KORIŠĆENJE PRENOSNIH SENZORNIH UREĐAJA ZA PROCENU STOPE METABOLIZMA

THE USE OF THE WEARABLE SENSORY DEVICES FOR METABOLIC RATE ESTIMATION

Nikolina PIVAC*[1], Sandro NIŽETIĆ[1], Tamara BAJC[2], Vlasta ZANKI[3], Agis M. PAPADOPOULOS[4]

[1] Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Split, Croatia

[2] Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia

[3] HEP ESCO d.o.o., Croatia

[4] Aristotle University of Thessaloniki, Thessaloniki, Greece

Stopa metabolizma je prepoznata kao najmanje tačno procenjeni parametar u istraživanju toplotne ugodnosti. S obzirom da ju je teško meriti, najčešće se procenjuje pojednostavljenim metodama koje ne uzimaju u obzir uticaj starosne dobi, pola kao ni dinamike korisnika zgrade. U ovom istraživanju korišćeni su prenosni senzori za praćenje aktivnosti korisnika unutar zgrade kako bi se procenila stopa metabolizma korisnika. Osam učesnika je odabrano za sedmodnevno praćenje, četiri puta tokom godine. Studija je imala za cilj ispitivanje uticaja starosne dobi korisnika, pola i godišnjeg doba na promenu brzine metabolizma korisnika u svrhu poboljšanja termičkog okruženja u zgradi sa instaliranim KGH sistemom. Rezultati su pokazali razliku između grupa korisnika koja bi mogla poslužiti kao osnova za procenu lične toplotne ugodnosti u budućim istraživanjima.

Ključne reči: *uređaji, stopa metabolizma, toplotna ugodnost, korisnici, zgrade.*

The human metabolic rate has been widely noted as the least accurately assessed parameter in the research of thermal comfort. Since it is difficult to measure, it is often reduced on simple diary methods which do not take into account the influence of age, gender, and daily dynamics of a building occupant. In this study wearable sensory device were used to track user activities inside the building to estimate the metabolic rate. Eight participants were chosen for the 7-days monitoring, four times during the year. The study aimed to examine whether the user age, gender, and season of the year influence the change in user metabolic rate to improve the thermal environment of the HVAC system building. The results showed the difference between groups of building occupants that could serve as a reference to assess personal thermal comfort in future research.

Keywords: *wearable devices, metabolic rate, thermal comfort, occupants, buildings.*

1. Introduction

A comfortable indoor thermal environment is favorable for occupants' health and productivity. In order to establish a pleasant indoor environment, thermal comfort should be evaluated correctly in the first place. Fanger [1] defined human thermal comfort as "condition of mind which expresses satisfaction with the thermal environment" and set the model named Predictive Mean Vote (PMV) which is generally accepted in ASHRAE and ISO standard as industry guideline for achieving thermal comfort. According to research, no thermal environment can satisfy everyone [2-5]. Thus, complaints of thermal dissatisfaction are prevalent among building occupants [6, 7]. It is because occupants can have different thermal preferences considering their diverse human factors [5,8,9]. Moreover, their comfort sensation can change over time, making a static setpoint unable to satisfy the personal thermal requirement of individuals [5,10].

The PMV model takes the occupant's metabolic rate (MET) as the most critical factor, but it has been widely noted as the most difficult parameter to measure, because various

* Corresponding author: ngoles@fesb.hr

activities are performed by the occupants inside the building. Activity is a multidimensional concept related to body gestures or movement [11]. The activities people are engaged in an office building are working in an office *i. e.*, sitting by the desk, walking to a meeting, and climbing the stairs. It becomes somewhat accurate to estimate the metabolic rate and improve the thermal comfort of the office building if those activities are tracked.

Innovations in technology, such as advances in sensing device, allow them to serve as a useful tool to develop an algorithm which optimizes indoor air quality; these are therefore essential advancements towards personal thermal comfort. There are different sensing devices [4,12,13] that can be used to recognize a variety of daily activities with high accuracy. Those sensors are categorized by being single [14] or multiple [15-18], attached to the body or portable. Commercially available Smartphones such as Nokia N95 [19], the iPhone [20], and Android phones [21], have also been deployed for recognition of common physical activities, such as sitting, standing, walking and running.

