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Prediction of Indoor Environmental Quality Using a Regression Model for Educational Buildings in Hot Arid Climate: A Case Study in the Al-Najaf Technical Institute – Iraq

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In hot climates, achieving a good indoor environmental quality (IEQ) in existing buildings is important especially with climate change challenges as future heat waves will increase in frequency, duration, and intensity. In educational buildings, there is much more focus on the IEQ parameters and the interactions among them that need to be in line with the continuously changing learning environment. This study assesses the IEQ parameters (represented by noise, temperature and humidity) at three selected campus areas (lecture rooms of an administrative department building (LR), main hall of a management department building (MH) and a central library building (CL)) at the

Al-Najaf Technical Institute (NTI), Al-Najaf City, Iraq, for the period from May to December 2019. A statistical analysis using a multi-linear regression model was performed to determine the relationship between the selected IEQ parameters and explain the noise level behavior as a function of the temperature and relative humidity. The research indicated that the noise levels and temperature values exceeded the maximum standard limits in all buildings reflecting the displeasing sound and heating quality within the studied areas, while the readings for relative humidity within each building environment complied with standards. Moreover, for both LR and MH buildings (R2 ≥ 0.8, significance F ≤ 0.01), the noise values were satisfactorily modeled by temperature and relative humidity highlighting the interactions between temperature, humidity and noise under consistent conditions. However, the results for the CL building (R2 = 0.6, significance F = 0.1) showed no relationship between the IEQ parameters, highlighting the fact that this building is exposed to unsteady conditions (an irregular number of people using this building during the daytime) resulting in a high variation of data measurements. The current results demonstrate that detailed modeling can be helpful to predict IEQ parameters depending on other known parameters in buildings. The results of the predictive model aligned with the directly measured data. Therefore, its performance is equally effective, but with a significant reduction in cost and time consumed.

Keywords: acoustic comfort, educational building, indoor environmental quality, regression model, thermal comfort.

Introduction

Recently, the public has become more aware of the quality of the indoor environment worldwide. Maintaining an acceptable indoor environment quality provides healthy and comfortable environments (Wang et al., 2021). This is particularly important for public buildings such as educational ones (El-Darwish & El-Gendy, 2018). Generally, the indoor environmental quality (IEQ) is important, because it is directly related to the learning capability of students and their well-being (Calama-González et al., 2019; Kapoor et al., 2021) as a healthy environment within an educational building can directly improve the health of students and their intellectual capacity, thereby promoting effective learning (Altomonte et al., 2019; Xu et al., 2021). Students spend about 70% of their time in university educational establishments due to year-round occupancy of lecture theatres, offices, seminars, library, group areas and laboratories. The indoor environment within these buildings has to be comfortable (Turunen et al., 2014; Savelieva et al., 2019). To gain more information, studies are performed analyzing the features of the indoor environment quality to decide if it is necessary to improve or renovate the building (Khalil et al., 2018; Work, 2020). This is to achieve better indoor comfort preferably together with low energy consumption (Zhong et al., 2019).

The parameters that influence the indoor environment are interconnected, and the main indoor environmental factors that affect the educational buildings are temperature, noise and humidity, especially in hot climate areas as high temperature with relative humidity can be a critical factor for faster sound wave travel (Calama-González et al., 2019; Pistore et al., 2020). The academic buildings' overall environmental quality takes into account all of these parameters. Each of the above environmental qualities is a determining factor in the assessment of the occupant's comfort, academic performance and health, which must be thoroughly considered in the lifecycle of an academic building (Martinez et al., 2021).

For example, acoustic comfort is an important requirement affecting the quality of indoor buildings (Akanmu et al., 2021). It relates to the ability of the building to provide an environment with minimal unwanted noise (Zuhaib et al., 2018). The source of this noise could be external to the academic building as in traffic (and other activities around the campus) or internal as from appliances in the classroom such as, for example, air conditioning and heating systems as well as distractions from fellow occupants (Mustafa, 2017). Thermal comfort should also be maintained as it affects the environmental quality of indoor buildings (Cui et al., 2013;

Forgiarini et al., 2015; Crosby & Rysanek, 2021). Indoor air temperature, rate of airflow, relative humidity and the transfer of radiant heat between the occupants and their surrounding environment are the main factors in determining the thermal comfort within buildings (Marincioni et al., 2021).

With climate change, attention to building quality has increased as the indoor environment is expected to become more of a refuge against heat and climate events (Mar et al., 2019; Hu, 2021). Reduced energy consumption in buildings (particularly energy consumed by cooling and mechanical ventilation systems) and the maintenance of adequate indoor environmental conditions are essential requirements in today's realization of climate change and global warming potential, particularly for buildings located in hot and arid climates (El-Darwish & Gomaa, 2017; Dias Pereira et al., 2021). However, most of the public buildings (specifically educational establishments) in hot arid climates consume large amounts of energy (El-Darwish & El-Gendy, 2018). Additionally, these buildings are seen as particularly likely to have environmental deficiencies, because of shortages in funding, which can contribute to inadequate operation and proper maintenance. Because educational facilities typically house a high number of people in a small space, the quality of the indoor environment is a public concern (Ali Al-Arja & Awadallah, 2016).

Research has recognized the effect of mitigating and adapting to the changing climate with regard to the indoor environment. However, further research in this area is still needed (Zalejska-Jonsson, 2019). It is crucial to understand how building elements affect temperatures inside buildings and monitoring these conditions in real time is essential information for determining which indoor environments are most vulnerable. This gives information about strategies used for mitigation and adaptation to decrease the effects of high temperature levels (Williams et al., 2019; Wang et al., 2021).

