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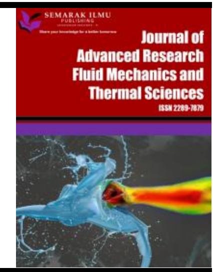

Analysis of Temperature and Relative Humidity Distributions in a Dental Treatment Room at a Government Health Clinic in Malaysia

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ABSTRACT

This study investigates the vertical distribution of temperature and relative humidity within dental treatment rooms at a Government Type 3 Health Clinic in Gial Perlis, Malaysia, addressing a significant gap in the literature regarding environmental conditions in dental healthcare settings. Precise measurements were conducted at four specific heights 0.3 m, 1.0 m, 1.7 m, and 2.7 m utilizing calibrated digital thermometers with hygrometers to capture accurate environmental data. The collected data were analysed using Analysis of Variance (ANOVA) to assess the significance of variations across these levels. Results revealed statistically significant differences in both temperature and relative humidity ($p < 0.05$). At the uppermost level (2.7 m), the highest mean temperature of 22.1°C and a mean relative humidity of 68.2% were recorded, while the lowest level (0.3 m) exhibited the lowest mean temperature of 20.9°C and the highest mean relative humidity of 73.8%. Temperatures at the patient level (1.0 m and 1.7 m) averaged between 21.0 °C and 21.6°C, which is slightly below the optimal comfort range of 22°C to 26°C. These vertical gradients indicate that the existing HVAC systems may not be effectively regulating indoor conditions, potentially impacting patient comfort, the performance of temperature-sensitive dental materials, and the effectiveness of infection control measures due to altered aerosol behaviour. The findings underscore the necessity of optimizing HVAC designs to achieve uniform temperature and humidity distributions within dental treatment rooms. This research provides valuable insights for healthcare professionals and policymakers, emphasizing the importance of tailored environmental management strategies to enhance patient comfort, procedural outcomes, and safety in dental healthcare settings.

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1. Introduction

1.1 Importance of Temperature Management in Healthcare Facilities

Proper temperature management is crucial for healthcare facilities, including dental treatment rooms, as it directly impacts patient comfort and the effectiveness of medical procedures [1]. Established guidelines for temperature control in healthcare settings aim to ensure that patients feel at ease and remain safe when receiving care [2]. However, there is a paucity of empirical evidence regarding the vertical temperature distribution within dental treatment rooms in Malaysia and its potential implications for patient comfort and treatment outcomes.

This study investigates the vertical temperature distribution at four distinct heights within dental treatment rooms in Malaysian Government Type 3 Health Clinics. This aims to address a notable gap in existing literature. Understanding the temperature distribution at these different levels is crucial for optimizing patient comfort and treatment effectiveness, as temperature variations can significantly impact both [3]. By employing advanced measurement tools and statistical analysis methods, the study seeks to identify opportunities for improvement and provide actionable insights to enhance temperature management.

This research seeks to explore opportunities for improving temperature management in dental treatment rooms, analyze the methods used to assess temperature distribution, and examine the implications of temperature variations on patient comfort and treatment effectiveness. The findings will offer valuable insights that healthcare professionals and policymakers can utilize to enhance patient comfort and treatment quality in healthcare facilities. Additionally, this research will contribute to the wider academic knowledge base on temperature management in healthcare settings, providing new perspectives for better planning and design of healthcare environments, particularly in the Malaysian context and beyond.

Maintaining appropriate temperature control in healthcare environments is crucial for establishing optimal conditions that promote patient comfort and enhance the effectiveness of medical procedures [2]. In dental treatment rooms specifically, maintaining an appropriate temperature distribution is paramount, as it directly impacts both patient comfort and the efficiency of dental procedures [4]. Some dental materials used during treatment are sensitive to temperature fluctuations, and inadequate temperature control can render them ineffective, resulting in suboptimal treatment outcomes [5]. Furthermore, extreme temperatures can adversely affect patient health, causing discomfort and potentially exacerbating existing medical conditions.

1.2 Developing Temperature Guidelines for Healthcare Facilities

Developing specific temperature guidelines for healthcare facilities is challenging due to the diverse needs and preferences of patients, staff, and visitors [6-7]. Previous research has explored thermal comfort in Malaysian hospitals and found that the acceptable temperature range for hospital wards is often lower than the standards set by Malaysian Standard MS1525 and the Industry Code of Practice on Indoor Air Quality [2,8]. This indicates a need for customized thermal comfort guidelines tailored to healthcare environments in Malaysia [2]. However, these studies have primarily focused on general hospital settings and patient wards, without addressing the specific requirements of dental treatment rooms [2,8].

In dental treatment rooms, maintaining a consistent and optimal temperature is especially important as temperature variations can significantly influence the effectiveness of dental materials and procedures [9]. Despite the critical role of temperature regulation, research on this topic, particularly in Malaysia's dental treatment rooms, remains scarce. Existing studies have largely

focused on general temperature trends in other facilities and do not delve into the specific dynamics within dental treatment rooms [10-16]. This gap in research limits the ability of healthcare professionals and policymakers to develop targeted interventions and design changes that would enhance patient comfort and treatment quality.

Addressing this research gap is not just an academic exercise but a practical necessity. This study aims to investigate temperature variations at different heights within dental treatment rooms at the Government Type 3 Health Clinic in Gial Perlis, Malaysia. By using a systematic research design, temperatures will be measured at four different vertical levels, and the data will be analyzed using Analysis of Variance (ANOVA) to identify significant temperature differences [17]. The findings from this study will provide valuable insights into optimizing temperature management in dental treatment rooms, leading to improved patient comfort and healthcare efficiency [5].

The significance of this research extends beyond merely filling a gap in literature. It offers an opportunity to contribute to the body of knowledge on temperature control in healthcare settings, specifically dental treatment rooms [5,18]. This is particularly relevant for healthcare centers in Malaysia and could be applicable to similar settings globally. Effective temperature management is also crucial in the context of infectious disease prevention, such as during the COVID-19 pandemic, highlighting the importance of controlled environments in healthcare activities [19]. Therefore, this research is timely and pertinent, addressing how healthcare centers can better prepare for and prevent health issues related to temperature extremes.

