, pollution, or security. In a minority of red buildings, windows are more often closed for these reasons.
- Nearly all green buildings have hot water circulation in insulated pipes, while half of the red buildings have no circulation.
- U-values of roofs and windows are slightly, but not significantly better in green buildings, Walls U-values are significantly better. The occupants however complain more often in red buildings that thermal insulation and draughts are sources of heating problems.
- More green buildings are equipped with heat recovery on exhaust air than red ones.
- Condensation is significantly higher in red buildings. Mould growth on more than 5% of walls is not frequent, but more frequent (7%) in red buildings than in green ones (5%)
- Appliances such as microwave oven and tumble dryer are more frequent in green buildings, and humidifiers or dehumidifiers less frequent.
- Orientations of the windows are equivalent in both groups for all facades except for south, more frequent in green buildings.
- Pests are less common in green buildings, and also pesticides are of much common use.

Offices

There are no significant differences between green and red office buildings about population in each age class and sex, percentage of women and ancient smokers, ownership, presence of air pollution and noise sources, height of surrounding buildings, and smoking allowance. Orientation of glazing is also similar.

Some more significant differences are shown in **Table 3**, others are listed below.

***Table 3**: Some significant (P< 5%) differences between "green" and "red" office buildings.*

Characteristics	Green	Red	P
Number of buildings	8	15	
Year completed	1999	1976	2.E-04
Delivered energy use/floor area [kWh/m²]	133	221	5.E-04
"Primary" energy use/floor area [kWh/m²]	228	455	3.E-04
Degree days during the heating season	2593	3304	1.E-03
Building-related symptom index	1.07	2.71	7.E-10
Comfort overall in summer	2.86	4.11	1.E-06
Comfort overall in winter	2.71	3.69	6.E-08
Percent recent smokers	44%	61%	3.E-02
Typical floor area per person	63	38	3.E-02
Number of storeys above ground	3.3	6.8	6.E-06
Ceiling height [m]*	3.8	2.9	7.E-02
Roof U-value	0.2	0.7	5.E-03
Glazing U value	1.5	2.7	7.E-05
Walls U value*	0.6	0.8	2.E-01
Density of nearby obstructions	3.3	2.5	3.E-03
Light overall in winter	2.6	3.1	1.E-03
Noise from building systems in winter	2.2	2.8	3.E-04
Noise from outside the building	2.3	2.8	1.E-03
Vibration in the building in winter	1.6	2.3	6.E-06

* Difference in ceiling height and walls U-value are not very significant

The occupants of green buildings perceive that they have a better control on their environment, in particular for ventilation, than in red buildings. The decoration, layout and cleanliness, as well as the speed of response to complaints are all significantly better in green buildings.

Occupants of red buildings spend more time working with a computer.

In all green buildings, all or a part (in one building) of the windows can be opened. In seven of the 15 red buildings, windows cannot be opened.

Perceived productivity is better in green buildings, and absenteeism because of indoor environment is smaller (95% of workers without absence against 87% in red buildings).

The Airless recommendations (Bluyssen et al., 2003) are completely or partly followed in green buildings, while they are only partly or not respected in red buildings.

***Table 4**: Number of buildings in both groups that comply with AIRLESS recommendations.*

		Green buildings			Red buildings		
		Yes	Partly	No	Yes	Partly	No
Ventilation	Offices	2	3	0	0	5	46
	Apartments	5	3	1	1	10	2
Heating/cooling	Offices	1	3	0	1	4	4
	Apartments	4	2	0	2	8	3

DISCUSSION

It is acknowledged that the thresholds allocating each building into the green, red or veto group for each criterion can be discussed. Therefore, they should not be taken as reference values. The aim of this sorting is to select a set of buildings that are satisfactory from all points of view, and a set of buildings that are not satisfactory. If the thresholds are changed, the number of buildings in each group will change, but not the conclusions that were drawn out of this analysis. However, provided an agreement is found on ways for determining thresholds, the methodology may be used as a multicriteria building labelling method

CONCLUSION AND IMPLICATIONS

The following conclusions related to energy and well-being can be drawn from this analysis:

- Low-energy buildings with good indoor environment quality and healthy occupants exist. This by itself proves that it is possible to design and construct such buildings.

- Good design is essential to achieve this objective. If planning, construction, and management are performed by energy conscious persons, the result will be low energy consumption with a good indoor environment quality.

ACKNOWLEDGEMENTS

The European Commission supported the HOPE programme, under the contract ENK6-CT-2001-00505. Its Swiss contribution was granted by the Swiss Federal Office for Education and Science (contract No 01.0061-1). The authors also thank all the HOPE participants who contributed, by their field studies, to collect data on which the present work is based.