Strategies and toolsets proposed by researchers aiming to evaluate IEQ parameters and optimize the energy consumption within buildings under climate change conditions have been examined in a considerable number of studies (Khalil et al., 2018; Zuhaib et al., 2018; Toyinbo et al., 2019; Williams et al., 2019; Zhong et al., 2019; Crosby & Rysanek, 2021; Akanmu et al., 2021). Most of the methods were used depending on routine data collection to investigate the IEQ levels inside newer as well as existing buildings (Williams et al., 2019; Moreno Santamaria et al., 2020). A study optimizing energy consumption in educational buildings (Ali Al-Arja & Awadallah, 2016) recommends optimum solutions for minimum energy demand, taking into consideration the provision of a thermally comfortable environment inside. Salcido et al. (2016) presented a strategy using mixed-mode ventilation (MMV) processes to effectively save energy as well as maintain indoor air quality for the occupants by sustaining adequate indoor environmental conditions (Salcido et al., 2016).

Other studies indicate reasons behind low environmental quality in their case studies. Tahsildoost and Zomorodian (2018) found that minimum attention to local standards with regard to indoor air quality, acoustic, and lighting, especially in the old and retrofitted buildings was the main reason for low environmental quality within buildings (Tahsildoost & Zomorodian, 2018). Statistical models to the questionnaire data have been applied to predict the overall comfort within buildings (Cui et al., 2013; Mustafa, 2017; Tahsildoost and Zomorodian, 2018; El-Darwish and El-Gendy, 2018; Calama-González et al., 2019). A study by Erlandson et al. (2019) assessed indoor air quality in higher education institutions. The results suggest that occupancy status and building zones are major predictors of indoor air quality in campus buildings. Jain et al. (2020) showed that if the building design focuses predominantly on energy, unintended consequences of indoor environmental quality underperformance may occur where there are conflicts between energy and indoor environmental quality objectives (Jain et al., 2020).

An improved and well-researched understanding of how building IEQ parameters interact under climate change scenarios for future planning is limited in availability and little focus has been given to investigate the interconnections among IEQ parameters and using these relationships to predict the IEQ within buildings (Hosseini et al., 2017; Moreno Santamaria et al., 2020; Dias Pereira et al., 2021). In general, the routine measurements of the IEQ within the building do not give enough consideration of the climate change effects within hot areas on the overall indoor quality environment. Existing knowledge is still limited concerning the interaction between indoor quality factors affecting the IEQ in educational establishments. As the IEQ of buildings is a result of the interconnection between several factors, further exploration of the interactions of IEQ parameters is needed to update currently available knowledge of relationships among IEQ parameters and effectively use these relationships to predict IEQ parameters in educational buildings over time.

In this study, the indoor environmental quality of the three selected campus areas (LR building, MH building and CL building) inside the NTI campus of Al-Najaf City in Iraq were assessed. Statistical analysis by means of using correlation and multi-linear regression models has been performed to determine the interaction between the IEQ parameters; these include temperature, humidity, and noise levels. This study provides statistical analysis results to reveal the science associated with the relationship that demonstrates the interaction between the IEQ parameters and predicts the noise levels as the impact of temperature and relative humidity parameters over time. This will provide comfortable, reliable and cost-effective methods to predict the environmental quality parameters efficiently.

Materials and methods

Study area

This research was carried out at the NTI campus, which is a public institution of higher education located in Al-Najaf Governorate, Republic of Iraq. It is one of the most important educational and training establishments in central Iraq, and was established over four decades ago. According to the *H. Bailey's* classification, the campus is located in the hot climate zone (Mutar et al., 2016), about 5 km to the south of the Al-Najaf city as shown in F*ig. 1*, and includes both the technical institute and the technical college buildings. The holy city of Najaf is located at the point of longitude 44 ˚ 44' east and latitude 31 ˚ 59' north. The area of Najaf comprises 28 824 km^2.

The Al-Najaf Technical Institute includes thirteen technical departments in various specialties (technology, administration and applied arts) organized in facilities.

Fig. 1. *Location map of the Al-Najaf Technical Institute within the Al-Ashraf city*

With regard to the building characteristics, the wall finishing was made of gypsum plastering. About 5% of the total wall surfaces were covered with window frames. Gypsum board was used for room ceilings assembled on-site. The materials of the buildings were designed to increase energy efficiency with low fabric U-values (walls: 0.31 W/m^{2}K; windows: 1.81 W/m^{2}K; roof: 0.31 W/m^{2}K; and ground: 0.18 W/m^{2}K). Spaces were provided with large windows covered by curtains used for daylight adjustments. They are partially opened from time to time for natural ventilation (heating or cooling processes). Single-glazed material was used in the openings within the lecture rooms to maintain speech intelligibility and best communication. Ceiling baffles were applied to maintain low acoustic levels in all building spaces. Doors for the rooms inside the institute buildings were made from wood. The air conditioning units combined with the ventilation fans were installed on rooftops or inside chosen spaces within the buildings to maintain appropriate cooling and heating in summer and winter seasons, respectively. However, these instruments resulted in an increase of the background noise levels inside the educational areas, and affected the acoustical calmness of space.

Occupants using the institute buildings have increased over time. Therefore, all institute buildings face challenges related to environmental and functional aspects. Global warming has resulted in increased temperature levels. The educational buildings have environmental deficiencies because of shortages in funding contributing to inadequate operation and proper maintenance.

This requires thorough research to investigate defects. Moreover, class rooms are too small (4 × 5 m) considering the growing number of students. There is a low lecturer to student ratio (1:35). Finally, because of the low quality sound insulation of the buildings, it is difficult to avoid high sound levels (SL) due to the large number of vehicles, which enter the campus as well as the close proximity of classrooms to roads resulting in high levels of urban noise (Iraqi Ministry of Transportation Constitutions, 2018).

The Al-Najaf city climate is characterized as a severe environment (hot and arid desert climate) known for its long and very hot summers (up to 50°C) and warm winters (average of 18°C).The mean relative humidity is about 60% (Ahmed & Hassan, 2018). *Table 1* presents the outdoor temperature and relative humidity during the study period (May 2019 to December 2019). Based on historical weather data of Al-Najaf city from 2013 to 2019, July and August are the hottest months with an average temperature of 50°C. The coldest month is December with an average temperature of 17°C (Iraqi Ministry of Municipalities and Public Works, 2018).

