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ARTICLE

Indoor Air Quality (IAQ) Evaluation of Higher Education Learning Environments

Supreet Lama[1] **Changfeng Fu**[1*] **Angela Lee**[2]

1. University of West London, London, UK
2. University of Salford, Manchester, UK

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ABSTRACT

Indoor Air Quality (IAQ), particularly in educational facilities, is gaining considerable interest and is a synonymous indicator towards evaluating human comfort. Factors such as CO_2 concentration, temperature, and humidity play crucial parts in determining an acceptable level of IAQ. Many studies have also demonstrated that the indoor air quality of classrooms affects students' concentration and performance. Today with the threat of a global pandemic, the demand of clean & fresh indoor air quality in education buildings is extremely intensive. This study focuses on investigating IAQ situations and changes in different typical functional spaces of a higher education building in the UK. CO_2, temperature, and humidity data in various learning environment were monitored via data loggers during the winter. Associated with data monitoring, a set of questionnaires surveys were carried out to evaluate the user's experience. The results of this study show that temperature and CO_2 concentration in the classrooms was constantly higher than the government guidance on a daily basis. The analysis also shows that temperature and humidity increased with CO_2 levels, but at a much lower rate. This study has revealed poor and concerning IAQ in higher education buildings in the UK, particularly in larger rooms with high occupancy. Along with the findings, this paper also identifies possible impact or factors and proposes solutions to overcome these issues.

1. Introduction

Indoor air quality (IAQ) plays a pivotal role in maintaining occupants' comfort, performance and wellbeing and is a major contributor to human health [36]. Indoor air pollution may cause or aggravate illnesses [28], increase mortality [36], and have a major economic and social impact [9]. Furthermore, it has been proven that a number of respiration related diseases are directly caused or developed by poor IAQ by means of pollutants such as radon, carbon monoxide, formaldehyde and various biological contaminants [1,28,23]. Maintaining good IAQ is important in today's digital age, where people spend around 90% of their time indoors [21,26]; and of which for

**Corresponding Author:*
Changfeng Fu,
University of West London, London, UK;
Email: Charlie.fu@uwl.ac.uk

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a typical student, around 30% of their time is spent in classrooms [5]. Therefore, it is pertinent to understand how various factors affect IAQ, and how this impacts the perception of comfort for its users. There are numerous factors that influence the overall indoor environment which includes indoor air quality (IAQ), humidity, ventilation, thermal comfort, lighting etc [26]. The lack of maintenance of any of these factors to appropriate levels can cause discomfort to some or all occupants.

Specifically, within educational buildings, poor IAQ in can cause various health implications such as headaches, eye irritation, coughing and nausea – and more importantly, it can impede on student performance as well as their learning ability. This can particularly cause negative effects for those suffering with allergies and pulmonary diseases [2]. Polluted indoor air can sometimes also contain carcinogens, which if exposed for a long period of time, can promote the formation of cancer [16].

Sources of pollutants in a higher education setting range from outdoor air and traffic to materials used for construction and furnishing, cleaning products, electrical equipment, and various lab appliances. In addition, buildings and HVAC (heating, ventilation and air conditioning) systems have deteriorated as a result of ageing and inadequate maintenance or have become obsolete as a result of technological advances. Added to this, the amount of fresh air being brought into buildings has decreased in order to reduce the amount of energy needed to heat or cool it. Thus, there is less fresh air available to dilute indoor air contaminants/ pollutants. Indoor air concertrations are largely uncharacterised, but they have likely increased over time as a wider mix of chemicals are used and air exchange rates in the buildings decrease to improve energy efficiency [35]. Chemical concentrations are often highest indoors because many of the pollutant sources are found inside buildings, and because of limited degradation indoors compared with outdoors. In addition, people who may be exposed to indoor air pollutants for the longest periods of time are often those most susceptible to the effects of indoor air pollution, and are namely the young, the elderly, and the chronically ill. Hence, maintaining a high level of IAQ can also be classed as a measure of prevention of various illnesses and diseases, and as such, can be evaluated by temperature, CO_2 levels and humidity. This study furthers existing research by providing by evaluation of IAQ of monitored levels and regulatory guidance, against user's satisfaction in practice, to determine true perceived and actual IAQ comfort levels.

1.1 Room Temperature and Regulations

The internal room temperature is one of the most important parameters that determines occupier's comfort. There are various thermal comfort criteria recommended by various organisations and bodies. The Chartered Institute of Building Services Engineers (CIBSE) [6] recommends indoor temperatures ranging between 19-21°C during the winter within a learning environment. Whereas the Health and Safety Executive [18] suggests maintaining a minimum temperature of 16°C in an indoor working environment, such as an office or a classroom; noting, a maximum temperature was not provided. However, Building Bulletin (BB) 101 [7] recommends temperatures between 17°C - 25°C during winter for school environment, where the recommended temperature for a classroom is around 20°C.

However, studies conducted in various educational establishments around the world have shown a significant difference in temperature preference by the occupants. A study conducted [13] in East Australia (Sydney) shows that students were comfortable at a temperature of 23.4°C, but preferred cooler temperatures of 22.6°C. In another study [32] during autumn in Nepal concluded that the mean comfort temperature was 26.9°C. Whereas in a study conducted in a university building in China [38] identified that temperatures between the range of 16°C – 22.4°C were acceptable in classrooms. Wargocki and Wyon [34] conducted similar studies in a school environment during the summer in Denmark and concluded that by providing sufficient cooling (from 25°C to 20°C), the student's speed of completing numeric and two language-based tasks significantly improved. The study also concluded that. By increasing the rate of air circulation from 5.2 L/s to 9.6 L/s, the students were able to significantly improve their performance on four numerical exercises.

Based on the Köppen−Geiger Climate Classification [22], the North part of China has arid climate, whereas Eastern Australia, mid-mountain region of Nepal and Denmark have temperate climate, similar to that of the UK where this study has been conducted. Hence, a comparison can be made between the results of this study and the results of previous studies.

1.2 Carbon Dioxide Levels & Regulations

As previously discussed, there are various types of pollutants present in indoor air, but due to its natural occurrence and substantial effect on human beings, carbon dioxide (CO_2) concentration is used as an indicator for IAQ [7,25]. Whilst CO_2 is not directly dangerous to humans, some studies [21,31] have shown that high levels of concentration can affect a person's physical and mental performance, such as their ability to make decisions. CO_2 levels are often higher indoors due to exhalation of CO_2 by occupants. This level can rise exponentially if the area has full/crowded occupancy, such as in a classroom or small meeting rooms that often lack adequate ventilation.

The atmosphere consists of 0.04% CO_2 (and 21% O_2), where the average concentration level in an outdoor environment is between 400-500 ppm; and within an indoor environment with good ventilation can range between 400-1,000 ppm [24,35]. In order to maintain a constant CO_2 concentration level below 1,000 ppm, an air circulation of 15 cubic feet per minute (cfm) per occupant is recommended [8]. In teaching and learning spaces, guidance document BB 101 [7,14] recommends an average concentration of 1,000 ppm or less where mechanical ventilation is used and 1500 ppm or less where natural ventilation is used. In both mechanically and naturally ventilated spaces, the maximum concentration of CO_2 should not exceed 1500 ppm and 2000 ppm, respectively, for more than 20 consecutive minutes.

However, within a fully occupied lecture hall, CO_2 can reach levels of 5,000 ppm, which can impact concentration and reduce high-level cognitive abilities [19,29]. The HSE [18] recommends staying within an area with CO_2 concentration of 5,000 ppm for a maximum of 8 hours and 15,000 ppm for 15 minutes or less. CO_2 concentration above 5,000 ppm can begin to cause health issues such as headache, nausea and sleepiness. Furthermore, a significant study in this area was carried out at the Lawrence Berkeley National Laboratory and SUNY Upstate Medical University [31]. It demonstrated that when the CO_2 level is between 1000 ppm and 2000 ppm, occupants may feel that the air is unfresh and often start to feel drowsy; when the CO_2 level is raised to between 2000 ppm to 4000 ppm, occupants in this environment may feel difficulty breathing, their faces often turn red and they may start to feel a convulsion; when CO_2 levels reach between 4000 ppm and 6000 ppm, occupants may experience permanent brain damage, and often lose consciousness, and more seriously, may die if they stay in such an environment for a long period of time.

In a study conducted by [14] in primary schools in the UK identified that sensation of air is more correlated to CO_2 levels than temperature during non-heating season and more correlated to temperature than CO_2 during heating season. They also concluded that air quality perception improved by around 43% when CO_2 levels were below 1000 ppm and temperature were within occupant's thermal comfort range. Hence, to improve occupant comfort, balance between various factors affecting indoor comfort needs to be maintained individually.

1.3 Humidity Levels and Effect on Performance

Humidity is the concentration of moisture present in the air. A relative humidity between 40-70 percent is required for a comfortable environment [20,26]. Studies [32,37] have shown that low and high levels of humidity can impact the concentration and performance of occupants. There are health risks associated with levels of humidity which includes increased risk of asthma and viral infections, dry eyes, flaky skin, sore throat etc.

Overall, IAQ plays a crucial role in achieving and sustaining human comfort, which is a condition of the mind that expresses satisfaction within the environment. Comfort is achieved upon fulfilment of several conditions including thermal, visual, noise, air quality and personal factors [15,26]. This research aims to investigate changes of indoor environment quality in various types of learning environments within Higher Education (University) learning spaces against user' satisfaction, in short, to evaluate IAQ in practice (users' satisfaction) against monitored levels and regulatory guidance.

2. Research Method

This research utilises both objective measurements and subjective surveys. Air temperature, CO_2 levels and humidity were measured and analysed as an indicator for IAQ. These objective datasets were collected using three different types of data loggers, namely: an internal Tinytag temperature and humidity data logger, an internal Tinytag CO_2 data logger, and an external temperature and humidity data logger. In order to capture and distinguish changes of indoor environment, the data collection of this study was carried out during winter of 2019 in the UK over a two-week period, whereby natural ventilation was limited (namely, the windows of the building were shut most of the time). The data loggers were connected to power outlets and placed at 1.2m above the floor (average human sitting height) and were in operation for the entire two-week duration. Other possible impact factors, such as the area of the monitored learning environment, the number of occupants, and the facilities within the rooms (such as computers) were also recorded (the room volume and the activities being carried out can also affect the levels of CO_2 and humidity, which ultimately affects human comfort [21].

