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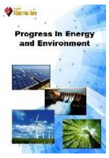

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Original Article

Evaluating thermal comfort in a vascular interventional radiology laboratory: Utilizing an onsite measurement approach

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Nur Dayana Ismail[1], Keng Yinn Wong[1], Hong Yee Kek[1], Yi Ka Fong[1], Muhammad Faiz Hilmi Rani[1], Wei Hao Ang[2], Wei Xian Ang[3], Huiyi Tan[4,*]

[1] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2] Wantar Engineering & Constructions, 81750 Masai, Johor, Malaysia
[3] Jurutera JRK Sdn. Bhd., 81100 Johor Bahru, Johor, Malaysia
[4] Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[*] **Correspondence email:** huiyitan@utm.my

Abstract

A vascular interventional radiology (VIR) laboratory is a specialized medical environment designed for diagnostic and therapeutic procedures focused on blood vessels. In this facility, healthcare practitioners employ diverse imaging technologies such as fluoroscopy and angiography to visualize blood vessels and conduct minimally invasive interventions. This research examines the thermal comfort within a VIR laboratory through the field measurements. Assessing thermal comfort in a VIR laboratory supports Sustainable Development Goals (SDGs) by enhancing the welfare and working conditions in the healthcare settings (SDG 3 and SDG 9). This effort also aligns with SDG 11 by advocating for sustainable urban environments through the optimization of indoor environmental conditions. The gathered data brings to light notable disparities in air temperature, relative humidity, and air velocity, underscoring the absence of homogeneity in the laboratory setting. It's evident that 67% of the spaces within the VIR laboratory will induce a "cool" sensation among medical staff members in standby mode, with the remaining 33% causing a "slightly cool" sensation. Both the Predicted Percentage of Dissatisfied (PPD) and Predicted Mean Vote (PMV) indices for thermal comfort deviate from the established ASHRAE 55 standard, emphasizing the considerable hurdles in achieving the desired thermal conditions. By integrating findings from this study into policy frameworks, stakeholders can prioritize investments in infrastructure and technology aimed at enhancing thermal comfort standards in healthcare facilities. This proactive approach not only fosters a conducive environment for medical procedures but also advances progress towards achieving key SDGs.

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1 Introduction

A vascular interventional radiology laboratory, commonly known as a VIR lab, is a specialized medical facility designed for diagnostic and therapeutic procedures focused on blood vessels. Within this setting, healthcare professionals, particularly interventional radiologists, utilize various imaging technologies like fluoroscopy and angiography to visualize blood vessels and perform minimally invasive interventions. These procedures, such as angioplasty, stent placement, and embolization, offer treatment for vascular conditions without the necessity for traditional open surgery. The VIR laboratory is specifically structured to provide a controlled and precise environment for these intricate medical procedures, ensuring both safety and accuracy while minimizing the impact on the patient. In recent years, a unidirectional airflow system is employed to guarantee effective air distribution. Under standard operating conditions, the room is maintained at a positive pressure relative to the corridor and surrounding areas.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 55 Standard [1] characterizes thermal comfort as the mental state indicating contentment with the thermal environment. According to ASHRAE 55 Standard [1], the factors influencing thermal comfort encompass relative humidity (RH), air temperature (Ta), air velocity (Va) and mean radiant temperature (Tmrt). Also, human factors such as clothing insulation and metabolic heat rate production also contribute to thermal comfort. Human thermal comfort is influenced by factors including ambient temperature, relative humidity, air movement, clothing, metabolic rate, personal characteristics, acclimatization, and psychological factors [2]. On the other hand, different climate requires different level of comfort parameters [3]. For instance, occupants typically feel comfortable when temperatures range from 12°C to 20°C during winter, whereas for summer, the range is between 21°C and 28°C [4, 5]. The significant diversity in thermal comfort, influenced by multiple factors, suggests a wide range of acceptability and tolerance among individuals [6]. International standards emphasize achieving satisfactory thermal comfort for up to 80%-90% of occupants to ensure sufficient comfort within indoor spaces [7].

Approximately 80–90% of individuals' time is spent indoors [8]. The thermal conditions established within this setting significantly impact both the emotional and physical well-being of its residents. Unlike other environments, the thermal comfort range within residential buildings is broader due to the varied needs and unpredictable activities of its inhabitants. Residents employ diverse strategies to adapt to their surroundings, which contributes to this expanded comfort spectrum [6]. Indoor temperatures are closely linked to outdoor temperatures [9]. Studies have shown that during outdoor temperatures below 10°C, indoor air temperatures in the majority of cases range from 14°C to 24°C [6]. However, the thermal comfort experienced in residential buildings is influenced by different climates and continents. For instance, countries in the Middle East typically maintain temperatures below 16°C in winter and range from 25°C to 32°C in summer [10]. The installation of efficient heating, ventilation, and air conditioning (HVAC) systems plays a vital role in controlling indoor temperatures and ensuring optimal air quality.