Table 1. *Outdoor air temperature and relative humidity for the case study area (at Al-Najaf Governorate) during May 2019 and December 2019*

Parameters	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Temperature (°C) between 9:00 and 17:00	37	42	48	50	36	34	24	17
Relative humidity (%) between 9:00 and 17:00	38	24	20	22	30	38	58	65

Note: The number of measured samples is 112 for each parameter.

Indoor environmental quality measurements and sampling duration

During the current study, the IEQ parameters were measured inside the selected educational buildings of the NTI campus. Researchers took measurements in a few selected classrooms of the following buildings: LR, MH and CL (*Fig. 2)*. Multiple factors play a key role in determining the IEQ including classroom design, internal classroom operation and occupant behavior. A statistical analysis was undertaken to assess variances between rooms within each building. The differences between rooms were not statistically significant for all IEQ factors. Therefore, the IEQ evaluation from the selected rooms can be used to represent the IEQ characterization for the whole building.

The Multi-Function Environment Meter PCE-EM882 (four in one digital multi-functional environmental meter) has been designed to measure sound level, light intensity, humidity and temperature (www.industrial-needs.com/measuring-instruments.htm). The monitors were installed following a standardized protocol, ensuring that they were away from direct sources of heat (computer screen, direct insulation, etc.) or drafts (e.g., windows and air conditioning vents). All tested monitors were calibrated in accordance with the manufacturer's instructions prior to all measurements.

Fig. 3 shows the photographs for the selected educational buildings of the NTI campus. The locations of the testing units in each building were selected to be at least 2 m away from any walls and doors and 0.5 m aboveground for all tested classes. For the selected rooms in the LR and CL buildings, one point at the middle of the room had been chosen to set the monitors for the IEQ measurements (*Figs. 2a and c*). Regarding the MH building, two points at 2 × 2.5 m at the beginning and the end of each selected room were chosen to monitor the IEQ parameters (*Fig. 2b*). Data were collected for eight months during the period between May and December 2019. Measurements were taken during the period between 7.30 and 15.30 (Sundays to Thursdays) for the months between September and December, May and June (full occupancy) as well as July and August (partial occupancy). Environmental noise values were measured during the study time of the academic year 2019/2020. Corresponding data represent the major occupation periods only, avoiding excessive data recording. The effect of temperature on human activity inside the campus was evaluated. Three different periods were selected during the study time for five days of the academic week; these were as follows: morning rush hours (7.30–9.30), middle time between lectures (10.30–12.30) and afternoon time at the end of most lectures (13.30–15.30) with a recording interval of 10 seconds. These times are recognized as the maximum educational and administrative times when most of the activities are being carried out.

Outdoor weather variables were measured inside the local Al-Najaf Technical Institute area. Instruments were located approximately 50 m away from the study site. The summer season is during the months of May till September when it is very hot. This is the period when cooling is required and the mean outdoor temperature at the time of the measurements was between 35°C and 50°C. The air conditioning systems supplied to the buildings were not always used and the rooms were naturally ventilated by opening doors and windows. In comparison, the winter season is between the months of October and December when it is slightly colder (15°C to 30°C).

Fig. 2. *Floor plans of the Al-Najaf Technical Institute: (a) lecture rooms of the administrative department building (LR); (b) the main hall of the management department building (MH); and (c) the central library building (CL). R represents the point of measurements*

