jADU

Vol 5 No 2, 2023
pp. 54-60

Journal of Architectural Design and Urbanism
https://ejournal2.undip.ac.id/index.php/jadu
E-ISSN: 2620-9810

Toward Utilizing IoT Open Data Set to Identify the Room Thermal Comfort

Ratih Widiastuti[a,b*]

[a] Civil Infrastructure Engineering and Architectural Design, Department of Civil and Planning, Vocational School, Diponegoro University, Semarang, Indonesia
[b] Faculty of Integrated Technologies, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong BE1410, Brunei Darussalam

Corresponding e-mail: ratihw@arsitektur.undip.ac.id; ratihwidiastuti@lecturer.undip.ac.id

Article info:
Received: 7-4-2023, Revised: 28-5-2023, Accepted: 11-6-2023

Abstract. Building sectors are responsible for 33% of global energy consumption and a one-third of CO_2 emission as buildings are expected to experience high performance to meet the standard of occupant comforts such as lighting, cooling, and heating. Internet of Things (IoT) as one of the leading developments in digital technologies led to the establishment of devices for improving the living style of the occupants. To date, studies on integrating the mechanisms of IoT to identify room thermal comfort are very scarce. Therefore, the aim of this study was to discuss the room thermal comfort with respect to room temperature and relative humidity. Three activities (read, write, and sit) were adopted. The value of air speed, metabolic rate, and clothing insulation was assumed constant. The analysis was conducted according to Fanger method and ASHRAE standard 55. Center for the Built Environment (CBE) Thermal Comfort Tool was used to calculate the Predicted Mean Vote (PMV) values. Results from data collection indicated the average room temperature was at ideal condition at 21.2°C with relative humidity 44.9%. Further calculation showed the average PMV values of each activity were -2.3 (read), -2.0 (write), and -1.4 (sit). Compared to the room climate data set, sitting performed the closest thermal comfort scale to the neutral. It means light activities with lower metabolic rate should be conducted in the room with higher room temperature and relative humidity.

Keywords: Internet of Things, relative humidity, room temperature, room thermal comfort

1. Introduction

Building sectors, either residential or commercial are responsible for global energy consumption and one-third of global CO_2 emission (Albatayneh et al. 2018). Recently, people tended to spend their activities indoors rather than outdoors. Data shows 30% - 40% of total primary energy consumption in the world comes from demands to improve comfort for people living inside the buildings (Sun, Wilson, and Wu 2018). The performance of indoor thermal comfort becomes the important factor to create occupant satisfaction.

According to (Yang and Moon 2018) thermal comfort is the human satisfaction scale to their environment based on the thermal sensation. Thermal comfort can be introduced as mind condition related to psychological factors (Albatayneh et al. 2018), that expresses the satisfaction to the thermal condition (Fanger 1984) since in the satisfied environment, physical and mental productivity of human will increase (Geng et al. 2017). Thermal comfort is strongly related to the thermal balance between the human body with its environment (Turhan and Gokcen Akkurt 2019). The thermal comfort sensations among building occupants could be different from each other since it was affected by personal experience, psychological, social, and organizational (Djongyang, Tchinda, and Njomo 2010). Air temperature, air speed, metabolic rate, clothing levels, mean radiant temperature, and

doi: 10.14710/jadu.v5i2.17924

humidity are the important parameters to calculate the comfort (D'Ambrosio Alfano et al. 2014).

Several thermal comfort models have been developed to identify human thermal comfort. Fanger proposed Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) to measure indoor thermal comfort (Fanger 1970). Many standards, such as ISO 7730 (Standardization 1994) and ASHRAE standard 55 (ASHRAE 2010) used PMV and PPD as the basis. There are seven-points thermal sensation scale assessed by PMV i.e. cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2), and hot (+3).

In other hand, advance technologies introduce Internet of Things (IoT) as one of promising methods to improve the work process, energy efficiency, capacities, and capabilities of building data monitoring. Previous study conducted by Andreas et al. (Plageras et al. 2018) utilized IoT system to enhance the efficiency of data collection process and analysis for smart buildings. Another study conducted using Internet of Things (IoT) for big data analytics and improved the energy management for buildings (Daissaoui et al. 2020). Using three sensors, data of indoor temperature and relative humidity in a seminar room was obtained through IoT gateway system that connected with C4EBOX (Irulegi et al. 2017). Another study conducted by (Brik et al. 2021) generated real data set using IoT to ensure the data collection process.

