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Symptoms experienced, environmental factors and energy consumption in office buildings

Argyro Lagoudi [a], Maria Loizidou [b], Mat Santamouris [a], Demosthenes Asimakopoulos [a]

[a] *University of Athens, Department of Applied Physics, Laboratory of Meteorology, 33 Ippokratous St., Athens 10680, Greece*

[b] *National Technical University of Athens, Chemical Engineering Department, 9 Iroon Polytechniou St., Zografou Campus, Athens 15780, Greece*

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Abstract

A major increase of complaints has been observed by the occupants of buildings, concerning health symptoms and comfort. In this study, the occupants' experience of symptoms as well as the occupants' sensation of the environmental parameters were estimated in six office buildings, where the indoor air quality was investigated. It was found that the percentage of building related symptoms experienced by the occupants of the buildings was high and it was strongly related to human comfort and human sensation concerning the environmental conditions. The human response to the environmental conditions showed that none of the parameters was judged as being unacceptable overall, which indicates that the number of symptoms observed in each building cannot be attributed to one cause but to the contribution of various environmental parameters. Moreover, it was found that the increase of energy consumption was associated with the increase of health symptoms for these buildings.

Keywords: Occupants' symptoms; Human comfort; Questionnaires; Energy consumption

1. Introduction

Major alternations have been accomplished in the indoor environment in an attempt either to save energy or to improve environmental conditions. However, these modifications have induced an increase in complaints from the occupants of the buildings, concerning health symptoms and comfort [1,2]. The set of health symptoms, that has been found to be associated with the buildings, is called sick building syndrome and these symptoms are experienced mainly in newly built and mechanically ventilated buildings. The main symptoms of the sick building syndrome include nasal, ocular, oropharyngeal and general diseases [3]. According to various studies that have been performed in public buildings by the National Institute of Occupational Safety and Health [4], the three most significant symptoms that are experienced in more than 70% of the buildings are dry eyes, dry throat and headaches.

The definition of the cause of the sick building syndrome is really difficult in most of the cases. Usually the problem in office buildings does not originate from a clear cause but from a combination of physical, chemical, biological or psychosocial factors. Concerning psychosocial factors, there are a lot of parameters that must be taken into account such as gender, smoking status, job stress, allergies, asthma as well as working using a VDU, shelf and fleecy factor, cleanliness, number of persons in the room, number of smokers in the room, etc. Most of the above-mentioned psychosocial parameters that seem to be related with the presence of symptoms are either indicators of some environmental parameters (e.g. the shelf factor is an indicator of total suspended particulates) or they determine the sensitivity of each occupant to the environmental parameters. According to a number of studies [5–13], it has been found that women usually experience more symptoms than men and that people who suffer from asthma, allergies or are sensitive to chemicals experience more symptoms than healthy subjects. Furthermore, job stress and dissatisfaction are parameters that can increase the number of symptoms experienced.

Nevertheless, there is no clear relation between most of the environmental parameters and symptom prevalence, since controversial findings are reported even today [14–19]. Concerning the most important environmental factors, such as high concentrations of air pollutants, high temperature, low humidity, air velocity, light intensity, glare and noise, a number of studies showed no relation between any of these factors and symptoms [5,15], while other studies showed a relation of several environmental factors from the ones mentioned above with either lower or higher experience of symptoms. For example, high temperature has shown a relation with

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higher symptom prevalence [8,9,14,16], while noise and low humidity have shown a relation with either increased or decreased symptoms [17,18].

As found in several studies, the only parameter that has shown a significant relation with symptoms' experience was the low airflow rate [14]. In particular, a statistically significant higher symptom prevalence was found to be associated with mean ventilation rates of fresh air lower than 10 l/s/person. Also, it has been found that the occupants working in buildings with mechanical ventilation, air conditioning or humidification systems experience more symptoms than occupants working in naturally ventilated buildings. However, there is not sufficient evidence concerning the relation between energy consumption in buildings and symptom prevalence or human comfort [20].

In this study, the occupants' experience of symptoms as well as the occupants' sensation of the environmental parameters were estimated in six office buildings in Greece, where the indoor air quality was investigated according to a standard method developed at a European level.

2. Methodology

Six representative office buildings were selected in the Athens area and were audited during March 1994. The investigation of the indoor air quality was performed according to a standard method that has been developed by the participants of an EC audit project [21]. The auditing of each building included an investigation of the characteristics of the building, use of symptoms' questionnaires and measurements of the most important environmental factors (physical parameters, odour, ventilation rate, air pollutants) [22].

