UTICAJ TOPLOTNE UGODNOSTI NA PAD RADNE PRODUKTIVNOSTI LJUDI U KANCELARIJAMA[1]

THE THERMAL COMFORT IMPACT ON OCCUPANTS' WORKING PRODUCTIVITY LOSS IN OFFICES

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The past few decades in the world are increasingly paying attention to energy efficiency, especially in systems that maintain environmental conditions in buildings, because they represent major energy consumers. In order for energy efficiency to be a sustainable reduction in energy consumption must coincide with the provision of desired environmental conditions. This is important because thermal comfort, air quality and other influential parameters do not greatly affect the health of people and their working ability, while staying in indoors. Through this work, will be reflected the influence of the orientation of the room on the state of the thermal comfort in it, which as a result will have an impact on the productivity of the users of those premises. The research was conducted in real terms, in two offices and all the data obtained through experimental measurements, questionnaires and numerical simulations were combined and adequately compared, resulting in important conclusions regarding the effect of heat comfort and the local state of thermal comfort on productivity of office users.

1 Introduction

Indoor air quality and thermal comfort have a great influence on a humans' health in indoor spaces. In combination with local thermal discomfort, they have very negative effect on occupants' productivity and concentration, especially in office buildings. This paper presents the impact of the indoor environment on productivity loss and thermal comfort of persons in real conditions of two offices at the Faculty of Mechanical Engineering.

Most of the similar studies are performed in artificially created conditions, that is, in laboratories. Given that un-adjusted conditions can be achieved in the laboratory, they can negatively affect the reaction of the observed respondents as the usual routines are changed as well as their environment. For this reason, in order not to influence the results of the studies, research in real, working conditions is often the most precise.

The research and measurements were carried out over three periods in the first half of 2018th and they represent three scenarios of this study. Throughout the entire research period, two persons of different gender were staying in both offices. Also a very important fact for this research is that the offices have completely different orientations.

Three scientific methods of research were used for the analysis of thermal comfort and air quality in offices, which are experimental, statistical and numerical methods of research.

2 Literature review

Before the measurements, it was necessary to analyze the results of the papers related to this topic. The most important conclusions derived from relevant papers are:

- the allowed, higher, environmental parameters are still too high for offices in the summer period [1,4];
- the desired temperature is usually lower for 0.5 ° C from neutral temperature [4];
- in offices there is a little influence of floor and ceiling temperatures on local thermal comfort [5];
- there is a significant cultural impact on the feeling comfortable in indoors [5];
- the influence of thermal discomfort on working productivity in offices is on average about 10% [6].

An important achievement in the field of thermal comfort is Fangers' thermal heat-balance model and it is used in this work. He argued that the human body is aiming for a thermal equilibrium, where the accumulated amount of heat is equal to the amount of heat transferred to the environment. In the Fangers' system, PMV and PPD indices are introduced, which can assess the comfort level in the room.

3 Description of the offices, location and climate conditions

Offices are located in Belgrade and they belong to a climate area that can be described as moderate - continental. Because climatic conditions are one of the most important factors in the feeling of comfort in indoors, measurements of the temperature and relative humidity of the outside air were made during the entire period of the research. These values are shown in the diagram, where the relative humidity is indicated by the blue line, and the red line is the temperature.

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[1] This paper was presented at the National Students Competition 2018 organized by the Serbian HVAC&R Society.