The university building investigated for this study is located in the Greater London area; and represented a typical Higher Educational building across the UK – steel frame construction with solid and curtain wall cladding system. The part of the building used for this study was originally constructed in the late 1800s and has since been refurbished with the notable addition of external insulation to the solid walls and double-glazed windows. Different types of learning spaces were selected within the Higher Education building, 5 in total, namely: classroom, lecture hall, computer rooms and a specialist learning space [textile room]. This also helped diversify the data, identify level of comfort in various rooms and also provided an opportunity to identify the effect of equipment in a room on user comfort. Table 1 provides background of the learning environments surveyed.

Table 1. Rooms surveyed

ROOM ID	*ROOM TYPE*	*FLOOR*	*AREA (m^2)*	*Height (m)*	*CLASS DURATION (hrs)*
R01	Computer room	Third	65	2.8	3
R02	Classroom	Third	52	2.8	2
R03	Lecture Hall	First	78	2.8	3
R04	Computer room	First	45	2.8	3
R05	Textiles room	Ground	69	2.8	4

The building has mechanical ventilation installed; however, it was not in operation in majority of the rooms surveyed. The only room that had mechanical ventilation in operation was the textiles room (R05), where various paints and other chemicals were in use and therefore mechanical means were used in support of health and safety guidelines. The remaining rooms are all naturally ventilated.

The objective measurements were to be compared to a subjective survey, which would be used to corroborate against user's perceived satisfaction. A survey was conducted in the form of a questionnaire with Likert-type questions to analyse comfort levels throughout the class, and against differing objective measurements gathered with the Tinytag devices. The survey was conducted at the beginning and at the end of the class to analyse changes in IAQ perception over the duration of the class. All users of each survey room (students and staff) were invited to partake in the study.

The analysis of Likert questionnaire was carried out by converting the overall responses from each room into percentages. This was administered by assigning a value from 0 to 4: where 0 equated to very uncomfortable, and 4 equated to very comfortable. Next, the maximum possible value for each survey was calculated by adding the number of responses and multiplying the result with the maximum assigned value, which was 4. Subsequently, the actual combined value of every survey was calculated by multiplying the number of times an answer was selected by its value and adding them together. Finally, the average percentage of satisfaction was calculated using the following formulae

$$\left(\frac{Actual\ combined\ value}{Maximum\ possible\ value}\right) \times 100$$

The average percentage of satisfaction was then used to conduct a simple and multiple regression analysis between the objective and subjective measures.

3. Data Collection

3.1 Temperature Measurement

Objective measurements were conducted over a two-week period which included, temperature, CO_2, and humidity levels. Figure 1 (a, b & c) shows changes in minimum and maximum temperature over 14 continuous days for each learning environment. The maximum recorded temperature was 26.6°C in room R04. The green shaded area within each graph denotes the range of comfortable temperature based on the guideline provided by CIBSE (2015), which is between 19°C - 21°C. The minimum temperature occurred mostly occurred during the night when no one was present in the building. It can be seen in the graphs that the temperature in all the classes exceeded the recommended range on a daily basis which can be deemed to be theoretically uncomfortable. The dip in maximum temperature seen in days 6 & 7 and 13 & 14 occurred during the weekend.

3.2 Carbon Dioxide Measurement

Figure 2 (a, b & c) shows the minimum and maximum recorded CO_2 levels across the 5 rooms over 14 continuous days. An observation of the graph shows that rooms R02 and R03 are the worst performing rooms in terms of CO_2 levels. All minimum CO_2 levels were recorded overnight when there were no occupants. The considerable fall in the level of CO_2 was recorded during the weekend. The green shaded area denotes the concentration level of CO_2 required in educational buildings i.e., 1500 ppm in naturally ventilated and 1000 ppm in mechanically ventilated. Room R03 had alarming levels of CO_2, which constantly surpassed the 2000 ppm (for a max of 20 mins) limit on a daily basis, and even exceeded 4000 ppm at one point.

3.3 Humidity Measurement

Figure 3 (a, b &c) shows the relative humidity percentages recorded within the 5 surveyed rooms over

Figure 1. Minimum and maximum temperature recorded over 2 weeks.

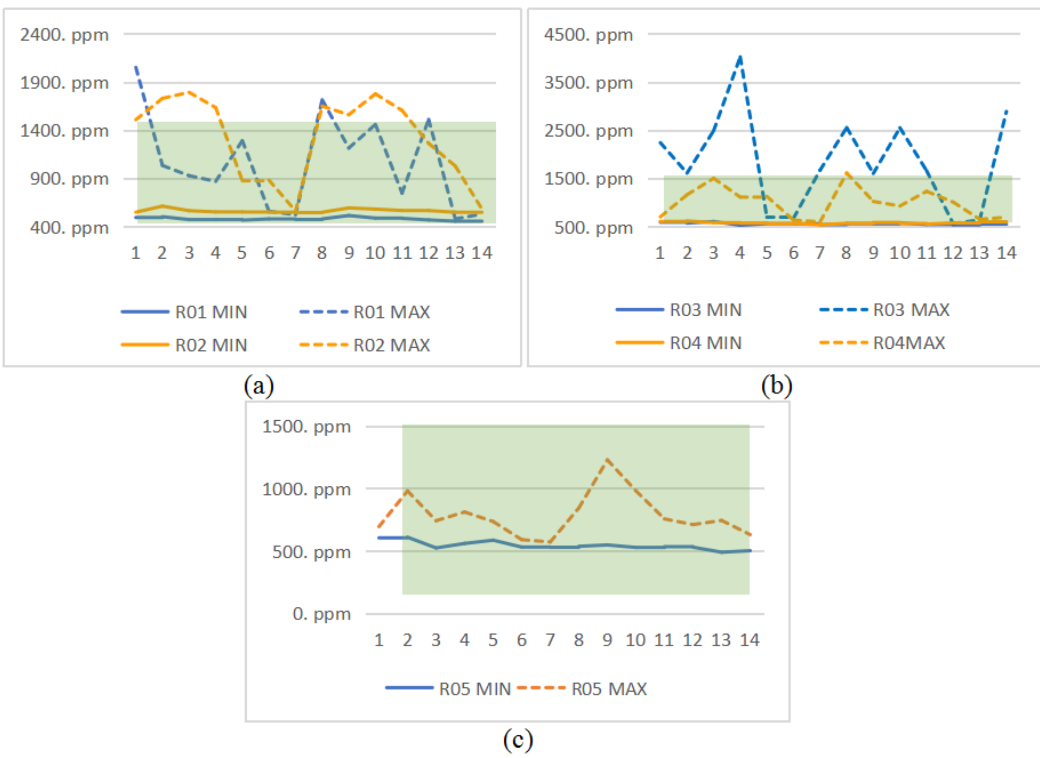
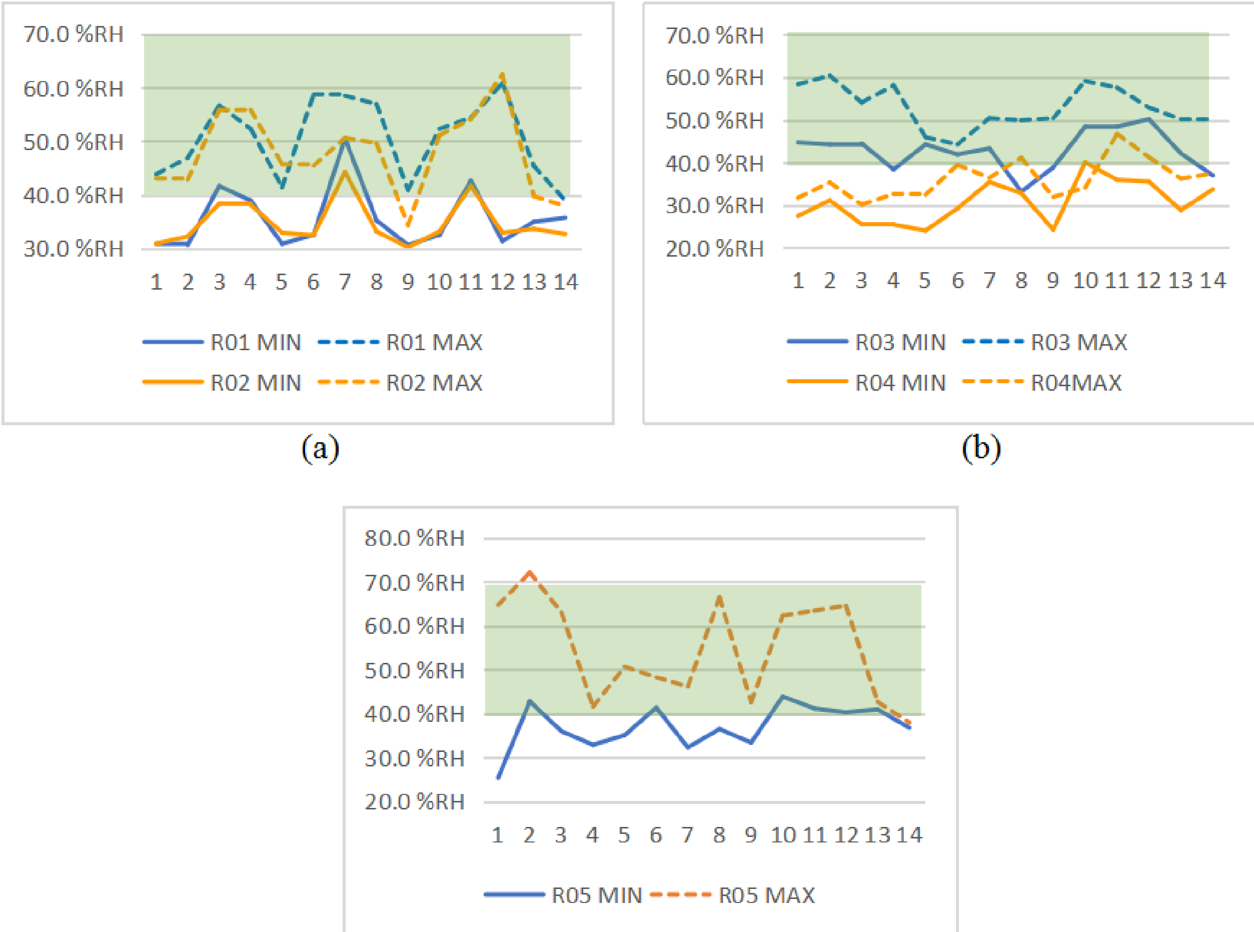


Figure 2. Minimum and maximum CO_2 reading over 2 weeks



(c)

Figure 3. Minimum and maximum humidity levels over 2 weeks.