Ensuring the optimal condition of work environments is crucial for maximizing productivity and concentration among occupants. The thermal comfort requirements for offices and classrooms vary slightly from residential buildings due to factors such as higher occupancy rates and anticipated activities within the space. Research conducted in Tokyo, Japan, revealed that well-equipped offices with HVAC systems typically maintain indoor temperatures ranging from 22°C to 25°C [11]. Another study suggested that the ideal temperature range for maximizing productivity falls between 20°C and 25°C [12]. In contrast, classrooms in Singapore are deemed acceptable in terms of thermal comfort when temperatures range from 26.3°C to 31.7°C [13]. This disparity in temperature between offices and classrooms can be attributed to the prevalence of HVAC systems in offices compared to the predominant use of fans in classrooms. However, it's important to note that the thermal comfort of these workspaces is also influenced by external factors such as the prevailing climate and ambient temperature of the surrounding area.

Public transportation constitutes a densely populated environment where maintaining high thermal comfort is essential. Various modes of public transportation, including taxis, buses, trains, subways, and flights, are commonly utilized. The thermal comfort experienced within these vehicles varies depending on factors such as temperature, air velocity, humidity, occupants' activity levels, and the insulating properties of clothing [14]. Comfort levels in transient spaces fluctuate widely due to the constant movement of occupants [15,16]. For instance, subways in Shanghai maintain a thermal temperature of 20.6°C, with occupants reporting a satisfaction rate of 92.1%, while during the summer season in South Korea, temperatures typically range between 26.5°C and 27.1°C [17]. In hot climates like those prevalent in Asia, buses are often equipped with indoor temperatures set at 23°C in summer and 19°C in winter. In aircraft, the average indoor temperature is typically maintained between 21°C and 25°C [18]. It's evident that thermal comfort levels in public transportation significantly differ from those in indoor buildings. To ensure adequate thermal comfort in transient environments, it's imperative to consider factors such as the surrounding environment, climate fluctuations, and occupants' behaviors. Specific observations and adjustments are necessary to meet these comfort requirements effectively.

The operating air temperature range recommended by ASHRAE for indoor environments is typically between 16-24 °C [19]. Research conducted by Niemela et al. found that productivity in a call centre decreased by 5-7% when the office temperature exceeded 25°C. Moreover, the performance of workers decreased by 2.4% per degree Celsius when the temperature rose between 21.9°C to 28.5°C [20]. Also, Pilcher et al. discovered that at 10°C, worker productivity decreased by an average of 13.91%, while at 32.22°C, worker performance decreased by 14.88% [21]. Similarly, in accordance with ASHRAE standards, the humidity level within an office environment should ideally be maintained between 30%-60%. Humidity levels below 30% can result in thermal discomfort, such as dryness and irritation, while higher humidity levels can feel oppressive and exacerbate sensations of heat discomfort [21]. Also, inadequate thermal comfort can pose a risk of contamination and infections. In environments requiring high levels of cleanliness and hygiene, such as operating rooms in hospitals, the temperature is typically maintained within the range of 20-23°C [22]. A higher air temperature, particularly when temperatures exceed 23°C, can lead to discomfort for surgeons, resulting in sweating and a decrease in performance during surgical procedures [24], due to their extra layer of personal protective equipment (PPE) [23]. When the surgeon's sweat comes into contact with a patient's open wound during surgery, it could increase the risk of patient contracting with surgical site infections (SSI) [24].

To the best of authors knowledges, no study has examined the thermal comfort in VIR laboratory. The intricacies and precision required in vascular interventions demand a conducive thermal environment within the radiology laboratory. Maintaining optimal temperature, air velocity, and relative humidity levels is crucial for the concentration and focus of medical personnel, ultimately enhancing procedural accuracy and patient care. The objective of this current study is to comprehensively assess thermal comfort within the vascular interventional radiology laboratory. The contribution of this research extends beyond the laboratory, impacting society by enhancing the working conditions for healthcare professionals and improving the overall experience and outcomes for patients undergoing vascular interventions. By optimizing thermal comfort, this study aims to positively influence the efficiency and quality of healthcare services in the broader context.

2 Methodology

This study took place in a VIR laboratory, belonging to a private hospital situated in Selangor, Malaysia. The onsite measurement was conducted during nighttime hours, from 10 pm to 1 am. To ensure that the air temperature, air velocity, relative humidity, and other operating parameters achieved steady state condition, the air-conditioning unit was turned on 1 hour prior to the measurement. The 3D model of VIR laboratory is shown in Fig. 1(a), while the detailed dimensions of the furniture are tabulated in Table 1.