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CORRELATIONS BETWEEN SBS, PERCEIVED COMFORT, ENERGY USE AND OTHER BUILDING CHARACTERISTICS IN EUROPEAN OFFICE AND RESIDENTIAL BUILDINGS.

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ABSTRACT
Within the European research project HOPE, 67 office buildings and 97 residential ones were investigated using checklists addressing the building characteristics and questionnaires to the occupants asking their perceived comfort (thermal visual, acoustical and IAQ) and health (SBS and allergies). The collected data are compared looking for correlations between building characteristics on one hand, and perceived comfort and health on the other hand. Strong correlations are found between perceived indoor air quality, thermal, acoustic and lighting comfort, confirming results from other studies. Significant correlations between the perceived comfort and building related symptoms were also found, comfortable buildings being healthier than uncomfortable ones. Differences of perceived comfort or health between low- and high- energy buildings show that it is possible to design buildings that are healthy, comfortable and energy efficient.

INDEX TERMS
Indoor Environment Quality; Sick Building Syndrome; Energy; Health; Comfort

INTRODUCTION
Many buildings are shown to be unhealthy, leading to a prevalence of several symptoms: headaches, lethargy, dry eyes or throat, itchy or watery eyes, blocked or stuffy nose, runny nose, dry itching or irritated skin, sneezing and breathing difficulty. Those symptoms are regrouped under a common name: the Sick Building Syndrome (SBS) (Maroni et al., 1995). On the other hand the prevalence of allergic illnesses increased during the last decades and indoor environment factors are being examined as one possible cause, though until now no evidence could be found. Indoor Environment Quality (IEQ) may also be linked to the energy use of a building. As an important part of our total primary energy use is consumed in buildings, energy-efficiency is a crucial aspect in present and future building design. However, there is little information about well-being in energy-efficient buildings, and the question of strategies to diminish energy use affecting well-being of occupants is still open.

The aim of this study is to examine the relations between health and comfort of occupants, the energy efficiency and some characteristics of the building, trying to get a better idea of the way to achieve a comfortable healthy and energy-efficient building.

RESEARCH METHODS
Collecting building's characteristics
Within the European research project HOPE (Bluyssen et al., 2003), 161 buildings were selected in nine European countries: Czech Republic, Denmark, Finland, Germany, Italy, Netherlands, Portugal, Switzerland, and United Kingdom. There are residential and office buildings and about 50% of those buildings are energy-efficient. Data was collected from interviews with the building management, checklists and questionnaires to the occupants (Roulet et al., 2005)

Some data was however not available for all buildings and some residential buildings had too few answers to the questionnaires. Therefore, only 61 office and 77 residential buildings out of the 161 are examined in this study. Most examined office buildings are relatively large, with an average floor area of about 13'000 m^2 and 90 returned personal questionnaires. The residential buildings are smaller; the average floor area being 8'000 m^2. On the average only 24 questionnaires were returned per apartment building.

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Comfort and health as perceived by occupants

The occupant's gave marks about the perception of their inner environment quality in personal questionnaires. All variables used in this study are mean values on buildings. Comfort is evaluated by several criteria, which are related to thermal comfort, acoustic comfort, lighting comfort and air quality. Those criteria are separately judged for summer and winter on scales going from satisfactory (1) to unsatisfactory (7). In this study, comfort variables are mean values of winter and summer values.