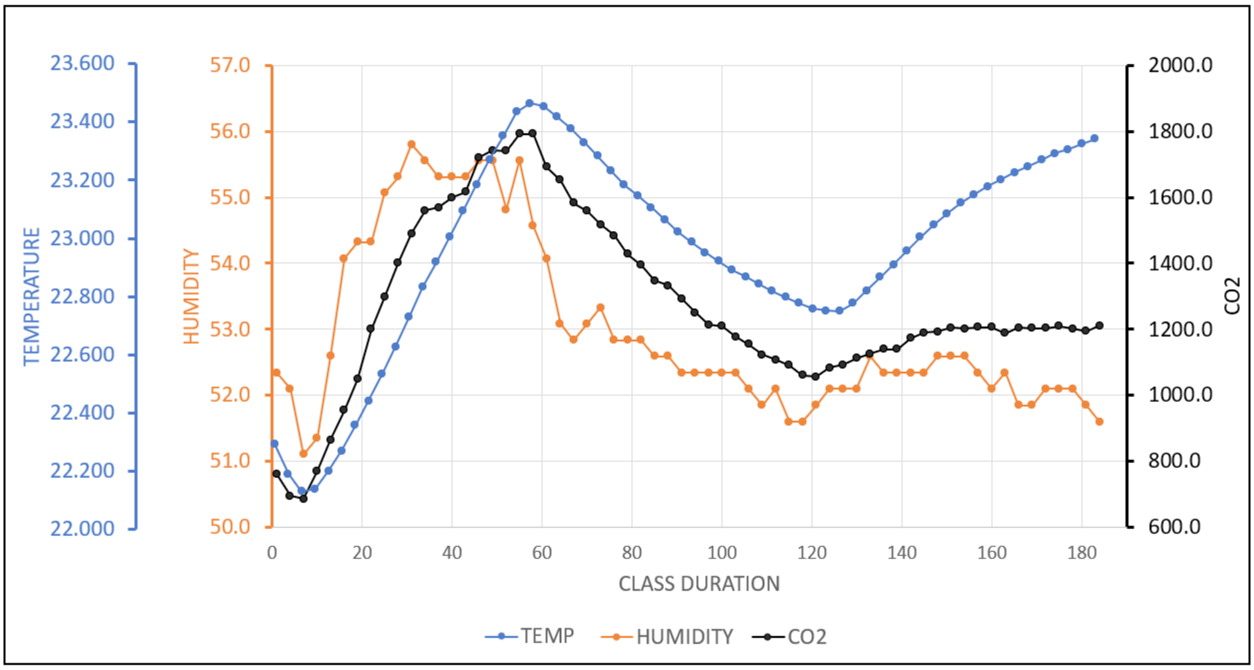
14 days. The graphs show that the relative humidity of the majority of the rooms fall within the recommended 40 – 70% level, denoted by the green shaded area. The minimum levels were mostly recorded during the night or weekends when no users were present in the building. Only room R04 shows humidity levels dropping below 40% during the 14 days of survey.

3.4 Overall Indoor Air Quality

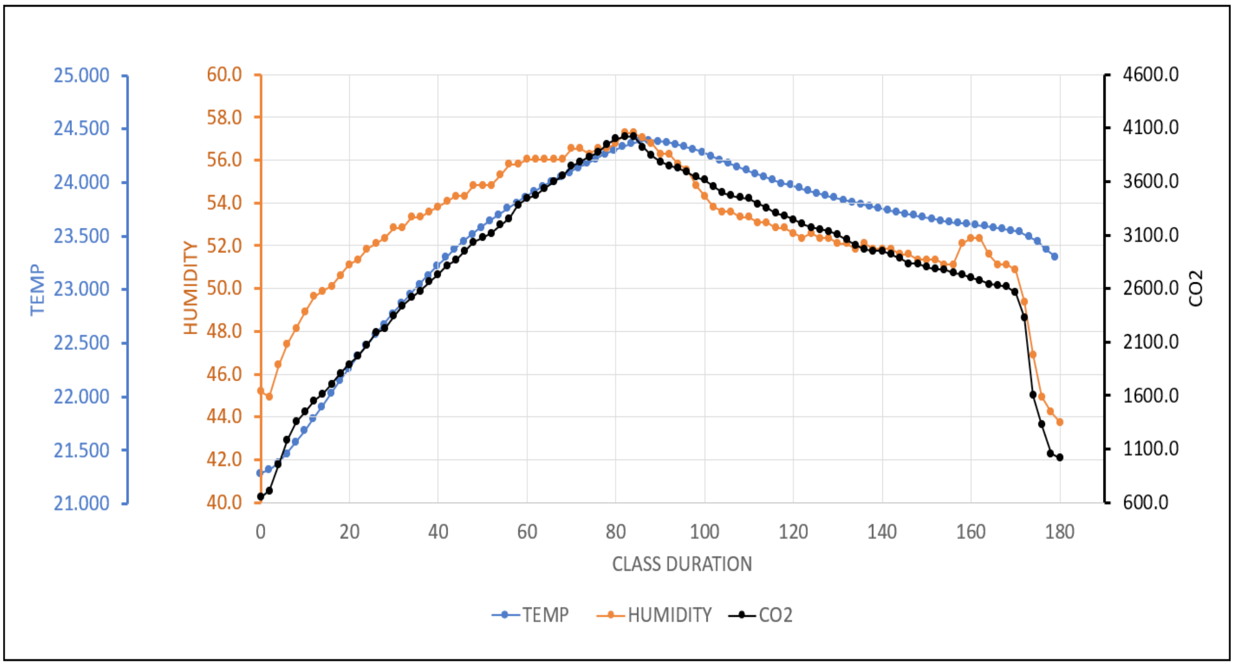
Considering all the factors measure during this study, room R02 and R03 were identified as the worst performing out of the 5 rooms. In order to further identify the rate of decline in indoor air quality, the day with the highest levels of temperature, CO_2 and humidity in R02 and R03 were selected. Figure 4 a & b shows the increase and subsequent decrease in level of the 3 factors over the duration of a 3-hour class. It can be seen that all 3 factors follow a similar upward and downward trend reaching their respective maximum levels at similar times.

3.5 Questionnaire Survey

A survey was also conducted in the form of a questionnaire with dichotomous questions at the beginning and end of class, shown in Table 2 & 3. A total of 61 completed forms were collected from the 5 rooms surveyed and included staff and students. The results of the survey showed lecture hall R03 had the greatest decrease of 14% and 12% in comfort related to air quality and temperature, respectively. The objective data collected over the 3-hour class also shows that CO_2 levels peaked at over 2500 ppm and temperature exceeded 24 °C, which is relatively higher than the their rooms. The room's overall human comfort also decreased by 8% throughout the duration of the class. Over 54% of the users desired the room to be cooler. However, air quality comfort in room R01 and R04 increased over the duration of the class by 6% and 4% respectively. This can be attributed to the opening of windows halfway through the class, as some of the students commented that the room 'felt stuffy'.



(a) 3-hour reading of Room R02



(b) 3-hour reading of Room R03

Figure 4. Fluctuation in temperature, CO_2 & humidity.

Table 2. Beginning of class survey

Survey questionnaire: Start of class

How comfortable are you with the current temperature of the room?	• Very comfortable • Comfortable • Neutral • Uncomfortable • Very uncomfortable	• 4 • 20 • 22 • 12 • 3
Would you like the current temperature of the room to change?	• Cooler • No change • Warmer	• 25 • 34 • 2
How comfortable are you with the current air quality of the room?	• Very comfortable • Comfortable • Neutral • Uncomfortable • Very uncomfortable	• 6 • 14 • 22 • 17 • 2
Do you feel that a mechanical ventilation would be beneficial in this room?	• Yes • No	• 48 • 5
How would you rate your overall comfort in this room?	• Very comfortable • Comfortable • Neutral • Uncomfortable • Very uncomfortable	• 4 • 23 • 22 • 10 • 2

Table 3. End of class survey

Survey questionnaire: End of class

Do you feel that your level of concentration reduced towards the end of class?	• Yes • No	• 49 • 12
Did the level of temperature affect your concentration?	• Yes • No	• 27 • 34
Did the quality of air affect your concentration?	• Yes • No	• 37 • 24
How comfortable are you with the current temperature of the room?	• Very comfortable • Comfortable • Neutral • Uncomfortable • Very uncomfortable	• 1 • 21 • 22 • 15 • 2
Would you like the current temperature of the room to change?	• Cooler • No change • Warmer	• 33 • 27 • 1
How comfortable are you with the current air quality of the room?	• Very comfortable • Comfortable • Neutral • Uncomfortable • Very uncomfortable	• 1 • 15 • 27 • 15 • 3
How would you rate your overall comfort in this room?	• Very comfortable • Comfortable • Neutral • Uncomfortable • Very uncomfortable	• 2 • 18 • 21 • 18 • 2

4. Results and Analysis

4.1 Temperature Change

Figure 5. Change in temperature.

As highlighted earlier, a comfortable working temperature during the winter period ranges between 19-21°C. However, the analysis of temperature data collected over the 2-week period shows that all of the classes exceed this range on a daily basis. Figure 5 shows readings from room R02 and R03 were the highest amongst the 5 rooms surveyed. In both cases, the temperature exceeded 21°C from the early morning till the end of day. In case of room R02, the temperature remained above 24°C for the entire day (9:00-17:00). The slight dip in temperatures seen in Figure 1 correspond to lunch hours for majority of the classes in the university, where occupancy significantly lowered.

Delving further into the rooms with the highest temperatures i.e., R02 a classroom and R03 a lecture hall, it was identified that by the time students enter the room the temperature was already over the higher level (21°C) of the recommended range and remained over this level for the entire duration of the class. On average the temperature rose at a rate of 3.75% and 3.81% per hour in R02 and R03, respectively. This means that if the temperature of R02 is 20°C at the beginning of the class, within an hour the temperature will reach around 20.75°C, and around 22.25°C, over a 3-hour duration, given that no windows or doors are opened.