Field measurements were conducted by assessing the air temperature, air velocity, and relative humidity within the vascular interventional radiology laboratory. All measurements were conducted manually, instead of using Internet of Things (IoT) approach as stated by Garcés, et al. [25]. Nine (9) different locations were measured in the laboratory, as shown in Fig. 1 (b). The measurements were taken at a height of 1.1 meters above the floor. Air velocity and air temperature were quantified using an Alnor balometer EBT 731 (ALNOR, Huntington Beach, CA, USA), while relative humidity and air temperature were measured with a Testo 625 digital thermo-hygrometer (Testo Inc., Lenzkirch, Germany). The accuracy of balometer on airflow velocity measurement is± 3%, while the accuracy of relative humidity and air temperature are ± 2.5% and ± 0.5°C, respectively. The radiant temperature was measured using UNI-T 120 infrared thermal imaging camera (Uni-Trend Technology, Guangdong, China), with an accuracy of ± 0.5°C. The data were recorded for three times and the average value was recorded. All the measurement devices were calibrated in compliance with ISO 9001: 2015 [26].

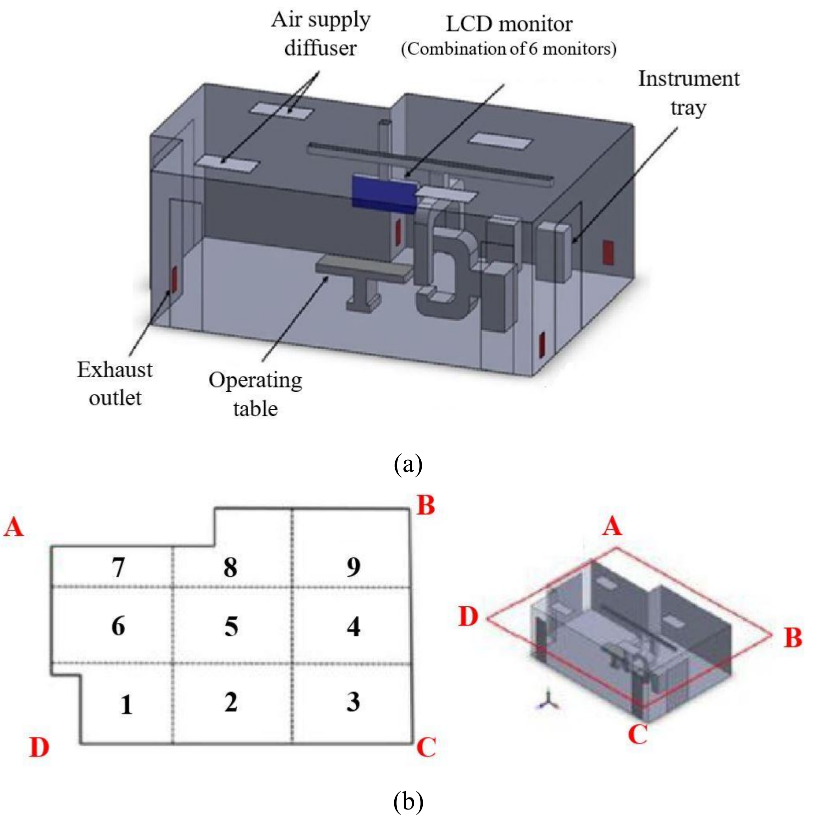

Fig. 1 (a) 3D model of VIR laboratory details, (b) Sampling points for onsite measurement.

Table 1 Description of the furniture dimension in the VIR laboratory.

Operating System	Dimension	Quantity
Cleanroom standard	ISO Class 8	NA
Types of Air Flow Supply	Laminar – low turbulence	NA
Room Size	≈250 m^3	NA
Exhaust Grilles	0.22 m (W) × 0.46 m (H)	4
Air Supply Diffusers	1.2 m (W) × 0.6 m (L)	4
LCD monitor	0.46 m (W) × 0.30 m(L) × 0.15 m (T)	6
Instrument tray	0.45 m (W) × 0.60 m(L) × 1.0 m (H)	2
Operating table	0.6 m(W) × 1.9 m (L) × 0.8 m (H)	1

**W represents width, L represents length and H represents height, T represents thickness, NA represents not applicable.

Optimal indoor air quality of VIR laboratory is aimed to reduce the risk of surgical site infections (SSI). Air change rate (ACH) of at least 20 times the domain's volume per hour need to be achieved. Low ACH will cause stagnant airflow and increased in microbial counts. As operating room acts as positive pressure. The onsite measurement of pressure in VIR laboratory is crucial to create barrier at VIR laboratory door gap to prevent build up microbial contamination. Alnor EBT 731 balometer is used to measure the differential pressure in OR. During measurement, all VIR laboratory doors are closed to prevent redirection of airflow and changes of temperature. Movement of opening and closing door will affect the pressure by 6Pa Air temperature and humidity is measured using digital thermo-hygrometer

(Testo 625, Lezkirch, Germany). These two parameters are measured simultaneously for each sample grid as shown in Fig. 1(b).

