OCCUPANT BEHAVIOR AND THERMAL COMFORT FIELD ANALYSIS IN TYPICAL EDUCATIONAL RESEARCH INSTITUTION
A Case Study

by

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An experimental field study has been conducted for typical educational research building facility (office building). The research data was gathered by the systematic monitoring of the offices and adaptive occupant behavior during the typical working day in the spring period. Different sensors and data loggers for temperature, relative humidity, CO_2 concentration, had been mounted in order to collect data for analysis of thermal comfort conditions. Moreover, occupant surveys and interviews in form of questionnaire were also brought to examine the psychological and social impacts of the occupants' behavior regarding energy consumption. The inductive scientific method is used for data processing, i. e. descriptive and inferential statistical analysis of the results was made. Based on the analysis of the conducted study, it was found that thermal environment of the observed building is within the standards (i. e. specific parameters are within the range) and that the occupants are generally satisfied with thermal conditions in their offices. However, they do not pay much attention to conserving energy which is an important finding as it is directly related to the energy consumption. Thus, more attention should be directed to the education of the users and in general, to enable energy savings in the future.

Key words: *thermal comfort, thermal environment, occupant behavior, office buildings, energy efficiency*

Introduction

Thermal comfort is the occupants' satisfaction with the surrounding thermal conditions. However, each individual experiences sensations a bit differently based on their physiology and state. For example, the stressful assignment could raise an occupant's sensation of heat in the room. Furthermore, the temperature of the skin is not consistent with all areas of the body which reflect the variations in blood flow and subcutaneous fat. Additionally, indoor thermal sensation within the same building could deviate significantly because of different room orientations or effects of buildings in the neighborhood [1].

As people spend a lot of time indoors, indoor air quality (IAQ) becomes a major concern. Pleasant atmosphere causes satisfaction and good state of health and it is an incentive for carrying out work duties. Opposite of that, inadequate or uncomfortable thermal envi-

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ronment will most likely boost occupant reactions aimed at raising the level of welfare, which can lead to increased energy consumption. Concluding, occupant behavior has got a significant impact on the building energy systems and thermal environment of building employees [2-5]. However, it comes out as one of the weakest links in the energy efficiency and conservation equation. For occupant behavior, it is usually simplified because of its stochastic, complicated and interdisciplinary nature. The use of simple methods or tools for quantifying the impact of occupant behavior in simulation programs significantly contributes to the gap between designed and achieved energy savings in buildings. Therefore, it is important to examine and to determine its impact on overall energy consumption in buildings [6, 7].

Existing methods for occupant behavior modeling include: heat balance models conducted in laboratory experiments and adaptive models based on field monitoring of occupants' behavior. One of the most applicable heat balance tools is Fanger's PMV-PPD model [8-13]. The advantages of the PMV-PPD method based on the heat balance model are that it considers a wider range of physical parameters of the indoor environment as well as human activity and clothing level than the existing adaptive models. However, it ignores factors such as climate, social economy, expectation, psychological, and behavioral adaptive abilities. Those adaptations are partially included in the adaptive model but the problem is that adaptive model gives reliable results only for the buildings with no mechanical cooling system [10-17]. Nevertheless, without rigorous field work, there is no real confidence that the outputs of the research efforts are relevant to end-users for whom they were intended. Lenzuni *et al*. [18] noted a gradual reduction in the effectiveness of the body in thermoregulation after the age of sixty. Furthermore, in his research of gender differences, Karjalainen [19] have found males report discomfort due to rises in temperature much earlier than females. However, while females have been more sensitive to temperatures, males tend to be more sensitive to relative humidity levels.

Therefore, the main objective of this study was to observe the thermal conditions at the educational research institution in Split. Moreover, the goal was to present and statistically analyze occupants' behavior and their sensation regarding existing thermal comfort conditions, *i. e*. it was given an insight into occupants' energy usage and the level of satisfaction of their thermal environment, respectively.

Methodology

The present study was conducted at the Faculty of Mechanical Engineering, Electrical Engineering and Naval Architecture (FESB) in Split, to investigate energy usage habits of the employees and to evaluate their level of energy conservation as well as their sensitivity to thermal conditions in the offices. Moreover, the measurements of indoor environmental conditions in the randomly selected offices were analyzed.

