Periodica Polytechnica Mechanical Engineering, 66(1), pp. 26–31, 2022

The Effect of Genders on the Perception of the Combined Effect of Local Discomfort Parameters

Balázs András-Tövissi[1*], László Kajtár[1]

[1] Department of Building Services and Process Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics, H-1111 Budapest, Műegyetem rakpart 3-9, D122, Hungary
[*] Corresponding author, e-mail: andras@epget.bme.hu

Received: 23 March 2021, Accepted: 01 June 2021, Published online: 22 December 2021

Abstract

If the draught and the radiant thermal asymmetry caused by the warm ceiling appear simultaneously, will women and men be affected in the same way? This research aims to answer this question, by clarifying the understanding of the joint mechanism of action of the two local discomfort factors with the help of instrumental and human subject measurements. The most important result of the present research is identifying that if PPD < 6%, radiant thermal asymmetry varies in the range of 5–15 °C and the draught rate DR = 15% or DR = 25%, then at a given range of the interval men are significantly more dissatisfied with warm ceilings than women; women's AMV votes are significantly lower than men's; In the case of DR = 15%, the work accuracy of women is significantly higher, while in the case of men, the work accuracy is higher at DR = 25%.

Keywords

thermal comfort, human subject measurement, actual mean vote, work performance

1 Introduction

A significant amount of most people's time is spent in indoor spaces [1] – be it in their homes or at their work places. The amount of time spent indoors makes it necessary for these spaces to be as comfortable as possible [2] and to provide an ideal frame for human activity [3].

Setting the ideal thermal comfort parameters for a public building is not trivial, as many people with different preferences and thermal environments may work together in a given space. With this in mind, the ideal parameters for optimal thermal comfort can be determined on a statistical basis, with the goal of finding the minimum rate of dissatisfaction.

The PMV-PPD model is the most widespread method used to describe thermal comfort [4]. Several local discomfort factors complete the beforementioned model, adding to its relevance. The effect of local discomfort factors is known separately [5, 6], but in a real situation, they occur together. Although the joint study of some local discomfort factors has been addressed [7–10] and the effect of draught under different temperature parameters has also been investigated [11, 12], there is still a high research potential in the field of the combined effect of draught and a warm ceiling.

The aim of the present research is to fill this gap and increase the knowledge material, the primary aspect being to investigate the combined effect of radiant thermal asymmetry caused by warm ceilings and draught, in the case of women and men. Fig. 1 shows the conceptual design of the measuring chamber.

During the research, we were out to answering the questions below:

- Is there significant difference between women's and men's dissatisfaction with warm ceilings?

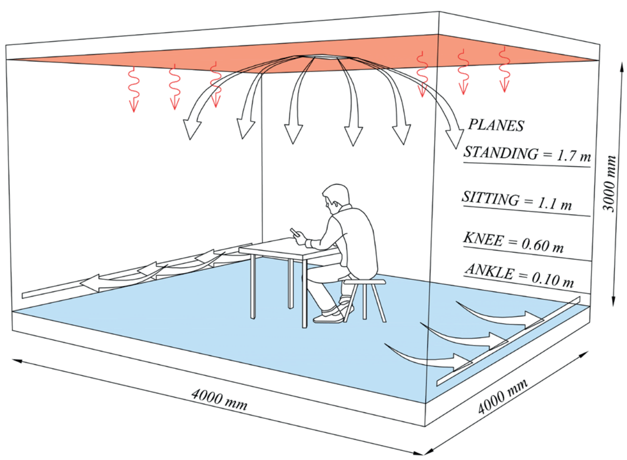

Fig. 1 Conceptual design of the comfort chamber

Cite this article as: András-Tövissi, B., Kajtár, L. "The Effect of Genders on the Perception of the Combined Effect of Local Discomfort Parameters", Periodica Polytechnica Mechanical Engineering, 66(1), pp. 26–31, 2022. https://doi.org/10.3311/PPme.18249

- Do women and men give different AMV votes when being exposed to the combined effect of radiation asymmetry and draught?
- Is there a significant difference in the work efficiency of women and men when the two local discomfort factors occur simultaneously?