An inspection of the buildings was performed in order to observe their characteristics and identify possible problems using a standard checklist. Additionally, the energy consumption data were collected for the audited buildings and the yearly energy indices were calculated in MJ/m^2 and MJ/person. Standard questionnaires that investigated human comfort and symptoms were distributed to the occupants of the six buildings. The total number of questionnaires distributed was 775, while the number of questionnaires returned was 533.

The questionnaires distributed included questions about building related symptoms and the environmental conditions observed in each building. There were two groups of questions concerning building related symptoms. The first group dealt with the experience of symptoms during the past month and the second with the experience of symptoms during the auditing day. The number of symptoms included in each group was eleven and they were dry eyes, watering eyes, blocked or stuffy nose, runny nose, dry throat, chest tightness, flu-like symptoms, dry skin, irritated skin, headaches and lethargy. From these symptoms six were the most significant (dry eyes, blocked or stuffy nose, dry throat, dry skin, headaches and lethargy) and these symptoms were considered as the short list of symptoms. The questions on symptoms for the past month had two parts; the first part was "how many days did you experience the symptom during the past month?" and the second part was "if a symptom was experienced, was it better on days away from the office?". In this case a particular symptom was considered to be related with the building only if the person experienced the symptom and was feeling better away from the office. In the same way, the symptoms experienced for the auditing day were taken into account only when they were considered to be relevant to the building.

According to the symptoms experienced by the occupants of each building, the Person Symptom Indices (PSI) and Building Symptom Indices (BSI) were calculated. The PSI indicate the occurrences of symptoms for each person and the BSI indicate the average occurrences of symptoms for the occupants of each building. The BSI that was calculated using the full list of symptoms (11 symptoms) presented during the auditing day (BSI_{sf}) or the past month (BSI_{ff}) is measured on a scale from 1 to 11, while the BSI calculated using the short list of symptoms (6 symptoms) presented during the auditing day (BSI_{ss}) or the past month (BSI_{fs}) is measured on a scale from 1 to 6.

A great number of environmental parameters were evaluated by the occupants of the buildings for the past month and the auditing day, such as thermal comfort, humidity, stuffiness, light and noise. Thermal comfort was evaluated on a scale from -3 (cold) to $+3$ (hot) with an ideal point at 0 (neutral). Perceived air quality was evaluated on a scale from -5 (clearly not acceptable) to $+5$ (clearly acceptable). The environmental parameters temperature, air stuffiness, air odour, light stability, glare, light satisfactory and noise satisfactory were judged on a scale from 1 (clearly acceptable) to 7 (clearly not acceptable) with an ideal point at 1. Furthermore, the environmental parameters air movement, air humidity, brightness and light homogeneity were judged on a scale from 1 (not enough) to 7 (too much). The mean value of the occupants' votes was calculated for each building in order to evaluate the acceptability of the environmental conditions.

The relations of the occupants' response to the various environmental conditions versus the experience of symptoms were observed using chi-squared tests while the relations between the occupants' response to the various environmental conditions versus PSI were observed using correlation coefficients.

3. Results and discussion

The inspection of the six buildings (A–F) showed that the selected buildings were situated in the centre of the town, in suburbs and in rural areas. The age of the buildings ranged between 2 and 30 years; significant renovation had not taken place in any of the buildings. Smoking was allowed everywhere. All of the buildings, except for building F, had a mechanical ventilation with recirculation and an air condi-

Table 1
Building characteristics and energy consumption data

Building	Situation	Total floor area (m^2)	No. of occupants	Age of building (years)	Ventilation		Energy indices (MJ/m^2)		Energy/person (GJ/person)		
					Type	Heating system	Total	Electricity	Fuel	Total	Electricity
A	suburb	7495	250	5	supply	air heating	772	459	313	23	14
B	rural	9540	380	3	dual ducts	air heating (fan coil)	847	642	206	21	16
C	rural	9190	300	2	dual ducts	air heating (fan coil)	526	254	276	13	6
D	downtown	2410	120	4	dual ducts	hot water (fan coil)	400	191	209	8	4
E	suburb	2492	120	21	dual ducts	air heating	487	170	318	10	4
F	downtown	4170	140	30	natural	hot water (radiators)	316	135	181	9	4

tioning system. However, only building A had a humidification system. Building F was naturally ventilated and was cooled with air conditioning units that were placed at the windows. The main building characteristics for the audited buildings, as well as the energy consumption indices are given in Table 1. It was found that the average total energy consumption was 553 MJ/m^2, the average electricity consumption was 309 MJ/m^2 and the average oil consumption was 250 MJ/m^2. The energy consumption for the audited buildings can be considered to be low, compared to the energy data for offices in northern Europe (970–1260 MJ/m^2 per year) [23] and the energy indices for offices all over Europe (mean yearly energy index 1100 MJ/m^2, mean electric index 540 MJ/m^2, mean fuel index 570 MJ/m^2) [24].