Description of the building facility

The FESB (fig. 1 middle) is an educational research building, employing 300 people. It is the stand-alone object, located in the windy part of Split, Croatia. It consists of two connected buildings, the old one and the new one, which together cover an area of 29.477 m^2. Notably, the new part of the building leans on the old one, leaving the square plaza in beneath. The Faculty contains 8 stories of 168 square offices, 18 classrooms, and 90 laboratories, which are not all fully occupied during the working hours. While the old part of the FESB building has double-pane wooden windows with inner as well as outer blinds and uses the radiators for heating and split-system for air-conditioning (fig. 1 left), the new part of the

Figure 1. The FESB (middle) with the offices in the old (left) and new (right) part of the building

building has double-pane aluminum windows with outer blinds and the central mechanical heating and cooling (HVAC) system installed (fig. 1 right).

Measuring and monitoring

A total number of 18 randomly selected offices (of 17 m^2) and two laboratories (of 34 m^2) were chosen for the study. The research data is based on the systematic monitoring of the offices and adaptive occupant behavior during the typical working day, tab. 1, in the spring season, by different sensors and data loggers. The measurement was conducted three times per day, in the morning at 9 a. m., in the middle of the day at 12 p. m., and in the afternoon at 3 p. m.. The device used for the measurement of the indoor air temperature, relative humidity and the concentration of CO_2 was Multifunctional IAQ Monitor KIMO AMI 300 with air quality probe: Pt100 class A for the temperature measuring, the capacitive sensor for hygrometry and NDIR sensor for CO_2 measuring [20].

Table 1. Prevailing outdoor conditions in the spring season

Time, [h]	Temperature, [°C]	Relative humidity, [%]	Air pressure, [hPa]	Solar radiation, [W/m^2]	UV index
9 a. m.	17.0	60.0	1006.8	599.0	2.70
12 p. m.	18.5	57.5	1006.7	591.5	3.35
3 p. m.	18.6	58.5	1006.2	480.0	2.05

Survey

A total number of 18 randomly selected offices (of 17 m^2) and 2 laboratories (of 34 m^2) were chosen for the A total number of 35 people participated in the study. The population under evaluation was composed of both female and male occupants with 60% of the respondents being women and 40% being men. Among the respondents, 42.86% of people share an office with one person, 25.71% of people share an office with two people and 31.43% of people do not share the office. The age range of respondents varied from 25 to 60. The investigation was carried out using a questionnaire to examine occupant psychological and social impacts. The questionnaire was divided into three main sections: (a) questions exploring occupants' personal information such as age, gender, whether they work in shared office or not, *etc*., (b) questions exploring occupant habits with respect to energy usage at work, and (c) questions exploring occupant sensation of their thermal environment. The respondents were asked to determine their level of energy-saving effort on the scale from 1 being the minimum to 5 being the maximum, regarding printing the documents and turning office equipment and light off when leaving the room. Furthermore, they were asked to determine their level of satisfaction regarding illuminance level of the working environment, indoor air temperature and air quality in the office. Numerical data is indexed and analyzed in IBM SPSS Statistics 23. The aim of the analysis was to investigate to what extent independent variables like age, gender, job type, years of employment, body mass index (BMI) or sharing an office with one more person are showing the significant statistical difference between occupant categories, *i. e.* Faculty employees. Two nonparametric tests (with the assumption that gather data is not normally distributed) with the significance level of 5%, Mann Whitney U-test and Kruskal--Wallis test were used for the analysis of the results. Mann-Whitney U-test was used for comparing two sample means that come from the same population, to see whether they are equal or not. In this research, Mann Whitney U-test was used to investigate whether the nature of different responses among the employees is connected to their job type, years of employment or sharing the office with the other employee. Kruskal-Wallis test assessed for significant differences on a continuous dependent variable by a categorical independent variable (with two or more groups). In this research, Kruskal-Wallis test was used to define the impact of BMI with the thermal conditions in the office as well as the statistical impact on occupants' answers. Moreover, it was used to explore the parameters of occupants' satisfaction with their thermal environment. The analysis was conducted on the assumption that non-teaching staff spends all of their working hours in the office, while teaching staff spends only a part of their working hours.

