Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Which sensor type at which location should offices with south orientated window choose to improve comfort and reduce energy consumption?

Which sensor type at which location should offices with south orientated window choose to improve comfort and reduce energy consumption?

O Minam Borier[1], O B Kazanci[2], B W Olesen[2] and D Khovalyg[1,3]

[1]Thermal Engineering for the Built Environment Laboratory, Ecole Polytechnique Fédérale de Lausanne, Switzerland
[2]International Centre for Indoor Environment and Energy, Danmarks Tekniske Universitet, Denmark
[3]dolaana.khovalyg@epfl.ch

Abstract. The common placement of thermostats in offices might not reflect the actual thermal environment around occupants and influence the energy use. In this research, it is questioned which type of thermostat at which location better represents the conditions in the occupied zone and what is the effect on energy use. To answer this, simulations of indoor thermal environment, experiments in a climatic chamber and calculation of the energy use are performed for a two-person office room with a south orientated window. The results obtained allow to provide recommendations about the thermostat type and its placement in the office space.
Keywords. Thermal comfort, Energy use, Thermostats, Casing effect, RPEHB

1. Introduction

The quality of the indoor environment plays a crucial role in occupant health, performance and well-being [1]. Thermal environment is one of the main parameters affecting the occupant comfort. Generally, satisfaction with the indoor comfort for mechanically conditioned buildings is characterized by the number of dissatisfied occupants which should be no more than 10% [2]. To provide an appropriate satisfactory thermal environment for occupants, typically, the indoor temperature is controlled by thermostats that are placed on a wall, far away from the occupied zone. Such a location is convenient from the maintenance point of view, however, the measurements of the thermostat might not reflect the actual thermal environment experienced by occupants. If a thermostat is located away from the occupied zone, it might provide inadequate thermal comfort and increase energy use for thermal conditioning. Thus, it is important to explore the effect of the location of the thermostat on the thermal comfort of occupants along with its effect on energy use.

2. Literature review

The questioning of the location of the reference sensor (thermostat) was firstly raised in the ’90s by Madsen [3]. He concluded that the positioning of the room temperature sensor in the occupied area may save energy in comparison to positioning on the wall. In 2001, Olesen [4] addressed the impact of the sunshine on indoor comfort by recommending that thermostats should react to the solar radiation immediately to avoid any discomfort of occupants. Wang et al. [5] also highlighted that people can feel overheated in summer because of the direct solar radiation through glazed facades. Studies by Wang et al., Olesen and Simone [6] tested temperature sensors at different locations such as on the wall and on the desk, but never near the window where the effect of solar radiation is shown.

According to the standard ISO 7730 [1], thermal comfort of an occupant is characterized by the operative temperature which is an average of the air and mean radiant temperature (if air speed less than 0.2m/s)., The operative temperature should be measured at heights of 0.6 m (for a seated person) or 1.1 m (for a standing person) [2]. While it is trivial to sense air temperature, sensing of the mean radiant temperature is thermostat type dependent. A research by Simone [7] determined that a spherical grey sensor 3-5 cm in diameter can sense the same effect of radiation as a seating person in the center of the room. If a person sits at a different location, the best shape to the sensor to measure mean radiant temperature depends on the position of the sensor in the space. Therefore, it is important to pay attention to the shape of thermostats. For example, a temperature sensor located inside a sealed enclosure could measure temperature closer to mean radiant temperature whereas the measurements could be closer to air temperature if the casing has a grid opening.

According to Wang's study [5], the control of the indoor environment after operative or air temperature has a different effect on thermal comfort level and energy use by the heating/cooling system. Thus, it is necessary to define what parameter is measured by thermostats available on the market. Recently, many manufacturers have developed wireless thermostats with very little heat generation allowing to move them closer to occupants. Typically, manufacturers recommend placing the thermostat on an interior wall, at a neutral place (not near heating/cooling sources, far from air currents and not exposed to sunlight), at the height of 1.5 meters. While comparisons of different thermostats can be found in the literature, for example in the work by Mylonas et al. [8], the effect of the location has not been addressed. Therefore, this study explores measurements of different thermostats placed at different locations in the office space (on the wall, at the desk, near the window). Major research questions are: (i) which thermostat available on the market can provide accurate measurements of the thermal environment, (ii) where a thermostat in an office room should be placed, and (iii) can the location of the thermostat impact on the energy use of the HVAC system?