2.1 Thermal comfort evaluation

This study examines the thermal comfort within the VIR laboratory by employing the predicted mean votes (PMV) index and predicted percentage of dissatisfied (PPD) index. PMV serves as a quantitative metric frequently employed in the analysis of thermal comfort, offering an evaluation of individuals' comfort levels within a specific area. This measure takes into account various factors including ambient air temperature, humidity, air velocity, clothing insulation, and metabolic rate [27,28]. Conversely, PPD, an index commonly utilized in assessing thermal comfort and optimizing HVAC systems for building design, quantifies the percentage of occupants likely to be dissatisfied with the thermal conditions of a space. PPD analysis primarily focuses on empirical data and statistical models, considering the same factors as PMV, namely air temperature, humidity, air velocity, clothing insulation, and metabolic rate [29-31]. The ASHRAE 55 Standard [1] utilizes a psycho-physical seven-point thermal sensation scale to articulate individuals' perceptions of their surroundings. Table 2 illustrates the quantification of people's thermal sensation. The ideal range of human preferences lies within -0.5 to 0.5.

Table 2 People's thermal sensation scale based on index of PMV [32].

Hot	Warm	Slightly Warm	Neutral	Slightly Cool	Cool	Cold
+3	+2	+1	0	-1	-2	-3

The PMV and PPD value can be computed via Eq. (1) to Eq. (6) [33]:

$$\mathrm{PMV} = \left[0.303\exp(-.036\mathrm{M}) + 0.028\right]L \tag{1}$$

where, 0.303 and 0.028 are constant values, M is the metabolic rate (W/m^2), and L is the thermal load on the body. The thermal load could be determined via Eq. (2).

$$L = M - W - \begin{cases} 3.96\times10^{-8} f_{cl}\left[(T_{cl}+273)\times4-(T_r+273)\times4\right]+ \\ f_{cl}h_c(T_{cl}-T)+3.05\times10^{-3}\left[5733-6.99(M-W)-P_V\right]+ \\ 0.42(M-V-58.15)+1.7\times10^{-5}(5867-P_V)+0.0014M(34-T) \end{cases} \tag{2}$$

where W denotes active work (W/m^2) and f_{cl} denotes the garment insulation factor (1 clo = 0.155 m^2 K/ W).

$$f_{cl} = \begin{cases} 1.05+0.6451I_{cl} & I_{cl} > 0.078 \\ 1+1.291I_{cl} & I_{cl} < 0.078 \end{cases} \tag{3}$$

The term I_{cl} stands for the resistance to sensible heat transfer provided by a clothing ensemble (m^{2}K/W), while T_{cl} (°C) term is defined as the cloth temperature.

$$T_{cl} = 35.7 - 0.028(M-W) - I_{CL} \tag{4}$$

T_r (°C) is the mean radiant temperature, T (°C) is local air temperature and h_c is the heat transfer coefficient between the cloth and air (W/m^2-k). The heat-transfer coefficient is given by:

$$h_c = 12.5u0.5 \text{ for } 2.38(T_{cl}-T)\ 0.25 < 12.1 \tag{5}$$

Standard values are assumed for occupants' metabolic rates and clothing insulation. Inside the VIR laboratory, measurements are taken for air temperature (T_a), air velocity (V_a), and relative humidity (RH). The PPD is a measure indicating the percentage of individuals experiencing discomfort beyond a slight degree, serving as an indicator of dissatisfaction with environmental conditions [3]. This metric is crucial for evaluating occupants' satisfaction with thermal comfort, with an ideal PPD value being below 10% [32]. The calculation of PPD involves using Eq. (6) with the PMV index as the input [33]:

$$\mathrm{PPD} = 100 - \exp\left(-0.03353\mathrm{PMV}^4 + 0.217\mathrm{PMV}^2\right) \tag{6}$$

3 Results and Discussion

Thermal comfort is highly significant in VIR laboratories, directly impacting the well-being and performance of both patients and medical personnel. Yet, previous research has predominantly focused on microbial contamination and indoor air quality in VIR laboratories or operating rooms [34]. There is a scarcity of studies examining thermal comfort in operating rooms, with no exploration of the thermal conditions in VIR laboratories [35]. Maintaining optimal thermal comfort in the VIR laboratory is essential as it directly influences surgeons' concentration, dexterity, and overall performance during invasive procedures [36]. Also, from a patient's perspective, inadequate thermal comfort (experiencing low temperature) could predispose them to hypothermia [37].