Despite the potential of IoT to enhance the building data monitoring, to date, studies on integrating IoT to identify room thermal comfort are very scarce. Most of the previous studies used manual data collection methods. The calculation of thermal comfort values also conducted manually using equation according to Fanger theory (Fanger 1984). To overcome this, the author proposed the identification of indoor thermal comfort in the classroom based on IoT climate room open data set. The calculation of thermal comfort sensation used Center for the Built Environment (CBE) Thermal Comfort tool (Tartarini et al. 2020). The discussion was particularly focusing on the critical issue about dealing with thermal sensation scales for the students.

2. Research Methodology

This study proposes the indoor thermal comfort assessment under a real room climate condition. The room climate data sets (relative humidity and room temperature) were obtained from open source (Frederik et al. 2017). To achieve monitoring room thermal condition efficiently, Internet of Things (IoT) was used in the data collection. The IoT framework consist of Moteiy Tmote Sky sensors and integrated with contiki operating system ver. 10 to collect the data in one second interval (Moteiv 2006)(Dunkels, Gronvall, and Voigt n.d.).

As mentioned in the introduction section, several thermal comfort standards have been developed to identify human thermal comfort. In this study, thermal comfort index evaluation was conducted using Fanger method (Fanger 1970). A free online tool named Center for the Built Environment (CBE) Thermal Comfort was employed to calculate PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfaction) (Tartarini et al. 2020), as illustrated in **Figure 2.1** Other than simplifying the PMV calculation, the web also visualized the thermal comfort indicates and had a significant impact to the building sector community. As suggested by The 13th edition of the Mechanical and Electrical Equipment for Buildings, CBE Thermal Comfort Tool can be used for thermal comfort calculation and visualizations (Grondzik and Kwok 2019). Data from Google Analytics also confirmed that CBE Thermal Comfort Tool had been used widely to demonstrate the project compliance of thermal comfort (Building Construction Authority 2015).