From the 553 occupants that completed the questionnaires, it was found that 51% were women and 49% were men. The percentage of smokers in the buildings ranged between 33 and 66% with an average value of 48%. The mean percentage of people suffering from hay fever was 25%, while the percentage of people suffering from asthma or eczema was small (7 and 8%, respectively).

Analysis of symptoms' questionnaires showed that the percentage of persons who experienced the six main building-related symptoms during the previous month was very high, as shown in Fig. 1. The most dominant symptoms were lethargy, headache and dry eyes and the mean percentage of people experiencing these symptoms was 74, 68 and 55%, respectively. The percentage of persons experiencing symptoms for the auditing day was lower, since the possibility to experience a symptom during one day is smaller than during a month. The most important symptoms were lethargy (32%), dry eyes (29%) and headaches (24%), as shown in Fig. 2.

The BSI, that were calculated using the number of symptoms reported for each building, are given in Table 2. For the past month, the average value of BSI_{ff} (full list of symptoms) was 3.6 at 11 and the average value for BSI_{fs} (short list of symptoms) was 2.6 at 6. The BSI values showed a great variance from building to building. The BSI_{ff} showed a range from 0.97 to 3.77, while the BSI_{fs} showed a range between 1.27 and 5.34. Regarding the auditing day, the average value of BSI_{sf} (full list) was 2.1 at 11 and the average value for BSI_{ss} (short list) was 1.5 at 6.

The high percentage of building related symptoms reported indicates that people were not satisfied with the indoor environment. The occupants' response to the environmental conditions can distinguish the parameters that were evaluated as being unsatisfactory and therefore could be the cause of the complaints. The mean value of the occupants' response to the environmental conditions for the auditing day as well as the ideal point for each parameter are given in Table 3. Thermal

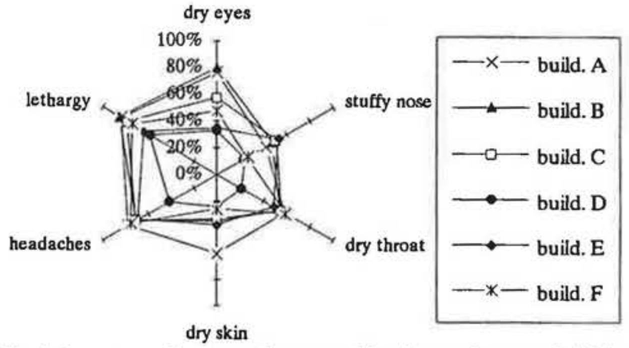

Fig. 1. Percentage of persons who reported the six most important building-related symptoms in each building for the past month.

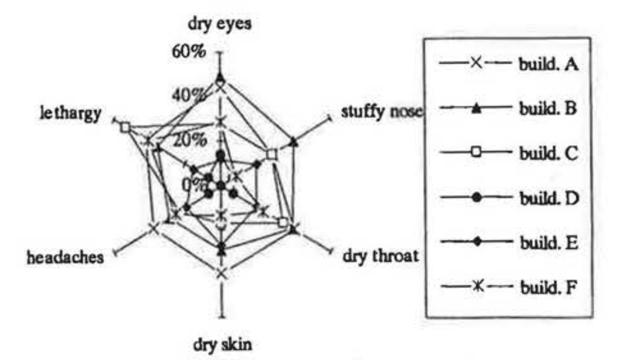

Fig. 2. Percentage of persons who reported the six most important building-related symptoms in each building for the auditing day.

