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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.

***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

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.

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

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.

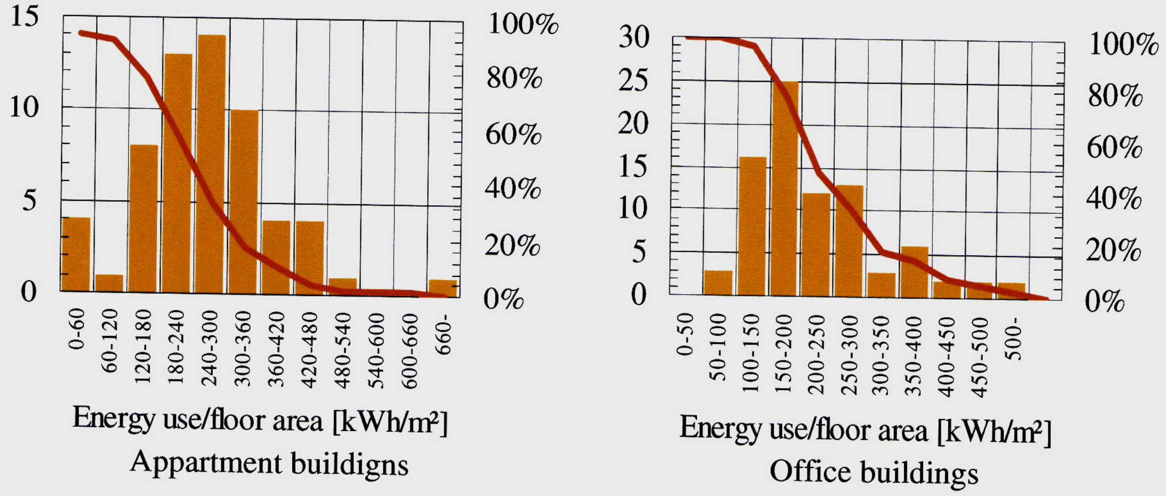

***Figure 1**: Distribution and cumulated frequency of the energy performance index*

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: R	BSI: P	Illness indicator R	Illness indicator 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

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**).

***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			

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.

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