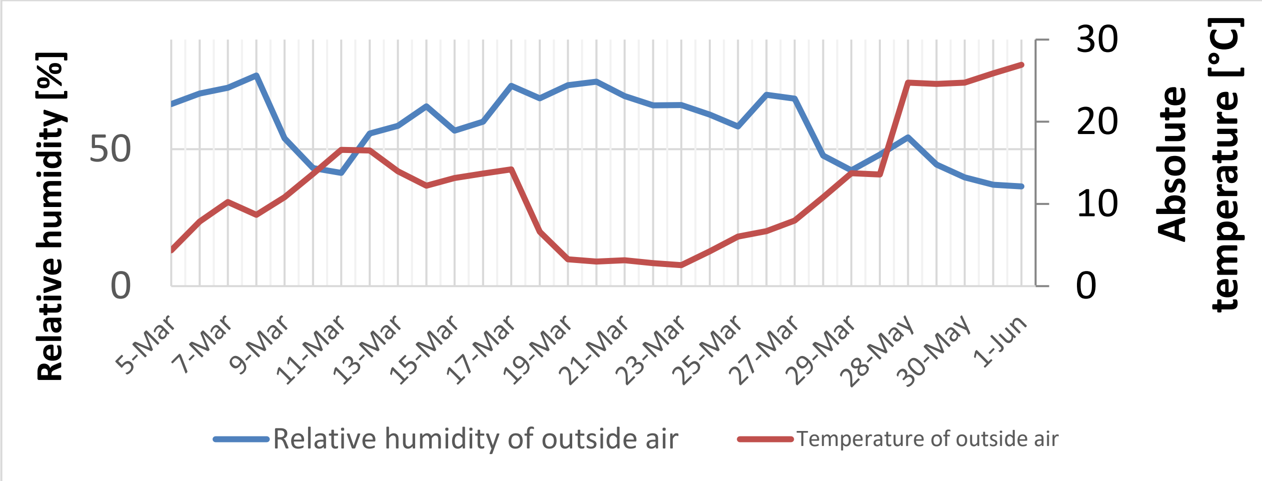

Figure 1. Diagram of changing the average value of temperature and relative humidity of the outside air for the relevant period per day

Offices have completely different orientations, office 1 south-west and office 2 north-east, and the outer wall of office 2 is sheltered from direct solar radiation, unlike the outer wall of the office 1. These differences are important from the aspect of later analysis of the results.

Both offices are supplied with hot water for heating from a two-pipe central heating system and radiators of similar dimensions are placed in a parapet, under the windows. Of the other mechanical installations, in the office 1, a split cooling system was used when needed. With the FLIR 540bx thermal imaging camera, images were taken based on which the locations of the greatest heat losses, or thermal bridges, were determined. They are confirmed by the fact that the outside walls are uninsulated and that the quality of the carpentry is bad.

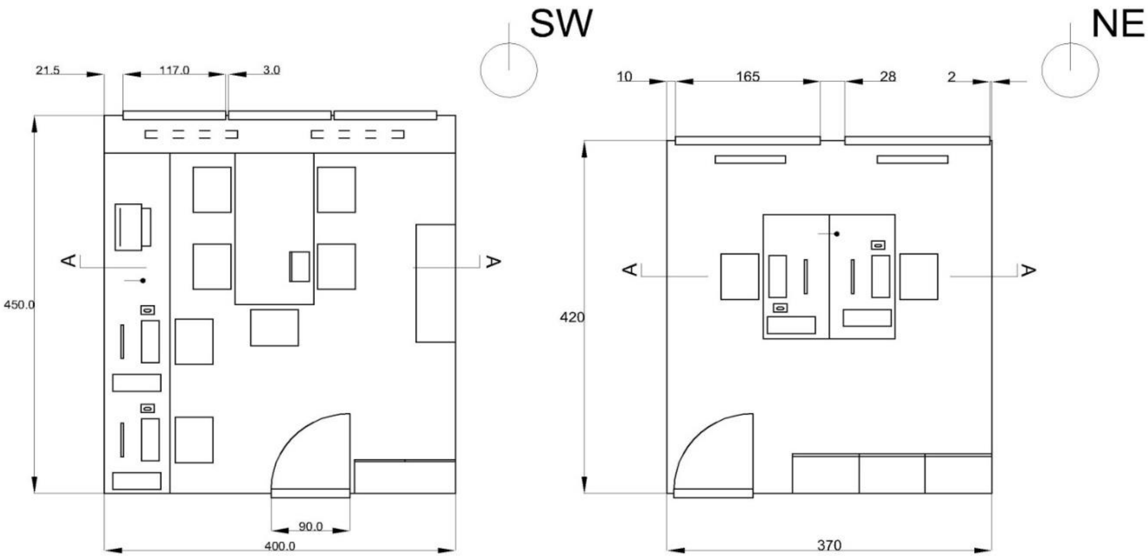

Figure 2. Drawings of the office 1 (left) and office 2 (right)

4 Experimental measurements

Experimental measurements were made to collect data on physical quantities that directly or indirectly influenced thermal comfort in offices. The temperature, as well as the relative humidity of the air, was measured at 4 selected points at 3 heights in both offices and these measuring points are shown in the Figure 3.