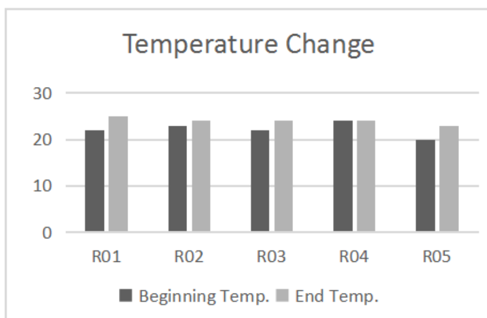


Figure 6. Change in temperature in the surveyed rooms.

Figure 6 shows the temperature of each of the five classrooms at the beginning and end of the class on the day survey questionnaire was completed. It can be seen that classrooms temperatures rose on four instances and remained the same on one occasion, which can be associated with increased capacity/use of the learning environment when heat is emitted by human bodies as well as equipment used in the room. It should be noted that every room, apart from room R05, began with a temperature of over 22°C. The greatest rise in temperature was 3°C in R01 and R05, reaching 25°C and 23°C respectively, which is above the recommended comfort level of 21°C. The mean temperature of the 5 rooms surveyed was 22.3°C, with a standard deviation of 2.06.

The temperature and satisfaction data obtained at the beginning and end of the class were combined together. A simple regression analysis was conducted in Excel to work out the relationship between classroom temperature and student comfort satisfaction. The results of the regression analysis in Figure 7 show that the variance (R^2) is 78%, F value is 29.06, p value (Significance F) = 0.0006. Based on the regression analysis principles, R^2 over 60% indicates that temperature strongly influences satisfaction. And p value less than 0.05 indicates that the results of the analysis are statistically significant. The analysis also demonstrates a negative relationship between temperature and satisfaction. According to temperature readings, all the classes were already above 20°C at the start of class where the mean satisfaction percentage was 57.8%. By the end of class, the satisfaction percentage had fallen to 52.2%, in short, satisfaction fell as temperature increased.

Table 4. Regression analysis - results

Regression Statistics	
Multiple R	0.8855
R Square	0.7842
Adjusted R Square	0.7572
Standard Error	4.1811
Observations	10

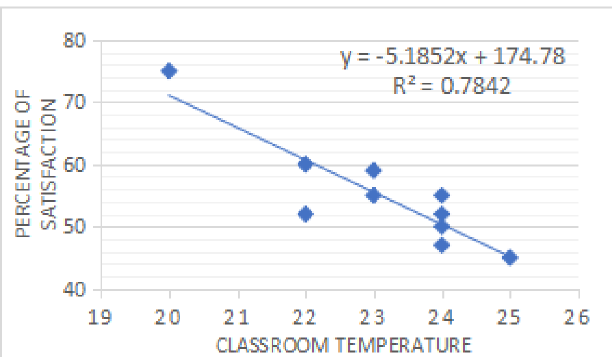


Figure 7. Regression analysis of temperature & satisfaction.

Table 5. Regression analysis –Analysis of variation

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	508.1481481	508.1481481	29.06779661	0.00065264
Residual	8	139.8518519	17.48148148		
Total	9	648			

4.2 Air Quality and Human Comfort

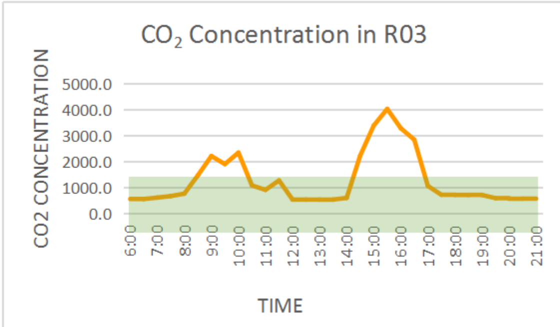


Figure 8. Carbon dioxide levels in Lecture Hall

The analysis of the data collected showed that CO_2 levels in 4 of the 5 rooms surveyed surpassed the required limit (green shaded area) of 1500 ppm during a 2- or 3-hour class as required by the Department of Education [7]. The maximum concentration level recorded was 4,020 ppm in R03, a 98-seat lecture hall, during a 3-hour lesson, as seen in Figure 8. During these 3 hours, the level of CO_2 was over 1500 ppm 90.11% of the time, i.e., around 2 hours and 40 minutes. It only took 12 minutes and 25 minutes from the start of class for CO_2 levels to exceed 1500 ppm and 2000 ppm, respectively. The level remained over 2000 ppm for around 2 and half hours, greatly exceeding the recommended 20 minutes limit. Over the course of 14 days, 42% of CO_2 levels in room R03 exceeded the required 2000 ppm limit. This limit increased to 60% if weekend readings are excluded.

Table 6 below shows the duration of time it took for CO_2 levels to reach 1500 ppm as well as the maximum recorded level in all of the 5 rooms over the 14 days period. The only exception in this study was room R05, a textiles room, which uses mechanical ventilation (MV). During the entire 2 weeks of recording in this room, CO_2 levels peaked at 1228 ppm and dropped to a low of 558 ppm during the night and weekend. This room does not consist of any windows; hence this relatively low level of CO_2 can only be attributed to the efficient use of MV.

In order to determine the rate of increase of CO_2 levels, the data from R02 and R03 were taken, which were read at 3-minute intervals by the logger. The analysis of this data showed that CO_2 in R02 rose at an average rate of

67.66% per hour, whereas in R03 CO_2 rose at 61.11% per hour. These data were taken from the beginning of a class till CO_2 reached the maximum level before falling significantly which would indicate that a window or door had been opened. It was also identified that in R02 levels of CO_2 exceeded the required level of 1500 ppm 12.38% of the time. However, in R03 CO_2 levels exceeded this level 70.26% of the time.

Table 6. Duration for CO_2 to reach required maximum limit.

Rom ID	Start CO_2	Max CO_2	Time to reach 1500 ppm	Time to reach Max
R01	959 ppm	1708.4 ppm	210 mins	270 mins
R02	686 ppm	1792.3 ppm	27 mins	48 mins
R03	596 ppm	4020.5 ppm	15 mins	90 mins
R04	796 ppm	1609.9 ppm	90 mins	96 mins
R05	558 ppm	1228.5 ppm	111 mins (to reach 1000 ppm)	231 mins

Furthermore, analysis of CO_2 data from R02 showed that during the day when levels reached its maximum of 1,792 ppm the rate of increase from the start of the class, 55 minutes earlier, was 116.79% per hour, whereas the rate of decrease, till the end of class, was much lower at -47.32% per hour. Similarly, in R03 the rate of increase from the start of the class, 90 minutes earlier, was 92.03% per hour to reach its daily maximum of 4020.5 ppm, whilst the rate of decrease was -52.64% per hour.

A regression analysis was carried out in order to determine the relationship between indoor air quality and user's comfort. The result of the analysis however, indicated that the model only explained 14% of the variance and was not statistically significant, $F(1,8) = 1.26, p = 0.30$. The overall satisfaction with IAQ was only 47%, which stands at odds with the result of the regression analysis.

A regression analysis carried out to test the relationship between user comfort and indoor humidity indicated that only 3% of the variance could be explained by the model. The overall result was statistically insignificant, $F(1,8) = 0.29, p = 0.60$.

4.3 Multiple Regression Analysis

After obtaining one significant and two insignificant models, a multiple regression analysis was performed with three independent variables (i.e., temperature, CO_2 & humidity) and one dependant variable i.e., student comfort. The result of this analysis indicated that the model explained over 70% (adj. R^2) of the variance and was a significant predictor of student comfort, $F(3,6) = 7.8, p= 0.017$. However, indoor temperature was the most significant contributor to this model, B = -5.07, p = 0.0053. Indoor CO_2 (B = -0.002, p = 0.9) and humidity (B = 0.15, p = 0.56) did not contribute significantly to this model.

5. Discussions

5.1 Temperature and CO_2 Interpretation

The aim of this study was to investigate whether changes in IAQ within a university building [during winter] corroborates user's perception towards IAQ over the duration of a class. The results of the study indicate that the IAQ of the 5 rooms surveyed decrease after around 30 minutes from the start of each class, either due to changes (an increase) in temperature or CO_2 or both. In general, classes were 3-4 hours in duration, and typically had one or two short breaks. 4 out of the 5 rooms surveyed were naturally ventilated, however the windows were mostly closed during the survey period [Winter] hence, the rate of air exchange was low. The doors in every room were fire resistant, which are required to remain closed at all times, and possibly aggravated the IAQ.

The temperature in the rooms surveyed remained constantly high in majority of instances, with the 98-seater lecture hall (R03) constantly exceeding the recommended temperature of 21°C. The windows in all rooms are aluminium framed, with double glazed awning windows. However, these windows could only open up to an angle of 20°, and roller blinds are used to keep light out during classes/presentations [via a projector], restricting the amount of air circulation. Both simple and multiple regressions have also shown a strong negative correlation between temperature and satisfaction.

The correlation between the change in CO_2 as well as humidity and student comfort was insignificant. This result has been observed in other studies including Griffiths & Eftekhari [12], who concluded that temperature, rather than air quality, affects comfort among staff and students. The findings of this study has also shown that classroom temperature plays a bigger role in determining student comfort. This, however, does not suggest that CO_2 and humidity did not play any part in determining student comfort. The analysis of the survey showed that over 53% of the occupants were not satisfied with the quality of air, and over 60% believed that the quality of air affected their concentration by the end of the class. This can simply mean that the occupants may have found it difficult to isolate their sensory experiences or base their comfort on a single factor [10]. This result also concurs with findings by Frontczak & Wargocki [11], which concluded that thermal comfort was the greatest parameter that influenced overall satisfaction with IAQ.

A simple observation of minimum and maximum temperature and CO_2 figures also show that the average internal temperature has been constantly higher than the maximum limit in a room. However, average maximum CO_2 and humidity have remained below the maximum limit in 3 of the 5 rooms surveyed, which might explain the lack of correlation between these variables and temperature.

On the other hand, CO_2 data gathered over the 2-week survey period have shown that at some point in the day, concentration exceeds the required 1500 ppm level in every room. Overall, around 39% of the CO_2 recorded exceeded the 1500 ppm limit over the 14 days, or 55% if weekends (no occupancy) are excluded. In worst situations, such as where a room is full, levels of CO_2 have exceeded 4000 ppm within 90 minutes. This can cause issues with occupants' concentration, performance and even create health issues.