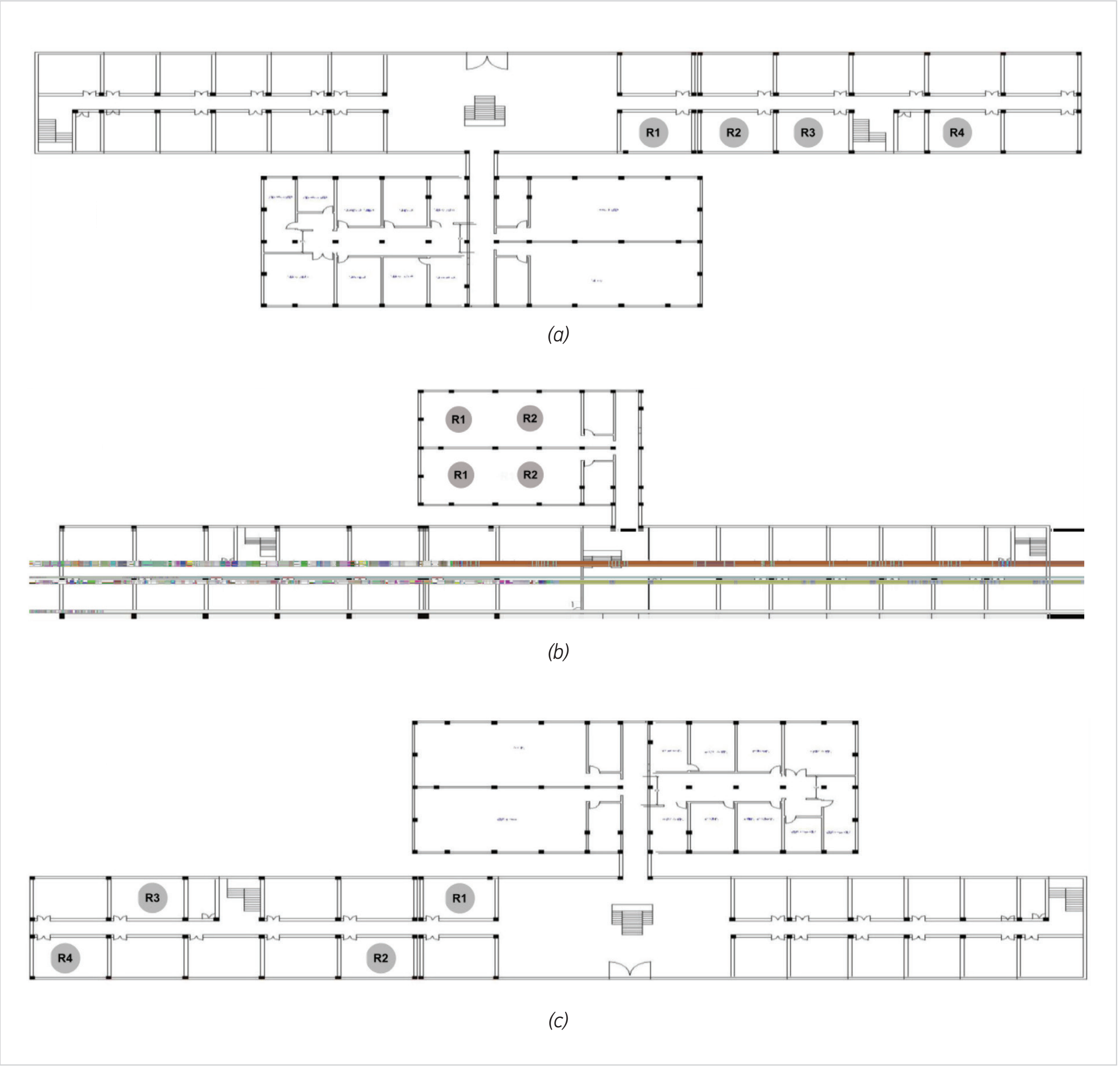
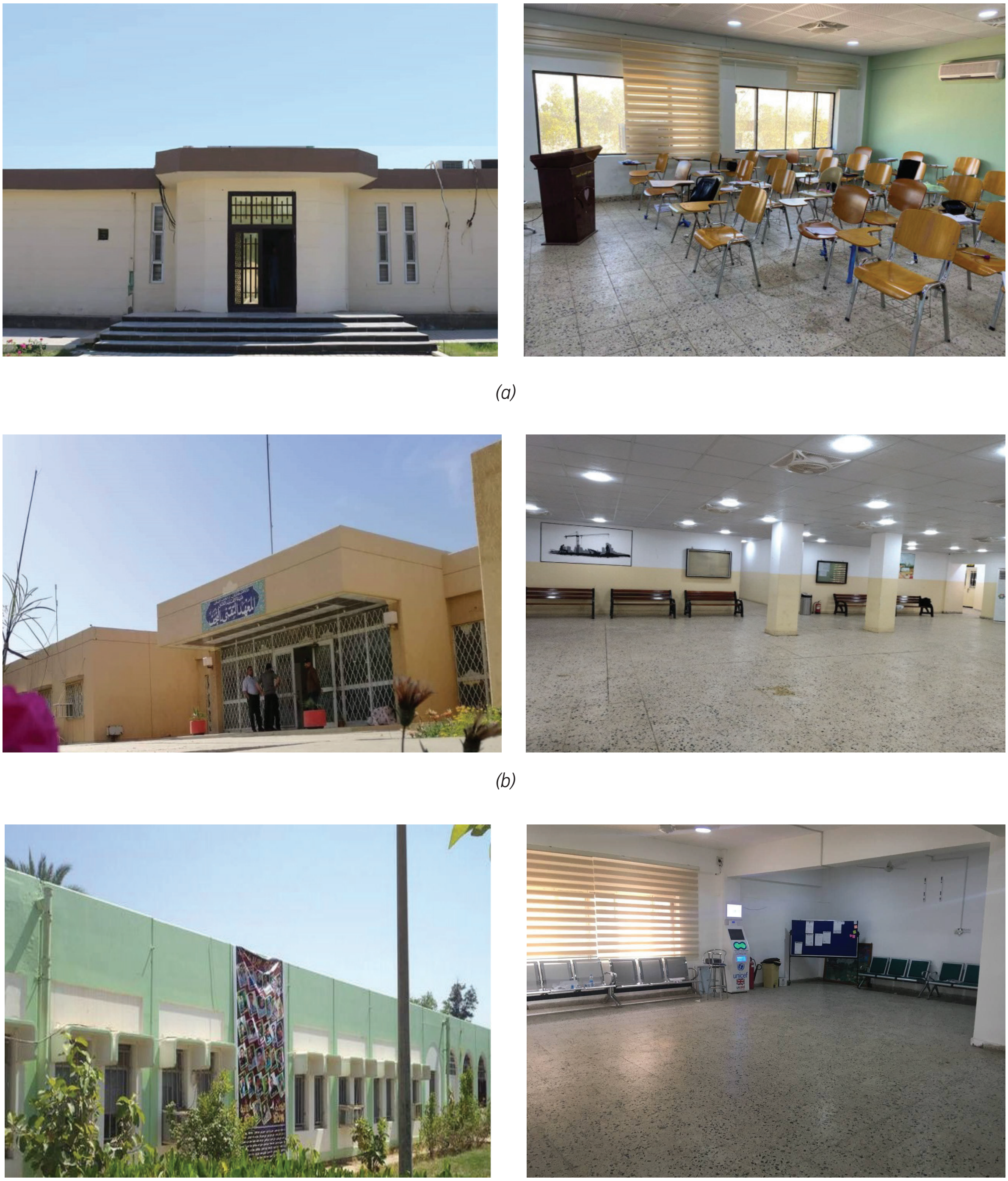


Fig. 3. *Photographs at Al-Najaf Technical Institute buildings: (a) lecture rooms of the administrative department building (LR); (b) the main hall of the management department building (MH); and (c) the central library building (CL)*



(a)

(b)

(c)

Data analysis

Continuous measurements of the IEQ elements were taken for the three buildings (LR, MH and CL) for statistical analysis to find their average values. Microsoft Excel 2016 V16.0 (Microsoft Headquarters One Microsoft Way Redmond, WA 98052, Washington, USA) was used for statistical analysis of measurement IEQ data. Via this program, average, standard deviation as well as maximum and minimum values were calculated. In addition, regression analyses including multiple linear regression models were explored. Correlation analyses were applied to identify any linear associations between variables. The correlation coefficients between IEQ indoor parameters were evaluated. The statistical significance levels of this relationship were evaluated by comparing the calculated p value and a chosen significance level (usually 0.05). If the p value is smaller than the significance level, the relationship is statistically significant.