1.3 Role of Environmental Factors in Patient Comfort

Additionally, this study contributes to the broader discussion about the role of environmental factors in shaping patient comfort and treatment efficiency in dental care facilities. While previous research has identified various environmental factors like ambient noise and lighting that affect patient experience and treatment outcomes [20,21], this study uniquely examines the impact of temperature distribution. By doing so, it expands the understanding of environmental management in healthcare settings and provides new insights for creating optimal conditions for both patients and healthcare providers.

In recent years, several studies have been conducted on temperature management in healthcare facilities. These include research on temperature management in dental treatment rooms, contributing to the existing knowledge about temperatures and their impacts on comfort and effectiveness in dental procedures, investigated temperature distribution in a hospital in Malaysia and found that the current thermal comfort standards might not be adequate to meet the desired occupants' needs in Malaysian hospital wards [5,22].

Prior research has investigated the influence of temperature and humidity on patient thermal comfort preferences in various hospital ward settings [2,23,24]. These studies have recommended implementing customized hospital cooling strategies based on patient preferences to improve energy efficiency. Additionally, other scholars have explored the association between temperature, humidity, and the prevalence of hand, foot, and mouth disease in Guangzhou, China, suggesting that higher temperatures and humidity levels are directly linked to increased HFMD incidence [25].

Previous studies have examined the influence of temperature on diverse room settings [26,27]. Research has investigated how temperature regulation in surgical theaters affects infection rates and patient recovery durations [28]. These findings indicate that maintaining an accurate temperature range can significantly reduce postoperative complications. Additionally, examinations of thermal comfort in neonatal intensive care units have highlighted the critical necessity of precise temperature control for the well-being of premature infants [29]. Similarly, other scholars have analyzed the

impacts of HVAC system design on energy consumption and thermal comfort in hospital environments, proposing improvements to enhance energy efficiency without compromising patient comfort [30]. However, despite the expanding body of research on temperature management across various healthcare contexts, a specific emphasis on dental treatment rooms remains limited.

This study endeavors to apply broader insights on thermal management to the specific context of dental treatment rooms. By delving into the thermodynamic dynamics within these specialized spaces, it aims to uncover innovative approaches that could enhance patient comfort and potentially identify more energy-efficient temperature control solutions than conventional HVAC systems [31]. To address the paucity of research on temperature distribution in Malaysian dental rooms, this investigation examines the vertical temperature profiles in the dental treatment rooms at the Government Type 3 Health Clinic in Gial Perlis, Malaysia, yielding valuable data to inform the development of effective interventions.

1.4 Research Gap and Objectives of the Study

While existing studies have explored temperature management in healthcare settings, particularly hospital wards, there is a notable paucity of research focusing on vertical temperature and relative humidity distributions within dental treatment rooms in Malaysia. This gap is critical because variations in both temperature and humidity can directly affect patient comfort, the performance of temperature-sensitive dental materials, and the effectiveness of infection control measures. Previous research largely overlooks the unique thermal and hygrometric dynamics of dental treatment environments, which differ significantly from those in general hospital wards due to factors such as specialized equipment heat loads and the generation of aerosols during procedures. Therefore, addressing this unexplored aspect within the Malaysian context is essential to enhance the understanding of environmental control's influence on patient outcomes and procedural efficacy.

This study aims to systematically examine the variations in temperature and relative humidity across four different heights within dental treatment rooms at a Government Type 3 Health Clinic in Gial Perlis, Malaysia. By employing precise digital measurements of both temperature and humidity and applying Analysis of Variance (ANOVA) for data analysis, the research seeks to uncover any significant vertical differences in these environmental parameters. The findings will contribute to optimizing environmental management in dental clinics, ultimately aiming to enhance patient comfort, improve the performance of temperature-sensitive dental materials, and strengthen infection control measures.

The significance of this research lies in its potential to provide practical insights for healthcare professionals and policymakers, enabling them to better design and manage dental treatment environments. Understanding the nuances of vertical temperature and humidity distributions could inform guidelines that enhance patient comfort and procedural efficacy, ensuring that dental treatment rooms meet optimal thermal and hygrometric conditions conducive to patient care and safety.

Furthermore, by addressing this gap in research, the study seeks to contribute to a broader academic understanding of environmental management in specialized healthcare settings. The focus on Malaysian dental treatment rooms will offer context-specific findings that can be generalized or adapted to similar healthcare environments globally, enhancing the overall body of knowledge and fostering advancements in healthcare facility design, particularly in relation to HVAC optimization and infection control protocols.

2. Methodology

2.1 Methodology Overview

This quantitative study aimed to assess the vertical distribution of temperature and relative humidity within dental treatment rooms at the Government Type 3 Health Clinic in Gial Perlis, Malaysia. Utilizing a convenience sampling methodology, environmental measurements were recorded at four discrete vertical levels. Measurements were conducted during standard operating hours, with personnel positioned at the dental chair and at the location where the dentist typically sits to simulate actual clinical conditions. This approach ensured that the data collected accurately reflected the thermal environment during typical dental procedures. The Heating, Ventilation, and Air Conditioning (HVAC) system had undergone multiple rounds of testing and commissioning and was prepared for handover from the Public Works Department to the Ministry of Health, ensuring optimal functionality during the data collection phase.

The spatial configuration of the dental treatment room is depicted in Figure 1, which provides a detailed 3D schematic illustrating the boundary conditions. The figure highlights the positions of critical elements such as the inlet diffuser, outlet diffuser, windows, cabinets, dental chair, and the typical locations of the dentist and patient. The inlet diffuser was located on the ceiling near the entrance, supplying conditioned air into the room, while the outlet diffuser was positioned opposite to facilitate effective air circulation and exhaust. The windows were situated on the side wall, providing natural light but remained closed during measurements to prevent external environmental influences. The placement of the dental chair and surrounding cabinets was designed to reflect standard clinical setups, ensuring that the study environment closely mirrored real-world conditions.

