TERENSKO ISTRAŽIVANJE PONAŠANJA KORISNIKA VEZANOG UZ POTROŠNJU ENERGIJE U MEDITERANSKOM PODRUČJU

FIELD RESEARCH ON OCCUPANTS' BEHAVIOR RELATED TO ENERGY CONSUMPTION IN MEDITERRANEAN AREA

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Provedeno je terensko istraživanje u proljetnom razdoblju u tipičnom edukacijsko-istraživačkom objektu kako bi se prikupile informacije o ponašanju ljudi s obzirom na potrošnju energije. Podaci su prikupljeni mjerenjem temperature i kvalitete zraka u uredskim prostorima, kao i provedenim anketnim upitnikom. Rezultati su pokazali da su svi izmjereni parametri unutar granica propisanih normama, ali temperature oscilacije između ureda ukazuju da ljudski faktor korisnika zgrade nije nezanemariv kao što se do sada smatralo. Također, rezultati ankete pokazali su da su korisnici u zgradi uglavnom zadovoljni s toplinskim uvjetima u prostoriji, te da parametre koji utječu na toplinski osjećaj korisnika čine razina rasvjete, temperatura i kvaliteta zraka. Međutim, budućnost predviđanja ponašanja korisnika leži u upotrebi biosenzora koji su u mogućnosti dati informaciju o osjećaju toplinske ugodnosti i zadovoljstva korisnika toplinskim uvjetima okoline u kojoj boravi.

Ključne reči: potrošnja energije; toplinska ugodnost; ponašanje korisnika; energetska učinkovitost; zgrade

This paper provides a field research in spring period at the typical educational-research building in order to collect the information about human behavior regarding energy consumption. The data were collected by measuring the air temperature and air quality in the office area, as well as the survey questionnaire. The results showed that all measured parameters are within the limits prescribed by standards, but there were temperature oscillations between rooms, which reveal the influence of the building user as a factor of great importance. Furthermore, the questionnaire results showed that people in the building are mostly satisfied with the prevailing room conditions and that the parameters which influence human thermal sensation are lighting level, air temperature and air quality. However, the future of occupants' behavior prediction lays in a prediction of human thermal sensation with the use of wearable sensory devices that can address individual needs of building users.

Keywords: energy consumption; thermal comfort; occupants' behavior; energy efficiency; buildings

1 Introduction

The development of a feasible and sustainable approach towards improving the building stock's energy performance is a prerequisite with respect to the ambitious European energy and environment goals for 2030. The same applies to the need to improve the prevailing indoor environmental quality conditions, both in new and existing buildings, in parallel with the improvement of their energy efficiency. This is clearly expressed in the European and national regulatory frameworks, in the form of International Standards EN ISO 7730:2005, EN ISO 15251:2006.

Still, thermal comfort is a highly personal phenomenon, as it depends on one's own perception of thermal comfort [1 – 7], the occupant develops his or her own behavior. In the most cases, that behavior reflects on energy system regulation of their environment, i.e. office they work in, and ultimately, the whole building. In this way, the gap between predicted (simulated) and actual energy consumption is formed. This problem increases the need for an effective quantification of occupant behavior, i.e. the detection of complex physical mechanisms that link thermal comfort to occupant behavior regarding energy consumption in a building [8, 9].

The understanding of occupant's behavior and of the energy efficiency potential that can be utilized, on a community level is only possible through interdisciplinary research, integrating technical and social sciences [10, 11], by conducting two types of measurements, objective and subjective. Objective measurement consists of measurement of external and internal ambient conditions (air temperature, relative humidity, carbon dioxide concentration). Subjective assessment is used for estimation of individual user responses to the thermal environment. Moreover, it consists of personal self-assessment, i.e. respondents reports about their own comfort and behavior, mostly through surveys [8].

Therefore, the main objective of this study was to gather and to analyze all the information about energy consumption and energy efficiency in the building, to monitor to what extent the occupants' behavior influences the energy performance and, if this is not the case, to determine the dominant factors which are affecting the user and the building management system's interaction.

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2 Methodology

A total number of 20 offices (each with an area of 17 m²) and 2 laboratories (each with an area of 34 m²) at the Faculty of Mechanical Engineering, Electrical Engineering and Naval Architecture (FESB) in Split were selected for the field study. Out of a total of 22 randomly selected workplaces, 10 are located in the old part of the building and 12 in the new part of the building. The collected data is based on (1) systematic experimental measurement of the workplace environment conditions (temperature, relative humidity (RH) and the level of carbon dioxide (CO₂ level) by IAQ Monitor KIMO AMI 300 and (2) monitoring the occupant behavior during a typical working day in spring using survey questionnaire.