Results and discussion

Indoor environmental quality analyses

The researchers assessed the following three significant parameters for indoor environmental quality in educational buildings in hot climate areas: air temperature, relative humidity and noise. These physical IEQ parameters were logged during study periods for each day for a period of about eight months (May to December 2019). The overall average, minimum, maximum and standard deviation of each IEQ parameter in the three buildings (LR, MH and CL) are presented in *Table 2*. The average indoor noise was 72.48 dB and the range was between 65.30 dB and 74.90 dB for the LR. The researchers measured 63.09 dB (range between 61.00 dB and 65.40 dB) for the MH building. Finally, the CL building was linked to a mean of 72.69 dB and a range between 70.00 dB and 77.00 dB (*Table 2*). All these values are above the standard specified by the Environmental Protection Agency, which recommends noise levels for education buildings between 30 dB and 40 dB (EPA, 2008). The results of this study indicate poor sound comfort. High noise levels reflect that the number of occupants (students and staff) is too high (more than 35) in comparison to the size of the rooms (4 × 4 m). Too high noise levels in the class rooms are associated with speech interference, disturbance of information extraction (e.g., comprehension and reading acquisition), message communication and general annoyance. To be able to hear and understand spoken messages in classrooms, the background sound level should not exceed 40 dB during teaching sessions (Mustafa, 2017).

Table 2. *Indoor environmental quality. parameter measurements for the whole period (May 2019 – December 2019) in all three buildings*

(IEQ) parameters	Unit	Number	Mean	Minimum	Maximum	Standard deviation
Lecture rooms of the administrative department building (LR)						
Noise	dB[1]	1214	72.48	65.30	74.90	2.53
Temperature	°C[2]	1247	30.50	18.00	45.00	8.81
Relative humidity	%	1244	46.50	36.09	55.00	7.21
Main hall of the management department building (MH)						
Noise	dB[1]	1210	63.09	61.00	65.40	1.20
Temperature	°C[2]	1245	30.75	19.02	40.00	7.54
Relative humidity	%	1245	44.50	36.70	54.02	7.31
Central library building (CL)						
Noise	dB1	1211	72.69	70.00	77.00	2.24
Temperature	°C[2]	1245	31.13	20.23	41.21	7.44
Relative humidity	%	1241	47.13	36.00	55.52	7.49

[1]*Decibel, a measure of the intensity of sound;* [2]*Celsius, a temperature measurement unit.*

The thermal comfort comprises two major elements: temperature and relative humidity. For non-residential buildings, the indoor temperature should be within the range of 23°C and 26°C (UNESCO, 1983). In this study, the average reading levels of indoor temperature in the LR, HM and LC buildings were 30.50°C, 30.75°C and 31.13°C with corresponding ranges of 18.00°C–45.00°C, 19.02°C–40.00°C, and 20.23°C–41.21°C, respectively (Table 2). The average measured indoor temperatures were higher than the action threshold advised by UNESCO (1983). When the outdoor temperature changes, fresh air circulation occurs due to a poor insulation system within the building and through open doors and windows during summer periods causing an increase in the values of indoor temperature readings. When windows and doors are open to control indoor temperature, outdoor environmental conditions are more prominent to the occupants within the buildings.

With regard to the relative humidity, the standard sets a range for an indoor building environment between 30% and 65% (UNESCO, 1983). The average indoor relative humidity readings in the three buildings (LR, HM and LC) were 46.5%, 44.5% and 47.13%. The corresponding ranges were 36.09%–55.00%, 36.70%–54.02%, and 36%–55.52%, respectively (*Table 2*). These readings indicate that the level of relative humidity within each building environment complies with the standards, satisfying UNESCO's good comfort condition.

The monthly changes in the average values of continuously measured IEQ elements (represented by temperature, relative humidity and noise) for the three buildings (LR, MH and CL) are presented in Figs. 3, 4 and 5, respectively. *Fig. 4* indicates the monthly average values of air temperature for the LR, MH and CL buildings. It is clear that temperature varied by season and ranged between 19C during cold periods (e.g., December) and 40°C during hot periods (e.g., August). According to UNESCO (1983), the optimum temperature for an educational building is between 23°C and 26°C. However, in arid countries such as Iraq, the majority of occupants working in buildings equipped with air conditioning systems suggest that 27°C might be comfortable enough (Toyinbo et al., 2019). It is assumed that 24°C will create overcooling for the occupants (Cui et al., 2013). Some indoor temperature values are higher than the standard (*Fig. 4*) suggesting the impact of poor air conditioning systems within the three buildings. This shows that the air conditioning system is insufficient in the summer. The buildings are not sufficiently insulated and there is warm air entering rooms due to infiltration.

Fig. 4. *Temporal variations of temperature measurements (mean and standard deviation) for the three buildings: (a) lecture rooms of the administrative department building (LR); (b) the main hall of the management department building (MH); and (c) the central library building (CL)*