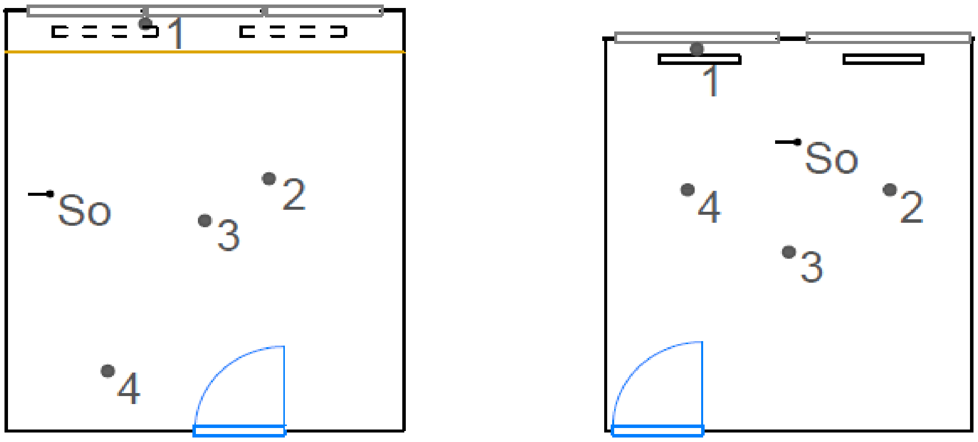

Figure 3. Position of measuring points in offices 1 (left) and 2 (right)

The temperatures of the interior surfaces of walls, doors, radiators, windows, floors and ceilings were measured in five points in order to obtain the average values of their temperatures. The CO_2 concentration was measured at point S0, while in 4 displayed measuring points are measured level of illumination in offices.

In order to collect data in different climatic conditions, three scenarios have been created. The first scenario, the so-called the "winter" scenario ran from March 5 to March 16. During this period almost every day there was a need for heating and the radiator valves with thermostatic heads were set to "5". The second scenario was carried out during the transitional period between winter and spring and lasted from March 19 to March 30. The characteristic of this scenario is that the radiator valves with thermostatic heads were set to "3" when there was a need for heating. The characteristic of this scenario is that the radiator valves with thermostatic heads were set to "3" when there was a need for heating. In the summer scenario, the outdoor air temperature reached 30 ° C, which caused the need for cooling the office 1, while in the office 2 the feeling was more comfortable and there was no need for cooling. The internal unit of the split system "GREE", in office 1, was set to a temperature of 27 ° C and its fan operated at the first speed. The third scenario lasted from 28 May to 1 June.

5 Statistical survey

For the needs of the statistical part of the research, the questionnaires were made in the framework of the doctor's dissertation Bajc [1] and they were adjusted to the research in the offices. Using the questionnaire, users' subjective impressions of the level of convenience of different types of comfort and the impact of different types of comfort on their productivity were recorded. The main objective of collecting and analyzing these data is to determine the relationship between environmental parameters, obtained by measurements and CFD simulations, and the subjective sense of convenience of persons in offices. Survey of these persons was carried out after experimental measurements. The first part of the questionnaire provides general information about the office user, while the rest of the questionnaire is related to general and local thermal comfort, as well as air quality, light and sound comfort.