***Table 1**: Statistics of some results from the HOPE audits in apartment and office buildings.*

		Appartement buildings				Office buildings			
	Item	Mean	Median	Lowest decile	Highest decile	Mean	Median	Lowest decile	Highest decile
Comfort	Air quality	2.95	2.90	2.26	3.69	3.76	3.86	2.92	4.50
	Thermal comfort	2.87	2.87	1.98	3.69	3.29	3.27	2.59	4.03
	Lighting	3.37	3.41	2.91	3.84	3.72	3.78	3.30	4.02
	Acoustics	2.67	2.60	2.00	3.52	2.51	2.48	2.03	2.94
	Comfort overall	3.09	2.94	2.00	4.46	3.32	3.33	2.89	3.83
	BSI	0.95	0.72	0.19	1.60	1.92	1.83	1.02	3.04
Prevalence of SBS symptoms	Blocked nose	33%	32%	14%	50%	21%	19%	8%	38%
	Dry eyes	21%	18%	6%	33%	27%	27%	11%	42%
	Dry throat	31%	27%	8%	50%	25%	23%	11%	39%
	Headaches	30%	27%	11%	53%	28%	27%	14%	46%
	Lethargy, tiredness	39%	34%	14%	62%	39%	39%	21%	56%
	Runny nose	26%	24%	5%	46%	14%	13%	3%	25%
	Watery eyes	20%	18%	0%	35%	25%	25%	5%	42%
Prevalence of declared illnesses and allergies	Illness indicator	0.47	0.47	0.15	0.65	0.19	0.18	0.09	0.26
	Allergic Rhinitis	56%	59%	23%	76%	30%	29%	8%	51%
	Migraine	53%	52%	33%	78%				
	Hayfever	49%	48%	5%	67%	22%	18%	7%	35%
	Eczema	49%	50%	5%	71%	16%	13%	5%	28%
	Other skin problem	51%	50%	14%	72%	14%	14%	4%	23%
	Asthma	42%	41%	9%	63%	12%	9%	3%	17%
	Bronchitis	51%	54%	11%	74%				
	Wheezin	48%	49%	10%	72%				
	Dermatitis	47%	46%	3%	71%				
	Other chest	43%	43%	4%	62%				
	Irritated skin	28%	26%	9%	48%				
Energy index	Delivered [kWh/m²]	182	140	74	334	221	204	100	356
	Primary [kWh/m²]	219	177	102	378	428	386	185	720

Perceived health of occupants is also judged on the basis of the personal questionnaires. For Sick Building Syndrome (SBS) symptoms, the cut of occupants of a building suffering regularly from such symptoms and feeling better when not in building is considered. The Building Symptom Index (BSI) is the average number of symptoms appearing when in building and disappearing out of the building per occupant. It is used here as a performance indicator of the building.

The indicator for each allergy is the cut of occupants having ever suffered (residential buildings) or been diagnosed as suffering (office buildings) from it. An illness indicator is calculated as the average of these cuts for all allergies. It should **not** be considered as a building performance indicator.

The questionnaires for apartment buildings are different from those distributed in office buildings and SBS symptoms and allergies are not evaluated exactly in the same way in both questionnaires. Therefore values obtained in office and residential buildings should not be compared.

Energy index

The delivered energy index [kWh/m²] is the total energy delivered during a full year to the building divided by the floor area of the building. Other indicators such as energy use per heated floor area, per person, or per building volume, etc. could be used. The conclusions will not change much by using other indicators. In buildings equipped with cogeneration, the produced energy used in the building was not accounted for, and the exported energy was deduced. A primary energy index is also calculated by using a multiplication factor of 2,5 for electricity before addition to the other energywares.

RESULTS

Comfort and health as perceived by occupants

The occupant's gave marks about the perception of their inner environment quality in personal questionnaires. All variables used in this study are mean values on buildings. Comfort is evaluated by several criteria, which are related to thermal comfort, acoustic comfort, lighting comfort and air quality. Those criteria are separately judged for summer and winter on scales going from satisfactory (1) to unsatisfactory (7). In this study, comfort variables are mean values of winter and summer values.

Table 1 gives some statistics over all buildings, separated in two groups: apartment buildings and office buildings. Statistical differences between low- and high- energy buildings as well as most significant correlations between several collected variables are presented below.

Health and comfort in low energy buildings

Half of the buildings audited within the HOPE project were chosen for being designed to have a good energy performance, assessed by a low energy performance index.

Figure 1 shows the frequency and cumulated distributions of the energy performance indicators in the audited homes and office buildings. Note that these distributions are not representative of the European building stock, since the sample is biased by the selection of low energy buildings for half of them. The median value for apartment buildings is 140 kWh/m² and 200 kWh/m² for office buildings.