Table 2
Mean values (and standard deviations) of the Building Symptom Indices (BSI) for the buildings A–F

	Building						Mean value
	A	B	C	D	E	F	
BSI_{fs}	3.40 (0.78)	3.77 (1.38)	2.85 (1.44)	0.97 (0.33)	2.33 (1.02)	1.96 (1.17)	2.6
BSI_{ff}	5.24 (1.21)	5.34 (2.07)	4.15 (2.19)	1.27 (0.64)	3.14 (1.69)	3.00 (1.85)	3.7
BSI_{ss}	2.31 (0.73)	2.22 (1.08)	1.79 (1.16)	0.43 (0.42)	1.08 (1.25)	1.20 (1.61)	1.5
BSI_{sf}	3.26 (1.08)	3.00 (1.20)	2.40 (1.61)	0.76 (0.50)	1.58 (1.76)	1.56 (1.61)	2.1

Table 3
Mean value of the occupants' response to the environmental conditions for each building (A–F) for the auditing day

	Building						Mean value	Scale			
	A	B	C	D	E	F		Min.		Ideal	Max.
Environmental conditions											
Thermal comfort	1.15	0.74	0.74	0.80	0.01	−0.41	0.50	cold	−3	0	3 hot
Temperature	3.76	2.92	3.04	2.77	3.05	3.17	3.12	comfortable	1	1	7 uncomfortable
Air movement	3.31	2.49	2.58	2.73	4.04	2.96	3.02	still	1	4	7 draughty
Humidity	2.28	2.25	2.65	2.60	2.59	2.85	2.54	dry	1	4	7 humid
Noise											
Noise satisfactory	4.30	4.06	3.66	3.02	3.35	5.49	3.98	satisfactory	1	1	7 unsatisfactory
Lighting											
Brightness	5.17	4.07	4.51	3.77	3.96	3.55	4.17	too dark	1	4	7 too bright
Stability	1.95	1.85	2.36	2.24	2.40	2.89	2.28	steady	1	1	7 flickering
Glare	2.18	2.18	2.85	1.85	2.29	2.48	2.30	no glare at all	1	1	7 too much glare
Homogeneity	2.76	2.78	3.13	2.42	2.72	4.06	2.98	very uniform	1	4	7 very uneven
Satisfactory	3.24	2.98	3.26	2.21	3.26	3.97	3.15	satisfactory	1	1	7 unsatisfactory
Air quality											
Perceived air quality	1.19	0.22	0.17	1.78	−1.40	0.77	0.46	clearly not acceptable	−5	+5	+5 clearly acceptable
Air stuffiness	4.83	4.67	4.64	2.94	4.62	4.49	4.36	fresh	1	1	7 stuffy
Air odour	3.86	4.07	4.11	2.03	3.49	4.59	3.69	odourless	1	1	7 smelly
Cleanliness	3.81	5.28	4.94	5.97	4.44	2.87	4.55	unsatisfactory	1	7	7 satisfactory

comfort was judged from slightly cool to warm in all the buildings with an average value of 0.71 (neutral to slightly warm) for the past month and 0.50 for the auditing day. Regarding thermal comfort, the percentage of dissatisfied people for the past month was in the range 22–54% and for the auditing day 10–47%. Fig. 3 shows the percentage of dissatisfied people regarding thermal comfort and perceived air quality for the auditing day. It was found that the percentage of dissatisfied people concerning perceived air quality and thermal comfort differed significantly from building to building since each building had different characteristics.

When the air velocity was examined, it was found that air was slightly still in all the buildings indicating that there were no complaints about draught. Furthermore, the air was judged as slightly dry in all the buildings, the values being 2.96 and 3.02 for the past month and the auditing day, respectively.

The noise was characterised from noticeable to unacceptable in all the buildings and the average vote for noise was 3.90 (noticeable) for the past month and 3.98 (noticeable) for the auditing day. In buildings A and E the noise from the ventilation system was from clearly noticeable to just unacceptable. In the other buildings the main sources of noise were other than the ventilation system. In building F the main problem was the outdoor noise from traffic. In buildings B and C the main noise source was due to the activities of many people in large offices.

The lighting conditions examined for the auditing day were brightness, stability, glare, homogeneity and lighting satis-

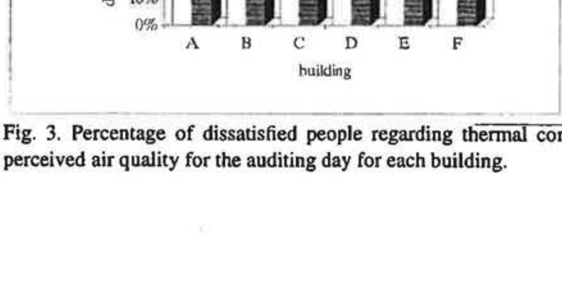

Fig. 3. Percentage of dissatisfied people regarding thermal comfort and perceived air quality for the auditing day for each building.