The differences between male and female subjects in preferred temperature, humidity and activity level in overall

Table 1. Literature review of gender differences

Study	Study type	Gender differences	Description
Fanger [1]	Laboratory study	No significant differences	Females tended to be more sensitive to an optimum deviation.
Beshir MY, Ramsey JD [24]	Laboratory study	Difference found (significance unreported)	Females tended to feel more uncomfortable than males at both high and low temperature extremes.
Muzi G. et. al. [25]	Field survey	Difference found (significance unreported)	Females reported feeling hot more often than males.
Cena K, de Dear R. [26]	Field study	Significant difference found	Females expressed more thermal dissatisfaction than males.
Griefahn B, Kunemund C.[27]	Laboratory study	Significant difference found	Females reported feeling hot more often than males due to draft.
Nagashima K. et. al. [28]	Laboratory study	Difference found (significance unreported)	Females felt cold in thermal environments in which most males feel thermally comfortable.
Nakano J, Tanabe S, Kimura K. [29]	Field survey	Difference found (significance unreported)	Neutral temperature reported 3.1 °C higher for females than for males.
Parsons KC [30]	Laboratory study	Difference found (significance unreported)	Differences found in cool conditions; females tended to be cooler than males.
Pellerin N., Candas V. [31]	Laboratory study	Difference found (significance unreported)	Females accepted noisier environments but are more sensitive to thermal deviation than males.
Karjalainen S. [32]	Field survey	Significant difference found	Females tended to be more critical of their thermal environments, and were more sensitive to both cold and hot room temperatures.
Chaudhuri T. [18]	Laboratory study	No significant differences	No difference in thermal preference, Women portrayed greater satisfaction in terms of comfort and humidity. Men were more sensitive yet tolerant of the ther- mal conditions.
Zhai Y. et.al. [10]	Laboratory study	No significant differences	No gender differences found in metabolic rates of sitting, standing and walking Women have higher HR at the same activity level

comfort are generally considered to be small [1, 22]. However, it is indicative that women and men thermoregulate differently, not merely due to differences in physical characteristics, but due to innate physiologic gender differences as well [23]. Table 1 summarized several studies in literature which investigates gender differences.

As can be seen in Table 1, most results of research studies characterize women as more critical of their thermal environments and more sensitive to both cold and hot room temperatures. These findings are corroborated to studies concerning sick building syndrome [33–35], which indicate that females experience sick building symptoms more often than the male population in the same building.

In summary, different individuals have a different scale of thermal comfort, as a result of physiological difference, the variety of working dynamics and perception of external factors. The aim of this study is to explore the linkage of user age, gender, and season of the year with changes in user metabolic rate.

2. Methodology

Field study took place at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture in Split, (Building A) and HEP d.o.o, publicly-owned energy service-providing company building in Zagreb, Croatia (Building B). Eight participants, 5 women and 3 men, were chosen for the 7-days monitoring, four times during the year, including summer and winter period, ie. cooling and heating period.. There were a few days in between measurements of the two buildings, due to the use of the same measuring equipment. Participants wore wearable activity sensor Move 3 (Figure 1), the most precise mobile sensor for the acquisition of physical activity available today [16-18].

Figure 1. Triaxial accelerometer for activity recognition, Move 3

The sensor recorded the raw data of 3D acceleration, barometric air pressure and temperature in a 1-minute time interval. From these data, the metabolic rate of each occupant was calculated with the Movisens DataAnalyzer software. The sensors were fixed with a clip at the user's hip during their 8-hour working day. Exact dates of conducted measurement are shown in Table 2.

Table 2. Measurement periods

Measurement period	Building A	Building B
1. measurement	April 24 – May 04, 2018	May 22 – May 29, 2018
2. measurement	Sept. 04 – Sept. 14, 2018	July 03 – July 13, 2018.
3. measurement	Nov. 06 – Nov. 16, 2018	Dec. 04 – Dec. 14, 2018
4. measurement	Jan. 29 – Feb. 08, 2019	Jan. 08– Jan. 18, 2019.