Instrumentation for this study included calibrated devices to ensure accuracy and reliability throughout the experimental period. As in Figure 2, the Industrial Digital Thermometer Hygrometer K-type Thermocouple Probe Lab Air Humidity Temperature Meter USB Data Logger GM1361 facilitated precise data acquisition by enabling the simultaneous recording of temperature and relative humidity at multiple points.

Prior to data collection, each instrument underwent rigorous calibration. Measurements at each height were recorded over a period sufficient to ensure data stabilization, capturing the nuances of the thermal and humidity profiles within the room. This comprehensive methodology, supported by validated equipment and conducted under conditions simulating authentic clinical environments, enabled the collection of robust environmental data essential for subsequent analysis.

By integrating detailed spatial information and employing precise measurement techniques, the study aimed to provide a thorough understanding of the vertical variations in temperature and relative humidity within dental treatment rooms. The inclusion of the room's schematic and experimental setup visuals enhances the transparency of the methodology and allows for reproducibility in future research endeavors.

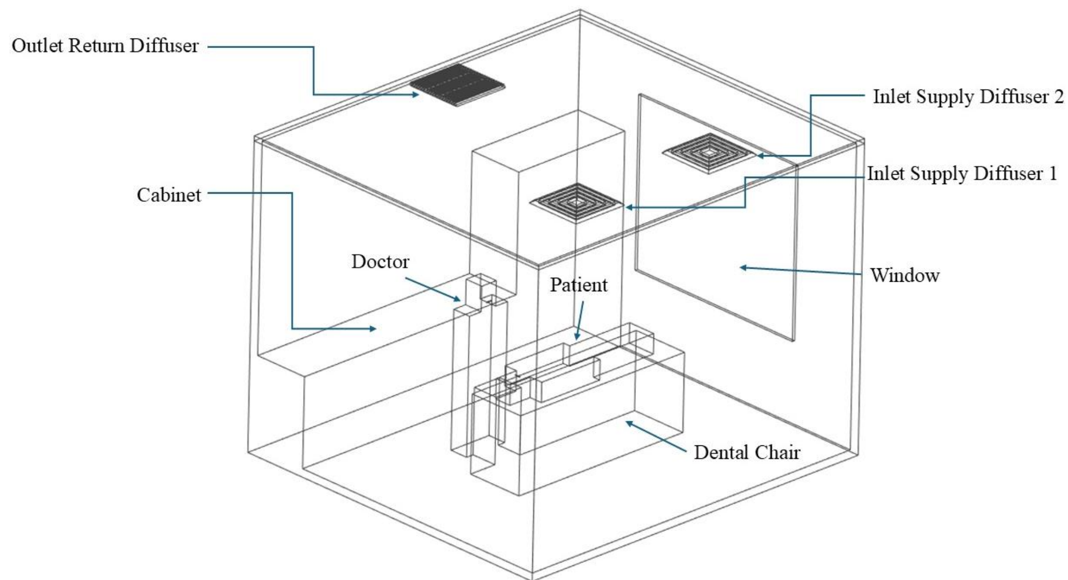
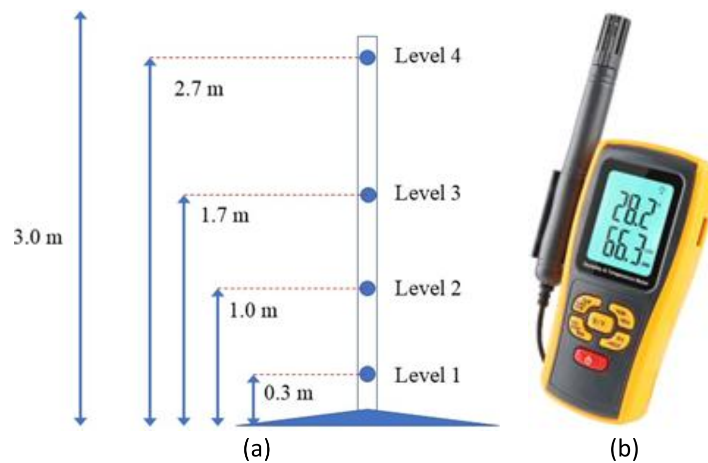


Fig. 1. Detail of the boundary condition in the dental treatment room

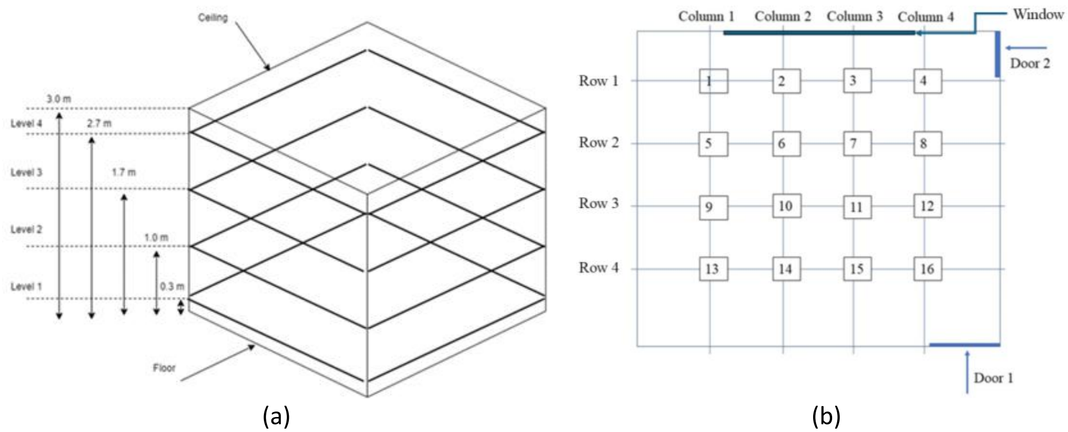


(a) (b)