In this study, the clothing insulation value was 0.61 clo (as proposed in CBE thermal comfort tool by ASHRAE 55 [1]). This clothing insulation value is chosen considering that the medical staff members are wearing trousers and long-sleeve shirt, mimicking the medical attire in VIR laboratory. Two metabolic rates were considered on the medical staff members, which are in upright standing standby mode and upright standing performing light to moderate activity, with metabolism rate of 1.2 met ($\approx$1.2 W/m^2) and 1.4 met ($\approx$1.4 W/m^2), respectively. Table 3 shows that the PMV and PPD index based on the 9 sampling locations.

Examining Table 3 reveals that the PMV ranges from -0.92 to -2.16. When comparing the present PMV values against the thermal sensation scale ($-3 \leqslant \mathrm{PMV} \leqslant 3$), it suggests that the VIR laboratory provides inadequate thermal conditions for the medical staff members. The PPD falls within the range of 25% to 84% for all locations within the VIR laboratory, indicating a prevailing "cool" and "slightly cool" thermal comfort condition. According to ASHRAE 55 [1], these values indicate discomfort levels. The recommended PMV range is between -0.5 to +0.5, with PPD ideally below 10%. The current thermal sensation experienced by the medical staff members is graphically represented in Fig. 2.

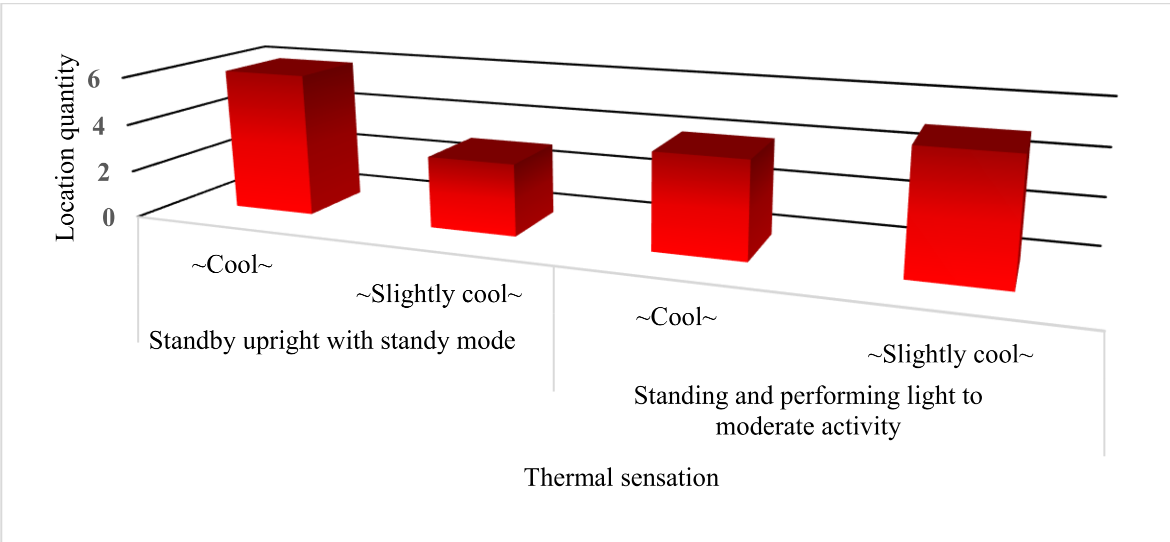

Fig. 2 Thermal sensation of medical staff members under the current operating conditions in VIR laboratory.

Table 3 PMV and PPD indices obtained in 9 different locations in the VIR laboratory.