3. Research Methodology

This project addresses the posed research questions by performing thermal comfort simulations and experimental study in a mock-up of a two-person office room of 17 m^2 shown in Figure 1 with a south orientated window (52% of the glazing area). Climatic conditions of Geneva (Switzerland) were chosen. The room was conditioned by means of radiant ceiling and mixing ventilation.

3.1. Set up of the thermal environmental simulations

Simulations of the indoor thermal environment are performed using the Radiant Performance Explorer/Heat Balance tool developed by ASHRAE [9]. To use the tool, a geometry of the room is firstly designed in SketchUp, then OpenSudio is used to set required parameters such as weather, thermal loads, schedules and building envelope layers. Afterward, the model of the room shown in Figure 2 is imported to RPEHB that generates thermal mapping. A two-dimensional map of operative temperature allows identifying the variation of this temperature for a chosen cross-section of the room and thus, to identify the least comfortable locations and guide the design of experiments (placement of thermostats). The operative temperature was simulated at 1.1 m for the hottest case in Geneva, the 10^{th} of July at 1 pm with EnergyPlus weather data.

3.2. Design of experiments

Experiments were performed in a controlled environment of a climatic chamber representing an office room. Different temperature sensors (air, globe, half-globe) and commercial wired and wireless thermostats were tested at three location (on the desk, near the window and on the wall), and at three heights such as 0.6 m, 1.1 m (recommended by the ISO 7730 Standard [1]) and 1.5 m (recommended by manufacturers for installation). For simulations and experiments, the ceiling temperature was determined iteratively to reach the cooling setpoint of 26°C of the Category II, Standard EN 15251 [10].

Simulations were performed for a low load case whereas experiments were under high load case (heated window and part of the floor to simulate sun loads), with a cooling ceiling and mixing ventilation that kept the room temperature of 26°C during the experiments (Table 1).

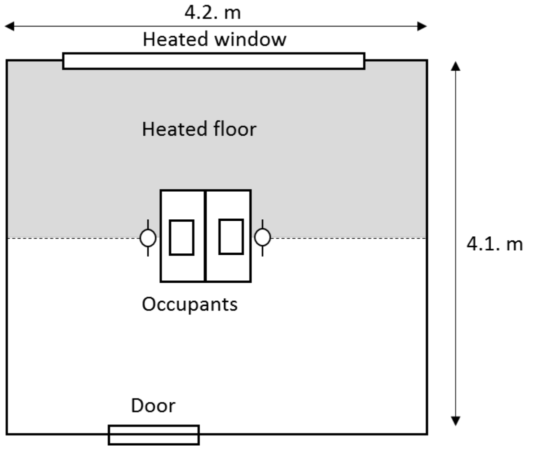

Figure 1. Top view of the experimental room

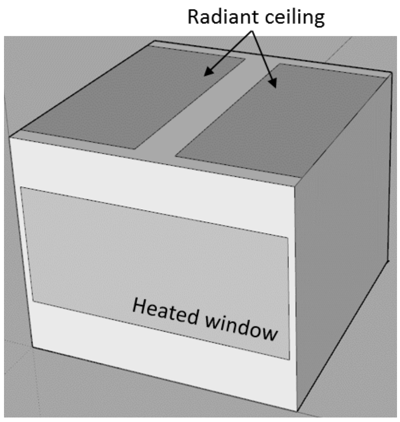

Figure 2. 3D model of the experimental room

Table 1. Thermal loads and temperatures for simulations and experiments

	Load [W]					Average surface temperature [°C]		
Component	Dummies	Computers	Lighting	Heating floor	Heating window	Window	Ceiling	Supply
Simulations	156	130	160	0	163	29.1	22	16
Experiments		52	171	250	423	34.4	21.4	16.3

Six thermostats available on the current market were selected for this study and their description is provided in Table 2. Conventional thermostats (sensors A and B) have been constructed to be installed on the wall and are wired whereas the new generation of thermostats (sensors C1, C2, D and E) have been designed by manufacturers to be movable (they can be placed on desks and most of them are wireless). The reference sensor with an accuracy of ±0.03°C was used to calibrate every sensor and to verify the steady state conditions of the room.