Results and discussion

In this field analysis, an inductive reasoning is used to develop general principles of occupant behavior and thermal comfort conditions at the University using the specific observations of investigation subject. The statistical analysis is divided into two main aspects: (1) measurements of the indoor environment conditions (the CO_2 concentration, relative humidity level and average indoor air temperature in the offices), and (2) a survey of occupants' sensation of indoor conditions as well as their behavior regarding energy conservation. The results of the survey are given in tabs. 2-5 and in fig. 2, while results of measured offices' conditions are given in figs. 3-8. The offices are grouped according to the room orientation and the type of measurement conducted.

Table 2 represents parameters that have an influence on occupants' satisfaction with thermal conditions in the office. The null hypothesis states that there is no relationship between the two variables being studied (one variable does not affect the other), *i. e.* it states that results are due to chance and have no statistical significance. If the significance level is less than 0.05 ($p < 0.05$), the null hypothesis is being rejected and the alternative hypothesis is being accepted which states that there is a statistical significance between variables investigated.

Based on research results, it is concluded that occupants' satisfaction with the thermal comfort in the office is influenced by illuminance level of the working environment, indoor air temperature and air quality in the office, and is not connected to the number of people in the office.

Table 3 shows that a perception of thermal comfort in the winter depends on the type of the job performing, meaning that teaching staff is more satisfied with the thermal conditions in the winter than non-teaching staff. Gained results are due to the assumption that the teaching staff does not spend all their working hours in the office. On the other hand, the perception of thermal comfort in the summer, as well as switching the lights off when leaving the room, depends on gender, *i.* e. women express a higher level of satisfaction than men regarding thermal comfort in the summer period. Moreover, women show a more conscientious use of lighting and a greater inclination to energy savings than men, in general. This can also be supported by Karjalainen' [19] investigation of gender differences in thermal comfort.

Table 2. Factors that have an influence on occupants' satisfaction of thermal comfort in the office

Null hypothesis	Test	Sig.	Desicion
The distribution of illuminance is the same across categories of satisfaction.	Independent-samples Kruskal-Wallis test	0,000	Reject the null hypothesis
The distribution of air temperature is the same across categories of satisfaction.	Independent-samples Kruskal-Wallis test	0,003	Reject the null hypothesis
The distribution of air quality is the same across categories of satisfaction.	Independent-samples Kruskal-Wallis test	0,011	Reject the null hypothesis

Asymptotic significances are displayed. The significance level is 0.05.

Table 3. Occupants' satisfaction and behavior with regard to occupants' job type and gender according to the questionnaire results analysis (Mann-Whitney Test)

Job type		N	Mean rank	Asimp. sig. (2-tailed)
Thermal comfort during the winter	Teaching staff	13	24.23	0,005
	Non-teaching staff	22	14.32	
	Total	35		
Gender		**N**	**Mean rank**	**Asimp. sig. (2-tailed)**
Thermal comfort during the summer	Men	14	13.86	0,027
	Women	21	20.76	
	Total	35		
Switching the lights off when leaving the room	Men	14	14.11	0,044
	Women	21	20.60	
	Total	35		

Table 4. Occupants' behavior with regard to office sharing according to the questionnaire results analysis (Mann-Whitney Test)

Office sharing		N	Mean rank	Asimp. sig. (2-tailed)
Turning the computer off when leaving on a lunch break	Do not share office	11	15.64	0.602
	Share office	21	16.95	
	Total	32		
Turning the computer off at the end of a working day	Do not share office	11	12.36	0.027
	Share office	21	18.67	
	Total	32		
Switch the lights off when leaving the room	Do not share office	11	21.18	0.032
	Share office	21	14.05	
	Total	32		
Recycling	Do not share office	11	18.68	0.330
	Share office	21	15.36	
	Total	32		
Reading documents on a screen	Do not share office	11	15.27	0.583
	Share office	21	17.14	
	Total	32		

Occupants' behavior that contributes to building energy conservation, according to the designed questionnaire, mostly does not depend on a number of people in the office by the conducted survey. The research results in tab. 4 show that most people who share an office tend to turn their computer off and switch the lights off at the end of a working day, but they do not care about turning their computer off when leaving on a lunch break, recycling or saving paper and electricity by reading documents from a computer screen. This trend is worrisome because, not only is this wasteful, but also detrimental to the environment. The building management could decrease or even stop this trend by raising occupants' awareness of the importance of energy conservation.