Location	T_a (°C)	V_a (m/s)	RH (%)	T_{mrt} (°C)	Clothing (Clo)	Activity (met)		Standing with standby mode		Standing and performing light to moderate activity		Thermal Sensation	
						Standing with standby mode	Standing and performing light to moderate activity	PMV	PPD	PMV	PPD	Standing with standby mode	Standing and performing light to moderate activity
P1	18.5	0.23	57	20.7	0.61	1.2	1.5	-1.99	76%	-1.54	53%	Cool	Cool
P2	19.6	0.16	58	20.7	0.61	1.2	1.5	-1.48	-50%	-1.14	32%	Slightly Cool	Slightly cool
P3	18.5	0.24	57	20.7	0.61	1.2	1.5	-2.01	77%	-1.56	54%	Cool	Cool
P4	19.7	0.16	59	20.7	0.61	1.2	1.5	--1.44	48%	-1.11	31%	Slightly cool	Slightly cool
P5	19.3	0.15	59	20.7	0.61	1.2	1.5	-1.53	53%	-1.19	35%	Cool	Slightly cool
P6	19.8	0.15	57	20.7	0.61	1.2	1.5	-1.39-	45%	-1.07	29%	Cool	Slightly cool
P7	18.3	0.25	58	20.7	0.61	1.2	1.5	-2.09	81%	-1.62	58%	Cool	Cool
P8	20.3	0.17	59	20.7	0.61	1.2	1.5	--1.29	40%	-0.98	25%	Slightly cool	Slightly cool
P9	18.0	0.24	57	20.7	0.61	1.2	1.5	-2.16	84%	-1.69	61%	Cool	Cool

Referring to Fig. 2, it is evident that 67% of the areas within the VIR laboratory will induce a "cool" sensation for medical staff members standing upright in standby mode, while the remaining 33% will result in a "slightly cool" sensation. Additionally, 44% of the locations in the VIR laboratory will cause medical staff engaged in surgery to experience a "cool" sensation, with the remaining 56% leading to a "slightly cool" sensation. Overall, none of the locations in the VIR laboratory are conducive to optimal thermal comfort for medical staff members. This discovery aligns well with Khalid, et al. [38] study, which suggests that the comfort temperature for patients, visitors, and nurses should be higher, at 25.7°C, 25.5°C, and 23.5°C, respectively. Yau and Chew [39] also revealed that the neutral temperature for hospitals in Malaysia is 26.4°C, with 90% of occupants expressing satisfaction within the temperature range of 25.3°C to 28.2°C. Notably, areas beneath the air supply diffusers, such as sampling points 1, 3, 7, and 9, exhibit higher air velocity conditions compared to other sampling locations. Achieving a more uniform airflow distribution and air temperature in a VIR laboratory is advisable to enhance thermal conditions for medical staff members.

4 Conclusion

Assessing thermal comfort in a VIR laboratory via onsite measurement methods supports various Sustainable Development Goals (SDGs). Enhancing comfort in healthcare settings corresponds to SDG 3 (Good Health and Well-being) by enhancing the welfare of medical staff, patients, and visitors. Employing advanced onsite measurement techniques represents advancement in infrastructure management, contributing to SDG 9 (Industry, Innovation, and Infrastructure), and fostering improved working conditions for healthcare personnel. Also, this effort aligns with SDG 11 (Sustainable Cities and Communities) by advocating for sustainable urban environments through the optimization of indoor environmental conditions.

This study explores the thermal comfort levels within a VIR laboratory through field measurements. The collected data indicates an uneven distribution of air temperature, relative humidity, and air velocity. It is apparent that 67% of the areas within the VIR laboratory will elicit a "cool" sensation for medical staff members in standby mode, while the remaining 33% will result in a "slightly cool" sensation. Both the PPD and PMV indices for thermal comfort fall outside the ASHRAE 55 standard. These results underscore the challenge of achieving optimal thermal comfort within the laboratory. The study advocates for further investigations to identify more effective strategies for attaining the desired thermal comfort level in the VIR laboratory.

Future studies should explore advanced ventilation strategies, gather direct feedback from healthcare professionals, and monitor long-term thermal conditions to enhance our understanding of thermal comfort in vascular interventional radiology laboratories. Also, investigating the impact of thermal conditions on procedural outcomes and incorporating human-centric design principles can contribute to the development of comprehensive guidelines for optimizing the working environment in these specialized medical settings.

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Declaration of Conflict of Interest

The authors declared that there is no conflict of interest with any other party on the publication of the current work.

References

[1] A. Standard, 55, Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air conditioning Engineers 145 (1992).