Table 2. Description of the thermostats and their casing

Sensor	Length [cm]	Width [cm]	Height [cm]	Accuracy [°C]	Wired	Temperature sensor in contact with air	Temperature sensor in contact with envelope
A	10	9	2	±0.5	Yes	No	Yes
B	8	8	1	±0.4	Yes	Yes	No
C1, C2	8	12.5	1.5	±0.5	No	No	No
D	8.5	8.5	3.5	±0.2	No	No	No
E	⌀ = 8		3	±0.4 (heating) 0.6 (cooling)	No	No	No
Air		-		±0.2°C	Yes	Yes	No
Globe		⌀ = 4		±0.2°C	Yes	No	No
Half-globe	⌀ = 4		2	±0.15 at 0°C	Yes	No	Yes
Reference		-		±0.03	Yes	Yes	No

Sensors were placed all together on a plexiglass board that can be moved to nine different locations chosen for two experimental scenarios illustrated in Figures 3 and 4. The dummies (heat loads representing occupants) were placed in the middle of the room in the first scenario, whereas they were near the window in the second one.

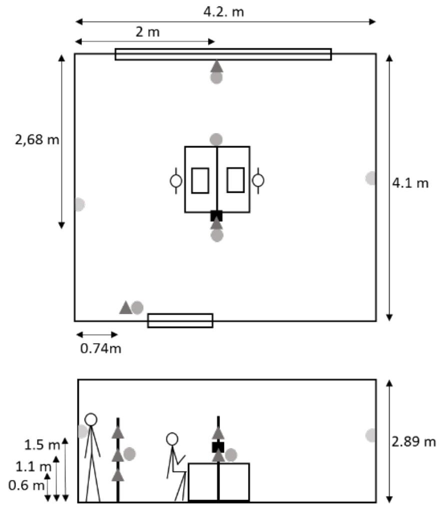

Figure 3. Experimental scenario 1

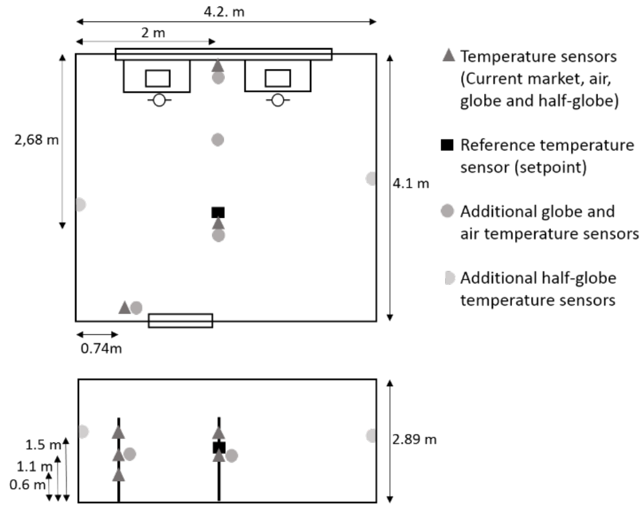

Figure 4. Experimental scenario 2

4. Results

4.1. Results based on the RPEHB simulations

The map of the operative temperature based on the simulations performed in RPEHB is presented in Figure 5 for the 1.1 m height. Contrary to experimental measurements by references globes and half-globe sensors for the 1.1 m height presented in Figure 6, simulations provide data for the homogeneous environment assuming that thermal loads are uniformly distributed.

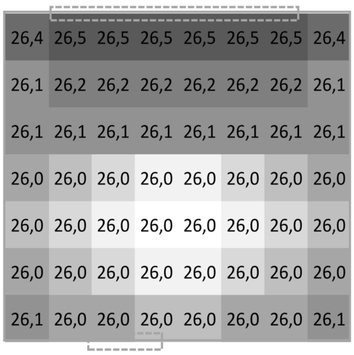

Figure 5. Operative temperature map obtained in RPEHB software

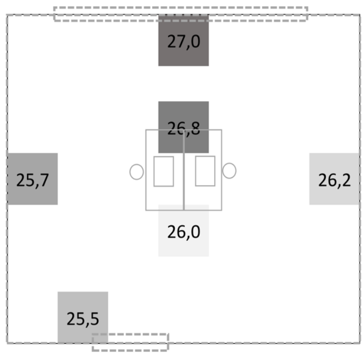

Figure 6. Point measurement of the globe sensors (window, desk, door) and half-globe sensors (walls)