Nevertheless, the satisfaction of thermal comfort conditions, on the other hand, mainly depends on the number of people in the room, fig. 2.

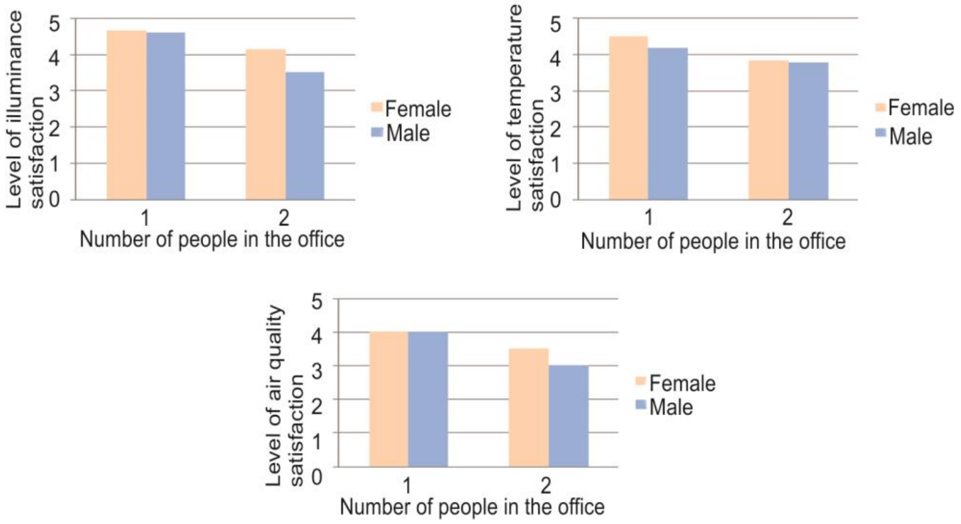

Figure 2. Occupants' satisfaction with thermal comfort condition in their office

As it was mentioned before, Faculty occupants are, either alone in the office, or they share it with one more person. Detailed analysis showed that the highest level of satisfaction showed respondents who are alone in the office, both female and male, for they control thermal conditions in an office (illuminance level, temperature level and ventilation) themselves.

Furthermore, according to the analysis of questionnaire results, the perception of thermal comfort depends on BMI, which is one of the individual characteristics on the thermal sensation that is taken into consideration, among the age, gender and years of employment. The ideal BMI interval is from 20 to 30 which correspond to weights of 52.5 kg and 61.3 kg to 78.7 kg and 91.9 kg for assumed average heights of 162 cm and 172 cm for females and males, respectively. Results showed that the group of occupants with the ideal BMI is the most satisfied; less satisfied is the group with the high BMI, while the group with the low BMI is the least satisfied with the thermal conditions in an office, tab. 5. This might be because the extra fat insulate the body's core, but this phenomenon obviously needs more detailed analysis in the future.

Table 5. Occupants' behavior with regard to BMI according to the questionnaire results analysis

BMI		N	Mean rank	Asimp.Sig.
Thermal comfort	Low	3	11.83	0.030
	Ideal	23	21.11	
	High	9	12.11	
	Total	35		

Moreover, field research conducted at the Faculty showed that there is no statistical significance of the age, gender and years of employment with neither the thermal comfort nor occupants' behavior.

The second part of research investigation was to measure IAQ which is not directly correlated with the occupants' comfort, but the indoor environmental conditions. Thus, indirectly, it relates to the health and productivity of building occupants. Following figures give an insight into occupants' office condition trends during the working day. In particular, average indoor air temperature, CO_2 concentration (which is connected to odors) and relative humidity of the space.