Fig. 2. (a) The attachment of an extension pole to the stand plate, (b) Industrial digital thermometer hygrometer

2.2 Experimental Setup and Instrumentation

The experimental setup was designed to assess the vertical distribution of temperature and relative humidity within the dental treatment rooms by systematically recording data at four specific heights, as depicted in Figure 3. The measurement heights were strategically set at 0.3 meters, 1.0 meter, 1.7 meters, and 2.7 meters (Figure 3(a)) to represent different vertical levels within the treatment room environment. Sixteen measurement points were established during the experiment, with the points equally divided across the four vertical levels (Figure 3(b)). This division ensured comprehensive spatial coverage and a balanced representation of both temperature and humidity variations throughout the room. At each height, temperature and relative humidity were measured using thermocouples and hygrometers capturing readings for approximately five minutes at each point to stabilize and record accurate data. This arrangement of levels and points allowed for a detailed examination of thermal and humidity gradients and contributed to understanding how these environmental parameters vary within the dental treatment space.



(a) (b)

Fig. 3. (a) Four temperature levels of height during the experiment, (b) the sixteen points were equally divided during the experiment

2.3 Data Analysis: ANOVA Application and Measurement Protocol

The analysis of variance (ANOVA) was used to determine the degree of variability among the different vertical levels of temperature measurement [32,33]. The test was applied to assess whether significant differences existed in the mean temperatures across four vertical heights (0.3 meters, 1.0 meter, 1.7 meters, and 2.7 meters) in the dental treatment rooms. The hypotheses tested included a null hypothesis (H_0), which suggested that the average temperature was consistent across all levels ($\mu_1 = \mu_2 = \mu_3 = \mu_4$), and an alternative hypothesis (H_a), which implied that at least one vertical level's mean temperature was significantly different from the others. To achieve this, the F -statistic was calculated as the ratio of the variance between groups (heights) to the variance within groups (individual measurements), as shown in Eq. (1):

$$F = \frac{\text{Mean Square Between Groups (MSB)}}{\text{Mean Square Within Groups (MSW)}} \quad (1)$$

where MSB and MSW were derived from the sum of squares between (SSB) and within (SSW) groups, divided by their respective degrees of freedom. The degrees of freedom for the between-groups variance were $k - 1$, and for within-groups variance, it was $N - k$, where k is the number of levels and N the total observations.

A p-value threshold of 0.05 ($p < 0.05$) was used for statistical significance, and an F-value greater than the critical F -value would lead to rejecting (H_0). Data were collected over a two-week period, measured twice daily from 8 AM to 7 PM to capture diurnal fluctuations. Stable five-minute periods were used to ensure consistent readings [34]. All temperatures were recorded in degrees Celsius for uniformity. The use of ANOVA facilitated the examination of temperature differences across heights, providing insights into the vertical temperature distribution within the treatment rooms.

2.4 Ensuring Validity and Reliability

To ensure the validity and reliability of the study, multiple measures were undertaken. The thermometer underwent calibration before data collection to guarantee accuracy, and its reliability was verified through a pilot study in the same dental treatment rooms. The research adhered to standard protocols to ensure that data collection processes were systematic and repeatable, enhancing the study's credibility. The design of the study aligns with temperature management

research in healthcare settings, with a particular emphasis on capturing temperature variations at different heights within the room. The use of a calibrated digital data logger and consistent measurement periods further reinforced the validity of the temperature readings, providing reliable data for analysis and interpretation.

3. Results

3.1 ANOVA Results for Temperature and Relative Humidity Distribution

Table 1 presents the detailed experimental results of temperature and relative humidity measurements at each of the four vertical levels within the dental treatment rooms. The data include readings from multiple points and provide a comprehensive view of the environmental conditions observed during the study.

The data in Table 1 illustrate the temperature and relative humidity (RH) readings collected at each level, with multiple measurements providing a robust dataset for analysis. Observations show that temperatures tend to increase with height, while relative humidity decreases, indicating an inverse relationship between these two parameters.

Proceeding to the statistical analysis, the collected data were subjected to Analysis of Variance (ANOVA) to determine if the differences observed across the vertical levels were statistically significant.

Table 1
The results of an experiment to measure temperature and relative humidity distribution across different levels were depicted in a table

Experimental Result For Temperature And Relative Humidity Distribution For Every Level									
		Column 1		Column 2		Column 3		Column 4	
Level 4	Row 1	24.5°C	58.9%	25.0°C	57.2%	23.0°C	64.1%	22.0°C	68.5%
	Row 2	23.5°C	62.1%	25.5°C	55.5%	24.0°C	60.5%	20.5°C	75.2%
	Row 3	21.3°C	71.2%	20.9°C	73.0%	20.6°C	74.4%	20.4°C	75.4%
	Row 4	21.8°C	69.1%	20.5°C	75.2%	20.5°C	75.2%	20.3°C	75.9%
Level 3	Row 1	22.0°C	68.5%	23.0°C	64.1%	24.0°C	60.5%	21.3°C	71.2%
	Row 2	21.5°C	70.5%	22.5°C	66.2%	22.9°C	64.5%	19.8°C	79.1%
	Row 3	21.0°C	72.5%	21.8°C	69.1%	22.6°C	65.8%	20.3°C	75.9%
	Row 4	20.8°C	73.3%	21.4°C	70.9%	21.4°C	70.9%	19.6°C	80.0%
Level 2	Row 1	21.2°C	71.9%	22.5°C	66.2%	22.7°C	65.4%	20.1°C	76.9%
	Row 2	21.2°C	71.9%	22.2°C	67.6%	20.8°C	73.3%	19.8°C	79.1%
	Row 3	21.4°C	70.9%	21.4°C	70.9%	19.9°C	78.1%	19.5°C	81.0%
	Row 4	21.4°C	70.9%	22.2°C	67.6%	20.2°C	76.4%	19.2°C	82.0%
Level 1	Row 1	20.8°C	73.3%	21.7°C	69.6%	22.3°C	67.0%	19.3°C	81.5%
	Row 2	21.5°C	70.5%	21.8°C	69.1%	20.3°C	75.9%	19.7°C	79.5%
	Row 3	22.0°C	68.5%	23.3°C	62.8%	20.1°C	76.9%	19.7°C	79.5%
	Row 4	20.2°C	76.4%	22.5°C	66.2%	19.4°C	80.5%	19.1°C	83.1%

As shown in Table 2, the mean temperature increases progressively from Level 1 to Level 4. Level 1 (0.3 m) has the lowest mean temperature of 20.9°C, while Level 4 (2.7 m) has the highest mean temperature of 22.1°C. The temperature range also expands at higher levels, with Level 4 exhibiting the widest range from 20.3°C to 25.5°C.