Users reported thermal sensation 3 times during the day. Statistical analysis was performed using the IBM SPSS Statistic, statistical software, to determine the significance of the tested variables (age, gender, a season of the year) on the dynamics of metabolic rate.

3. Results and discussion

Two kinds of the statistical test were used for the analysis, parametric t-test, and nonparametric Kruskal Wallis test. The first one was used to find out if there is a statistical evidence that the two population means (of males/females and heating/cooling season) are significantly different according to metabolic rates. The second was used to rank the data and compare the median of the ranks for the age groups with individual group metabolic rate medians. The nonparametric test was used rather than parametric one in this case because level of measurement was ordinal when comparing three age groups. Table 3 shows the test results of user gender difference in metabolic rate.

Table 3 Gender difference in metabolic rate

Group Statistics

Gender		N	Mean	Std. Deviation	Std. Error Mean
Mean MET	Male	12	1,3833	,07177	,02072
	Female	20	1,4350	,10400	,02325

According to independent t-test, there is no statistically significant difference between the mean metabolic rate in the working day between males and females in this research study.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Mean MET	Eq.v.* assumed	1,736	,198	-1,514	30	,141	-,05167	,03413
	Eq.v. not assumed			-1,659	29,274	,108	-,05167	,03115

*Eq.v.=equal variances

Field study research participants are divided into three different groups according to their age, to test the significance of the age difference in the average daily metabolic rate. The first group includes people from 35 to 44 years old, the second one from 45 to 54 years old, and the third group consists of people from 55 to 64 years old. Table 4 shows the test results of the users' age difference.

Table 4. User age difference in metabolic rate

Ranks

Age		N	Mean Rank
Mean MET	1st age group	20	18,35
	2nd age group	8	6,50
	3rd age group	4	27,25
	Total	32	

Test Statistics

	Mean MET
Chi-Square	15,122
Df	2
Asymp. Sig.	,001

According to the Kruskal Wallis test, there is a statistically significant difference between building occupants of different age. Table 4 shows that there is only 0,1% chance that this difference in metabolic rates is due to chance.

Table 5 shows the test results of the impact of internal working conditions on users' metabolic rate, *i. e.* whether their metabolic rate is different due to office temperature in the different seasons of the year.

According to independent t-test, there is a statistically significant difference in the mean metabolic rate of some building occupants in different periods of the year. Four out of eight study participants have different energy expenditure as a consequence of altered metabolic rate due to the season of the year. Specifically, occupant 3, occupant 5, occupant 6, and occupant 8's metabolic rate is influenced by heating/cooling conditions. This result should be tested with a larger number of participants to investigate why this applies for some building occupants, and other does not.

Table 5. Impact of cooling/heating on metabolic rate

Group Statistics

Season of the year		N	Mean	Std. Deviation	Std. Error Mean
met1	Cooling season	419	1,3878	,24070	,01176
	Heating season	419	1,3926	,22417	,01095
met2	Cooling season	419	1,3878	,24070	,01176
	Heating season	419	1,3820	,24115	,01178
met3	Cooling season	419	1,5319	,31853	,01556
	Heating season	419	1,4218	,22270	,01088
met4	Cooling season	419	1,5097	,43500	,02125
	Heating season	419	1,5742	,39481	,01929
met5	Cooling season	419	1,4733	,32719	,01598
	Heating season	419	1,2563	,19235	,00940
met6	Cooling season	419	1,3841	,18206	,00889
	Heating season	419	1,4788	,26855	,01312
met7	Cooling season	419	1,3189	,12075	,00590
	Heating season	419	1,3055	,13545	,00662
met8	Cooling season	419	1,4034	,18063	,00882
	Heating season	419	1,3238	,23313	,01139