The temperature measured as one of the thermal comfort parameters was average indoor air temperature during occupants' stay in their office. The temporal average is based on three minutes intervals. Figures 3 and 4 show indoor air temperature level in the offices according to the room orientation (East, South, North, and West) measured in the new and the old part of the building, respectively.

The old part of the building has no offices on the North (N) side. Thus, only East (E), South (S), and West (W) side were monitored. In the morning the indoor air temperatures are the highest in the offices in the east in the new part of the building. Meanwhile, most of-

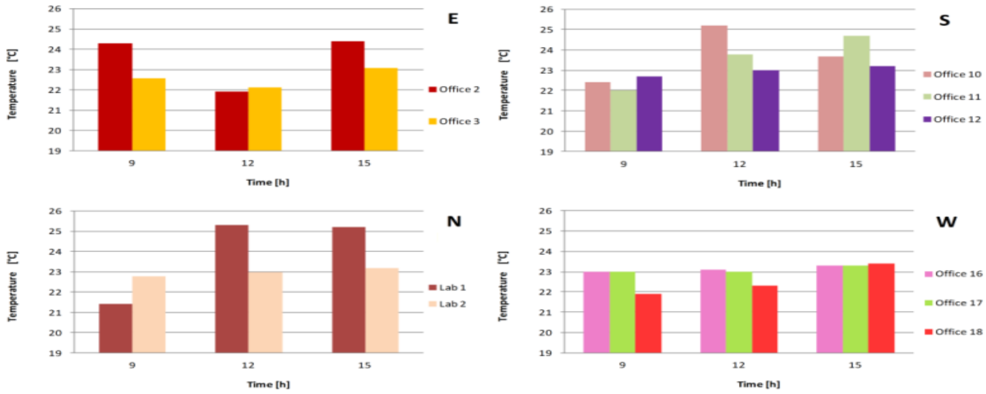

Figure 3. Average indoor air temperature of the offices in the new part of the Faculty building depending on the room orientation

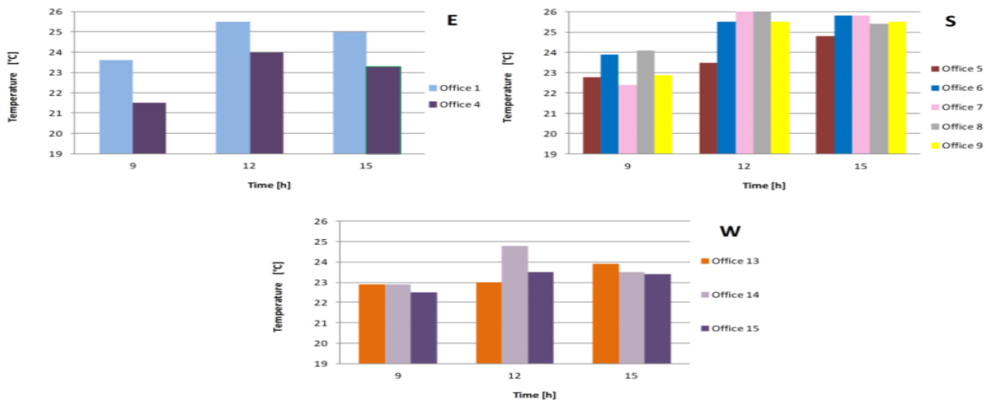

Figure 4. Average indoor air temperature of the offices in the old part of the Faculty building depending on the room orientation

fices measure the lowest indoor air temperature with a rising tendency in the second part of the day. This happens because the new part of the building is more exposed to the sun in the morning. In general, it can be concluded that the temperatures are higher in the old part of the Faculty building observing the whole working day. This is by cause of building position, as the old and the new part of the building are located south and north, respectively.

Figures 5 and 6 show CO_2 concentration in the offices according to the room orientation (E, S, N, and W) measured in the new and the old part of the building, respectively.