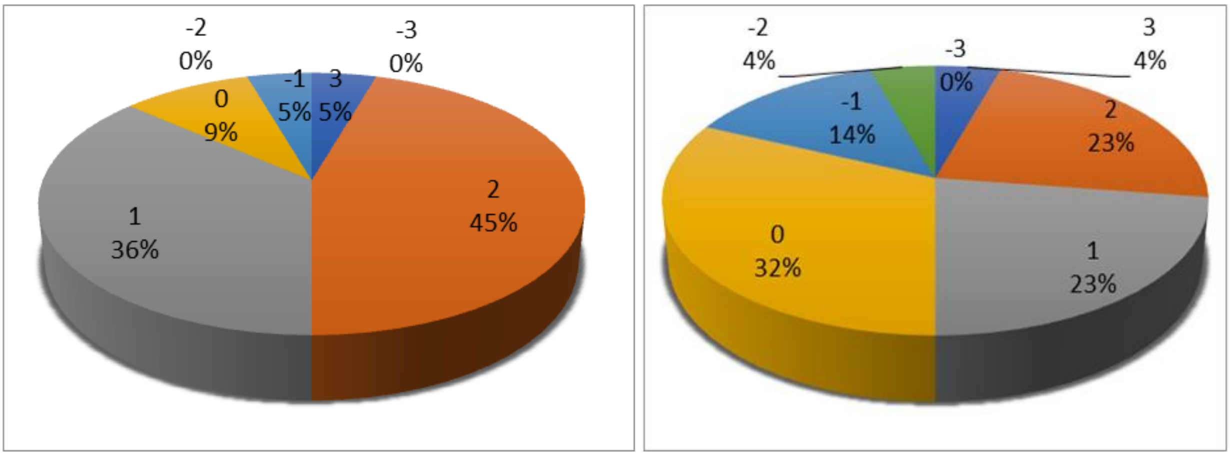

Figure 4. Summarized answers of the thermal comfort – male (left) and female (right) person in office 1

Charts in Figure 4 summarize the responses of the thermal comfort of the male and the female person in office 1, on the scale of subjective feeling of thermal comfort level.

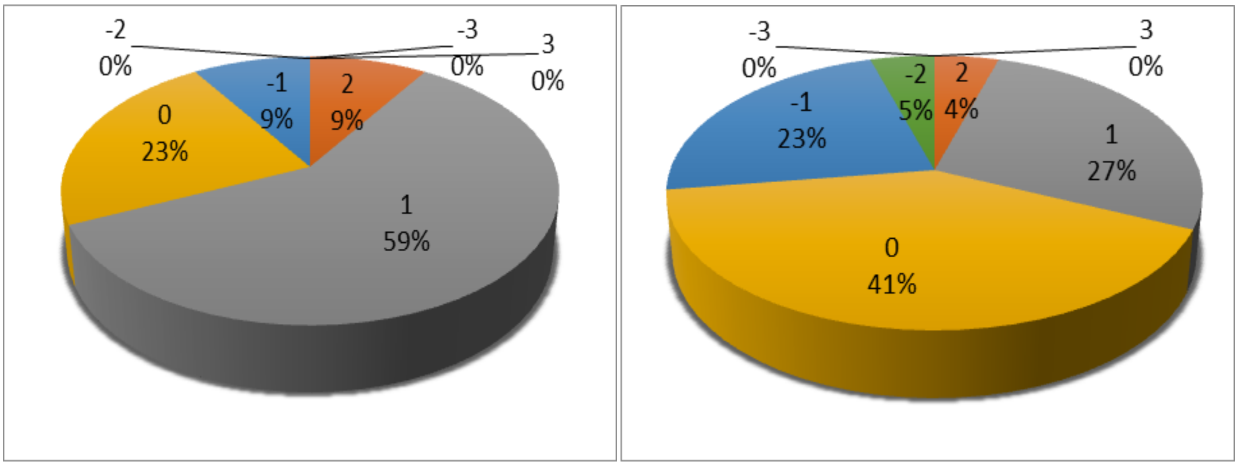

Figure 5. Summarized answers of the thermal comfort – male (left) and female (right) person in office 2

The difference between the impressions of the male and female person about the heat comfort is presented, since the largest number of responses of the male person was 2, which is the impression that it was warm in the office, while in the female person 0, which represents a neutral impression of the thermal comfort.

A similar situation applies to office 2, between the responses of men and women. However, in most cases, the responses are shifted to one point on a comfort scale, which means that often the comfort level caused by thermal comfort is better in office 2 than in office 1.