Table 2
The temperature experimental results are presented in the form of statistical data

Variable	N	Mean	SE Mean	St. Dev	Min.	Q1	Median	Q3	Max.
Level 1	16	20.86	0.33	1.31	19.10	19.70	20.55	21.95	23.30
Level 2	16	20.98	0.28	1.10	19.20	19.95	21.20	22.00	22.70
Level 3	16	21.62	0.30	1.20	19.60	20.85	21.45	22.58	24.00
Level 4	16	22.14	0.46	1.83	20.30	20.50	21.55	23.88	25.50

The ANOVA results for temperature yielded a p-value less than 0.05, indicating that the differences in mean temperatures across the levels are statistically significant. This confirms that temperature varies notably with height within the dental treatment rooms.

As summarized in Table 3, Relative humidity decreases with increasing height. Level 1 exhibits the highest mean RH of 73.8%, while Level 4 has the lowest mean RH of 68.2%. The variability in RH measurements is also evident, with Level 4 showing a wider range from 55.5% to 75.9%. The ANOVA results for relative humidity also yielded a p-value less than 0.05, confirming that the differences in mean relative humidity across the levels are statistically significant.

Table 3
The relative humidity experimental results are presented in the form of statistical data

Variable	N	Mean	SE Mean	St. Dev	Min.	Q1	Median	Q3	Max.
Level 1	16	0.7377	0.0156	0.0622	0.6280	0.6865	0.7460	0.7950	0.8310
Level 2	16	0.7313	0.0131	0.0525	0.6540	0.6843	0.7190	0.7780	0.8200
Level 3	16	0.7019	0.0134	0.0534	0.6050	0.6590	0.7070	0.7310	0.8000
Level 4	16	0.6821	0.0184	0.0736	0.5550	0.6090	0.7015	0.7520	0.7590

3.2 Interpretation of Results

The significant vertical variations in both temperature and relative humidity indicate a clear stratification within the dental treatment rooms. The inverse relationship between temperature and relative humidity is consistent with thermodynamic principles, where warmer air at higher levels can hold more moisture, resulting in lower relative humidity percentages. At the patient level (Levels 2 and 3), the mean temperatures range from 21.0°C to 21.6°C, which is slightly below the optimal comfort range of 22°C to 26°C. Relative humidity at these levels is above the recommended comfort range of 40% to 60%, potentially leading to discomfort for patients and staff.

The variability in temperature and RH at different heights suggests that the existing HVAC system may not be effectively maintaining uniform environmental conditions. This stratification could impact patient comfort, the performance of temperature-sensitive dental materials, and the effectiveness of infection control measures due to changes in aerosol behaviour.

3.3 ANOVA Table and Factor Information Analysis

Table 4 presents the results of the Analysis of Variance (ANOVA), a statistical technique employed to determine if there are significant differences among the mean values of two or more groups. The null hypothesis in ANOVA assumes that all group means are equal, while the alternative hypothesis posits that at least one mean is significantly different from the others. The key to interpreting ANOVA is to examine the variability within each group, which allows researchers to ascertain whether the observed means are statistically distinct. ANOVA is a crucial analytical tool used across diverse fields, including social sciences, medicine, and engineering, to evaluate data and draw meaningful inferences.

Table 4
The hypothesis statistical method used (ANOVA)

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

Table 5 presents detailed information on the four vertical levels analyzed in this research: Level 1 (0.3 meters), Level 2 (1.0 meter), Level 3 (1.7 meters), and Level 4 (2.7 meters). This table summarizes the temperature and relative humidity data collected at each level, which were essential for the Analysis of Variance (ANOVA). Data were collected for each level, and the necessary ANOVA assumptions were verified, allowing for a valid comparison of the means across the different levels. The analysis determined significant differences among the means of the temperature and humidity measurements at these levels, indicating the presence of thermal and humidity stratification within the dental treatment rooms.

Table 5
Levels and values for ANOVA analysis

Factor	Levels	Values
Factor	4	Level 1, Level 2, Level 3, Level 4

The ANOVA analysis results presented in Table 6 provide insights into the statistical significance of the differences observed across the vertical levels of the dental treatment rooms. The analysis had 3 degrees of freedom for the factor, with adjusted sums of squares of 17.15 and adjusted mean squares of 5.717. The F-value for the factor was 2.96, and the associated p-value was 0.039. These findings indicate that the differences in mean temperatures across the factor levels were statistically significant, as the probability of such differences occurring by chance was less than 5%. Furthermore, the analysis reveals that the error term had 60 degrees of freedom, with adjusted sums of squares of 115.75 and mean squares of 1.929. The total degrees of freedom in the analysis were 63, and the total adjusted sums of squares were 132.90. These results suggest that there were significant differences in the mean temperatures across the various levels of the factor, and this information can be used to explore the underlying factors contributing to these differences and inform future decision-making.