4.2. Experimental results

Average temperature measured by each sensor at different locations for both scenarios is presented in Figure 7. It can be observed that the sensor E was measuring values close to the reference sensor temperatures whereas measurements from the sensor D were close to the globe sensor measurements. Except for the window location, measurements of the globe and air temperature were very close to each other as the cool radiant ceiling compensated for the other warmer radiant surfaces in the room (window and floor) [11]. The air temperature sensor had the lowest temperature difference at different locations as it was shielded from the radiation effects by a metal cylinder (the change in temperature was principally due to the radiation coming from the window). Oppositely, sensor A measurements were the highest at all locations. This can be explained by its casing which was the largest, forming an enclosure that has greater sensitivity to the effect of radiation [7]. Sensors A, B, and a half-globe sensor were the most influenced by the radiation. Temperatures measured at the desk at 1.1 m of height were all close to each other, whereas a significant variation in measurements can be observed near the window at 1.1

m of height. This illustrates how each sensor responded differently to the effect of radiation (from the heated window and the floor), to the thermal stratification, and air movement (0.2 m/s near the window and near the wall *vs*. 0.1m/s at the desk level).

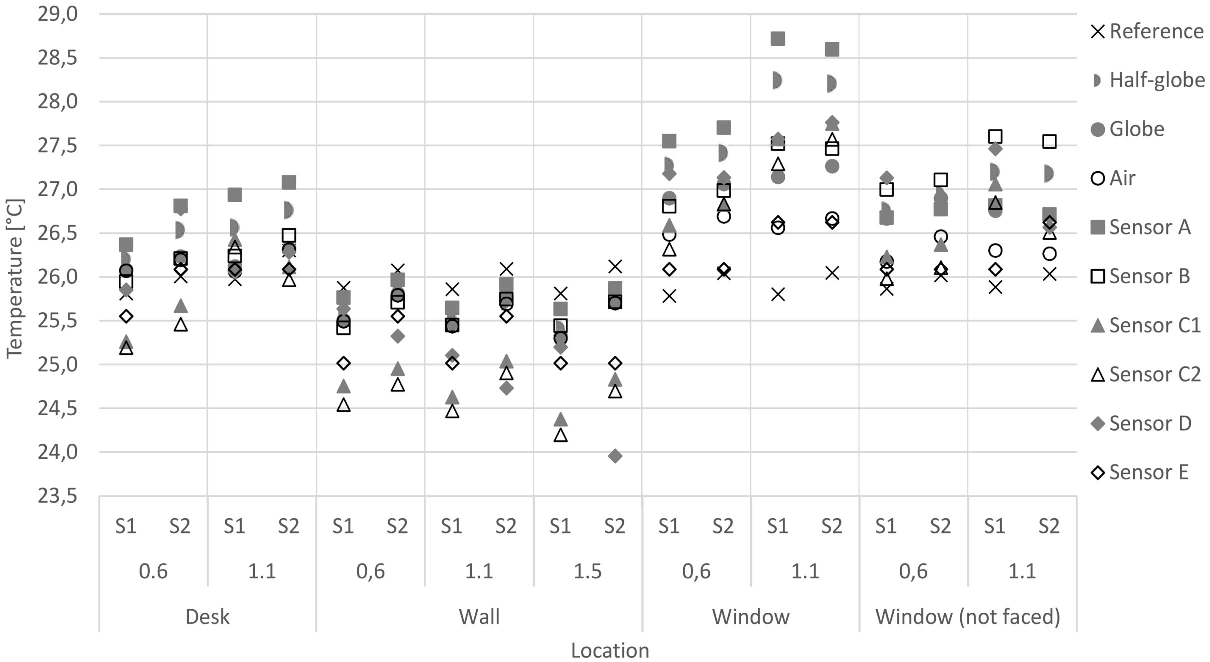

Figure 7. Average temperature per sensors placed according to the Scenario 1 (S1) and Scenario 2 (S2)

4.3. Energy performance calculations

The energy performance of the thermostat, compared to the reference sensor, can be calculated with the relationship between the setpoint change and energy use as provided in a previous study [12]. For the summer conditions, if the temperature measurements are elevated, the cooling system turns ON more often resulting in greater use of energy for cooling. On the opposite, if the temperature measurements are low, the cooling system turns OFF more often resulting in overheating discomfort. It can be observed in Figure 7 that conventional thermostats were measuring the highest temperatures. The energy use required to condition the space, compared to the input from a reference sensor, could be up to 14.6% (if measurements of sensor A, near the window, at 1.1 m are considered) and down by 9.4% (if measurements of sensor C2, at the wall, at 1.5 m are considered). The lowest differences in energy use were observed with sensor E and D measurements, which were respectively close to the reference and globe sensor values.