The following two diagrams show the effects of thermal comfort on the work productivity of persons in offices. The answers of a woman are shown in red stairs, while the responses of the male are shown as blue. In office 1, the majority of women's responses to the effect of thermal comfort on productivity are from 1% to 10%, while in the male person this impact is more drastic, in most cases between 21% and 30%. Regarding Office 2, the results of the female person are similar, it can even be noticed that the effect of heat comfort on decreasing the productivity of a female person is even lower than in office 1. On the other hand, the male person has an even more significant reduction in the effect of heat comfort on productivity, but in office 2 this influence is higher for the male person.

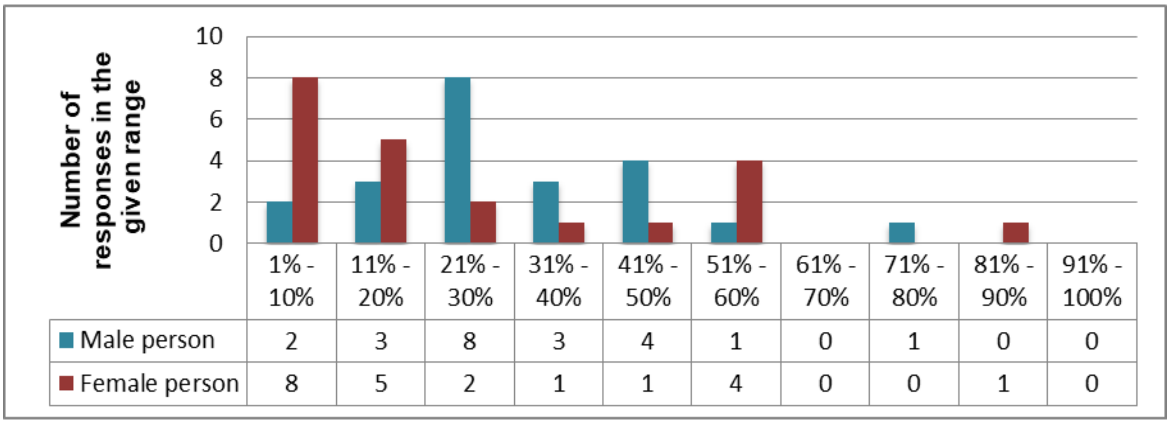

Figure 6. Influence of thermal comfort on the productivity of persons in the office 1

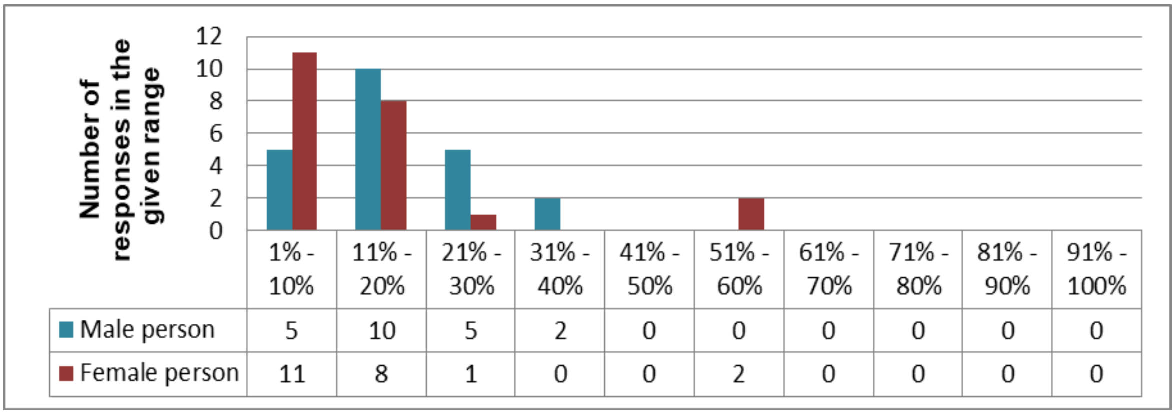

Figure 7. Influence of thermal comfort on the productivity of persons in the office 2

6 Numerical simulations

For numerical part of the research CFD software Phoenix FLAIR was used. CFD is a tool for analyzing problems involving fluid flow, heat transfer or mass, by solving partial differential equations obtained from the three fundamental laws of fluid mechanics, such as the law of mass maintenance (equation of continuity), the law of energy maintenance and the law on the change in the amount of fluid movement. It is commercial software, used for environmental conditions simulations in buildings and in this paper it was used to determine the temperature of air, radiant temperature, CO2 concentration, PMV, PPD and PLOS indices at each point of the office. Designed models of both offices are given in the Figure 8.