[2] Q. Zhao, Z. Lian, D. Lai, Thermal comfort models and their developments: A review, Energy and Built Environment 2(1) (2021) 21-33. https://doi.org/https://doi.org/10.1016/j.enbenv.2020.05.007.
[3] N. Djongyang, R. Tchinda, D. Njomo, Thermal comfort: A review paper, Renewable and Sustainable Energy Reviews 14(9) (2010) 2626-2640. https://doi.org/https://doi.org/10.1016/j.rser.2010.07.040.
[4] X. Gong, Q. Meng, Y. Yu, A Field Study on Thermal Comfort in Multi-Storey Residential Buildings in the Karst Area of Guilin, Sustainability 13(22) (2021) 12764.
[5] H.B. Rijal, K. Yoshida, M.A. Humphreys, J.F. Nicol, Development of an adaptive thermal comfort model for energy-saving building design in Japan, Architectural Science Review 64(1-2) (2021) 109-122. https://doi.org/10.1080/00038628.2020.1747045.
[6] N. Aqilah, H.B. Rijal, S.A. Zaki, A Review of Thermal Comfort in Residential Buildings: Comfort Threads and Energy Saving Potential, Energies 15(23) (2022) 9012.
[7] J.A. Orosa, A.C. Oliveira, J.A. Orosa, A.C. Oliveira, Thermal comfort and indoor air quality, Passive Methods as a Solution for Improving Indoor Environments (2012) 1-13.
[8] Y. Al horr, M. Arif, M. Katafygiotou, A. Mazroei, A. Kaushik, E. Elsarrag, Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature, International Journal of Sustainable Built Environment 5(1) (2016) 1-11. https://doi.org/https://doi.org/10.1016/j.ijsbe.2016.03.006.
[9] K. Lee, D. Lee, The Relationship Between Indoor and Outdoor Temperature in Two Types Of Residence, Energy Procedia 78 (2015) 2851-2856. https://doi.org/https://doi.org/10.1016/j.egypro.2015.11.647.
[10] S. Monna, A. Barlet, M.H. Hussein, D. Bruneau, M. Baba, Human thermal comfort for residential buildings in hot summer and cold winter region, a user based approach, Journal of Physics: Conference Series 1343(1) (2019) 012150. https://doi.org/10.1088/1742-6596/1343/1/012150.
[11] S. Kawakubo, M. Sugiuchi, S. Arata, Office thermal environment that maximizes workers' thermal comfort and productivity, Building and Environment 233 (2023) 110092. https://doi.org/https://doi.org/10.1016/j.buildenv.2023.110092.
[12] S. Nagarathinam, H. Doddi, A. Vasan, V. Sarangan, V.R. Padullaparthi, A. Sivasubramaniam, Energy efficient thermal comfort in open-plan office buildings, Energy and Buildings 139 (2017). https://doi.org/10.1016/j.enbuild.2017.01.043.
[13] W. Yang, N.H. Wong, S.K. Jusuf, Thermal comfort in outdoor urban spaces in Singapore, Building and Environment 59 (2013) 426-435. https://doi.org/https://doi.org/10.1016/j.buildenv.2012.09.008.
[14] M. Simion, L. Socaciu, P. Unguresan, Factors which Influence the Thermal Comfort Inside of Vehicles, Energy Procedia 85 (2016) 472-480. https://doi.org/https://doi.org/10.1016/j.egypro.2015.12.229.
[15] V.E.M. Cardoso, N.M.M. Ramos, R.M.S.F. Almeida, E. Barreira, J. Poças Martins, M.L. Simões, L. Sanhudo, A discussion about thermal comfort evaluation in a bus terminal, Energy and Buildings 168 (2018) 86-96. https://doi.org/https://doi.org/10.1016/j.enbuild.2018.03.013.
[16] C. Chun, A. Kwok, A. Tamura, Thermal comfort in transitional spaces—basic concepts: literature review and trial measurement, Building and Environment 39(10) (2004) 1187-1192. https://doi.org/https://doi.org/10.1016/j.buildenv.2004.02.003.
[17] S. Pan, Y. Liu, L. Xie, X. Wang, Y. Yuan, X. Jia, A thermal comfort field study on subway passengers during air-conditioning season in Beijing, Sustainable Cities and Society 61 (2020) 102218. https://doi.org/https://doi.org/10.1016/j.scs.2020.102218.
[18] J. Fan, Q. Zhou, A Review about Thermal Comfort in Aircraft, Journal of Thermal Science 28(2) (2019) 169-183. https://doi.org/10.1007/s11630-018-1073-5.
[19] M.L. de la Hoz-Torres, A.J. Aguilar, D.P. Ruiz, M.D. Martínez-Aires, An investigation of indoor thermal environments and thermal comfort in naturally ventilated educational buildings, Journal of Building Engineering 84 (2024) 108677. https://doi.org/https://doi.org/10.1016/j.jobe.2024.108677.
[20] R. Niemelä, M. Hannula, S. Rautio, K. Reijula, J. Railio, The effect of air temperature on labour productivity in call centres—a case study, Energy and buildings 34(8) (2002) 759-764.
[21] J.J. Pilcher, E. Nadler, C. Busch, Effects of hot and cold temperature exposure on performance: a meta-analytic review, Ergonomics 45(10) (2002) 682-698.
[22] T.L. Heinke, A. Joseph, D. Carroll, Safety in Health Care: The Impact of Operating Room Design, Anesthesiology Clinics 41(4) (2023) 789-801. https://doi.org/https://doi.org/10.1016/j.anclin.2023.05.005.
[23] R. Viseur, A. Charleux, B. Fally, How makers responded to the Personal Protective Equipment shortage during the COVID-19 pandemic: An analysis focused on the Hauts-de-France region, European Management Journal 41(4) (2023) 634-647. https://doi.org/https://doi.org/10.1016/j.emj.2023.04.014.
[24] Y. Ma, K. Shen, D. Wu, Z. Lu, Sweat contamination induced surgical site infections after spine surgery: Three case reports and literature review, International journal of surgery case reports 94 (2022) 107153. https://doi.org/10.1016/j.ijscr.2022.107153.