Table 6
Sources of variation, degrees of freedom, and F-value at α = 0.05

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	17.15	5.717	2.96	0.039
Error	60	115.75	1.929		
Total	63	132.90			

3.4 Hypothesis Testing and Statistical Significance

The core premise of this research was to investigate whether the temperature distribution within different vertical levels of dental treatment rooms is uniform. The null hypothesis assumed that the average temperature across the four measurement levels was the same. Conversely, the alternative hypothesis posited that there were differences in the average temperature. The researchers employed Analysis of Variance (ANOVA), a statistical technique, with a significance threshold of α = 0.05. The ANOVA results revealed a p-value of 0.039, which is less than the alpha level. This suggests

that the hypothesis of uniform temperature across the various heights should be rejected, as there was a statistically significant variance in the vertical temperature distribution.

3.5 Alignment with Previous Research and HVAC Implications

The findings of this study align with previous research on temperature regulation in diverse healthcare settings. A common theme across the reviewed literature is that simply installing HVAC systems is insufficient. Factors within the treatment environment can significantly influence the performance of HVAC systems. These elements, such as ventilation and external temperatures, are critical not only for enhancing patient comfort and treatment outcomes, but also for maintaining healthcare temperature standards. The results of this investigation indicate that there were statistically significant variations in temperature across the vertical levels within the dental treatment room, as evidenced by the p-value of 0.039.

3.6 Model Summary and R-squared Interpretation

The model summary in Table 7 provides the standard error (S) and R-squared statistics for the ANOVA model. The R-squared value of 12.91% suggests that the model explains only a modest portion of the variation in temperature and humidity data. The adjusted R-squared value is 8.55%, accounting for the number of predictors in the model, while the predicted R-squared value is a mere 0.91%, indicating limited ability to predict future observations. These low R-squared values imply that the model may not adequately capture all the factors influencing the temperature and humidity variations observed.

Table 7
Model summary for an ANOVA analysis: S, R-squared, and predictive power

S	R-sq	R-sq(adj)	R-sq(pred)
1.38893	12.91%	8.55%	0.91%

The modest explanatory power of the model suggests the presence of other variables or confounding factors affecting the indoor environmental conditions that were not included in the analysis. It may be necessary to explore additional factors such as occupancy levels, equipment heat load, or external weather conditions to improve the model's fit. Assessing the normality of the data distribution and identifying any potential outliers could also enhance the model's accuracy. By refining the model and incorporating additional relevant variables, a more robust understanding of the factors affecting temperature and humidity distribution within the dental treatment rooms can be achieved.

3.7 Mean Temperature Differences and Confidence Intervals

Table 8 presents the means, standard deviations, and 95% confidence intervals for the four levels of the analyzed factor. The mean values range from 20.856 to 22.144, with standard deviations between 1.102 and 1.832. The 95% confidence intervals provide the range within which the true population mean is expected to lie, based on the sample data. An examination of the 95% confidence intervals reveals substantial differences among the four factor levels, as the intervals do not overlap. The mean for Level 4 is notably higher than the means for the other three levels, while the mean for

Level 3 is below that of Level 1. The means for Levels 2 and 3 are closely related, with Level 3 being slightly higher than Level 2.

Table 8
Descriptive statistics for four levels of a factor in an ANOVA analysis: mean, standard deviation, and 95% confidence interval

Factor	N	Mean	StDev	95% CI
Level 1	16	20.856	1.309	(20.162, 21.551)
Level 2	16	20.981	1.102	(20.287, 21.676)
Level 3	16	21.619	1.198	(20.924, 22.313)
Level 4	16	22.144	1.832	(21.449, 22.838)

These findings shed light on the relationships between the different factor levels and the outcome variable being measured. They suggest that the various levels could have distinct effects on the dependent variable. This table is therefore integral to the ANOVA analysis, as it provides meaningful insights into the relationships between the different factor levels and the dependent variable. The 95% confidence intervals can also help identify which means differ significantly, guiding researchers to the most important findings for their analysis.

3.8 Fisher's Post-hoc Analysis and Pairwise Comparisons

Table 9 presents the results of the Fisher's post-hoc pairwise comparisons, which enable the identification of significant differences between the means of the various factor levels following a significant ANOVA result. The grouping information is based on the Fisher's Least Significant Difference (LSD) method and 95% confidence intervals. The analysis reveals three distinct groups of means. The first group consists solely of Level 4, with a mean of 22.144, which is significantly different from all the other mean values at the 95% confidence level. The second group includes Level 3, with a mean of 21.619, and this mean is significantly different from the means of Levels 1 and 2, which are 20.856 and 20.981, respectively. Finally, the third group contains Levels 1 and 2, and these two levels are significantly different from each other.

Table 9
Fisher pairwise comparisons of mean values for four levels of a factor

Factor	N	Mean	Grouping	
Level 4	16	22.144	A	
Level 3	16	21.619	A	B
Level 2	16	20.981		B
Level 1	16	20.856		B

These findings provide valuable insights into the relationships between the factor levels and the outcome variable under investigation. The notable difference between Level 4 and all other levels suggests a unique effect of Level 4 on the outcome variable, while the observed difference between Level 3 and Levels 1 and 2 indicates that Levels 1 and 2 are more similar to each other than to Level 3. Fisher's pairwise comparisons serve as a robust post-hoc tool for determining which specific groups of means differ significantly following a significant ANOVA result. This knowledge can enhance the understanding of the relationships between factor levels and the outcome variable, and inform future analyses and research decisions.

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3.9 Fisher's Individual Confidence Intervals and Temperature Comparisons

Fisher's individual 95% confidence intervals (CIs) serve as a valuable statistical tool to compare the means of different groups, providing insights into the significance of differences between levels. As illustrated in Figure 4, the Minitab output displays these CIs as vertical lines plotted against the difference of means, with a reference line at zero representing no difference from the overall mean. A CI that does not intersect these zero lines indicates a statistically significant difference from the overall mean at the 95% confidence level. In the present analysis, the factor had four levels that were compared. To investigate the differences between the means of these four levels, we can examine the individual CIs of each level in relation to the others when compared pairwise.