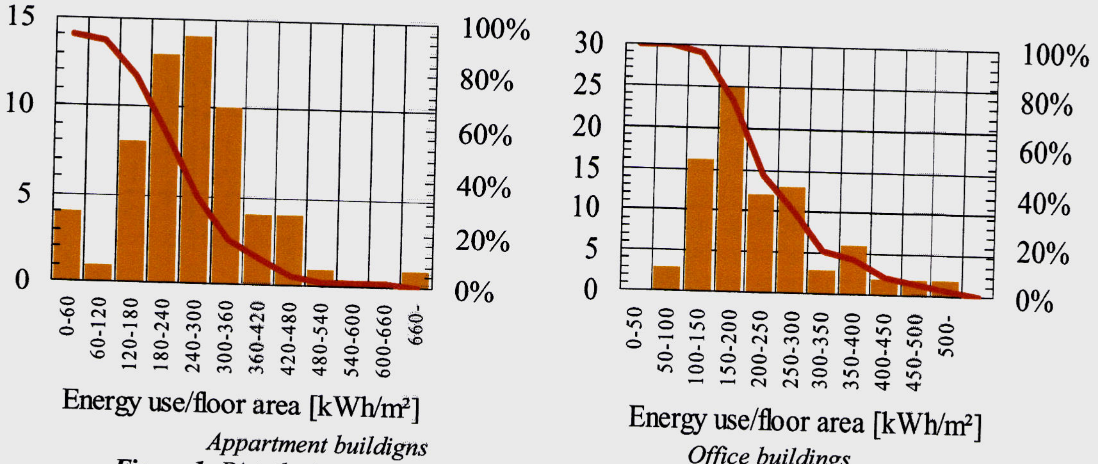

***Figure 1**: Distribution and cumulated frequency of the energy performance index*

Significant differences are found between buildings that use less and more than the median values. Some of these differences are reported in **Table 2** On the average, low energy buildings are perceived as more comfortable than other buildings. Also low energy office buildings are healthier than high energy ones. The same difference is not observed on apartment buildings, where there are slightly more symptoms in low energy buildings. This difference is however not very significant.

***Table 2**: Some statistically significant differences between "low" and "high" energy buildings in the HOPE sample. P is the probability to get the difference by pure chance.*

Characteristics	Mean values for "low" energy	Mean values for "high" energy	*P*
BSI in apartment buildings	0.98	0.86	16%
BSI in office buildings	1.95	2.11	2%
Comfort overall in offices in Summer (1-7 scale)*	3.21	3.47	2%
Comfort overall in offices in winter (1-7 scale)*	3.08	3.26	6%
How comfortable is your home? (1-7 scale)*	2.97	3.22	0.2%

* scale from 1 = satisfactory to 7 = unsatisfactory.

There are of course healthy and comfortable buildings that use much energy, and also low energy buildings that are neither healthy nor comfortable.

Correlations
Pearson's correlation coefficients are calculated, and the probability *P* to get zero correlation is calculated with Student's *T* test. We obtained highly significant correlation coefficients above 0.6 with $P \leq 10^{-10}$ between all comfort variables (air quality, thermal comfort, light and noise). An especially high value is obtained for the correlation between thermal comfort and perceived air quality (>0.8 for both homes and office buildings).

Air quality and thermal comfort are significantly correlated to BSI for both building types, whereas the correlation for acoustic and lighting comfort is significant only for office buildings (**Table 3**). Air quality perception has clearly the strongest correlation with perceived building related symptoms. This doesn't necessarily mean that pollutants or other agents in the air influence our health, but it could be. Nevertheless we see that, for office buildings, comfort is clearly correlated to sick building syndrome symptoms and that comfortable buildings were generally perceived as healthy (see also (Roulet et al., 2005)).

***Table 3**: Correlation coefficients between comfort and health variables. P is the probability that these coefficients are actually zero.*

		BSI:		Illness indicator	
		R	P	R	P
Office Buildings	Air Quality	0.66	5.E-09	-0.02	90%
	Thermal Comfort	0.48	7.E-05	0.11	38%
	Lighting Comfort	0.37	3.E-03	-0.12	37%
	Acoustic Comfort	0.30	2.E-02	-0.11	37%
	Comfort overall	0.58	9.E-07	0.01	94%
Apartment Buildings	Air quality	0.41	2.E-04	24%	3%
	Thermal comfort	0.24	4%	20%	9%
	Lighting	0.25	3%	14%	22%
	Acoustics	0.17	14%	3%	82%
	Comfort overall	-0.08	51%	17%	13%

This correlation is not as significant in apartment buildings, and is even not significant for the answers to question "do you feel your apartment comfortable overall?". The illness indicator is significantly correlated only to air quality, and in apartment buildings only.

In office buildings, the BSI is clearly correlated with the perceived environment, and to the control that the occupant has (or perceive as having) on its environment (**Table 4**)

***Table 4**: Correlation coefficients between BSI and perceived environment and control.*

Correlation with BSI of:	*R*	*P*	Correlation with BSI of:	*R*	*P*
Amount of privacy in the work	0.51	2.E-05	Control on Temperature	0.44	3.E-04
Layout in the office	0.64	3.E-08	Control on Ventilation	0.47	1.E-04
Decoration in the office	0.64	2.E-08	Control on Lighting	0.31	1.E-02
The cleanliness of your office	0.60	2.E-07	Control on Noise	0.48	8.E-05

***Table 5**: Correlation coefficients of SBS symptoms, allergies and illnesses with average outdoor temperature during the heating season.*