The respondents were asked to evaluate the level of energy consumption regarding the use of artificial lighting and office equipment according to the Likert scale ranging from 1 to 5, with 1 representing the minimum and 5 representing the maximum savings. Also, they were asked to determine the level of satisfaction with respect to the lighting of space, temperature and air quality in the office. Numerical data were indexed and analyzed in the statistical program IBM SPSS Statistics 23. The statistical analysis aimed to investigate to what extent independent variables such as age, sex, years of employment, and sharing an office with another employee, show a significant statistical difference between the groups of users or the employees of FESB.

A total number of 35 people, between the ages of 25 and 62, participated in the study. In addition, 60% of them were women and 40% were men, whilst they had between 0 and 43 years of employment. Furthermore, 25.7% of respondents are smokers and 74.3% non-smokers. Also, the respondents were grouped by the number of people in the office, so 50% of the respondents share an office with one more employee, and 50% do not share the office.

3 Results and discussion

The scientific method of incomplete induction was used for the result analysis, which means that general conclusion on the occupant behavior and thermal comfort conditions at FESB was adopted based on a limited number of individual cases. The statistical analysis consists of three parts:

- (1) measured values of the thermal comfort parameters at workplace,
- (2) occupants' behavior towards energy conservation in the workplace,
- (3) occupants' satisfaction with the thermal environment.

3.1 Measured values of thermal comfort parameters

Measurement of the internal parameters of the thermal comfort in the room, i.e. air temperature, RH and CO₂ level was performed. The average measured values are shown in Figures 1-3.

Figure 1. The average indoor air temperature during the day in comparison to the outdoor temperature

The average air temperature in the building during the morning is 22.7 °C, but it varies from room to room by almost 3 °C. In the middle part of the day, the average indoor air temperature is 24 °C. However, at the same time, the highest temperature variation (over 4 °C) is monitored between the different rooms. The indoor air temperature in the afternoon is 24.3 °C, while the variation level is 3 °C. This temperature variation between different proves that the influence of the occupants is not irrelevant.

Figure 2. The average relative humidity level during the day in comparison to the outdoor relative humidity level

Generally, the relative humidity in FESB rooms is in the range from 40% to 50%, which corresponds with the recommendation by the ASHRAE Standard 55-2010 "Thermal Environmental Conditions for Human Occupancy". Also, the results of the analysis proved that offices and laboratories show almost no deviation from the relative humidity in the outdoor environment, as opposed to temperature.

Figure 3. The average CO₂ level in the office rooms at FESB during the day

The concentration level of CO₂ in the room can be considered an indicator of odors acceptable to the occupants. According to ASHRAE standard 62.1-2016, "Ventilation for Acceptable Indoor Air Quality", the recommended CO₂ level limit is approximately 700 ppm above the CO₂ level measured externally. As the external CO₂ level is commonly between 300 and 500 ppm, permissible concentrations for indoor areas, where users spend most of their time in the sitting position, are within the range of 1000 to 1200 ppm, which is also the case at FESB, according to the results of the analysis. However, a relatively high oscillation in CO₂ levels between the rooms confirms the influence of occupants once again.

3.2 Occupant behavior related to energy consumption in the workplace

In addition to occupants' satisfaction, several impacts that could influence the energy consumption in office buildings were considered. In detail, gender differences were investigated, whether the users share the office with another or not, and whether the user is a smoker or not. The results are shown in Tables 1-3.

Table 1. Energy consumption regarding gender differences

Ranks	Gender	N	Mean Rank	Sum of Ranks
Turning the computer off when leaving on a lunch break	Men	14	17.21	241.00
	Women	21	18.52	389.00
	Total	35		
Turning the computer off at the end of a working day	Men	14	16.11	225.50
	Women	21	19.26	404.50
	Total	35		
Switch the lights off when leaving the room	Men	14	18.00	252.00
	Women	21	18.00	378.00
	Total	35		
Reading documents on a screen (without printing)	Men	14	16.36	229.00
	Women	21	19.10	401.00
	Total	35		
Test Statistics	<i>Turning the computer off when leaving on a lunch break</i>	<i>Turning the computer off at the end of a working day</i>	<i>Switch the lights off when leaving the room</i>	<i>Reading documents on a screen (without printing)</i>
Mann-Whitney U Test	136.000	120.500	147.000	124.000
Wilcoxon W	241.000	225.500	378.000	229.000
Z	-0.484	-1.087	0.000	-0.794
Asymp. Sig. (2-tailed)	0.628	0.277	1.000	0.427
Exact Sig. [2*(1-tailed Sig.)]	0.727	0.377	1.000	0.454

Based on the test results (Table 1), it can be concluded that there is no statistically significant difference in energy consumption between female and male employees at FESB related to lighting and to the use of a computer.