[25] H.O. Garcés, C. Durán, E. Espinosa, A. Jerez, F. Palominos, M. Hinojosa, R. Carrasco, Monitoring of Thermal Comfort and Air Quality for Sustainable Energy Management inside Hospitals Based on Online Analytical Processing and the Internet of Things, International Journal of Environmental Research and Public Health, 2022.
[26] H. Tan, K.Y. Wong, B.B. Nyakuma, H.M. Kamar, W.T. Chong, S.L. Wong, H.S. Kang, Systematic study on the relationship between particulate matter and microbial counts in hospital operating rooms, Environmental Science and Pollution Research (2021). https://doi.org/10.1007/s11356-021-16171-9.
[27] S. Zhang, Z. Lin, Predicted Mean Vote with skin temperature from standard effective temperature model, Building and Environment 183 (2020) 107133. https://doi.org/https://doi.org/10.1016/j.buildenv.2020.107133.
[28] S. Zhang, Y. Cheng, M. Olaide Oladokun, Y. Wu, Z. Lin, Improving predicted mean vote with inversely determined metabolic rate, Sustainable Cities and Society 53 (2020) 101870. https://doi.org/https://doi.org/10.1016/j.scs.2019.101870.
[29] D. Markov, Practical evaluation of the thermal comfort parameters, Annual International Course: Ventilation and Indoor climate, Avangard, Sofia, 2002, P. Stankov (Ed), pp. 158 – 170, ISBN 954-9782-27-1 (2002).
[30] S. Yan, N. Liu, W. Wang, S. Han, J. Zhang, An adaptive predicted percentage dissatisfied model based on the air-conditioner turning-on behaviors in the residential buildings of China, Building and Environment 191 (2021) 107571. https://doi.org/https://doi.org/10.1016/j.buildenv.2020.107571.
[31] G. Liu, X. Wang, Y. Meng, Y. Zhang, T. Chen, Research on Prediction and Regulation of Thermal Dissatisfaction Rate Based on Personalized Differences, Applied Sciences 13(13) (2023) 7978.
[32] A. Standard, 55, Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air conditioning Engineers 145 (2004).
[33] J. Atkinson, Natural ventilation for infection control in health-care settings, World Health Organization2009.
[34] H.Y. Kek, H. Tan, D.D.C. Vui Sheng, Y. Lee, N.D. Ismail, M.S. Deris, H. Mohamed Kamar, K.Y. Wong, A CFD assessment on ventilation strategies in mitigating healthcare-associated infection in single patient ward, Progress in Energy and Environment 24 (2023) 35-45. https://doi.org/10.37934/progee.24.1.3545.
[35] M. Zwolińska, A. Bogdan, Thermal sensations of surgeons during work in surgical gowns, International Journal of Occupational Safety and Ergonomics: JOSE 19(3) (2013) 443-53. https://doi.org/10.1080/10803548.2013.11077000.
[36] R. Van Gaever, V.A. Jacobs, M. Diltoer, L. Peeters, S. Vanlanduit, Thermal comfort of the surgical staff in the operating room, Building and Environment 81 (2014) 37-41. https://doi.org/https://doi.org/10.1016/j.buildenv.2014.05.036.
[37] G. Deiana, A. Arghittu, M. Dettori, M.G. Deriu, A. Palmieri, A. Azara, P. Castiglia, M.D. Masia, Ten-Year Evaluation of Thermal Comfort in Operating Rooms, Healthcare (Basel, Switzerland) 10(2) (2022). https://doi.org/10.3390/healthcare10020307.
[38] W. Khalid, S.A. Zaki, H.B. Rijal, F. Yakub, Thermal comfort requirements for different occupants in Malaysian hospital in-patient wards, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 43(1) (2018) 128-140.
[39] Y.H. Yau, B.T. Chew, Thermal comfort study of hospital workers in Malaysia, Indoor Air 19(6) (2009) 500-10. https://doi.org/10.1111/j.1600-0668.2009.00617.x.