2 Methods

In order to answer the questions formulated in the introduction, instrumental and human subject measurements were performed in a thermal comfort chamber.

2.1 Description of the methodology

The thermal comfort measuring chamber which hosted the measurements has two heat sources; the boundary structures of the chamber can be heated and cooled individually, so that any desired radiant thermal asymmetry can be set between any structural element, and the mean radiant temperature can also be precisely defined. The temperature, humidity and volume flow of the supply air can also be controlled.

The effect that the warm ceiling and the draught parameter pairs have on the thermal comfort, was examined through measuring the local discomfort parameters jointly. Meanwhile, the thermal environment was maintained at a neutral value, within the frame given by the PMV model. Throughout the measurements, the PPD value always remained below 6% at the center of the measuring chamber. An ideal thermal environment (according to the PMV model) had to be kept constant throughout the measurements. In the meantime, we also had to focus on keeping the draught, as well as the radiant thermal asymmetry at the value desired. To do so, the following steps were needed:

- Defining the surface of the delimiting structures - a step which allows setting the desired radiant thermal asymmetry.
- Identifying and setting the temperature of the supply air - the temperature and volume of the supply air allows the measuring chamber to maintain a thermally stationary state. However, both parameters also influence the draught rate.
- Setting the air flow in the measuring chamber to a rate which would ensure the achievement and maintenance of the desired draught rate.

During the measurements, the factors influencing thermal comfort were examined in four planes: at the ankle level (0.1 m), at the knee level (0.6 m), at the head height level of a sitting person (1.1 m) and at the head height level of a standing person (1.7 m).

Figs. 2 and 3 show the position of the measurement points in section and top view.

2.2 Instrumental measurements

During the instrumental measurements, the following parameters were measured and recorded at the previously described spatial points: the distribution in space of air velocity, of temperature and of the humidity, of the average radiation temperature, of PMV, PPD, Tu and DR. A total of 10 cases were examined, defined by five radiant thermal asymmetries and two draught rates as follows:

- radiant thermal asymmetry values: 5 °C, 7 °C, 10 °C, 12 °C, 15 °C;
- draught rates: 15% and 25%.