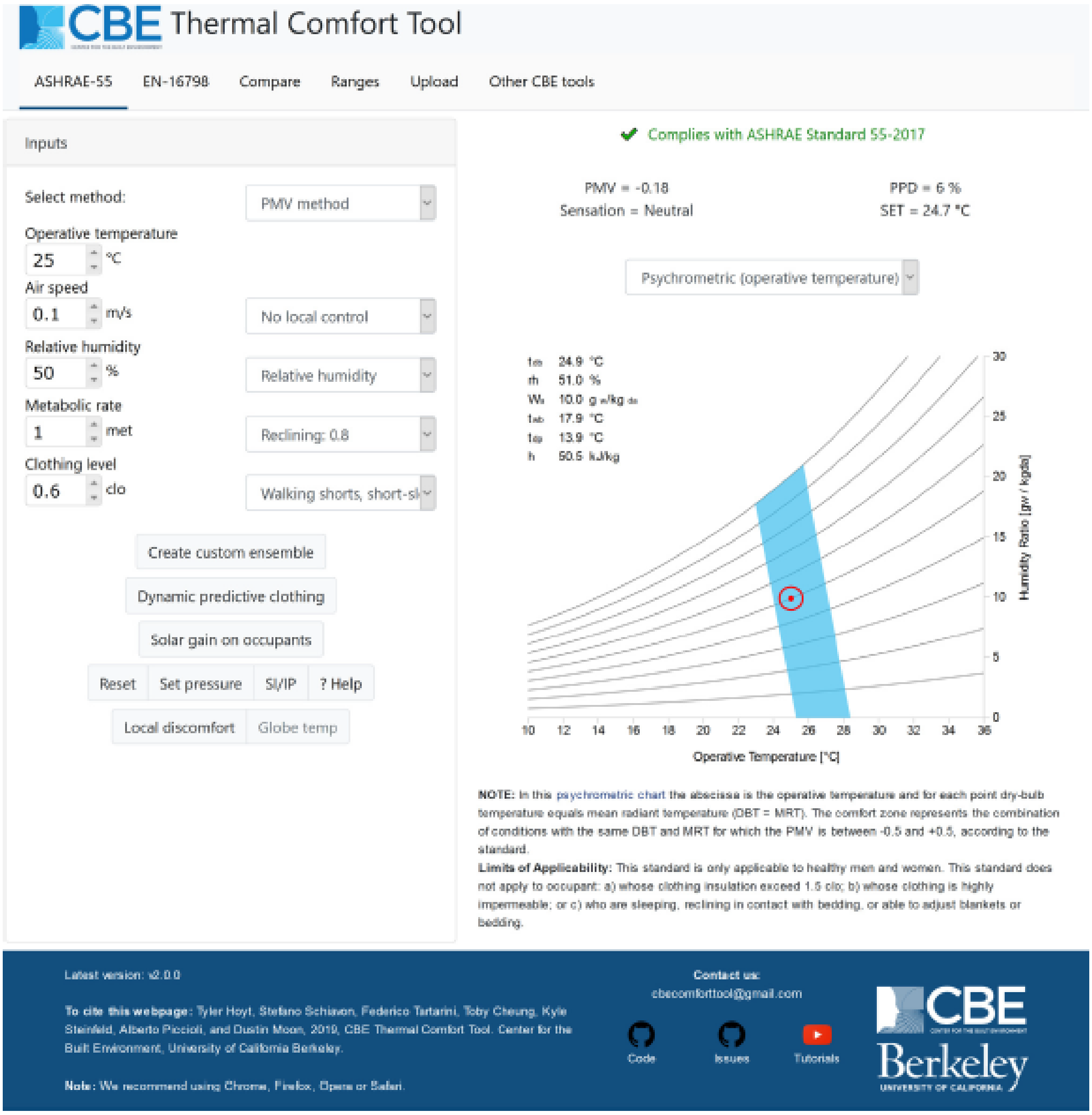

Figure 2.1. Official CBE Thermal Comfort Tool homepage (Tartarini et al. 2020)

There are five input parameters to calculate PMV and PPD values in CBE Thermal Comfort Tool as follow operative temperature, air speed, relative humidity, metabolic rate, and clothing level. The indoor air speed was 0.25 m/s which refers to the comfortable air speed for human (G. Lippsmeier 1994). To comply with thermal comfort parameters, various activities referred to as the student activities in the class, such as read, read, and sit were adopted. The metabolic rate for each activity was 1.0 (read), 1.0 (write), and 1.0 (sit) (Tartarini et al. 2020). The value of clothing insulation (clo) was 0.5 which is typical summer indoor clothing. **Figure 2.2** illustrates the IoT framework and the method of thermal comfort calculation using CBE Thermal Comfort Tool.

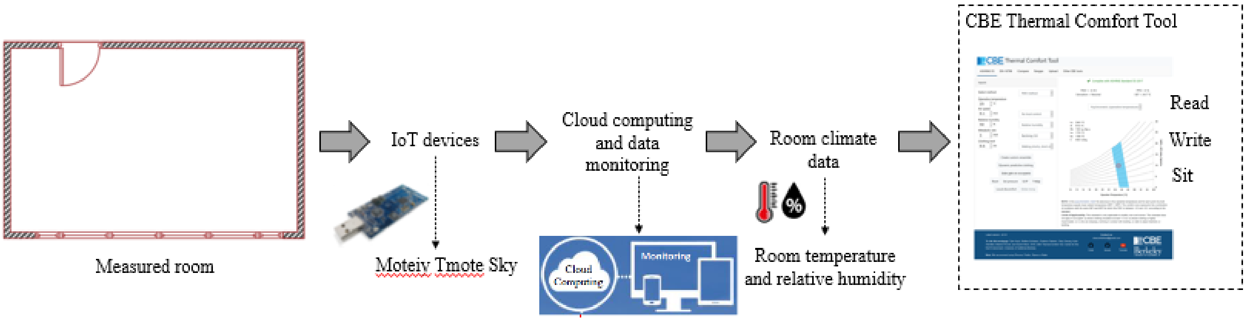

Figure 2.2. IoT framework and thermal comfort calculation using CBE Thermal Comfort Tool