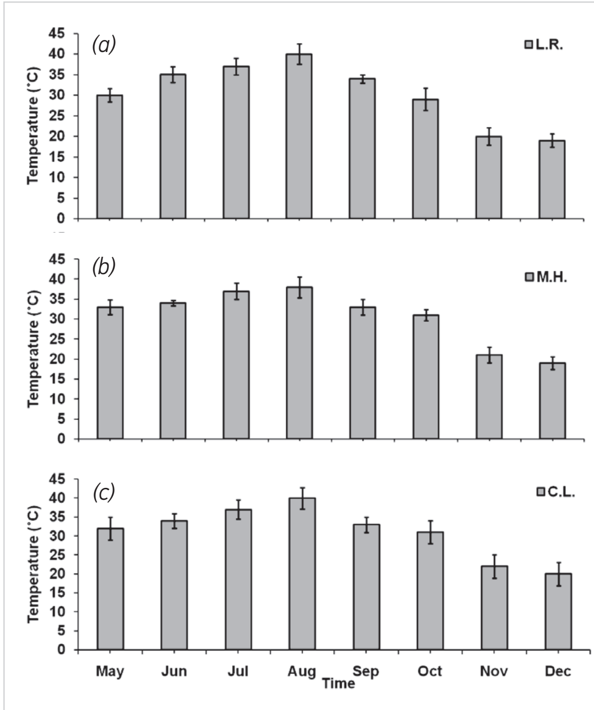


Fig. 5 demonstrates the monthly average values of relative humidity for the LR, MH and CL buildings. The relative humidity was almost the same (except for July and August; 33%–37%) in all buildings (LR, MH and CL) during the study period ranging between 44% and 55%. The air conditioner system combined with the ventilated fans provided constant conditioned air to the rooms within the buildings. The system was resilient to fluctuations from other indoor and outdoor factors across the heating season. According to UNESCO (1983), the optimum relative humidity for educational buildings is 30%–65%. Low humidity levels (below 35%) cause dryness of the human skin. Moreover,

if the humidity in a room is high, people will sweat and feel uncomfortable in this condition (Savelieva et al., 2019).

Fig. 5. *Temporal variations of relative humidity measurements for the three buildings: (a) lecture rooms of the administrative department building (LR); (b) the main hall of the management department building (MH); and (c) the central library building (CL)*

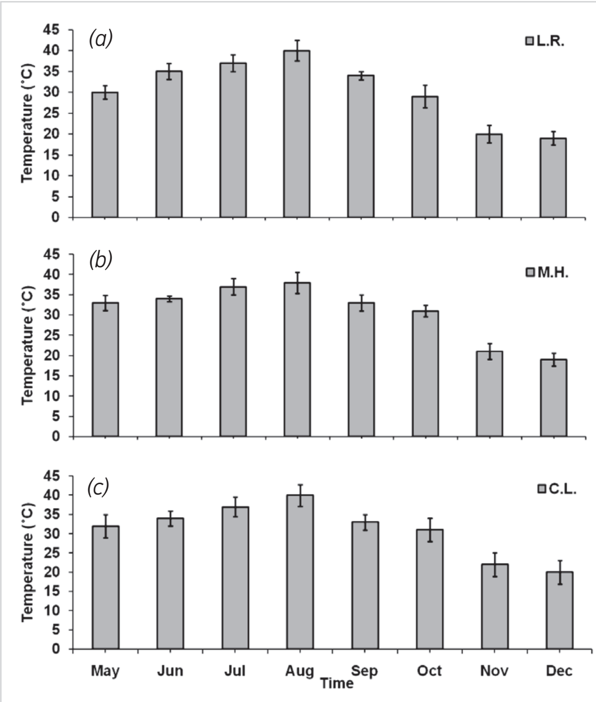
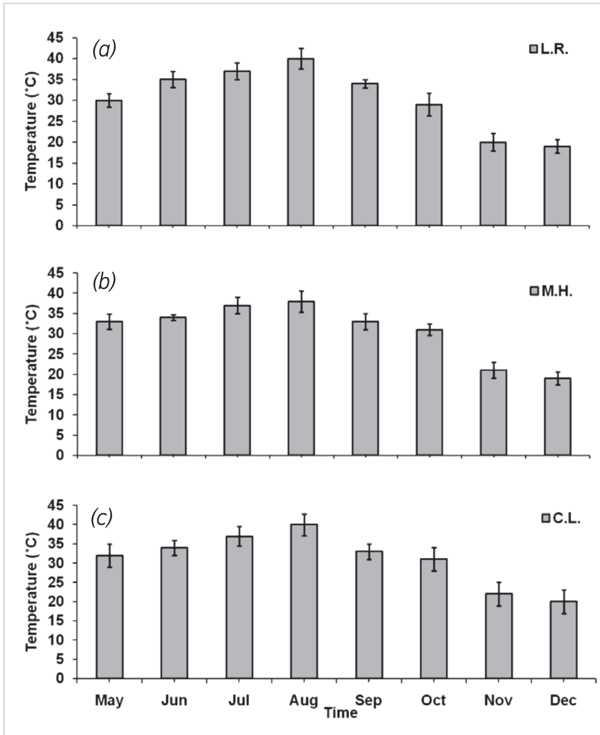


Fig. 6 shows average values of noise for the three LR, MH and CL buildings. The results for the whole study period indicate that, in all selected buildings, the occupants were being exposed to higher than the recommended threshold of noise (below 40 dB) (EPA, 2008). All case study buildings can be described as non- comfort zones, since the noise levels are higher than the permissible limit. This can be demonstrated by multiple factors: outdoor environment, air conditioning system operation, occupant behavior (number, voice frequency and learning activity), use of indoor facilities (microphone and aeration fans). If sound levels are high, human hearing deteriorates (Zalejska-Jonsson, 2019). Research has shown that high frequency noise (60–70 dB) can result in many occupants experiencing the following symptoms: fatigue, headache, nausea, concentration difficulties, disorientation, seasickness, digestive disorders, cough, vision problems and dizziness (Turunen et al., 2014). Noisy buildings result in their occupants to have mood swings. Besides, certain high or low levels of noise can make a person to lose interest or decrease his or her concentration ability, stressing these people (Zuhaib et al., 2018; Hu, 2021).

Fig. 6. *Temporal variations of noise level measurements for the three buildings: (a) lecture rooms of the administrative department building (LR); (b) the main hall of the management department building (MH); and (c) the central library building (CL)*



The levels of the environmental noise inside the campus were influenced by the magnitude of student activity. During the study period, the highest noise levels for the three buildings LR, MH and CL were 73.90 dB, 63.80 dB, and 75.70 dB, respectively, in June (*Fig. 6*). The noise can be associated with an increase in the indoor temperature (35°C, 34˚C and 34°C) at that time (*Fig. 4*). The attenuation of noise in the surrounding air is affected by temperature and RH. Moist air is less dense at a higher temperature holding more water vapor. Thus, dry air at low temperature absorbs far more acoustic energy than moist air at high temperature. It follows that sound passes through hot air easier than through cold air (Zhong et al., 2019).