5. Discussion

Due to the effect of the direct radiation (both from the floor and the window) and higher air temperature (because of the heat source concentration), the closer the sensor was to the heated window, the higher the measured temperature was. The further away the sensor was from the heat loads (window, floor, dummies, computers and lights), the lower the measured temperature was. This observation is limited to the case study room of 17 m^2 floor area where the air temperature variation can be insignificant compared to the bigger spaces with a clear sun path throughout the day.

Experiments were conducted assuming that occupants did not interact with the thermostat to compensate for the temperature difference between the reference setpoint. In a single person office, the temperature settings can be easily corrected by the user, particularly if the sensor is on the desk. This is not the case in offices with multiple occupants having diverse preferences. This urges to question how many sensors are needed according to the occupant number, floor area, office geometry and glazing percentage. The interrogation remains open.

6. Conclusion

This work provides the following observations for all the sensors combined:

- The highest temperatures measurements were near the window at 1.1 m level, and the lowest values were at the wall at 1.5 m level

For all sensor locations combined:

- Conventional thermostats measurements were the highest that might lead to the increased energy use (up to 14.6% with sensor A) compared to the reference condition. The lowest temperature was measured by one of the new generation thermostats that could result in reduced energy use (down by 9.4% with sensor C2).
- Other new generation thermostats E and D had temperature measurements very close to the reference sensor and to the globe sensor respectively. Thus, almost no difference in energy use with the reference case was observed.

Based on the outcomes of the research, the following recommendations about thermostats and their placement can be provided for a two-person office (17m^2 floor area, window/floor ratio of 37%):

- If a thermostat is installed on the wall, it can be either fixed at 0.6 m, 1.1 m or 1.5 m (as it is recommended by manufacturers).
- If occupants are sitting in the middle of the room, a thermostat should not be placed in front of the windows. While each type of thermostat can provide adequate measurements when placed on the desk, conventional type of thermostat should still be installed on the wall.
- If occupants are sitting in front of the windows, a new generation of thermostats are preferred to be used but conventional should not.

References

[1] ISO EN 7730 2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria *International Organization for Standardization* (Genève)

[2] ANSI/ASHRAE Standard 55-2017 Thermal Environmental Conditions for Human Occupancy *American Society of Heating, Refrigerating, and Air conditioning Engineers* (Atlanta)

[3] Madsen T L, Schmidt T P and Helk U 1990 How important is the location of the room thermostat? *ASHRAE Trans. Part 1* (Atlanta)

[4] Olesen B W 2001 Control of floor heating and cooling systems *Clima World Congress* (Napoli)

[5] Wang H, B. Olesen B W and O. Kazanci O 2019 Using Thermostats for Indoor Climate Control in Offices: The Effect on Thermal Comfort and Heating/Cooling *Energy Use Energy and Buildings* **188-189** pp 71–83

[6] Simone A and Rode C 2009 Temperature distribution in Risø Flexhouse Room 3 with different heating control principles *BYG Sagsrapport* **09-07**

[7] Simone A, Olesen B W, Babiak J, Bullo M and Langkilde G 2007 Operative temperature control of radiant surface heating and cooling systems *Proc. of Clima 2007 Wellbeing Indoors*

[8] Mylonas A, Kazanci O B, Andersen R K and Olsesen B W 2019 Capabilities and limitations of wireless CO2, temperature and relative humidity sensors *Building and Environment* **154** pp 362–374 doi:10.1016/j.buildenv.2019.03.012

[9] ASHRAE 2017 Development of a Unified Tool for Analysis of Room Loads and Conditions

[10] EN15251 2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics *European Standard*

[11] Kazanci O B, Khovalyg D, Takayoshi I, Uno Y, Ukiana T and Olesen, B W 2018 Experimental comparison of the thermal indoor environment created by a radiant, and a combined radiant and convective cooling system. *Proc. of Roomvent & Ventilation 2018* (Espoo) pp 223–228

[12] Hoyt T, Lee K H, Zhang H, Arens E and TomWebster T 2005 Energy savings from extended air temperature setpoints and reductions in room air mixing International *Conf. on Environmental Ergonomics 2009* (Boston)