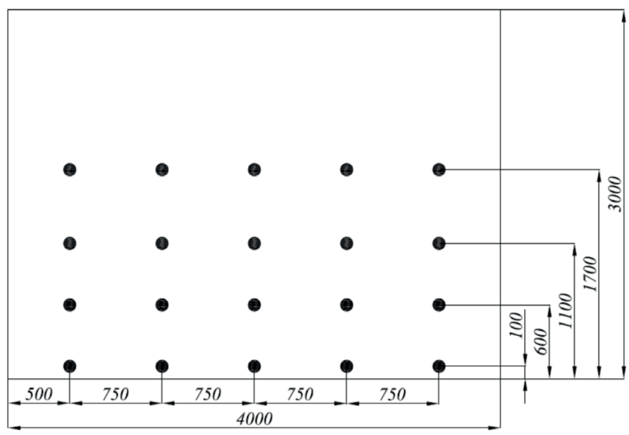

Fig. 2 Section

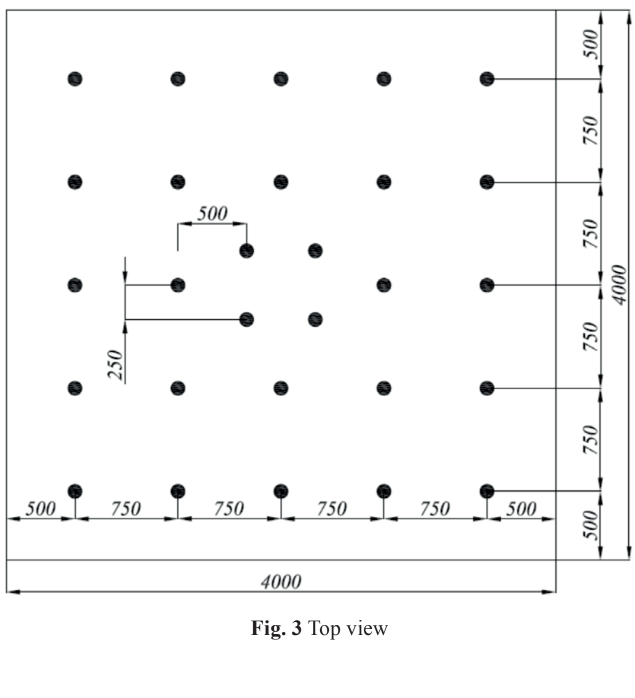

Fig. 3 Top view

Every asymmetry and draught parameter pair meets the following conditions: first of all, the PPD value is below 6%; second of all, the radiant thermal asymmetry can be kept at the designed value, and so can the DR value (which shows the draught rate).

In order to make the best possible evaluation of the the dissatisfaction rate determined by the warm ceiling at 15% and 25% draught, human subject measurements were required.

2.3 Human subject measurements

Human subject measurements took place in the comfort chamber presented on Figs. 1 and 2. They took into account the methodology used in the literature for subject comfort measurements [13–21], the gender differences observed in and as a result of similar research [22], as well as the methodology and results of previous research on productivity [23].

20 people, 10–10 healthy men and women, participated in the human subject measurements. The subjects gave their votes regarding the thermal environments they were being exposed to. Throughout the course of the measurements, they evaluated 10 thermal comfort environments, defined by ceiling-floor temperature asymmetry (5, 7, 10, 12, 15 °C) and 2 draught rate (15%, 25%). During one measurement occasion, there was only one constant thermal environment. This could be guaranteed by the measuring chamber being kept in a thermally stationary state.

Each measurement was three hours long and during each session, the human subjects faced only one thermal environment defined by one asymmetry and one draught rate, respectively. These thermal settings were followed in random order so that no upward and downward trends could not be inferred.

The amount of supply air was 230 m^3/h, an air exchange rate high enough to ensure the subjects' satisfaction with the air quality. Close attention was also paid to the elimination of acoustic discomfort and the provision of adequate visual comfort. Thus, the visual, acoustic and indoor air comfort environment of the subjects was uncompromised during the measurements.

Six repetitive measurement blocks were carried out during each measurement session. Each of them lasted for thirty minutes and consisted of free activity, measurement of work efficiency, and thermal voting. The information collected on paper was processed and analyzed using mathematical methods.

2.4 Mathematical evaluation

While evaluating the results, we identified and examined the correlations existing between the votes given under different conditions. In the evaluation process, two sets of values were always compared and the results evaluated using two different mathematical approaches: the Mann-Whitney exact test and the Welch test. Considering the difference which exists between the nature of the two methods, it was safe to accept the independence or dependence of two sets of votes, provided that both methods led to the same result.

During the Welch test, the significance level was set to 0.05, and the confidence interval used in the Mann-Whitney test was defined as 95% [24].

3 Discussion and results

To study the combined effect of draught and radiant thermal asymmetry caused by warm ceilings, we examined differences in gender, in terms of the voters´ dissatisfaction with the warm ceiling (PD), actual mean vote (AMV), and work efficiency. When processing the results, we compared them using the two mathematical methods presented in the Methods section. A finding was accepted if we have reached the same result using both mathematical methods.

Figs. 4 and 5 show the dissatisfaction of women and men with warm ceilings at 15% and 25% draught, respectively.

Dissatisfaction with the warm ceiling is shown as a function of radiant thermal asymmetry.