However, there is a noticeable decrease in the noise level value in the three buildings during the holiday period (July and August) *(Fig. 6)* despite further increase in temperatures. This can be explained by the decrease in the number of occupants during the holiday period. Furthermore, the LR and MH buildings showed the lowest noise levels (70.3 dB and 61.7 dB in this order) in December (*Fig. 6*). This highlights the impact of other IEQ parameters in these two buildings during this month such as a decline in temperature (both 19°C) (*Fig. 4*) and the increase in relative humidity (55% and 53% in this order) (*Fig. 5*). This finding explains the relationship between IEQ parameters and is in line with previous findings (Calama-González et al., 2019), demonstrating that there is a correlation between indoor temperature and noise levels in the non-domestic buildings.

Regression model analysis

Distributions of measured average total indoor noise levels with temperature in the three buildings were analyzed using a multi-linear regression test to examine the relationship between the IEQ parameters. Noise and temperature are the major parameters for the educational areas that can interfere with the student activities and eventually deteriorate the health of the students both physically and psychologically (Zhong & Yuan, 2019). Two main independent variables, which are temperature and relative humidity, and one dependent variable predict noise levels. Correlations between these parameters and noise were evaluated. Then a regression equation was used to estimate multivariate relationships. The significance of a regression equation is calculated to determine whether the sample correlation represents a real relationship or is simply the result of a sampling error (Heinzerling et al., 2013).

Table 3 demonstrates the overall regression statistic output showing the relationship between the indoor environmental quality parameter measurements (noise, temperature and relative humidity) for the data between May 2019 and December 2019 for all three buildings (LR, MH and CL).

Table 3. *Overall regression statistics output showing the relationship between the indoor environmental quality parameter measurements (noise, temperature and relative humidity) in all three buildings for the period between May 2019 and December 2019*

Building name	LR[a]	MH[b]	CL[c]
Correlation coefficient[d]	0.918	0.957	0.775
Coefficient of determination (adjusted)[e]	0.843	0.916	0.600
Observations points[f]	8	8	8
F statistic[g]	13.462	27.211	3.761
Significance F[h]	0.010	0.002	0.100

Note: Multiple linear regression analysis was applied to assess the correlation between a dependent variable (indicated by noise) and an independent variable (indicated by temperature and relative humidity);

[a] Lecture rooms of the administrative department building;

[b] The main hall of the management department building;

[c] The central library building;

[d] Multiple R, degree of association between temperature and relative humidity (independent variables) variables on one side and noise (dependent variable) on the other. It is measured on a scale that varies from +1 to –1. The closer this value is to 1, the more linear are the IEQ data. If this value is close to 0, there is no linear relationship between IEQ variables;

[e] Adjusted R^2, percentage of variation in the IEQ parameter response that is explained by the test. It is a value between 0% and 100%, and higher than the adjusted R^2 value. It is used to evaluate the goodness of the regression line for IEQ data;

[f] Number of measurements for each IEQ parameter used in the regression analysis test;

[g] Ratio of the overall mean regression sum of squares with the mean error sum of squares;

[h] Test of significance for the regression coefficient to determine whether the sample correlation represents a real relationship or not. If the *significance F* is less than 0.05, the set of independent variables is reliable (statistically significant). If this value is greater than 0.05, it is better to stop using this set of independent variables.

According to the statistical analysis results, there is a significant correlation between noise levels with temperature as well as with relative humidity for both the LR (adjusted R^2 = 0.84; significance F = 0.010) and MH buildings (adjusted R^2 = 0.91; significance F = 0.002). The findings confirm a fair linear relation between the IEQ parameters for the LR building and a strong relation between the IEQ parameters for the MH building. The multi-linear regression model was accurate in describing the university acoustic levels with thermal conditions in the studied context. This is in good agreement with the literature (Tahsildoost & Zomorodian, 2018; Zhong et al., 2019). However, the statistical results for the CL building showed a statistically insignificant relation between the IEQ parameters as the performance of this regression model was low (adjusted $R^2 = 0.6$; significance F = 0.1). This might be explained by the fact that this building is exposed to an irregular number of people including students, staff and unexpected visitors, resulting in high variation of data. Moreover, the CL building is naturally air-ventilated most of the time due to open doors and windows. This results in the outdoor temperature having an effect on the indoor temperature causing data fluctuations, especially during the hot season.

Table 4 shows an overview of the statistical analysis between the indoor environmental quality (IEQ) variables of the three buildings (LR, MH and CL) using a multi-linear regression model for the collected data between May 2018 and December 2018. Temperature and relative humidity correlated ($P = 0.005$ and $P = 0.013$, respectively) with noise for the LR building. Moreover, there is also a significant correlation between temperature and relative humidity with noise for the MH building ($P = 0.002$ and $P = 0.014$, respectively). This provides evidence for a strong correlation between noise and other IEQ parameters. Zhong and Yuan (2019) reported that there is a connection between noise and temperature parameters for non-residential buildings, which can affect each other.