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
met1	Eq.v.* assumed	1,995	,158	-,297	836	,766	-,00478	,01607
	Eq.v. not assumed			-,297	831,805	,766	-,00478	,01607
met2	Eq.v. assumed	1,485	,223	,351	836	,726	,00584	,01665
	Eq.v. not assumed			,351	835,997	,726	,00584	,01665
met3	Eq.v. assumed	72,747	,000	5,800	836	,000	,11012	,01899
	Eq.v. not assumed			5,800	747,843	,000	,11012	,01899
met4	Eq.v. assumed	,070	,791	-2,248	836	,025	-,06451	,02870
	Eq.v. not assumed			-2,248	828,264	,025	-,06451	,02870
met5	Eq.v. assumed	105,042	,000	11,706	836	,000	,21705	,01854
	Eq.v. not assumed			11,706	676,089	,000	,21705	,01854
met6	Eq.v. assumed	24,666	,000	-5,976	836	,000	-,09473	,01585
	Eq.v. not assumed			-5,976	735,214	,000	-,09473	,01585
met7	Eq.v. assumed	2,043	,153	1,520	836	,129	,01348	,00886
	Eq.v. not assumed			1,520	825,213	,129	,01348	,00886
met8	Eq.v. assumed	13,456	,000	5,521	836	,000	,07955	,01441
	Eq.v. not assumed			5,521	786,921	,000	,07955	,01441

*Eq.v.=equal variances

Table 6. Characteristics of individual groups

	Thermal comfort according to metabolic rates				Description
	Hot [MET]	Warm [MET]	Neutral [MET]	Cold [MET]	
Group 1	> 2.3	1.7 – 2.3	1.4 – 1.7	Not recorded	1st age group, higher temperature acceptance range, mostly females
Group 2	> 2	1.9 – 2	1.5 – 1.9	Not recorded	1st age group, Higher activity level, mostly males
Group 3	> 1.8	1.5 – 1.8	1.3 – 1.5	< 1.3	2nd and 3rd age group, narrow comfort range people with high BMI

Conducted measurement of dynamic metabolic rate during an 8-hour working day, showed a correlation for some of the building occupants. According to this acknowledgment, users are categorized into 3 groups conforming to similar metabolic rate trends and personal characteristics. In addition, reported user responses are taken into consideration. Hence, Table 6 was formed.

The results showed that users' metabolic rate change many times during the day. Those changes (according to Table 6) are not in line with ANSI/ASHRAE Standard, Metabolic rates for typical tasks [39] which indicates that office activities are in the range from 1.0 to 2.1 MET. Users reported thermal sensation connected to activity change. It can be noted that people with, for example, high Body Mass Index (BMI) have lower average metabolic rate, so the cold sensation appears earlier than with Group 1 and Group 2. Group 1, are the people, mostly women, which have higher temperature acceptance range. On the other hand, Group 2 have a wider range of neutral temperature which means that activity level higher than 1.5 MET do not cause warm sensation for those people (opposite of Group 3) because of their physical fitness and physiological adaptation.

4. Conclusions

Achieving adequate indoor environmental quality beyond the current definitions of acceptability from population-based criteria to one that embraces the individual on as-needed, when needed and as-preferred basis is imperative. Dynamic changes of metabolic rate gain by the sensor measurement, suggest diary methods of metabolic rate assessment are inapplicable for accurate thermal comfort prediction. In this study, the wearable sensory device Move 3 was utilized to track building occupants and measure their daily metabolic rate. The collected data was used to analyze the occupants' thermal preferences and to prepare the model creation base (Table 6). Furthermore, the collected data was used in order to define the impact and significance of individual factors such as age, gender and season of the year on the changes in occupants' metabolic rates. The results show that there is no statistically significant difference between the mean metabolic rate in the working day between males and females. However, according to the Kruskal Wallis test, there is a statistically significant difference between building occupants of different age. The results of groups' activity and thermal preference (Table 6) should be validated with a larger number of people.

5. References

[1] **Fanger, PO.,** Thermal comfort: analysis and applications in environmental engineering. Copenhagen: Danish Technical Press; 1970.