This is particularly worrying due to the on-going SARS-CoV-2 virus, which can remain active in the air for at least 3 hours and is capable of airborne transmission [4]. Should the rate of ventilation in these rooms remain the same, then there might be a high probability of transmission of the virus, possibly though an asymptomatic carrier.

5.2 Proposed Changes to Maintain Comfortable IAQ

5.2.1 Installation of Temperature and CO_2 Sensors inside Classrooms

It was observed during this study that the University uses temperature sensors to control the heating in the survey building, which is typical of many Higher Education facilities across the UK. However, these sensors, in this instance, were placed in the corridor, which are generally cooler than the learning spaces due to the lack of stationary occupants. This may be a contributing factor as to why the temperature in the learning rooms were regularly above 20°C, even during the night when there was no occupancy. There were no CO_2 sensors present in the building. Installation of CO_2 sensors in each room is advocated, or at least in larger lecture halls and classrooms is proposed in order to accurately monitor and control temperature and CO_2 levels.

5.2.2 Mechanical Ventilation System

As seen in room R05 which was served by a MV system, the temperature, CO_2 and humidity levels were mostly within the required limits, without the presence of any windows. The level of comfort in that room was also the highest at 75% at the start of class.

Installation of a MV system is proposed to maintain a comfortable IAQ. However, due to the vast time and cost involved with MV systems, a sensor controlled mechanical window could be installed instead. Along with individual sensors in each room, these mechanical windows could be installed and automatically open when the temperature and CO_2 levels rise, and close once the levels drop back within the desired range.

CO_2 concentration levels can be used as an indicator of IAQ [7] in a room which may contain various pollutants including Volatile Organic Compounds (VOCs) as well as the SARS-CoV-2 virus. Natural and mechanical ventilation (HVACs) are both considered good measures to remove respiratory particles [3]. However, in the interest of minimising risk of transmission of the SARS-CoV-2 virus, building management should look into filtering recirculated air or even stop the recirculation of air in mechanically ventilated rooms altogether [27].

5.2.3 Changes in Timetable

It was observed during the data collection of this study, that the temperature and CO_2 levels were already high in the learning space when a new group of students entered the class. This was particularly true in case of afternoon classes when a class had already taken place in that room earlier. To tackle this issue, a more robust timetable needs to be arranged. Buildings service teams could arrange for personnel to manually open windows between classes to ensure adequate circulation of air. The length of classes may also be an issue as temperature and CO_2 levels considerably rise over the duration of a 3-to-4-hour class. At least 2 to 3 breaks between classes are recommended as a measure to lower these levels. The data have also shown that CO_2 levels can reach levels of 1500 ppm within 15-30 minutes in a full class, hence a break every 40-50 min, along with opening of windows, may help maintain the room at a comfortable level.

6. Conclusions

This study analysed temperature, CO_2 and humidity data from 5 [learning/study] rooms in a higher education building in London across a 2-week period during the winter, the data of which was evaluated against perception survey data regarding users' level of comfort. The temperature data have shown that in all of the rooms surveyed, exceeded the recommended comfortable temperature range of 18°C - 21°C on a daily basis. The mean temperature was 22.3°C, and over 54% of the occupants expressed discomfort and a desire for a cooler temperature. The result of a simple and multiple regression analysis was significant and explained around 78% and 70% of the variance in user comfort, respectively. It also showed a negative correlation between the two variables. It was concluded that the heat emitted by the radiators in the learning rooms contributed to the high temperatures. This occurred because the sensors that control the radiators in classrooms are located in the corridors, which are always relatively cooler, hence causing the radiators in the classrooms to run continuously. On average, the rate of increase in temperature was around 3.75% per hour.

Monitoring and controlling the temperatures of classrooms can also lead to considerable savings in energy usage. Nicol, Humphreys & Roaf [30] argue that reduction in temperature by 1°C can reduce energy usage by around 10%. Based in this calculation the university building in this study can save between 13% – 43% of energy being used. The university building used in this study has an area of over 20,000m^2, which means that the savings in energy usage can be very significant.

The CO_2 data was found to be a good an indicator of air quality overall; the CO_2 levels regularly exceed the required limits within the 5 surveyed rooms, and this often occurred within the first 30 minutes of a class commencing. The highest recorded levels of CO_2 exceeded 4000 ppm in a [large occupancy] lecture hall. This study has also shown that during the afternoon, CO_2 levels are already close to the required maximum limit when the students and staff enter the room for a 3/4-hour class, which further aggravated the IAQ. The average rate of increase of CO_2 levels in R02 and R03 were 67.66% and 61.12% per hour, respectively. Amongst the three factors used in this study, levels of CO_2 rose at the highest rate of over 60% per hour, followed by humidity at over 9% per hour and then temperature at 3.75% per hour.

The regression analysis between CO_2, humidity and student comfort were insignificant. However, this does not mean that these factors did not affect the student's comfort, as over 53% of them were not happy with the air quality. This study has also shown that over 55% of the CO_2 levels exceeded the required 1500 ppm limit if weekends are excluded. During class time in R03, CO_2 levels were over 1500 ppm 70.26% of the time on average.

These issues need to be addressed by the University and building management as a matter of urgency, particularly during the on-going COVID-19 pandemic to reduce the transmission of the SARS-CoV-2 virus, which can remain active in the air for hours. A change in priorities might also be necessary in favour of keeping the pollutants and virus at bay. A couple of windows can be opened for around 30 minutes before or at the start of each class (depending on the timetable) to circulate the air, even if it means that the room temperature might drop by a few degrees.

The results of this study reflect low human comfort levels and have shown that the IAQ in this building is concerning and may have a negative effect on the wellbeing of its students and staff. Alarmingly, this is likely to be typical across the Higher Education sector in the UK. A number of changes are proposed in this paper, such as adjusting timetables, use of mechanical ventilation and installation of sensors in every room to monitor and control the IAQ individually, that will improve the prevailing IAQ – both physically and in perception.

Abbreviations

°C: Degree Celsius

CO_2: Carbon dioxide

HSE: Health & Safety Executive.

CFM: Cubic Feet per Minute

IAQ: Indoor Air Quality

MV: Mechanical ventilation

NV: Natural ventilation

O_2: Oxygen

PPM: Parts Per Million

WHO: World Health Organisation

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ARTICLE

Bosnian Chardaklia House: Abazovic Family House in Donja Koprivna Near Cazin

Ahmet Hadrovic*
Faculty of Architecture, University of Sarajevo, Sarajevo, Bosnia and Herzegovina

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ABSTRACT

In the wide range of vernacular architecture in Bosnia and Herzegovina, the Bosnian chardaklia house is one of those achievements that with its spatial organization, materialization and external appearance most vividly reflects the nature of Bosnian people, the nature of his family and worldview. This house is an objectified history of man and his family, at the same time as modern a museum whose content testifies to the past and predicts the future. The Bosnian chardaklia house, especially the one realized in the area of Central Bosnia, stands out by the fact that its disposition at the time of the original construction perceives the future, sometimes four generations of the human generation that follows each other. It is a building designed in the way of the functioning of a living organism, so by its nature it is an example of understanding flexibility in architecture and the forerunner of modern understanding of bioclimatic, that is, sustainable architecture. The Abazovic family house is located in the Donja Koprivna village, about 6 km away from the center of Cazin (geographical coordinates: 44º59' 32.13" N, 15º58' 48.15" E, Elevation: 396 m). The house was built (1937) by Bajram Abazovic (1892-?), a native of Buzim, who was appointed local imam in Donja Koprivna. It is interesting that this house was “transferred” from the Hodzici village near Krzalic, where it was built and used for several years.

1. Introduction

The Bosnian chardaklia house is, above all, the house of rich people in the countryside. On the one hand, it is firmly rooted in the tradition of folk architecture, but it also has elements of the city house as a transitional form from purely folk architecture to the solution of the town hall where the influences of other, often geographically distant cultures and solutions are visible [1-5].

The house he designed and built, in which he lives in the complexity of his overall being, is the most concrete objectified image of a man, his family and the immediate and wider community in which he lives. By getting to know the Bosnian chardaklia house, we will also get to know those dimensions of the being of the Bosnian man that have not been directly written about [6-11].

Corresponding Author:
Ahmet Hadrovic,
Faculty of Architecture, University of Sarajevo, Sarajevo, Bosnia and Herzegovina;
Email: hadrovic.ahmet@gmail.com; ahmet.hadrovic@af.unsa.ba

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The Bosnian chardaklia house in the area of Bosnian Krajina is specific in that it is at the same time a habitat for man and his "treasure" (bosnian: "blago"), i.e. cattle. This fact largely determined its disposition, that is, the manner of its use. One of the consequences of the house designed in this way is the space of the "vodnica" ("water storage") arranged as a storage room for water (upstairs) and toilet, always located above the laystall next to the barn (on the ground floor). The existence of toilets inside the house is a rare occurrence in the disposition of the Bosnian chardaklia house (and even city houses) in other parts of Bosnia and Herzegovina from the time of its original origin [1].

The Abazovic family house is located in the Donja Koprivna village, about 6 km away from the center of Cazin (geographical coordinates: 44º59' 32.13" N, 15º58' 48.15" E, Elevation: 396 m), (Figure 1). The house was built (1937) by Bajram Abazovic (1892-?), a native of Buzim, who was appointed local imam in Donja Koprivna ①.

It is interesting that this house was "transferred" from the Hodzici village near Krzalic, where it was built and used for several years ②.