With a draught rate of 15% (with the exception of the 7 °C asymmetry), there is a significant difference between

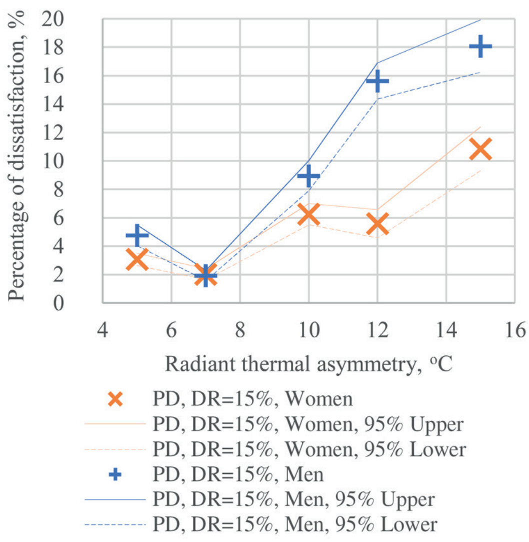

Fig. 4 Dissatisfaction with the warm ceiling in function of radiation asymmetry, Women vs. Men, DR = 15%

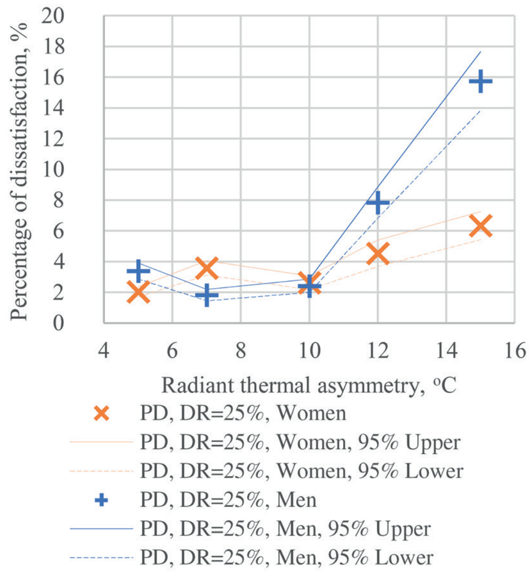

Fig. 5 Dissatisfaction with the warm ceiling in function of radiation asymmetry, Women vs. Men, DR = 25%

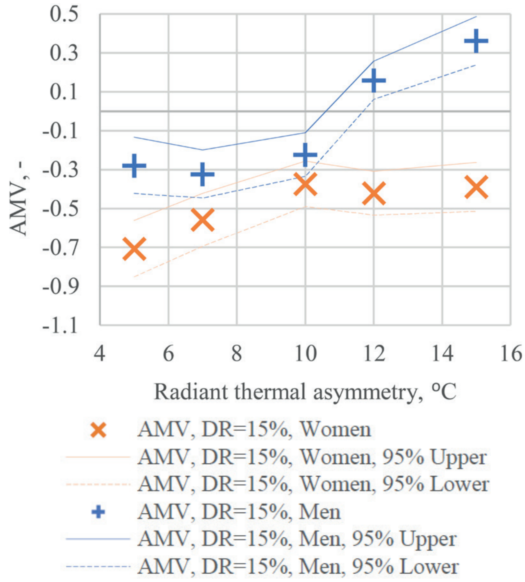

Fig. 6 AMV in function of radiation asymmetry, Women vs. Men, DR = 15%

female and male votes over the entire interval, men being more dissatisfied with the warm ceiling in cases. Based on the Mann-Whitney and Welch statistical indicators, it can be stated that the difference is pronounced for asymmetry values above 10 °C.

At a draught of 25%, with the exception of the 10 °C asymmetry value, there was also a significant difference in the dissatisfaction votes of women and men over the entire interval. In this case, too, after an asymmetry value of 10 °C, there was an increased difference between the votes of the genders – the dissatisfaction of men with warm ceilings was higher.

Figs. 6 and 7 present the AMV values given by women and men at 15% and 25% draught, respectively. It shows the AMV as a function of the radiation temperature asymmetry.

With a 15%, draught rate, the AMV vote of women and men is different in the whole interval and the vote of women is lower. The difference between the votes of the genders increases in the case of temperature asymmetry above 10 °C.

Even in the case of 25% asymmetry, a statistically significant difference can be detected between the female and male votes by both mathematical methods, in this case also the female votes are lower, the difference between the gender votes increases above 10 °C radiation asymmetry.