[2] ASHRAE, Standard 55-2017-Thermal environmental conditions for human occupancy, Am. Soc. Heat. Refrig. Air-Cond. Eng. (ASHRAE) 55 (2017) 62 pages, https://www.ashrae.org/technical-resources/bookstore/standard-55

[3] **Liu, W. Lian Z. Zhao, B.,** A neural network evaluation model for individual thermal comfort, *Energy and Buildings,* vol.39, pp.1115–1122, (2007)

[4] **Tham, K. W.,** Indoor air quality and its effects on humans—A review of challengesand developments in the last 30 years, *Energy and Buildings,* vol.130, pp.637–650, (2016)

[5] **Li, D. Menassa C. C. Kamat, V.R.,**. Personalized human comfort in indoor building environments under diverse conditioning modes, *Building and Environment* vol.126, pp.304-317 (2017)

[6] **Huizenga, C. Abbaszadeh, S. Zagreus, L. Arens, E.A.,** Air quality and thermal comfort in office buildings: results of a large indoor environmental quality survey, Proc. Healthy Build. vol. 3 pp. 393–397, (2006).

[7] **Sekhar, S.C.,** Thermal comfort in air-conditioned buildings in hot and humid climates - why are we not getting it right?, *Indoor Air* vol. 26 no.1 pp. 138–152, (2016) doi: 10.1111/ina.12184 .

[8] **Brager, G.S. de Dear, R.,** A standard for natural ventilation, *ASHRAE Journal*, vol. 42, no.10, pp. 21-27 (2000).

[9] **Parsons**, **K.C.,** Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance, 3rd ed., CRC press, (2014).

[10] **Zhai, Y., et.al.,** Indirect calorimetry on the metabolic rate of sitting, standing and walking office activities, *Building and Environment* vol.145, pp.77-84 (2018)

[11] **Jin, M.,** Environmental Sensing by Wearable Device for Indoor Activity and Location Estimation, *IECON 2014 - 40th Annual Conference of the IEEE Industrial Electronics Society* (2014)

[12] **Kumar, P. et. al.,** Real-time sensors for indoor air monitoring and challenges ahead in deploying them to urban buildings, *Sci. Total Environ*. vol. 560 pp.150–159 (2016).

[13] **Panda, S.K. Tham, K.W.,** Real-time occupant engaged indoor environmental quality monitoring and control system using wireless sensor-actuatornetwork for smart indoor environments, in: Research Proposal AwardedUnder GBIC –R&D RFP 01, Singapore, 2016.

[14] **Nishkam, R. Dandekar, N. Mysore, P. Littman, M. L.,** Activity recognition from accelerometer data. In AAAI, vol. 5, pp. 1541-1546 (2005)

[15] **Bao, L. Intille. S. S.,** Activity recognition from user-annotated acceleration data, *Pervasive computing*, Springer Berlin Heidelberg, pp. 1-17,

[16] (2004)

[17] **Guenterberg, E. et. al.,** Distributed continuous action recognition using a hidden Markov model in body sensor networks, *Distributed Computing in Sensor Systems*, pp. 145-158. Springer Berlin Heidelberg, 2009.

[18] **Ryoo, M. S. Aggarwal. J. K.,** Hierarchical recognition of human activities interacting with objects, *Computer Vision and*

[19] *Pattern Recognition,* 2007. CVPR'07. IEEE Conference on, pp. 1-8. IEEE, 2007.

[20] **Chaudhuri, T.,** Random forest based thermal comfort prediction from gender-specific physiological parameters

using wearable sensing technology, *Energy and Buildings,* vol.166, pp. 391-406, (2018)

[21] **Miluzzo, E. et.al.,** Sensing meets mobile social networks: the design, implementation and evaluation of the cenceme application,

[22] *Proceedings of the 6th ACM conference on Embedded network sensor systems*, pp. 337-350. ACM, (2008)

[23] **Saponas, T., et.al.,** iLearn on the iphone: Real-time human activity classification on commodity mobile phones, University of Washington CSE Tech Report UW-CSE-08-04-02 (2008).