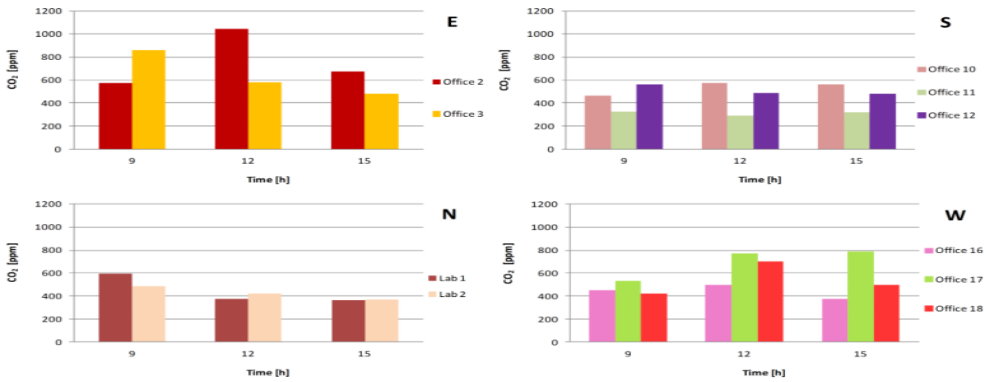

Figure 5. The CO_2 concentration of the offices in the new part of the Faculty building depending on the room orientation

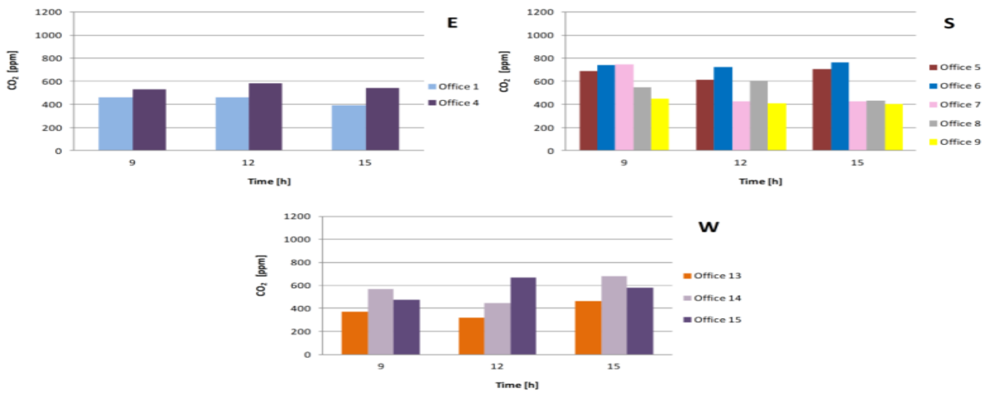

Figure 6. The CO_2 concentration of the offices in the old part of the Faculty building depending on the room orientation

The CO_2 can be considered as the indicator of the occupant odors. Indoor CO_2 concentration is an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity. According to the ASHRAE Standard 62.1-2016, recommended concentration of CO_2 is about 700 ppm above the measured outdoor CO_2 concentration. As the external CO_2 range 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, while the CO_2 concentrations greater than 5000 ppm can cause health problems.

Results of the conducted survey indicated that the concentration of CO_2 is within the range allowed, with the higher concentration of CO_2 being present in the old part of the Faculty building. This could be due to the fact that the old building has no ventilation system. The exception makes offices on the east side in the new part of the building, but they are professors' cabinets which are not fully-occupied during the day.

Figures 7 and 8 show relative humidity conditions in the offices according to the room orientation (E, S, N, and W) measured in the new and the old part of the building, respectively.