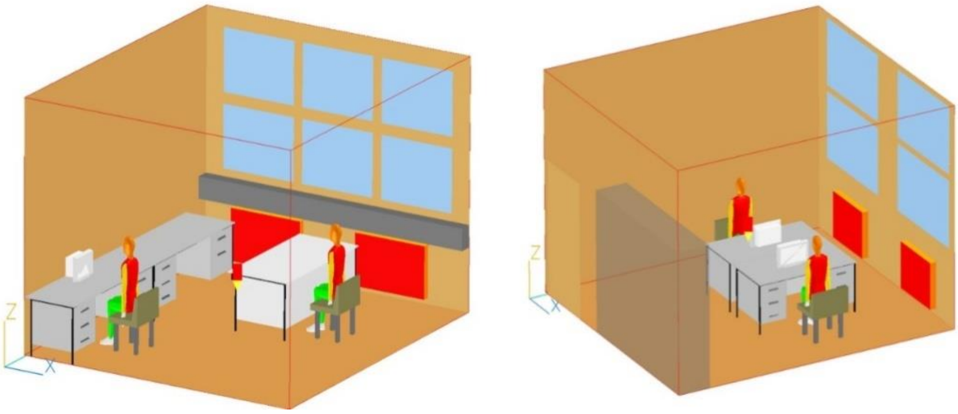

Figure 8. Models of office 1 (left) and office 2 (right) in Phoenix FLAIR software

7 Conclusion

By comparing the results of the numerical and statistical part of the study of the thermal comfort, it is concluded that the values of the PMV index obtained by the numerical simulation do not deviate much from the impressions of the users of the space, even these values often coincide with the median response values of the respondent. Differences in users' responses about thermal comfort in the same environment indicate that there is an evident influence of the personal factor on the level of thermal comfort, and in this case, this factor can be characterized as a gender difference. On the other hand, the difference in respondents' responses to offices indicates that there is an impact of the most important difference between these two offices, which is the orientation. Regarding air quality, by measuring the concentration of CO_2 it was understood that this value did not exceed 1000 ppm in the offices, which is within the limits of a satisfactory. From this data and negative user ratings on air quality, it can be concluded that the threshold of the user's office is lower than expected. From everything attached it is concluded that the two most important conclusions of this paper are that the orientation of the offices can significantly influence the indicators of the thermal comfort and that the personal factor, in most cases, has a greater influence than the parameters of the environment, especially on the decrease in productivity of persons.

8 References

[1] **T. S. Bajc,** "The local thermal comfort impact on working productivity loss in non-residential buildings", PhD thesis, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia 2017.

[2] *** ASHRAE, ANSI/ASHRAE Standard 55. 2004.

[3] *** ISO, International standard ISO 7730. 2005.

[4] **T. Nottingham and N. E. User,** "Wu, Jindong (2015) Thermal comfort and occupant behaviour in office buildings in south-east China. PhD thesis, University of Nottingham. Nottingham, United Kingdom," 2015.

[5] **G. Schiller, E. A. Arens, F. Bauman, C. Benton, M. Fountain, and T. Doherty,** "A Field Study of Thermal Environments and Comfort in Office Buildings," *ASHRAE Trans. 462-RP*, vol. 98, no. Part 2, pp. 280–308, 1988.

[6] **C. Huizenga, S. Abbaszadeh, L. Zagreus, and E. Arens, "**Air Quality and Thermal Comfort in Office Buildings : Results of a Large Indoor Environmental Quality Survey," *Proc. Heal. Build.*, vol. III, pp. 393–397, 2006.