3. Results and Discussions

3.1. Trend of Room Temperature and Relative Humidity

Figure 3.1 shows the trend of room temperature and relative humidity during the data collection. Statistical calculations show the maximum, minimum, average room temperature was 21.6°C, 21.0°C, and 21.2°C, respectively. In other hand, the maximum, minimum, and average relative humidity was 47.1%, 43.0%, and 44.9%, respectively. The relative humidity tended to decrease over room temperature. It might affect the thermal sensation scale, especially for higher activity levels (Djamila, Chu, and Kumaresan 2014).

According to ASHRAE standard 55 (ASHRAE 2010), the ideal room temperature is 20.5°C – 22.8°C. Analysis using vertical temperature gradient, the room temperature in this study was at ideal condition. Interestingly, ASHRAE standard 55 (ASHRAE 2010) only set the maximum relative humidity at 60%, which is no minimum relative humidity level was recommended. As the consequent, humidity is negligible and people more focus on the room temperature.

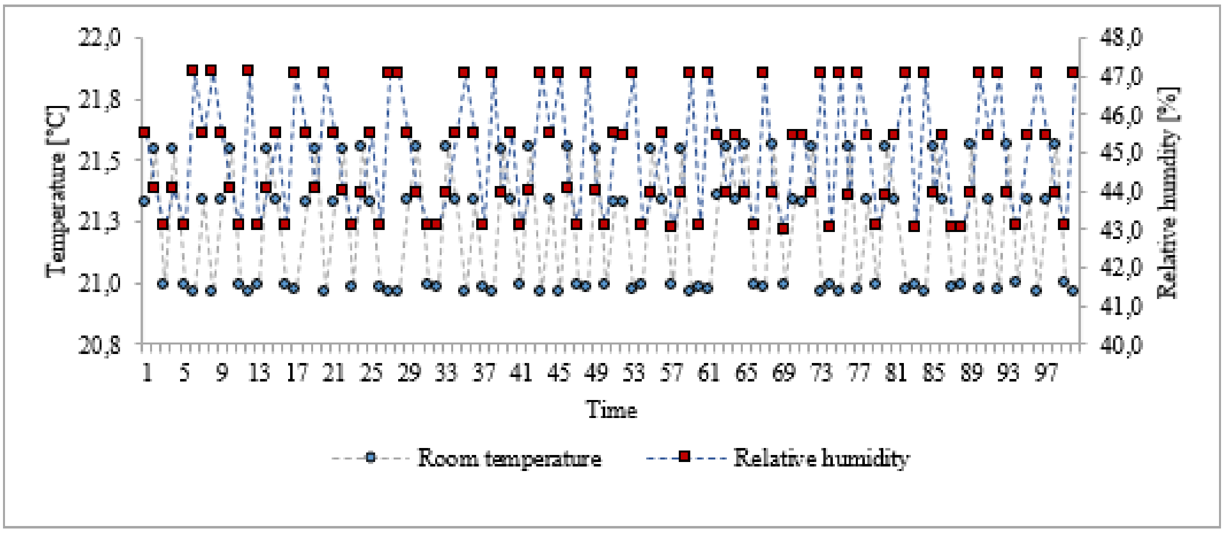

Figure 3.1. trend room temperature and relative humidity

3.2. Evaluation of Thermal Comfort Prediction

According to the data calculation, average indoor thermal comfort when the students read, write, and sit were -2.3, -2.0, and -1.4, respectively. It means, two activities had cool sensation as the thermal comfort scale. As mentioned in **Section 2** (**Research Methodology**), the value of air speed, metabolic rate, and clothing insulation was constant. While the average room temperature and relative humidity for each activity was 21.0°C and 44.9% (read), 21.2°C and 44.8% (write), and 21.5°C and 45.1% (sit). It can be concluded that room temperature and relative humidity were the most contributed factors that affected indoor thermal comfort.