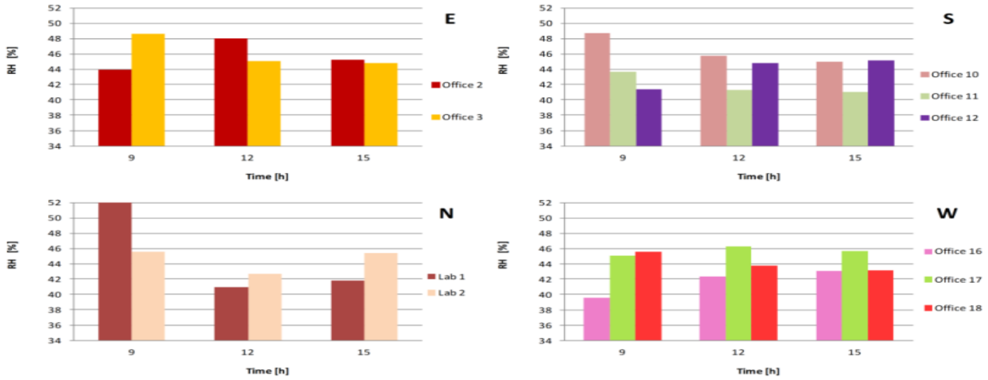

Figure 7. Relative humidity in the offices in the new part of the Faculty building depending on the room orientation

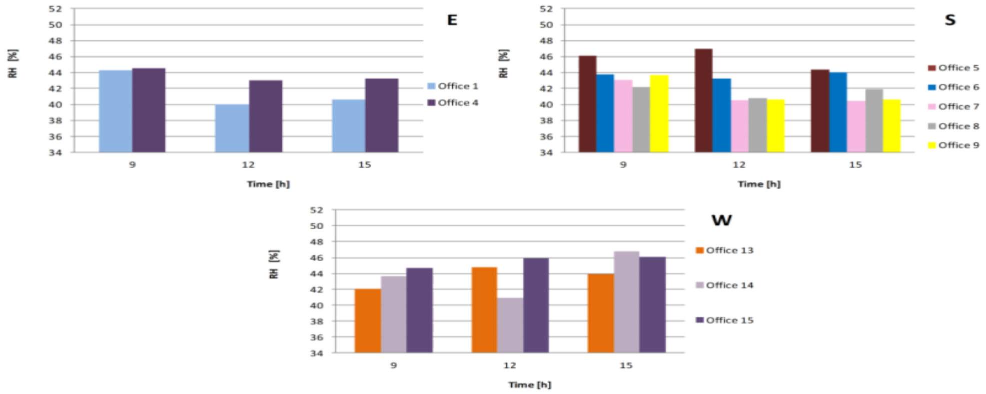

Figure 8. Relative humidity level in the offices in the old part of the Faculty building depending on the room orientation

In general, the relative humidity level in the Faculty offices is between 40% and 50%, as recommended by the American ASHRAE Standard 55-2010. Also, it was noted that offices and laboratories show no discrepancy from the relative humidity in the surrounding environment. Based on previous research papers [21, 22], as well as this one, it can be concluded that the relative humidity in offices is in correlation with the window opening. However, this will be further explored.

Conclusions

An experimental field study has been conducted for common educational research building facility during the typical working day in the spring period. Research data was gained by the measuring of thermal conditions, *i. e.* concentration of CO_2, relative humidity and the indoor air temperature in the offices. As per making a quantitative analysis of the inner space more thorough, the survey about occupant perception of thermal comfort surrounding was conducted. Research results showed that teaching staff is more satisfied with the thermal comfort in the offices in the winter period than non-teaching staff. Furthermore, women generally show a more rational use of energy at work. In most cases, the number of people in the office does not affect the behavior of the occupants during the working hours, because the occupant habits remain the same regardless whether they share an office or not. On the other hand, the number of people in the office has an impact on the occupant satisfaction with the thermal comfort. Thus, the higher levels of satisfaction show occupants who are alone in the office. Regarding the comfort parameters measured in the offices, the results of the analysis show that the higher air temperatures and CO_2 concentration are present in the old part of the Faculty building, while relative humidity is in recommended limits for both parts of the building.

Concluding, the conducted analysis showed a correlation between thermal comfort sensation and comfort parameters measured in the occupants' offices, which have impacts on their productivity and well-being. However, while the research results showed that the working environment at the Faculty is pleasant, it was noticed that the most of the measured parameters depend on occupant behavior (window opening and lowering the blinds). Therefore, there is a need for further investigation of occupant behavior causes, which will be correlated in the planning procedure for development of the bio-sensors in the future study.

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