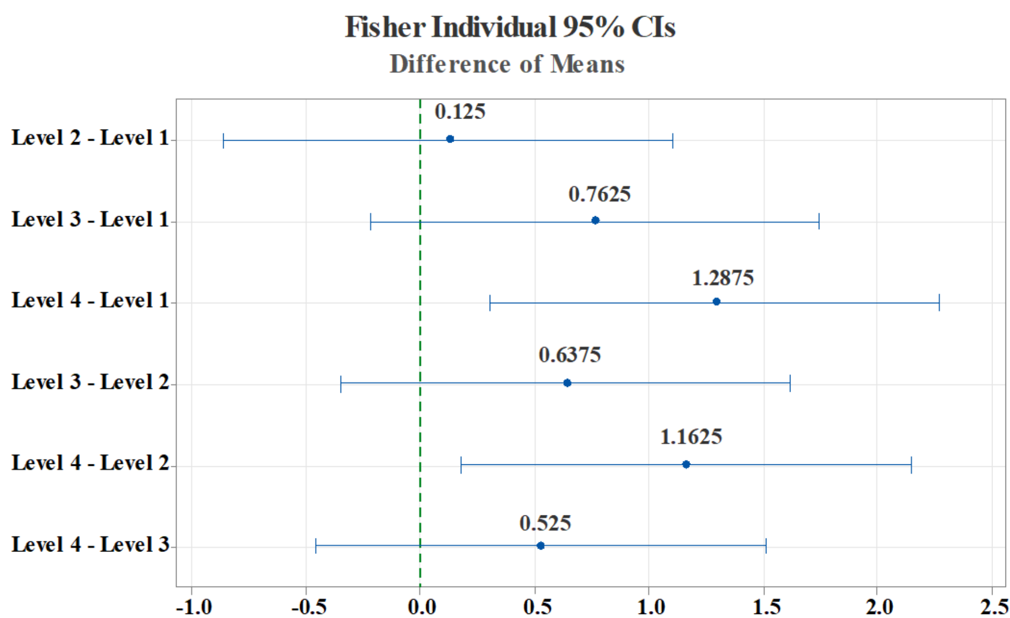

Fig. 4. Fisher individual 95% confidence intervals for pairwise comparisons of means in an ANOVA analysis

Comparing to Level 1, the CI for Level 2 is above the zero line, indicating that its mean is significantly higher than the overall mean at the 95% confidence level. Conversely, the CI for Level 1 is below the zero line, suggesting that its mean is significantly lower than the overall mean. When comparing to Level 1, the CIs for Level 3 and Level 1 are both above the zero line, but the CI for Level 3 is higher, implying that its mean is even more significantly different from the overall mean than that of Level 1. Similarly, the CI for Level 4, when compared to Level 1, is significantly above the zero line, indicating that its mean is substantially higher than that of Level 1.

The CI for Level 3 is also above the zero line when compared to the CI for Level 2, suggesting that the Level 3 mean is significantly higher than the mean for Level 2. The same pattern is observed for the comparison of Level 4 and Level 2, where the CI for Level 4 is above the zero line, indicating its mean is significantly higher than Level 2's mean. Lastly, both CIs for Level 3 and Level 4 are higher compared to Level 2, but the CI for Level 4 is higher compared to Level 3, implying that its mean is more significantly different from Level 3's mean. In summary, Fisher's individual 95% CIs can be a valuable tool for comparing means between different groups, providing insights into the relationships between the factor levels and the outcome variable. The visual representation of these CIs in Minit.

4. Discussion

4.1 Re-examination of the Hypothesis in Context

The core hypothesis of this research posited that vertical temperature and humidity distributions within dental treatment rooms significantly influence patient comfort and the efficacy of dental procedures. Previous studies have consistently underscored the paramount importance of precise temperature and humidity control in healthcare environments, noting that fluctuations and inconsistencies can adversely affect patient well-being and compromise the performance of temperature-sensitive dental materials [1-3]. Specifically, materials such as resin composites, glass ionomer cements, and dental adhesives are known to exhibit altered physical and chemical properties outside the optimal temperature range of 20°C to 24°C and relative humidity levels between 40% and 60% [9]. For instance, resin composites may experience reduced polymerization efficiency and diminished mechanical strength when ambient temperatures fall below 20°C or exceed 24°C, leading to suboptimal restorative outcomes [35]. Similarly, impression materials can undergo dimensional instability at temperatures above 24°C or in environments with high humidity, resulting in inaccuracies in dental impressions and subsequent prosthetic fittings [36].

Moreover, patient comfort is significantly influenced by the thermal environment, with optimal comfort typically achieved within a temperature range of 22°C to 26°C and relative humidity between 40% and 60% [37]. Deviations from these ranges can lead to discomfort, reduced satisfaction, and potential physiological stress responses in patients [38]. Despite this recognition, specific investigations into vertical temperature and humidity variations within Malaysian dental treatment rooms have been conspicuously limited, creating a significant gap in the existing body of literature [4,5]. Addressing this deficiency, the present study offers a focused analysis of thermal and humidity profiles across different heights within these specialized settings, aiming to elucidate how such variations may impact patient experiences, procedural outcomes, and overall environmental quality.

4.2 Interpretation of Results and Statistical Analysis

The empirical findings revealed pronounced variations in temperature and relative humidity across the four designated vertical levels within the dental treatment rooms. The uppermost level (Level 4 at 2.7 meters) exhibited the highest mean temperature of 22.1°C and a mean relative humidity of 68.2%, whereas the lowest level (Level 1 at 0.3 meters) recorded the lowest mean temperature of 20.9°C and the highest mean relative humidity of 73.8%. Intermediate levels, Level 2 (1.0 meter) and Level 3 (1.7 meters), demonstrated mean temperatures of 21.0°C and 21.6°C, with corresponding mean relative humidity levels of 74.0% and 71.1%, respectively.

The application of Analysis of Variance (ANOVA) yielded p-values indicating statistically significant differences across the vertical levels ($p < 0.05$). This statistical evidence substantiates the rejection of the null hypothesis, confirming that temperature and humidity distributions within the dental treatment rooms are not uniform.