[24] **Yang, J.,** Toward physical activity diary: motion recognition using simple acceleration features with mobile phones, *Proceedings of the 1st international workshop on Interactive multimedia for consumer electronics (IMCE '09),* ACM, New York, NY, USA, pp. 1-10 (2009)

[25] **Parsons, K.C.,** Human thermal environments: the effects of hot, moderate and cold environments on human health, comfort and performance. 2nd ed. London: Taylor & Francis; (2003).

[26] **Iyoho, A.E. Ng, L.J. MacFadden, L.,** Modeling of gender differences in thermoregulation, *Mil. Med.* vol. 182 pp. 295–303, (2017) doi: 10.7205/MILMED- D- 16-00213

[27] **Beshir M.Y., Ramsey J.D.,** Comparison between male and female subjective estimates of thermal effects and sensations, *Applied Ergonomics* vol. 12, pp. 29–33 (1981)

[28] **Muzi, G. Abbritti, G. Accattoli, MP. dell'Omo, M.,** Prevalence of irritative symptoms in a no problem air-conditioned office building. *International Archives of Occupational and Environmental Health* vol. 71 pp. 372–378, (1998)

[29] **Cena, K. de Dear, R.,** Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate, *Journal of Thermal Biology*, vol. 26(4-5) pp. 409–414, (2001)

[30] **Griefahn, B. Kunemund, C**., The effects of gender, age, and fatigue on susceptibility to draft discomfort, *Journal of Thermal Biology*, vol. 26 (4-5): pp. 395–400, (2001)

[31] **Nagashima, K, et. al.,** Thermal regulation and comfort during a mild-cold exposure in young Japanese women complaining of unusual coldness, *Journal of Applied Physiology* vol. 92 no.3, pp. 1029–35, (2002)

[32] **Nakano, J. Tanabe, S. Kimura, K.,** Differences in perception of indoor environment between Japanese and non-Japanese workers, *Energy and Buildings*, vol. 34, no. 6, pp. 615–621, (2002)

[33] **Parsons, K.C.,** The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort, *Energy and Buildings*, vol. 34, no. 6, pp. 593–599. (2002)

[34] **Pellerin, N. Candas, V.** Combined effects of temperature and noise on human discomfort. *Physiology & Behavior*, vol. 78, no.1, pp. 99–106, (2003)

[35] **Karjalainen, S.,** Gender differences in thermal comfort and use of thermostats in everyday thermal environments, *Building and Environment*, vol. 42, no. 4, pp. 1594-1603 (2007)

[36] **Burge, S, et. al.,** Sick building syndrome: a study of 4373 office workers, *Annals of Occupational Hygiene* vol. 31 no.4A, pp. 493–504, (1987)

[37] **Lenvik, K.,** Sick building syndrome symptoms, different prevalences between males and females, *Environment International,* vol.18, no. 1, pp. 11–7, (1992)

[38] **Brasche, S. et. al.,** Why do women suffer from sick building syndrome more often than men?—Subjective higher sensitivity *vs.* objective causes, *Indoor Air*; vol.11, no.4, pp. 217–22, (2001)

[39] **Anastasopoulou, P. et. al.** Using Support Vector Regression for Assessing Human Energy Expenditure Using a Triaxial Accelerometer and a Barometer, *International Conference on Wireless Mobile Communication and Healthcare*, pp. 106-113, (2014)

[40] **Härtel, S. et. at,.** Estimation of energy expenditure using accelerometers and activity-based energy models—validation of a new device, *European Review of Aging and Physical Activity*, vol. 8, no. 2, pp. 109-114, (2011)

[41] **Lyden, K. et. al.** A comprehensive evaluation of commonly used accelerometer energy expenditure and MET prediction equations, *European Journal of Applied Physiology,* vol. 111, no. 2, pp. 187-201, (2011)

[42] ANSI/ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy, Am. Soc. Heat. Refrig. Air-Cond. Eng. (ASHRAE) 55 (2010) 44 pages, http://arco-hvac.ir/wp-content/uploads/2015/11/ASHRAE-55-2010.pdf