Table 2. Energy consumption regarding office sharing

Ranks	Office sharing	N	Mean Rank	Sum of Ranks
Turning the computer off when leaving on a lunch break	No Yes Total	11 21 32	15.64 16.95	172.00 356.00
Turning the computer off at the end of a working day	No Yes Total	11 21 32	12.36 18.67	136.00 392.00
Switch the lights off when leaving the room	No Yes Total	11 21 32	21.18 14.05	233.00 295.00
Reading documents on a screen (without printing)	No Yes Total	11 21 32	15.27 17.14	168.00 360.00
Test Statistics	<i>Turning the computer off when leaving on a lunch break</i>	<i>Turning the computer off at the end of a working day</i>	<i>Switch the lights off when leaving the room</i>	<i>Reading documents on a screen (without printing)</i>
Mann-Whitney U Test	106.000	70.000	64.000	102.000
Wilcoxon W	172.000	136.000	295.000	168.000
Z	-0.522	-2.206	-2.146	-0.549
Asymp. Sig. (2-tailed)	0.602	0.207	0.032	0.583
Exact Sig. [2*(1-tailed Sig.)]	0.725	0.074	0.042	0.611

The occupant behavior regarding the rational use of energy partly depends on the number of people in the office, which can be seen in Table 2. Thus, most people sharing the office with at least one person, turn off the computer at the end of working day and switch off the lights when leaving the office room. However, energy consumption awareness is very low at the community level of FESB employees. Hence, leaving on the lunch break without turning the computer off is a part of a daily routine and collective behavior, as well as not saving paper and electricity by reading documents from the computer screen.

Table 3. Energy consumption regarding whether the user is a smoker or not

Ranks	Smoker	N	Mean Rank	Sum of Ranks
Turning the computer off when leaving on a lunch break	Yes No Total	9 26 35	18.83 17.71	169.50 460.50
Turning the computer off at the end of a working day	Yes No Total	9 26 35	15.22 18.96	137.00 493.00
Switch the lights off when leaving the room	Yes No Total	9 26 35	20.17 17.25	181.50 448.50
Reading documents on a screen (without printing)	Yes No Total	9 26 35	19.44 17.50	175.00 455.00
Test Statistics	<i>Turning the computer off when leaving on a lunch break</i>	<i>Turning the computer off at the end of a working day</i>	<i>Switch the lights off when leaving the room</i>	<i>Reading documents on a screen (without printing)</i>
Mann-Whitney U Test	109.500	92.000	97.500	104.000
Wilcoxon W	460.500	137.000	448.500	455.000
Z	-0.370	-1.150	-0.767	-0.503
Asymp. Sig. (2-tailed)	0.711	0.250	0.443	0.615
Exact Sig. [2*(1-tailed Sig.)]	0.781	0.362	0.469	0.643

As it can be seen from Table 3, the results of the research show that the occupant behavior in terms of energy consumption does not depend on whether the user is a smoker or not.

3.3 Occupant satisfaction with the thermal environment

Table 4 lists the parameters considered to be affecting occupant thermal sensation of his or her workspace. In detail, the linear connections of numeric variables such as window view, lighting, temperature, and air quality are given.

Table 4. Linear correlation of parameters that affect the occupant satisfaction with the thermal environment

Correlation		Window view	Lighting in the room	Indoor air temperature	Indoor air temperature	Occupant satisfaction
Window view	Pearson Correlation, r	1	0.281	0.127	0.331	0.280
	Sig. (2-tailed), α		0.102	0.467	0.052	0.104
	N	35	35	35	35	35
Lighting in the room	Pearson Correlation, r	0.281	1	0.508*	0.442*	0.606*
	Sig. (2-tailed), α	0.102		0.002	0.008	0.000
	N	35	35	35	35	35
Indoor air temperature	Pearson Correlation, r	0.127	0.508*	1	0.510*	0.650*
	Sig. (2-tailed), α	0.467	0.002		0.002	0.000
	N	35	35	35	35	35
Indoor air quality	Pearson Correlation, r	0.331	0.442*	0.510*	1	0.639*
	Sig. (2-tailed), α	0.052	0.008	0.002		0.000
	N	35	35	35	35	35
Occupant satisfaction	Pearson Correlation, r	0.280	0.606*	0.650*	0.639*	1
	Sig. (2-tailed), α	0.104	0.000	0.000	0.000	
	N	35	35	35	35	35

*Correlation is significant at the 0.01 level (2-tailed).