Table 4
Correlations between the occupants' response to symptoms and the Persons Symptom Index (PSI)

Past month		Auditing day	
Occupants' response to conditions vs. PSI	Correlation coefficient	Occupants' response to conditions vs. PSI	Correlation coefficient
Thermal comfort/PSI_{ff}	0.18	thermal comfort/PSI_{sf}	0.10
Temperature/PSI_{ff}	0.32	temperature/PSI_{sf}	0.30
Air movement/PSI_{ff}	−0.11	air movement/PSI_{sf}	−0.1
Air humidity/PSI_{ff}	−0.15	air humidity/PSI_{sf}	0.22
Light satisfactory/PSI_{ff}	0.16	light satisfactory/PSI_{sf}	0.31
Noise satisfactory/PSI_{ff}	0.23	noise satisfactory/PSI_{sf}	0.31
Perceived air quality/PSI_{ff}	−0.32	perceived air quality/PSI_{sf}	−0.26
Air stuffiness/PSI_{ff}	0.41	air stuffiness/PSI_{sf}	0.46
Air odour/PSI_{ff}	0.38	air odour/PSI_{sf}	0.33
Cleanliness/PSI_{ff}	−0.21	cleanliness/PSI_{sf}	−0.19

factory overall, as shown in Table 3. The lighting conditions overall were voted as being just acceptable for the auditing day (3.15) and the past month (3.11) in most of the buildings. However, most of the other lighting parameters were voted as being acceptable. It was evaluated that there was little glare and the light was uniform, steady and bright in most of the buildings, although in a number of buildings uneven lighting was noticeable. Therefore, people even if they judged the lighting conditions as being just acceptable did not specify any problem concerning the lighting conditions. The acceptability of lighting conditions in most of the buildings can be explained by the use of fluorescent lamps at equal distances on the ceiling and the high ability of the occupants to control the lighting.

The perceived air quality was voted in all the buildings from just unacceptable to just acceptable. The mean value on a scale from −5 to +5 for the past month was 0.37 while for the auditing day it was 0.46. The percentage of dissatisfied people for the auditing day concerning perceived air quality ranged from 19% to 53%. The evaluation of the perceived air quality was found to be related to the evaluation of stuffiness (correlation coefficient −0.48) and the evaluation of the smell of the air (correlation coefficient −0.43), which seem to be the main parameters that characterise the occupants' sensation of air quality. The air was characterised as being stuffy (just unacceptable) in all the buildings with a mean vote of 4.36 and additionally it was voted as being smelly (just unacceptable) in most of the buildings with a mean vote of 3.69.

Correlation between the occupants' response to the environmental parameters and the PSI showed a weak relation for several parameters. The correlation coefficients found for the relations between the environmental parameters and the PSI are shown in Table 4. Concerning physical parameters, the best correlation found was between the PSI and light or noise evaluation, the correlation coefficient being around 0.3. Perceived air quality had a negative correlation coefficient of −0.32 which shows that when the air quality acceptability decreases, the symptoms' occurrences increase. The stuffiness and the smell of the air had correlation coefficients

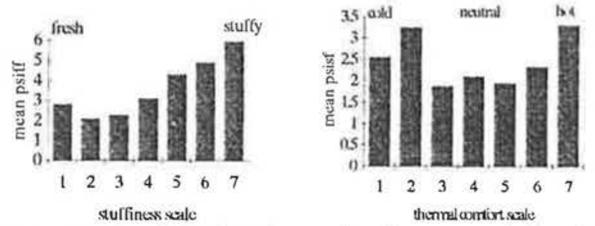

Fig. 4. Mean value of PSI_{ff} for each vote of stuffiness on a scale from 1 to 7 and mean value of PSI_{sf} for each vote of thermal comfort on a scale from 1 to 7.

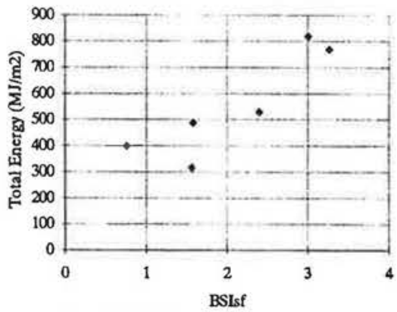

Fig. 5. Relation between BSI and yearly energy consumption index.

around 0.4. Fig. 4 shows the mean value of PSI_{ff} for each vote of stuffiness on a scale from 1 to 7 and the mean value of PSI_{sf} for each vote of thermal comfort on a scale from 1 to 7. Moreover, a significant correlation was found between the number of symptoms experienced by a person and the existence of smokers in that room. Chi-squared tests (χ^2 test) showed that the probability of the absence of a correlation between the PSI_{ss} and the presence of smokers was 4×10^{-12}. Regarding the relation between human health and energy consumption, a significant positive correlation between the BSI and the total energy index per year was found, as shown in Fig. 5. Also, the sensation of thermal comfort was found to be significantly related to the energy consumption of the buildings, which means that thermal comfort was characterised as being warmer in buildings where the energy consumption was higher.