Figs. 8 and 9 show the work efficiency of women and men as a function of radiant thermal asymmetry caused by warm ceilings with a 15% and 25% draught rate, respectively.

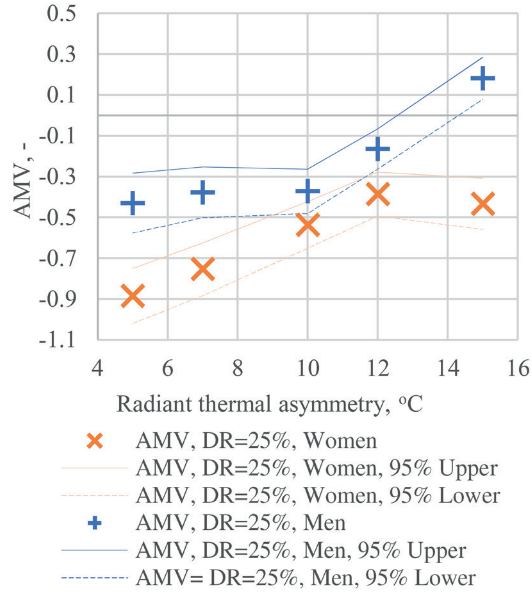

Fig. 7 AMV in function of radiation asymmetry, Women vs. Men, DR = 25%

At 15% draught, the speed of work of women and men is significantly the same over the entire interval (except 12 °C), the accuracy of work is significantly different except for 5 and 10 °C, and the work accuracy of women is higher.

At 25% draught effect, the speed of work shows smaller differences between the genders, but the work speed differs significantly over the entire interval.

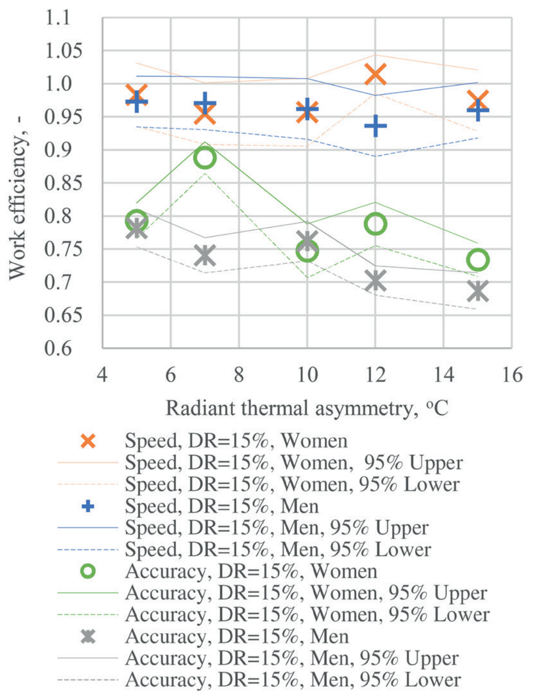

Fig. 8 Work speed and accuracy in function of radiation asymmetry, Women vs. Men, DR = 15%

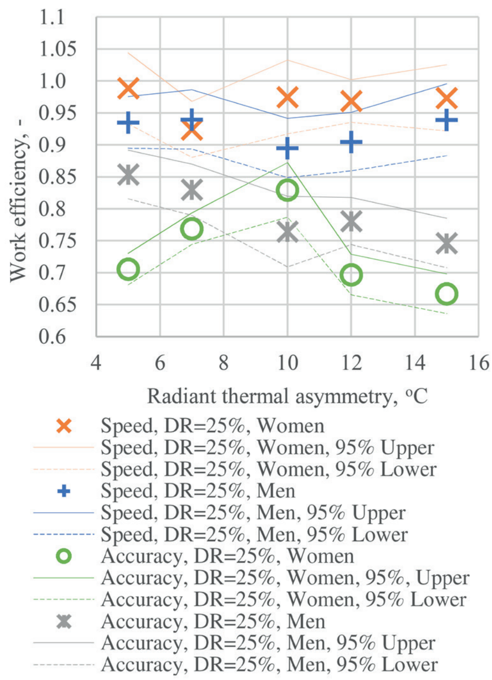

Fig. 9 Work speed and accuracy in function of radiation asymmetry, Women vs. Men, DR = 25%

4 Conclusion

In a joint study of radiant thermal asymmetry caused by warm ceilings and draught, we studied whether there is a significant difference between the PD, AMV votes and work efficiency among the genders.