The linear correlation test is conducted using the Pearson coefficient (r). In accordance with the size of this coefficient, the direction and intensity of the linear correlation between the observed variables [10] can be deduced. With r being 0.6 which represents the mean strong correlation, it can be concluded that thermal comfort sensation is influenced by the room lighting, indoor air temperature and air quality. Meaning, the feeling of thermal comfort will increase if the values of considered variables increase. Since the empirical significance of the coefficient of correlation (α) is approximate to being 0, the coefficient of correlation between satisfaction and the mentioned variables in the observed building is statistically significant with the test significance of the 5%. Moreover, the same conclusion on the significance of the coefficient may also occur with the test significance of 1%.

Table 5 shows the correlation of numeric variables such as gender, whether a person is a smoker or not, age, years of employment, office sharing and occupant satisfaction.

Table 5. Rank correlation of parameters to determine ones that affect the occupant satisfaction

Spearman's rho		Gender	Smoker	Age	Years of employment	Office sharing	Occupant satisfaction
Gender	Correlation Coef., rs	1.000	0.053	-0.023	0.067	-0.293	0.397
	Sig. (2-tailed), α		0.761	0.895	0.703	0.088	0.018
	N	35	35	35	35	35	35
Smoker	Correlation Coef., rs	0.053	1.000	-0.156	-0.107	0.000	-0.107
	Sig. (2-tailed), α	0.761		0.371	0.539	1.000	0.541
	N	35	35	35	35	35	35
Age	Correlation Coef., rs	-0.023	-0.156	1.000	0.919*	-0.114	-0.047
	Sig. (2-tailed), α	0.895	0.371		0.000	0.516	0.788
	N	35	35	35	35	35	35
Years of employment	Correlation Coef., rs	0.067	-0.107	0.919*	1.000	-0.243	0.041
	Sig. (2-tailed), α	0.703	0.539	0.000		0.159	0.814
	N	35	35	35	35	35	35
Office sharing	Correlation Coef., rs	-0.293	0.000	-0.114	-0.243	1.000	-0.383
	Sig. (2-tailed), α	0.088	1.000	0.516	0.159		0.023
	N	35	35	35	35	35	35
Occupant satisfaction	Correlation Coef., rs	0.397	-0.107	-0.047	0.041	-0.383	1.000
	Sig. (2-tailed), α	0.018	0.541	0.788	0.814	0.023	
	N	35	35	35	35	35	35

*Correlation is significant at the 0.01 level (2-tailed).

Table 5 shows the interdependence of occurrences with modalities associated with the ordinal scale. The rank correlation measurement test uses Spearman's rank correlation coefficient (rs). The coefficient can take values in the interval between -1 and 1. The value closer to the edges of this interval indicates a higher correlation of the rank of observed variables [10]. In this case, with a test significance of 5%, Spearman's rank correlation coefficient is positive between *Occupant satisfaction* and *Gender* and is 0.397. Since the gender variable has value 1 representing the man and the value 2 representing the woman, the results of the analysis show that women feel more comfortable in the office room they work in than men. Furthermore, Spearman's rank correlation coefficient is negative between variability in *Occupant satisfaction* and *Office sharing*, which means that both, male and female users are more satisfied if they do not share the office with anyone else, because in this way, they are in complete control over the regulation of comfort conditions (lighting, temperature and air quality) of the working environment.

According to the results of the survey conducted by the questionnaire, other variables such as whether a person is a smoker or not and age of the users does not have any effect on the feeling of comfort in space, with test significance of 5%. Those findings do not necessarily coincide with the findings of other studies, confirming that the personal assessment of comfort is a very complex phenomenon, which needs further research to be understood [6].

4 Conclusions

A field analysis of thermal comfort was carried out in a typical educational and research institution during a typical working day in the spring period, in order to evaluate the relativity of influence of the occupants regarding the energy consumption at FESB. The data were collected by measuring the ambient parameters, which includes indoor air temperature and relative humidity, and the level of carbon dioxide. In addition, occupant behavior towards energy conservation in the workplace was monitored and occupants' satisfaction with the thermal environment was examined.

The conducted field study showed that all the indoor environmental parameters are within the values recommended by the standards. However, variations in indoor room temperature and level of CO₂ proved that the impact of the occupants is significant. This is a clear index of the role users can have and provides also the case for no-cost measures, like raising awareness of the employees and the occasional users. Furthermore, according to the results of the qualitative assessment of the users' perception of the indoor environment, there is no statistical difference in behavior between male and female users, smokers and non-smokers and people who share an office in comparison with those who are alone in the office. Nevertheless, physical parameters which clearly affect the occupants' satisfaction of the thermal environment are lighting in the room, indoor air temperature and air quality.

In conclusion, this paper presents the overall picture of the thermal comfort of the FESB building. Further research will be based on the quantification of the influence of the user, in order to know how his impact on the overall energy consumption of the building. One of the ways to achieve this, is by using wearable personal sensory devices which estimate the incentives for the certain behavior.

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