	Perceived SBS symptoms	*R*	*P*	Declared illnesses	*R*	*P*
Apartments buildings	Dry eyes	-0.52	3.E-06	Hayfever	-0.62	1.E-08
	Lethargy, tiredness	-0.50	9.E-06	Eczema	-0.57	3.E-07
	Irritated skin	-0.44	1.E-04	Other chest	-0.55	7.E-07
	Blocked nose	-0.38	1.E-03	Bronchitis	-0.51	6.E-06
	Dry throat	-0.35	3.E-03	Dermatitis	-0.48	2.E-05
	Runny nose	-0.32	6.E-03	Asthma	-0.43	2.E-04
	Watery eyes	-0.29	2.E-02	Wheezing	-0.43	2.E-04
	Sneezing	-0.23	6.E-02	Allergic rhinitis	-0.35	3.E-03
	Headaches	-0.06	6.E-01	Migraine	-0.14	3.E-01
Office buildings	Headaches	0.62	2.E-06	Allergic rhinitis	14%	3.E-01
	Blocked nose	0.45	1.E-03	Skin condition	11%	5.E-01
	Lethargy	0.39	6.E-03	Asthma	-12%	4.E-01
	Runny nose	0.35	1.E-02	Illness indicator	-14%	4.E-01
	Itchy eyes	0.34	2.E-02	Eczema	-25%	9.E-02
	Absenteeism	0.34	2.E-02	Hayfever	-35%	1.E-02
	Irritated skin	0.27	6.E-02			
	Dry throat	0.21	1.E-01			
	Dry eyes	0.10	5.E-01			

As it could be expected, average outdoor temperature in winter is significantly correlated to perceived dryness of the air in winter (-0.52, $P < 10^{-5}$). It is also negatively correlated with the prevalence of several SBS symptoms and illnesses in apartment buildings (**Table 5**).

In homes, the correlation is close to zero for headaches and migraine. In offices, the situation is not at all the same. Correlation is positive for all SBS symptoms and significant for headaches, blocked nose and lethargy, but not for dry throat, dry eyes and for most allergies. The difference may come not only from the questionnaire, but also from humidification, more frequent in office buildings. Deeper interpretation is however required to confirm this point. Outdoor temperature is also, as expected, negatively correlated with the energy index in apartment buildings (R = -0.43, P =$3 \cdot 10^{-4}$) but not at all in office buildings where R = -0.06 and P =0.7.

DISCUSSION

It is well known that correlation is not a cause-effect relationship. It may only indicate a direct or indirect relation, for example a common cause. For correlations concerning individuals (e.g. computer work and itchy eyes), a direct look into personal questionnaires, still to be performed, could provide better indications.

CONCLUSION AND IMPLICATIONS

Comfort is strongly correlated to perceived health, and energy efficient buildings are, on the average, more comfortable and not significantly worse (apartment buildings) or even healthier (office buildings) than buildings that use more energy. It seems therefore obvious that it is possible to make comfortable, healthy and energy-efficient buildings and even that this goes together. At least there should be no contradiction between existing strategies to diminish the energy use and those aiming at raising the occupant's well-being.

The strong correlation between perceived comfort variables themselves as well as the correlations between BSI and comfort variables observed in office buildings indicates that occupants, at least on a building average, perceive their well being in the building in a global way: they feel either well or bad for all aspects together. An interpretation of this fact could be "occupants feel healthy in comfortable buildings and vice versa"

Another important point is that BSI is strongly correlated with other characteristics of the perceived environment: control on temperature, light, ventilation, and noise, privacy, layout and decoration or cleanliness.

Correlation of BSI and allergies with climate assessed by the average outdoor temperature is not that clear, the picture differing strongly between offices and homes. Note that also national differences may influence the results.

ACKNOWLEDGEMENTS

The European Commission supported the HOPE programme, under the contract ENK6-CT-2001-00505 and the management of Dr. G. Deschamps. The co-ordination is done by Dr. Philomena M. Bluyssen and Christian Cox from TNO Environment and Geosciensces in The Netherlands. Its Swiss contribution was granted by the Swiss Federal Office for Education and Science (contract No 01.0061-1). The authors also thank all the HOPE participants who contributed, by their field studies, to collect data on which the present work is based. These are: University of Milano (Italy); Weerdenburg Huisvesting Consultants and Technische Universiteit Eindhoven (TU/e) (The Netherlands); University of Porto (Portugal); Danish Building Research Institute (Denmark); Technical University of Berlin (Germany); Helsinki University of Technology and Technical Research Centre of Finland (VTT) (Finland); BRE (United kingdom); Charles University of Prague (Czech Republic); and Vaudois State University Hospital Centre (Switzerland)

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