We found that gender of the study group had a significant impact on PD, AMV and work speed. Dissatisfaction with warm ceilings was higher in the case of men, the AMV value was lower in the case of women. In the case of women the speed of work was higher at a draught rate of 15%, while in the case of men, it was higher at a draught effect of 25%.

During the study of the combined effect of draughts and warm ceilings, it was noticeable that, in the radiant thermal asymmetry range of 5–15 °C, for DR = 15% and DR = 25%, the difference in gender had a significant effect on the rate of dissatisfaction with the warm ceiling, on work accuracy and on AMV:

- PD: In the temperature asymmetry range of 10–15 °C, men are significantly more dissatisfied with warm ceilings than women;
- AMV: In the case of the combined effect of draught and warm ceilings, women's AMV votes are significantly lower than men's;
- PROD: the work accuracy is significantly higher for women at DR = 15%, while for men, it is higher at DR = 25% (Figs. 8 and 9).

Acknowledgement

The research reported in this paper and carried out at BME has been supported by the NRDI Fund (TKP2020 IES, Grant No. BME-IE-MISC) based on the charter of bolster issued by the NRDI Office under the auspices of the Ministry for Innovation and Technology.

This work has been supported by the Hungarian National Research, Development and Innovation Office (OTKA Number 124777).

References

[1] Bánhidi, L., Kajtár, L. "Komfortelmélet" (Comfort Theory), BME Technical Press, Budapest, Hungary, 2000. (in Hungarian)

[2] Wargocki, P., Wyon, P. D. "Providing better thermal and air quality conditions in school classrooms would be cost-effective", Building and Environment, 59, pp. 581–589, 2013. https://doi.org/10.1016/j.buildenv.2012.10.007

[3] Wargocki, P., Wyon, P. D. "Ten questions concerning thermal and indoor air quality effects on the performance of office work and schoolwork", Building and Environment, 112, pp. 359–366, 2017. https://doi.org/10.1016/j.buildenv.2016.11.020