Considering the thermal comfort prediction, write and sit had same indoor thermal comfort prediction, illustrated in **Figure 3.2** However, sitting showed 70% of the thermal sensation scale was slightly cool and writing indicated 58% of the thermal sensation scale was cool. While reading showed cool sensation dominated the thermal sensation scale. Compared to the room climate data set, sitting performed the closest thermal comfort scale to the neutral. However, it can be concluded light activities with lower metabolic rate should be conducted in the room with higher room temperature and relative humidity. To obtain the neutral thermal comfort scale, the room temperature and relative humidity need to be increased at range 23.8°C – 24.9°C and 58% - 60%. It means a Heating, Ventilation, and Air-Conditioning (HVAC) system is needed in this process. Future study needs to be considered to calculate the amount of energy consumption to increase or decrease the room temperature and relative humidity.

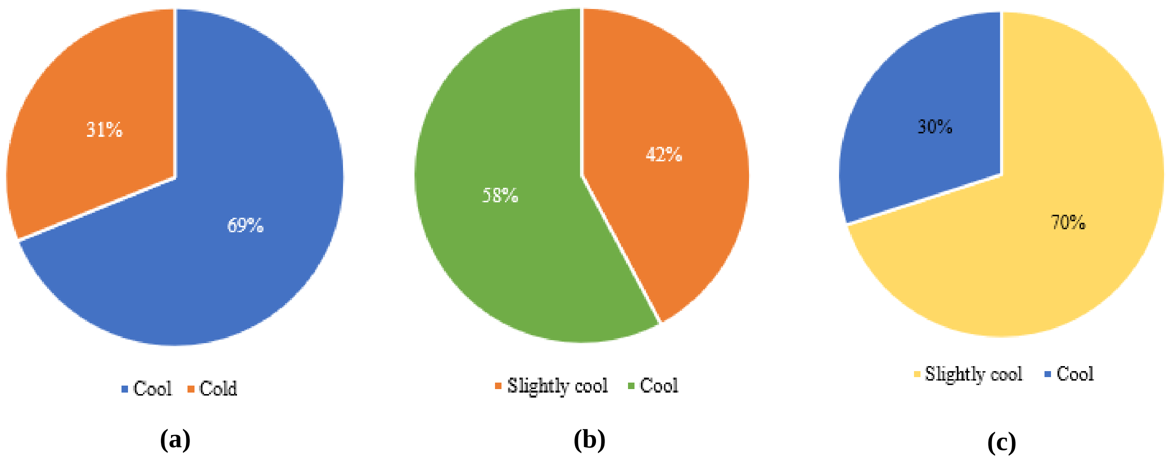

Figure 3.2. Room thermal comfort evaluation (a) read; (b) write; and (c) sit

4. Conclusion

Nowadays, buildings are the major source of total energy consumption in the world since the demand for people to live inside buildings increases. This study identified the room thermal comfort with respect to the room temperature and relative humidity. Room climate data were obtained from open source. The IoT system was used to observe and collect data. The analysis was conducted according to Fanger method and ASHRAE standard 55.

Data showed the room temperature in this study was at ideal condition according to ASHRAE standard 55. However, the relative humidity tended to decrease over room temperature and might affect room thermal comfort. Considering the thermal comfort prediction, sitting showed the closest thermal scale to the neutral. It indicated lower metabolic rate should be conducted in the rooms with higher room temperature and relative humidity. In the future study, calculation on the number of energy consumption to increase or decrease the room climate profile is needed.

5. References

Albatayneh, Aiman, Dariusz Alterman, Adrian Page, and Behdad Moghtaderi. 2018. "The Impact of the Thermal Comfort Models on the Prediction of Building Energy Consumption." *Sustainability (Switzerland)* 10(10).

ASHRAE. 2010. "ASHRAE Standard 55-2010: Thermal Environmental Conditions for Human Occupancy."

Brik, Bouziane, Moez Esseghir, Leila Merghem-Boulahia, and Hichem Snoussi. 2021. "An IoT-Based Deep Learning Approach to Analyse Indoor Thermal Comfort of Disabled People." *Building and Environment* 203(May):108056.