The presence of particular symptoms was found to be significantly correlated with the evaluation of the environmental

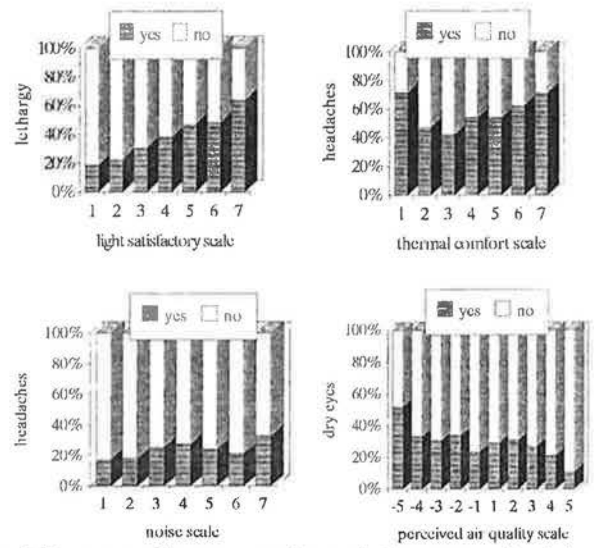

Fig. 6. Percentage of persons reporting particular symptoms in relation to their vote concerning lighting, thermal comfort, noise and perceived air quality.

parameters. Statistical analysis using chi-squared tests showed a significant correlation between thermal comfort and symptoms such as headaches and dry eyes for the past month and the auditing day. Moreover, a significant correlation was found between particular symptoms and humidity sensation, light satisfaction, noise satisfaction, cleanliness of the building and perceived air quality. Fig. 6 shows the percentage of persons reporting symptoms in relation to their vote concerning environmental conditions. It can be seen that the percentage of a particular symptom increases proportionally with the voting scale of lighting and noise from 1 (satisfactory) to 7 (unsatisfactory), while it decreases proportionally with the voting scale of perceived air quality from -5 (clearly unacceptable) to $+5$ (clearly acceptable). On the scale of thermal comfort from 1 to 7, the ideal point is 4 (neutral), where the lowest percentage of headaches was observed.

4. Concluding remarks

In conclusion, it can be stated that the percentage of building related symptoms experienced by the occupants of the buildings was high. The most significant symptoms were lethargy, headaches and dry eyes and the percentage of these symptoms for the past month was higher than 60%. This indicates that people were not satisfied with the indoor environment.

The occupants' response to several environmental parameters showed a weak relation with the PSI, although a significant relation was found between a number of particular symptoms and all the environmental parameters. The significant correlation that was found between the occupants' symptoms and their response to the environmental parameters reveals that human comfort and human sensation of environmental conditions influence the prevalence of building-related symptoms. Therefore, human response to symptoms can lead to the parameters that cause human discomfort and increased symptoms.

The human response to symptoms showed that people did not characterise approximately any of the parameters as unsatisfactory overall. Therefore, the number of symptoms observed in each building cannot be attributed to one cause but to the contribution of various environmental parameters such as indoor air pollutants, thermal comfort, noise, lighting, etc. The main problems concerning physical conditions were that the thermal comfort was judged as being warm and that the noise was judged as being noticeable. Concerning the air quality, the main problems were that the air was voted as being just unacceptable to just acceptable, slightly dry, smelly and stuffy.

Lastly, the average energy consumption of the audited buildings was low compared to other office buildings in Europe. This fact can be attributed to the mild climate that occurs in Greece. However, the increase of energy consumption was strongly associated with an increase in health symptoms and with the characterisation of the air as being warmer. Thus, an increase of energy consumption does not guarantee the reduction of complaints and symptoms, as would be expected. This can be explained by the fact that the buildings having higher energy consumptions were mostly new and modern buildings, where problems and complaints appear more frequently. Moreover, it is shown that the consumption of energy in order to keep the indoor environment too warm is not generally acceptable.

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