[4] Fanger, P. O., Christensen, N. K. "Perception of draught in ventilated spaces", Ergonomics, 29(2), pp. 215–235, 1986. https://doi.org/10.1080/00140138608968261
[5] Fanger, P. O., Ipsen, B. M., Langkilde, G., Olessen, B. W., Christensen, N. K., Tanabe, S. "Comfort limits for asymmetric thermal radiation", Energy and Buildings, 8(3), pp. 225–236, 1985. https://doi.org/10.1016/0378-7788(85)90006-4
[6] Fanger, P. O. "Thermal Comfort: Analysis and Applications in Environmental Engineering", Danish Technical Press, Copenhagen, Denmark, 1970.
[7] Barna, E., Bánhidi, L. "Combined effect of two local discomfort parameters studied with a thermal manikin and human subjects", Energy and Buildings, 51, pp. 234–241, 2012. https://doi.org/10.1016/j.enbuild.2012.05.015
[8] Toftum, J. "Human response to combined indoor environment exposures", Energy and Buildings, 34(6), pp. 601–606, 2002. https://doi.org/10.1016/S0378-7788(02)00010-5
[9] Bartal, I. "Joint Impact of Cold Wall and Airflow", PhD Thesis, Budapest University of Technology and Economics, Budapest, Hungary, 2012.
[10] Schellen, L., Loomans, M. G. L. C., de Wit, M. H., Olesen, B. W., van Marken Lichtenbelt, W. B. "Effects of different cooling principles on thermal sensation and physiological responses", Energy and Buildings, 62, pp. 116–125, 2013. https://doi.org/10.1016/j.enbuild.2013.01.007
[11] Toftum, J., Nielsen, R. "Draught sensitivity is influenced by general thermal sensation", International Journal of Industrial Ergonomics, 18(4), pp. 295–305, 1996. https://doi.org/10.1016/0169-8141(95)00070-4
[12] Toftum, J., Nielsen, R. "Impact of metabolic rate on human response to air movements during work in cool environments", International Journal of Industrial Ergonomics, 18(4), pp. 307–316, 1996. https://doi.org/10.1016/0169-8141(95)00066-6
[13] Amai, H., Tanabe, S., Akimoto, T., Genma, T. "Thermal sensation and comfort with different task conditioning systems", Building and Environment, 42(12), pp. 3955–3964, 2007. https://doi.org/10.1016/j.buildenv.2006.07.043
[14] Kim, J., Bauman, F., Raftery, P., Arens, E., Zhang, H., Fierro, G., Andersen, M., Culler, D. "Occupant comfort and behavior: High-resolution data from 6-month field study of personal comfort systems with 37 real office workers", Building and Environment, 148, pp. 348–360, 2019. https://doi.org/10.1016/j.buildenv.2018.11.012
[15] Langkilde, G., Gunnarsen, L., Mortensen, N. "Comfort limits during infrared radiant heating of industrial spaces", In: Clima 2000 World Congress on Heating, Ventilating and Air-Conditioning, Copenhagen, Denmark, 1985, pp. 33–40.
[16] Zhou, X., Liu, Y., Luo, M., Zhang, L., Zhang, Q., Zhang, X. "Thermal comfort under radiant asymmetries of floor cooling system in 2 h and 8 h exposure durations", Energy and Buildings, 188–189, pp. 98–110, 2019. https://doi.org/10.1016/j.enbuild.2019.02.009
[17] He Y., Li, N., Zhang, W., Peng, J. "Overall and local thermal sensation & comfort in air-conditioned dormitory with hot-humid climate", Building and Environment, 101, pp. 102–109, 2016. https://doi.org/10.1016/j.buildenv.2016.02.025
[18] Fang, Z., Liu, H., Li, B., Tan, M., Olaide, O. M. "Experimental investigation on thermal comfort model between local thermal sensation and overall thermal sensation", Energy and Buildings, 158, pp. 1286–1295, 2018. https://doi.org/10.1016/j.enbuild.2017.10.099
[19] Toftum, J. "Human response to combined indoor environment exposures", Energy and Buildings, 34(6), pp. 601–606, 2002. https://doi.org/10.1016/S0378-7788(02)00010-5
[20] Wyon, D. P. "Methodology for indoor environment research", Magyar Épületgépészet, 181, pp. 38–49, 2018.
[21] Van Craeneendonck, S., Lauriks, L., Vuye, C., Kampen, J. "A review of human thermal comfort experiments in controlled and semi-controlled environments", Renewable and Sustainable Energy Reviews, 82(3), pp. 3365–3378, 2018. https://doi.org/10.1016/j.rser.2017.10.053
[22] Schellen, L., Loomans, M. G. L. C., de Wit, M. H., Olesen, B. V., van Marken Lichtenbelt, W. D. "The influence of local effects on thermal sensation under non-uniform environmental conditions – Gender differences in thermophysiology, thermal comfort and productivity during convective and radiant cooling", Physiology & Behavior, 107(2), pp. 252–261, 2012. https://doi.org/10.1016/j.physbeh.2012.07.008
[23] Zhang, F., de Dear, R., Hancock, P. "Effects of moderate thermal environments on cognitive performance: A multidisciplinary review", Applied Energy, 236, pp. 760–777, 2019. https://doi.org/10.1016/j.apenergy.2018.12.005
[24] Baran, S., Fazekas I., Glevitzky, B., Iglói, E., Ispány, M., Kalmár, I., Nagy, M., Tar, L., Verdes, E. "Bevezetés a matematikai statisztikába" (Introduction to mathematical statistics), Kossuth Egyetemi Kiadó, Debrecen, Hungary, 2000. (in Hungarian)