Building Construction Authority. 2015. "GM NRB: 2015 Green Mark for Non-Resedential Buildings NRB: 2015 Technical Guide and Requirements."

D'Ambrosio Alfano, Francesca Romana, Bjarne W. Olesen, Boris Igor Palella, and Giuseppe Riccio. 2014. "Thermal Comfort: Design and Assessment for Energy Saving." *Energy and Buildings* 81(2014):326–36.

Daissaoui, Abdellah, Azedine Boulmakoul, Lamia Karim, and Ahmed Lbath. 2020. "IoT and Big Data Analytics for Smart Buildings: A Survey." *Procedia Computer Science* 170:161–68.

Djamila, Harimi, Chi-Ming Chu, and Sivakumar Kumaresan. 2014. "Effect of Humidity on Thermal Comfort in the Humid Tropics." *Journal of Building Construction and Planning Research* 02(02):109–17.

Djongyang, Noël, René Tchinda, and Donatien Njomo. 2010. "Thermal Comfort: A Review Paper." *Renewable and Sustainable Energy Reviews* 14(9):2626–40.

Dunkels, A., B. Gronvall, and T. Voigt. n.d. "Contiki - a Lightweight and Flexible Operating System for Tiny Networked Sensors." *29th Annual IEEE International Conference on Local Computer Networks, 2004, IEEE, 2004*.

Fanger, P. O. 1984. *Moderate Thermal Environments Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort*.

Fanger, Poul O. 1970. *Thermal Comfort. Analysis and Applications in Environmental Engineering.* Copenhagen: Danish Technical Press.

Frederik, Armknecht, Benenson Zinaida, Morgner Philipp, Müller Christian, and Riess Christian. 2017. "Room Climate Datasets." *GitHub*. Retrieved August 1, 2020 (https://github.com/IoTsec/Room-Climate-Datasets).

G. Lippsmeier. 1994. *Tropenbau Building in the Tropics (in Bahasa: Bangunan Tropis by Syahmir Nasution)*. 2nd ed. P. Jakarta, Indonesia: Erlangga.

Geng, Yang, Wenjie Ji, Borong Lin, and Yingxin Zhu. 2017. "The Impact of Thermal Environment on Occupant IEQ Perception and Productivity." *Building and Environment* 121(September 2018):158–67.

Grondzik, Walter T., and Alison G. Kwok. 2019. *Mechanical and Electrical Equipment for Buildings*. John wiley & sons.

Irulegi, O., A. Ruiz-Pardo, A. Serra, J. M. Salmerón, and R. Vega. 2017. "Retrofit Strategies towards Net Zero Energy Educational Buildings: A Case Study at the University of the Basque Country." *Energy and Buildings* 144(2017):387–400.

Moteiv, Corporation. 2006. *Tmote Sky Datasheet*. Moteiv Corporation.

Plageras, Andreas P., Kostas E. Psannis, Christos Stergiou, Haoxiang Wang, and B. B. Gupta. 2018. "Efficient IoT-Based Sensor BIG Data Collection–Processing and Analysis in Smart Buildings." *Future Generation Computer Systems* 82:349–57.

Standardization, International Organization for. 1994. *ISO 7730: Moderate Thermal Environments - Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort*. ISO.

Sun, Yanyi, Robin Wilson, and Yupeng Wu. 2018. "A Review of Transparent Insulation Material (TIM) for Building Energy Saving and Daylight Comfort." *Applied Energy* 226(May):713–29.

Tartarini, Federico, Stefano Schiavon, Toby Cheung, and Tyler Hoyt. 2020. "CBE Thermal Comfort Tool: Online Tool for Thermal Comfort Calculations and Visualizations." *SoftwareX* 12:100563.

Turhan, Cihan, and Gulden Gokcen Akkurt. 2019. "The Relation between Thermal Comfort and Human-Body Exergy Consumption in a Temperate Climate Zone." *Energy and Buildings* 205:109548.

Yang, Wonyoung, and Hyeun Jun Moon. 2018. "Cross-Modal Effects of Noise and Thermal Conditions on Indoor Environmental Perception and Speech Recognition." *Applied Acoustics* 141(June):1–8.