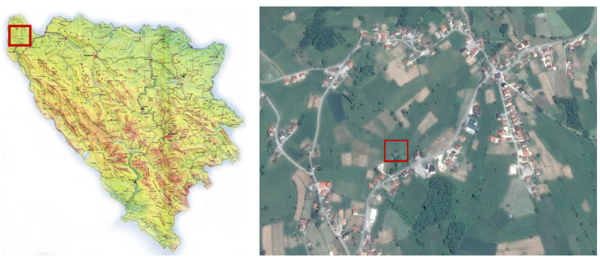

Figure 1. Geographical position of Cazin in Bosnia and Herzegovina (left) and location of the Abazovic family house in Donja Koprivna near Cazin (right)

Source: https://slidetodoc.com/regionalna-podjela-bosne-i-hercegovine-geografske-regije-bosne/ (left)

Google Earth: Accessed 3/10/2022 (right)

2. Spatial and Design Characteristics of the House

According to the horizontal plan of the ground floor, the Abazovic house is two-tract, while on the level of the first floor the house has a plan of a three-tract house [1]. The house is developed vertically through the ground floor and first floor, with the floor along the entire contour of the outer walls of the ground floor cantilevered into the space (Figure 2). The house has all the characteristics of a chardaklia house in Bosnian Krajina: ground floor arranged as a barn (where the "treasure"/"blago" is kept) ③, floor with several rooms-chardaks, sofa ("divanhana") and space with toilets cantilevered into the space (usually above the manure barn), high voluminous shingled roof (Figures 2, 7-16). On the ground floor of the house is the entrance hayat for living space on the first floor and a stable for cattle. To the left of the entrance to the house is (traditionally for the Krajina house) a woodshed area, while in its hinterland is a manure house (Figures 3, 6). The first floor is a living space to which a wooden staircase with a railing gives a particularly festive look (Figures 12-16). In this house, this is especially emphasized by the "divanhana", which (apart from the usual floor overhang) has an accentuated cantilever access to the open space, a polygonal contour of its floor plan and accentuated transparent and light exterior walls (Figures 2-5).

Four spacious rooms in the residential floor with a characteristic solution of the bathroom, give this house a particularly rich look. It reflects the high housing needs and rich housing culture of its owners (Figures 15, 16). Some elements of the construction of the house have the values of some archaic solutions. Thus, the foundation walls were reduced to single stones over which the foundation beams (wedding dresses) of the house go (Figures 2, 6).

This solution has its thoughtful values in the bioclimatic approach to construction. Namely, the space between the ground and the basement floor is closed with dry ferns in winter (and becomes a warm, protected zone of closed air that protects the basement space from low outside temperatures) while in summer this space is open (and thus provides the necessary basement ventilation).

The basement walls are made of massive chestnut logs, while the basement walls are made in the bondruk system of a wooden skeleton with a braided filling filled with earth (Figures 3, 4). The ground plan-floor and floor-attic structure is made of wooden beams (chestnut wood) with a floor of thick, hand-hewn wooden planks (Figures 8, 9).

The roof is relatively high and markedly voluminous in relation to the overall volume of the house. It was constructively solved as "horns with a crucifix" ("rogovi sa raspinjacom"). The cover is made of wooden shingles (Figures 2-5).

① The author visited this house on 7/25/2016.

② The author received this information from Mrs. Esmira Farah Budimlic during her second visit to this house (9/17/2016).

③ The name "treasure" (bosnian: "blago") refers to livestock, which in the conditions of life in the Bosnian Krajina has always been a primordial wealth-treasure (blago).

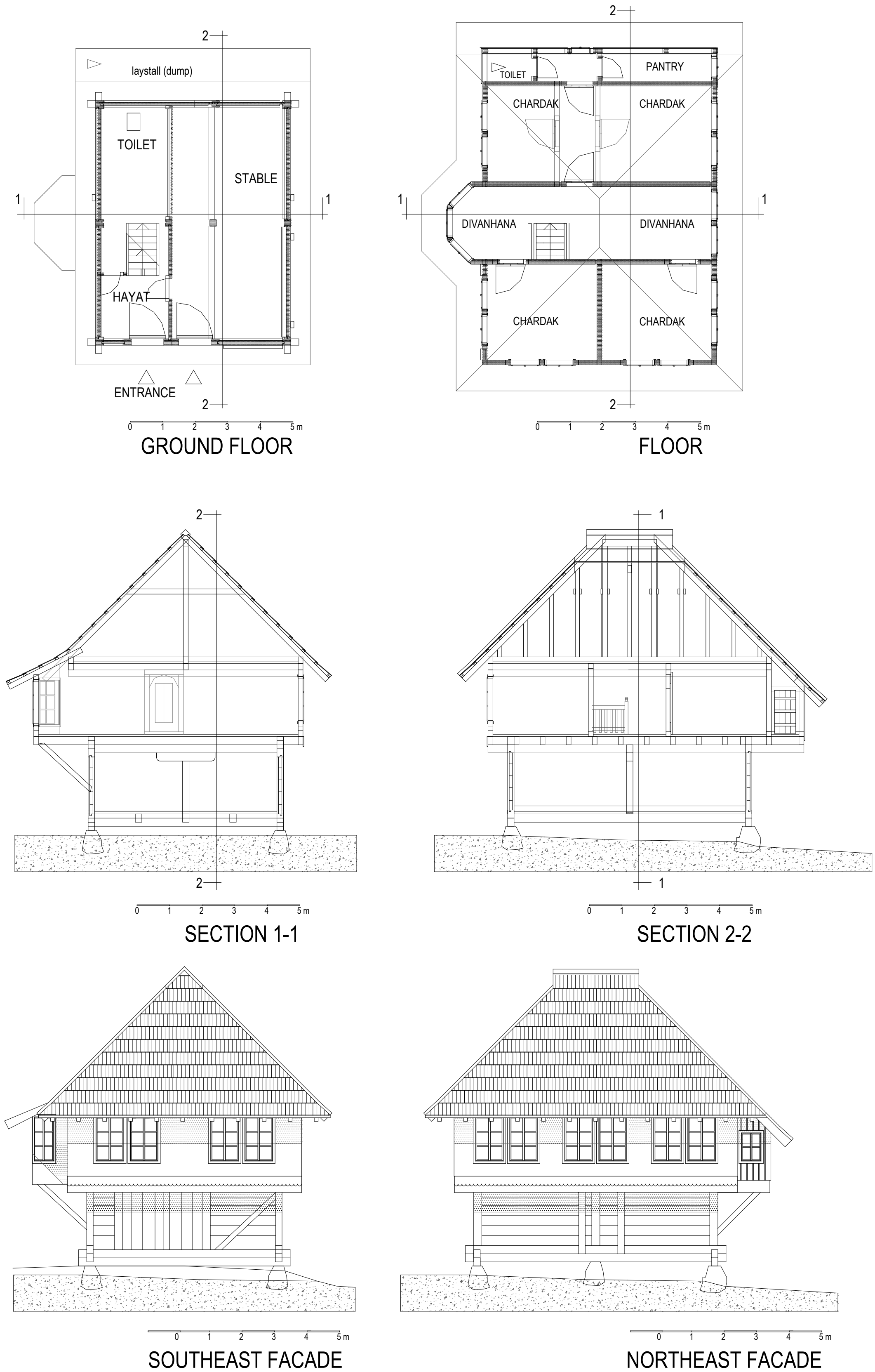

Figure 2. Abazovic family house in Donja Koprivna near Cazin. Disposition

Source: Author (drawing, 2016)

Figure 3. Abazovic family house in Donja Koprivna near Cazin. View of the house from the southeast, entrance facade. The unity of modesty and wealth

Source: Lejla Hadrovic (7/25/2016)

Figure 4. View of the house from the northeast. Spatial-constructive assembly

Source: Author (7/25/2016)

Figure 5. View of the house from the northwest. House in nature and nature in the house

Source: Author (7/25/2016)

Figure 6. Archaic solutions of house elements with universal and timeless values

Source: Author (7/25/2016)

Figure 7. The entrance for people to the apartment and the entrance for cattle in the barn stand next to each other. This is a materialized picture of the life philosophy of man in the Bosnian Krajina

Source: Author (7/25/2016)

Figure 8. The space of the former barn on the ground floor

Source: Author (7/25/2016)

Figure 9. Toilet in the corner of the ground floor

Source: Author (7/25/2016)

Figure 10. Hyat on the ground floor with a staircase to the first floor. To the left of the staircase is the passage to the toilet

Source: Author (7/25/2016)

Figure 11. View from the barn towards the hayat with a staircase to the first floor

Source: Author (7/25/2016)

Figure 12. View from the staircase to the sofa (divanhana) area

Source: Author (7/25/2016)

Figure 13. Divanhana space with staircase

Source: Author (7/25/2016)

Figure 14. Doxate protruding part of the divanhana

Source: Author (7/25/2016)

Figure 15. Arrangement of the chardak (above the hayat)

Source: Author (7/25/2016)

Figure 16. Arrangement of the chardak on the southeast corner of the floor

Source: Author (7/25/2016)

3. Construction and Materialization

The walls of the ground floor of the house are made of hand-hewn chestnut logs, while the walls of the first floor are made of wooden skeleton (bondruk) with wooden wicker filling filled with unbeaten earth with the addition of straw and chaff (Figures 3-10, 17). The ground plan-floor and floor-attic structure is made of chestnut wood beams, with a floor made of massive wooden planks [12] (Figures 18-20). The roof is four-pitched, of medium slope (45º), with wooden shingles as a cover (Figure 21).

Figure 17. The Abazovic family house in Donja Koprivna near Cazin. Legibility of all elements of the house (lifestyle, construction, materialization ...)

Source: Author (7/25/2016)

Figure 18. Ground floor (stable) space with structural assembly

Source: Author (7/25/2016)

Figure 19. Ground-floor structure

Source: Author (7/25/2016)

Figure 20. Massive columns and beams of the ground-floor structure are made of chestnut wood

Source: Author (7/25/2016)

Figure 21. Roof construction

Source: Author (7/25/2016)

4. Surface Treatment

In the Bosnian chardaklia house, the applied natural materials give each element of construction an honest expression, in accordance with the complex of properties that each material possesses, from physical-mechanical to aesthetic-expressive. Rarely is paint used as a coating in any building element to make a "better impression" than one that leaves the material in its natural expression.

Interior surface treatment. The main building materials used in the Bosnian chardaklia house are: stone, wood and earth (such as adobe, charge in the walls of wooden skeleton and wicker and in mezzanine structures). These are elementary materials that we find in nature, so their application in creating the spatial-constructive structure of the house has an extremely strong aesthetic and psychological effect that establishes a direct and intimate relationship between observers from the side and the house. And the materials that man gets by a certain intervention on natural materials (lime, brick, tile, ceramic "pots" for lining kilns ...) are not much "away" from their natural sources, so they also seem intimate, tailored to man. All interior surfaces of the Bosnian chardaklia house, walls, floors and ceilings can be made of only one of these natural materials, but mostly combinations of materials are used in accordance with their properties and place of application in the spatial structure of construction and their availability in nature.