Table 4. *Overview of the statistical analysis between the indoor environmental quality variables of the three buildings using a multiple linear regression model for the collected data between May 2019 and December 2019*

Building name	Regression coefficients[c]	Standard error[d]	Tstatistice	*P* value (h)[f]	Lower 95%[g]	Upper 95%g
Lecture rooms of the administrative department building (LR)						
Noise (Intercept)[a]	49.819	5.309	9.383	0.000 (1)	36.171	63.467
Temperature (°C)[b]	0.322	0.066	4.868	0.005 (1)	0.152	0.492
Relative humidity (%)[b]	0.276	0.073	3.787	0.013 (1)	0.089	0.463
Main hall of the management department building (MH)						
Noise (Intercept)[a]	56.193	1.855	30.285	0.000 (1)	51.423	60.963
Temperature (°C)[b]	0.151	0.026	5.736	0.002 (1)	0.084	0.219
Relative humidity (%)[b]	0.050	0.025	1.981	0.014 (1)	–0.015	0.116
Central library building (CL)						
Noise (Intercept)[a]	57.4 27	7.674	7.483	0.000 (1)	37.700	77.155
Temperature (°C)[b]	0.103	0.109	0.946	0.387 (0)	–0.177	0.385
Relative humidity (%)[b]	0.255	0.102	2.481	0.055 (0)	–0.009	0.519

[a] Noise represents a response (dependent) variable;

[b] Temperature and relative humidity represent exploratory (independent) variables;

[c] Coefficients, change in one of the response IEQ variables for one unit of change in the predictor indoor environmental quality variable. The coefficient size for each independent variable represents the size of the effect that a variable has on a dependent variable. A positive sign for the coefficient indicates how much the dependent variable is expected to increase when that independent variable increases by one.

[e] Standard error, an estimate of the *standard deviation* of the coefficient;

[f] *t* statistic, *coefficient* divided by its *standard error*;

[d] *P* value, probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true; *h*, response indicator; if $h = 1$, units are statistically significantly different (*P value* < 0.05) for the corresponding IEQ parameter; if $h = 0$, the difference is not significant;

[g] Lower 95% and upper 95% define a 95% confidence interval for the population coefficient of the regressors (*intercept, temperature* and *relative humidity*).

Using the regression coefficient shown in *Table 4*, the linear least square regression equation demonstrates the relationship between the independent variables (temperature and relative humidity) and the dependent variable (noise) for each studied area (building) as shown in equations (1) to (3):

$$N_{LR} = 49.819 + 0.322 * T_{LR} + 0.276 * H_{LR} \quad (1)$$

$$N_{MH} = 56.193 + 0.151 * T_{MH} + 0.050 * H_{MH} \quad (2)$$

$$N_{CL} = 57.427 + 0.103 * T_{CL} + 0.255 * H_{CL} \quad (3)$$

where: N_{LR}, N_{MH} and N_{CL} – noise levels in the lecture rooms of the administrative department building, the main hall of the management department building and the central library building, respectively;

T_{LR}, T_{MH} and T_{CL} – temperature values in the lecture rooms of the administrative department building, the main hall of the management department building and the central library building in this order;

H_{LR}, H_{MH} and H_{CL} – relative humidity values in the lecture rooms of the administrative department building, the main hall of the management department building and the central library building, respectively.

The above equations predict the indoor noise levels with temperature and relative humidity. In other words, the equations (1) to (3) predict noise levels based on relationships with temperature and relative humidity inside the buildings. *Table 5* shows the predicted noise levels obtained from the application of the multiple linear regression model using equations (1) to (3) for the IEQ parameters and the measured noise levels for each case study building (LR, MH and CL) for the period between May 2019 and December 2019. The residual reflects how much the predicted value of noise varies from the actual one. It can be noticed that the predicted noise values were achieved with just a few small discrepancies from the actual measured values (*Table 5*). The regression analysis results show that the model can represent a good predictor for noise levels depending on temperature and humidity values in educational buildings.

Table 5. *Comparison between the predicted noise values obtained from the application of the multiple linear regression model for IEQ parameters and the measured noise data for the period between May 2019 and December 2019*

Time (months)	Units	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Lecture rooms of the administrative department building (LR)									
Noise (measured)	dB	72.80	73.90	72.00	72.50	73.50	72.90	71.90	70.30
Noise (predicted)	dB	72.73	73.79	71.95	72.64	73.74	72.68	71.16	71.12
Residuals	–	0.07	0.11	0.05	−0.14	−0.24	0.22	0.74	−0.82
Main hall of the management department building (MH)									
Noise (measured)	dB	63.60	63.80	63.20	63.80	63.70	62.90	62.00	61.70
Noise (predicted)	dB	63.60	63.55	63.50	63.61	63.50	63.30	61.89	61.74
Residuals	–	0.00	0.25	−0.30	0.19	0.20	−0.40	0.11	−0.04
Central library building (CL)									
Noise (measured)	dB	74.70	75.70	70.00	71.00	71.90	72.00	73.20	73.00
Noise (predicted)	dB	73.51	74.23	70.46	70.51	73.87	73.15	72.48	73.29
Residuals	–	1.19	1.47	−0.46	0.49	−1.97	−1.15	0.72	−0.29

Conclusions and recommendations

For the studied academic areas, the values of noise and temperature exceeded the maximum limits. It is evident that the key issues affecting IEQ in the studied university building include poor temperature and excessive noise levels, which indicate a poor overall quality of the indoor environment. The results indicate the need for interventions, highlighting the necessity to improve building cooling and heating strategies and corresponding insulation systems to meet standards of comfort in response to climate change. Furthermore, the statistical analysis indicates that there is a statistically significant correlation between noise level values and temperature for relative humidity concerning the LR and MH buildings, highlighting the fact that the attenuation of noise in the surrounding air was affected by temperature and relative humidity. This is shown by the value of significance F = 0.01 and adjusted R^2 = 0.84 for the LR building and the value of significance F = 0.002 and adjusted R^2 = 0.92 for the MH building. There were small discrepancies between the actual measured noise values with the predicted ones (≤ 0.44) for both buildings, reflecting high accuracy of the multi-linear regression for describing the university acoustic levels with thermal conditions under consistent conditions.However, there is no statistically significant relationship between the IEQ parameters for the CL building (significance F = 0.1; adjusted R^2 = 0.6; and discrepancies between the actual measured noise values with the predicted ones (≤ 1.97)). These results indicate the unsuitability of the multilinear regression model to predict noise levels with time. This is most likely due to the fact that this building is exposed to an irregular number of people including students, staff and visitors during the daytime, resulting in high data variability.

Further investigations are recommended to fully understand the application of the predictive model to other academic areas in different regions and under various indoor environmental conditions to study the effectiveness of the model to demonstrate the associations among indoor environmental quality parameters under climate change scenarios.

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