Notably, the temperatures at the patient level (approximately 1.0 to 1.7 meters) averaged around 21.0°C to 21.6°C, which is slightly below the optimal comfort range of 22°C to 26°C. Similarly, the relative humidity levels at these heights were above the optimal range of 40% to 60%, potentially leading to sensations of coolness or discomfort among patients, particularly those sensitive to lower temperatures and higher humidity levels [38]. Conversely, the temperatures at the uppermost level approached the lower threshold of the optimal comfort range, but this level is above the typical occupant zone.

These results align with the initial premise that vertical disparities in thermal and humidity conditions can materially affect patient comfort and the efficacy of dental procedures, particularly those involving temperature-sensitive materials. The observed temperatures and humidity levels at the patient zone falling outside the optimal comfort ranges may necessitate adjustments to the HVAC system to ensure patient comfort and satisfaction.

4.3 Implications for HVAC Systems and Thermal Stratification

The observed thermal stratification and humidity gradients suggest that existing Heating, Ventilation, and Air Conditioning (HVAC) systems may not be adequately regulating the indoor environment within the dental treatment rooms. The elevated temperatures and variable humidity at the uppermost level can be attributed to the stratification of air, a phenomenon where warmer air rises and forms distinct layers due to its lower density [9]. This stratification is often a consequence of inadequate ventilation or suboptimal HVAC design, which fails to promote sufficient air mixing and circulation.

The mean temperature differential of approximately 1.3°C and the relative humidity differential of 5.6% between the lowest and highest levels are substantial, potentially impacting patient comfort, the performance of temperature-sensitive dental materials, and the diffusion of aerosols [36]. Higher temperatures and lower humidity levels at upper levels can enhance aerosol evaporation rates, leading to smaller droplet nuclei that remain airborne longer, thereby increasing the risk of airborne transmission of infectious agents [39].

The temperatures at the patient level being below the optimal comfort range highlight the need for HVAC adjustments to raise the temperature within the occupant zone to enhance patient comfort. Additionally, maintaining uniform temperature and humidity distributions can improve the effectiveness of infection control measures by influencing aerosol behaviour [40].

4.4 Comparison with Existing Literature

The results of this study corroborate previous research that underscores the critical importance of maintaining consistent temperatures and humidity levels in healthcare settings to ensure patient comfort, optimize procedural outcomes, and enhance infection control [7,8,40]. Prior studies have highlighted that deviations from optimal thermal conditions can lead to patient discomfort and negatively influence the properties of dental materials sensitive to temperature and humidity fluctuations [5,8]. The temperature and humidity variations observed at different levels within the treatment rooms align with established theories of thermal dynamics and air circulation in enclosed spaces, where inadequate ventilation leads to air stratification [9].

This study extends the existing literature by providing empirical evidence specific to Malaysian dental treatment rooms, thereby addressing the previously identified gap [4,5]. By comparing the observed temperature and humidity levels with established optimal ranges for patient comfort and material performance, the findings highlight specific areas where environmental conditions can be improved.

4.5 Limitations of the Study

While the study provides valuable insights, certain limitations must be acknowledged. The research was conducted within a single healthcare facility, which may not be representative of all dental treatment rooms in Malaysia. The measurement period was relatively brief, encompassing

only a two-week timeframe, which may not capture longer-term trends or seasonal variations in temperature and humidity distribution. Additionally, external factors such as outdoor climatic conditions, occupancy rates, and specific HVAC operational parameters were not accounted for, potentially influencing the observed indoor environmental conditions.

4.6 Contributions to Knowledge and Practice

This research contributes to the academic discourse by filling a significant gap regarding vertical temperature and humidity distribution in Malaysian dental treatment rooms [4,5]. The findings have practical implications for healthcare professionals and policymakers, highlighting the need for tailored thermal and humidity management strategies within dental environments. By identifying inadequacies in current HVAC performance and their potential impact on patient comfort, procedural effectiveness, and infection control, the study emphasizes the importance of designing and implementing more effective ventilation, temperature, and humidity control systems. Such improvements are crucial not only for enhancing patient satisfaction and treatment outcomes but also for ensuring adherence to healthcare environmental standards, ultimately contributing to better healthcare delivery in Malaysia and potentially informing practices in similar contexts globally.

5. Conclusions

This study examined the vertical distribution of temperature and relative humidity within dental treatment rooms at a Government Type 3 Health Clinic in Gial Perlis, Malaysia. Measurements were taken at four specific heights 0.3 m, 1.0 m, 1.7 m, and 2.7 m using calibrated digital thermometers and hygrometers. Analysis of Variance (ANOVA) revealed significant differences across the vertical levels ($p < 0.05$). The uppermost level exhibited the highest mean temperature of 22.1 °C and a mean relative humidity of 68.2%, while the lowest level recorded the lowest mean temperature of 20.86 °C and the highest mean relative humidity of 73.8%. Temperatures at the patient level (1.0 m and 1.7 m) averaged between 21.0 °C and 21.6 °C, slightly below the optimal comfort range of 22 °C to 26 °C.

These vertical gradients have important implications for patient comfort, the performance of temperature-sensitive dental materials, and infection control measures. The cooler temperatures at the patient level may lead to sensations of discomfort and reduced satisfaction among patients. Additionally, fluctuations in temperature and humidity can adversely affect dental materials, potentially compromising procedural outcomes. Variations in environmental conditions may also influence aerosol behaviour, increasing the risk of airborne transmission of infectious agents due to altered evaporation rates.

The findings suggest that the existing HVAC systems are not adequately regulating the indoor environment to achieve uniform temperature and humidity distribution. Optimizing HVAC designs is essential to enhance patient comfort and procedural effectiveness. Implementing improved ventilation strategies and enhancing air circulation can mitigate stratification effects, promoting consistent environmental conditions that support both patient well-being and infection control.

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