The use of stone in the construction of the Abazovic family house in Donja Koprivna near Cazin is, at first glance, hardly noticeable, but it is extremely interesting and convincing: large pieces of stone are used as foundation feet on which wooden log walls on the ground floor rely (Figure 2). It could be said that wood is the material that gives the house of the Abazovic family such a recognizable architectural physiognomy. The noble properties of wood are most pronounced in the treatment of ceilings, floors and elements of the opening. In some cases, individual parts of wood surfaces are surface treated with lime milk, as protection against the harmful effects of moisture from condensation (in place of thermal bridges), (Figure 26).

Lime deposits about 1 cm thick are possible on some wall surfaces (Figure 22). Rugs of different levels of cost are added to the primary treatment of floor surfaces: fur of domestic animals, coarse cloth of goat hair, woven strips of wool or cloth ("waist", "rot" – bosnian: "struke", "zātke", "trulje"), more modest carpets made by joining woolen strips), more or less expensive woolen carpets ("Bosnian carpets" – "cilim"), and expensive carpets whose origin is in some of the countries of the East

(Figures 36, 37).

Exterior surface treatment. Similar to the interior, in the exterior we most often encounter materials in their natural expression: stone, wood and earth.

Contrast is one of the most important ways of expressing oneself in composing the architectural physiognomy of the Abazovic family house in Donja Koprivna near Cazin. Stone, as a heavy material that carries pressure and is resistant to the weather, is used to build foundations that carry the complete structure of the house, in contrast to the ground floor walls of wooden logs and floors whose lightness is further underlined by perforations (once numerous) windows. The whitewashed walls of the floor volume contrast with the dark color of the wood from which the divanhana was made. The dark color of the wooden logs contrasts with the white surfaces of the painted walls. The dark volume of the shingled roof is in contrast to the white volume of the main body of the house... (Figures 3-5).

Figure 22. Surface treatment of the divanhana space

Source: Author (7/25/2016)

Figure 23. Massive wooden floors in the divanhana

Source: Author (7/25/2016)

Figure 24. Wooden ceiling in a large chardak

Source: Author (7/25/2016)

Figure 25. Wooden ceiling in the chardak above the hayat

Source: Author (7/25/2016)

Figure 26. Wooden ceiling in the chardak at the southeast corner of the floor

Source: Author (7/25/2016)

5. Doors and Windows

At the Abazovic family house, three groups of doors can be seen: the door to the basement (stable), the main entrance door, and the door inside the architectural space (Figures 27-30). In the classic solutions of the Bosnian chardaklia house, all the doors, both on the outer walls and the one inside the house, are made of wood.

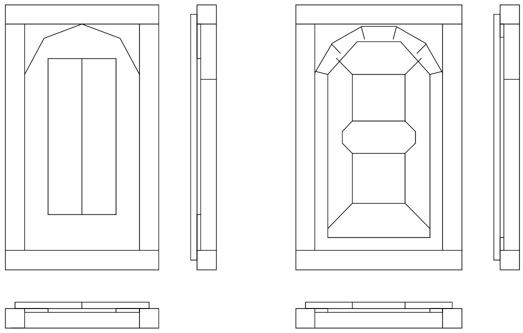

Figure 27. Archaic door design

Source: Author (drawing, 2016)

At the same time, the doors on this type of house are identical throughout Bosnia and Herzegovina. Differences occur in the performance of doors in recent times (since the mid-20th century), where their creators are educated craftsmen-masters, who, through the design of doors wanted to show their uniqueness in the market (Figures 29, 30). The door at the entrance to the basement is massive and rustic, mostly single-leaf. Regardless of the material from which the basement wall is made, the door has a frame, a door frame made of massive, more or less finely worked wooden logs, and a wing made of hewn boards about 5 cm thick. The planks on the door leaf are interconnected on the inside by two or three rungs, and sometimes by a beehive connecting the rungs (Figures 27, 28). The door hinges are made of wrought iron, and are placed, most often, so that the door leaf cannot be removed. The dimensions of the door are "on the scale of a man", sometimes such (80 cm × 120 cm) that a man must walk when passing through them (Figure 3). In richer houses, a more or less accentuated arch of wood is made on the door frame, which also emphasizes the door (Figure 27).

Figure 28. Archaic design of the front door to the residential part of the house and the barn

Source: Author (7/25/2016)

Figure 29. Door on the chardak located in the southeast corner of the floor

Source: Author (7/25/2016)

Figure 30. Door on the chardak above the hayat

Source: Author (7/25/2016)

At the Bosnian chardaklia house we meet a wide range of different window design solutions. In general, the design of windows corresponds to the purpose of the room where they are installed. Similar to the design of doors, in the design of windows we find the same solution throughout Bosnia and Herzegovina, where some regional specifics can be observed. The most common solution is a double-leaf, single window with three panes on each wing (Figure 31). The dimensions of such windows range from

60 cm × 80 cm to 100 cm × 130 cm.

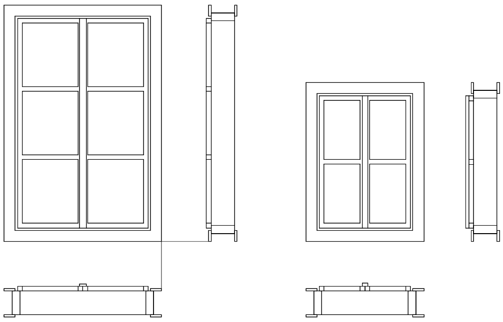

Figure 31. Window design

Source: Author (7/25/2016)

At the Abazovic family house in Donja Koprivna near Cazin, we find solutions for "merging" two relatively small double-leaf windows into one "large window". This is a transitional solution towards "big windows" (Figures 32-35).

Figure 32. Windows establish the unity of two worlds, internal (personal) and external (public)

Source: Author (7/25/2016)

Figure 33. By connecting windows, their functionality and aesthetic-psychological impression of a person is enhanced, both inside the space and in the open space when looking at the object

Source: Author (7/25/2016)

Figure 34. View through the windows on the divanhana

Source: Author (7/25/2016)

Figure 35. View through a chardak window on the southeast corner of the floor

Source: Author (7/25/2016)

6. Space Equipment

The basic impression that one gets by looking at the space of the Bosnian chardaklia house is that it is "empty". It is his "emptiness" that makes him "bigger" and richer than he is. This impression is especially expressed in the classic solutions of the Bosnian chardaklia house where, for example, its entire interior can be seen from the space of the "kuća", from the gallery space in the air space of the "kuća" or from the attic space. A similar impression was obtained by looking at the staircase space from the perspective of the divanhana and from the perspective of the "kuća" (Figure 12).

The key elements of the equipment of the classic solutions of the Bosnian chardaklia house are open fireplace, brick stoves with ceramic "pots", open or closed niches in the walls ("dulafi"), baths (stone or wood) in the corners of the room, wooden shelves (shelves), large wooden boxes for storing flour (sometimes called "barns" – "hambari"), wooden boxes for storing formal clothes and valuables for women (sehara), especially decorated bathrooms (hamadzici), swings for small children ("bešika"), round, low dining table ("sinija"), dishes (metal, ceramic and wooden) that are visibly displayed on the shelves and walls of the room. "Furniture" (sofas, armchairs, showcases ...) also appears in the house of the Abazovic family, which is already the influence of "Western culture" (Figures 36, 37).

Figure 36. Kitchen cabinet ("cupboard" – "kredenac") in the divanhana area

Source: Author (7/25/2016)

Figure 37. Showcase in the chardak above the hayat

Source: Author (7/25/2016)

7. Today's Condition and Purpose of the House

The Abazovic family house in Donja Koprivna near Cazin is still in relatively good physical condition. In order to preserve its physical structure, it is necessary to urgently make a new roof covering, which would "conserve" the building until its activation at full housing capacity or some new purpose [4].

The "danger" for the survival of this house (and Bosnian chardaklia houses in general) is the issue of inheritance, when the house, due to the large number of heirs (as a result of its age), practically becomes "everyone's and nobody's".

Figure 39. Original motifs of embroidery (from the Abazovic family house) in a contemporary art composition (Works by Esmira Farah Budimlic exhibited in the Art Gallery Farah in Cazin)

Source: Author (7/25/2016)

④ One of the heirs of this building is the famous and versatile artist EsmiraFarah Budimlic-Dzafic. The artist is aware of the cultural-historical and architectural-artistic values of this building and it is expected that she will take measures to protect and preserve it.

Figure 40. The Abazovic family house in Donja Koprivna near Cazin is a common motif in the artist's paintings. The photo shows the work of Esmira Farah Budimlic on display at the Art Gallery Farah in Cazin

Source: Author (7/25/2016)

8. Conclusions

The Abazovic family house in Donja Koprivna near Cazin is an example of a traditional Bosnian house of čardaklija and an example of bioclimatic architecture. In accordance with the natural and social environment, this house is an example of a more modest version of the Bosnian house čardaklija which is smaller than the more developed type of this house and without semi-open spaces - sofa (specific solutions uncovered terrace on the first floor). Here is a divanhana enclosed space with the function of a hall.

Features of the bioclimatic architecture of this house can be read in:

— Construction and materialization of the facility, where traditional methods of construction are used in many years of experience and the use of all materials from the immediate natural environment. In this way, this house looks like a "natural environment created by man"[13-15];

— Ensuring comfort in the house (in all seasons) is achieved by adequate design of the house, materialization of its envelope and the use of energy from the immediate environment (firewood, beeswax candles or sheep fat - before introducing electricity into the house);

— Recycling of generated waste in the house. All residues of human food are given to domestic animals, while other types of waste are used as firewood (wood residues in the manufacture of household tools, for example);

— Use of rainwater to maintain the hygiene of people and the premises and laundry;

— Thanks to the relatively stable physical structure of the house, it is now used as a holiday home for people who live and work in the city. The "embodied spiritual energy of houses" (memories of childhood, parents and relatives, precious events) relaxes people and makes them especially confident in their devotion to their ancestors.

Conflict of Interest

There is no conflict of interest.

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ARTICLE

Repair and Restoration of the Historical Wellesley Bridge at Srirangapatna: A Case Study

Madan Kumar L[1] Pruthviraj S R[2*] Ravi Kumar C M[2]

1. Department of Civil Engineering Department, The National Institute of Engineering, Mysore, Karnataka, India
2. Department of Studies in Civil Engineering, University B.D.T College of Engineering, Davangere, India

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ABSTRACT

The Historical Wellesley Bridge, built by the Krishnaraja Wadiyar under the supervision of Dewan Purnaih across river Cauvery at Srirangapatna. Situation of bridge is got when heavy rainfall followed by heavy inflow from Cauvery Catchment area in Kodagu District. At present, the Government of Karnataka has taken measures to do the restoration works using the same previously used materials with slight changes. Hence, in the present investigation the authors are doing a case study on the above structure by testing the ingredients of the materials used for it and also by conducting Non-Destructive Test on the structure to know its strength before and after restoration. Based on the test results obtained, the authors will give a conclusion with respect to durability aspects. In addition to the above, the authors will test for few alternative materials i.e., lime mortar with Cement (i.e. MM2 Grade Masonary mortar). Finally, from the obtained test results here the authors can suggest suitable material for the structures.

1. Introduction

The system via which limestone (calcium carbonate) is converted to quicklime with the aid of heating, then to slaked lime by using hydration, and clearly reverts to calcium carbonate via carbonation is referred to as the lime cycle. The situations and compounds present all through each step of the lime cycle have a robust effect of the end product, therefore the complicated and varied physical nature of lime products.

An example is whilst slaked lime (calcium hydroxide) is blended right into a thick slurry with sand and water to shape mortar for building functions. Whilst the masonry has been laid, the slaked lime inside the mortar slowly begins to react with carbon dioxide to shape calcium carbonate (limestone) in line with the reaction:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O.$$

The carbon dioxide that takes component in this reaction is mainly available in the air or dissolved in rainwater so natural lime mortar will now not re-carbonate beneath water or internal a thick masonry wall.

The lime cycle for dolomitic and magnesium lime is

**Corresponding Author:*
Pruthviraj S R,
Department of Studies in Civil Engineering, University B.D.T College of Engineering, Davangere, India;
Email: pruthvi960637@gmail.com

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not nicely understood but greater complex because the magnesium compounds additionally slake to periclase which slake more slowly than calcium oxide and whilst hydrated produce several different compounds hence those limes comprise inclusions of portlandite, brucite, magnesite, and other magnesium hydroxyl carbonate compounds. Those magnesium compounds have very constrained, contradictory research which questions whether they may be substantially reactive with acid rain that could result in the formation of magnesium sulphate salts. Magnesium sulphate salts may also damage the mortar when they dry and recrystallize because of expansion of the crystals as they shape that is called sulphate attack.

Because lime has an adhesive property with bricks and stones, it is regularly used as binding material in masonry works. It is also utilized in whitewashing as wall coat to adhere the whitewash onto the wall.

Generally talking the trouble of recuperation of these buildings differs substantially from the trouble of repair and strengthening of regular buildings. For enormous buildings emphasis is given to the maintenance in their aesthetic and historical values, even as the assignment to remain in use may be considered of secondary importance, and anyhow because of the effort in the direction of fulfillment of the main project [1].

The problems associated with the healing of antique stone bridges are numerous but the civil engineer must take under be aware every technique and agent which can be applied in every separate case due to the notable importance of those structures [2].

The presence of damage, specifically cracking, isn't always inevitably a sign of danger, since it may produce most effective a redistribution of stresses, for which failure chance might be absent. Despite the fact that, while harm threatens protection of historic bridges, it becomes important to assure their structural balance, by way of sporting out restore and strengthening measures, stimulated through both the significance they nevertheless count on in the real street network and the architectural, ancient or social value they represent [3].

The masonry walls and pillars subjected to compression are the most important elements of the ancient masonry buildings. It is necessary to take into consideration reliability techniques to reap correct compressive energy substances which the structures had been erected. Because of the ancient person of many masonry centers, the possibilities for casting off the best number of samples are confined [4].

2. Literature Review

Rutika Bhoir and Yogesh Bhoir (2019) carried out repair and rehabilitation of a building by considering the building as a case study and checked the existing building components majorly to find out the current structural performance and condition. The investigation is mainly based on visual inspection of the building and Non-Destructive Tests (Rebound Hammer). In this investigation, they have conducted three tests i.e., ultrasonic pulse velocity test, rebound hammer test and carbonation test techniques. The detail investigation for the building with all NDT test results indicated that there is a variation in the compressive strength of concrete in beams as well as in column members. At certain locations of the building, the compressive strength found around 10MPa which indicating poor quality of concrete adopted at the time of execution of the building which increases the permeability of the concrete leading to allow the harmful gases such as carbon dioxide gas, chlorides etc. from the outside environment resulting in corrosion effect for steel leads to decreases the durability of the structure.

M. Karaveziroglou-Weber, et al. (2017) conducted study on the repair of an old stone bridge, where this investigation deals with the restoration and rehabilitation of an arched bridge situated in Central Greece. This stone bridge, built in the 18th century, with its elegant form is an excellent reminder of the Greekarchitectural heritage in Central Greece. This bridge was seriously damaged due to aging and, earthquakes, floods and some interventions but there is no serious attempts of restoration has made. The restoration works suggested through this paper includes - the pathology of the existing bridge and its analysis, considering only the dead loads and taking the consideration of seismic actions and the proposals for its repairing and strengthening was made. For that, various data's were considered along with in situ investigations and laboratory tests.

Daniel V. Oliveira and Paulo B. Lourenço conducted the study on the repair of stone masonry arch bridges. This investigation deals with the analysis and design of repair measures for two Portuguese masonry arch bridges. The first one is related with a masonry bridge constructed in the 19th century. It composed of six stone arches and which located in the centre city of Portugal. The second example is a medieval masonry bridge consisting of three semi-circular stone arches and which is located in the North of Portugal city. Repair measures are adopted to establish the safety of the bridge and these measures were taken in order to respect the modern principles of structural intervention in architectural heritage.

Rodrigues et al. (2008) deals with some diagnostic testing, conservation, maintenance and rehabilitation recommendations for existing masonry bridges with special attention to the historical bridges. They have done rehabilitation work on the steel bars, joint repointing, and injection of the fill material, waterproofing drainage of pavement and dismantling and re-construction. This investigation finally concludes that the many of these recommendations are very easy and it is common to apply. However, there are some of them that must be well planned and analysed before application to avoid the destruction and/or deprive the performance of bridge and its characteristics.

Aditya S. Gangane and Pravin V. Khandve (2015) conducted the extensive study on special repair techniques by using some special material for waterproofing, grouting, protective coatings and chemical adhesive. The old plastering was chipped and fresh plastering should be suggested in order to avoid the bridge among the plasters. These techniques are new and which involve an appreciable amount of money generating which is required for trainee skilled labours and supervision by trained personnel to increase the better workmanship. The demand of restoration can be achieved by enhancing the life and look of the structure. In such cases, the special repair work, good quality of special chemicals admixtures, grouts material should be used systematically to manage the activities pertaining to 4M's will certainly leads to good results and work with economy and sustainability.

Ladislav Klusaceka et al. (2017), carried out the restoration of arch bridge by additional horizontal pre-stress to the structure, by adopting the methods of strengthening the arch bridge that has longitudinal cracked. The process of this is done by inserting reinforced concrete spandrel walls which was stabilized by transverse pre stressed mono strands. Specifically, their aim is to reconstruction of the brick arch railway bridge, which was in disrepair. At the beginning of the design work it had to be decided whether it would be effective to carry out reconstruction of the existing bridge, or to accede to build a new bridge on the existing place. The test results indicate that experimental measures and the engineering numerical models confirmed to the high effectiveness of introducing the pre stress into the bridge arch as well as suitability of using. After introducing the pre-stress, the separated parts of the bridge began to work as one unit again, and a part of the stress on the arch is carried by attached concrete front walls.

The Department of Transportation for the state of Iowa (Wipf. et al. -2003)conducted research work that focused on the maintenance, repair and rehabilitation methods for bridges. They have conducted research on substructure member's that is pile repair for the bridge. There is no consideration placed on analysing cost or life data for the provided repairs. In addition to that, the repairs are not objectively compared to one another for the purposes of deciding which repair would be the most effective and efficient for a given element. This study also provides useful information about how repairs should be conducted, but never analyses them in terms of efficacy or estimated life.

Literature Survey Outcomes

After going through literature review, it depicts that the historical structures are needed to maintain with good condition - hence, the restoration of these structures is very much necessary. Cauvery River at Srirangapatna by testing the materials used for restoration and by checking the strength of the structures through Non-Destructive Test before and after restoration. Also, here we are testing few alternative jointing materials i.e., lime mortar with cement (MM2 Grade Masonary Mortar).

3. Objectives

- To determine the strength of the jointing material i.e., lime mortar which will be used for restoration works.
- To check the strength of the existing structure before and after restoration using Non-destructive Test.
- To predict the durability of the structure based on the test results obtained.
- Finally, a Scanning Electron Microscopic (SEM) test will be done on the jointing material to visualize the microstructure of it and in turn the obtained output will be helpful to know the reason beyond the variations of the strength.

4. Methodology

- Site visits and site Observations.
- Collection of materials.
- Non-Destructive Test on structure before restoration.
- Testing on materials.
- Non-Destructive Test on structure after restoration.
- To predict the durability of the structure after restoration.
- Scanning Electron Microscope test on jointing material.

4.1 Basic Tests on Materials Used for Repair and Restoration

4.1.1 Fine Aggregates: (Specific Gravity)

The specific gravity of the fine aggregate (i.e. sand) is calculated as the ratio of the weight of given volume of aggregates to the weight of equal volume of standard liquid (i.e. water). The test is conducted according to IS: 2386 (part 3) -1963 and the experimental setup has been shown in Figure 1.

$$\text{Specific Gravity} = \frac{\text{wt of given volume of Aggregates}}{\text{wt of equal volume of water}}$$

Specific Gravity determination is one of the most important tests to be conducted. There are particles which are lighter or heavier than aggregates, tracking of Specific gravity can help us identify if the aggregates are up to the standards or if there are any possible contaminations. Contaminations can be dangerous for the lime mixture.

The specific gravity of taken sands is considered to be around 2.65 after the basic test on Specific gravity.

Observation and calculation

Wt. of empty bottle (W_1)	=	615 g
Wt. of empty bottle and cement (W_2)	=	1124 g
Wt. of empty bottle, sand and water (W_3)	=	1786 g
Wt. of empty bottle and water (W_4)	=	1469 g

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

$$= \frac{1124 - 615}{(1469 - 615) - (1786 - 1124)}$$

$$\text{Specific gravity} = 2.65$$

Figure 1. Pyconometer

Result: The specific gravity of the fine aggregates is **2.65.**

4.1.2 Sieve Analysis

Sieve analysis helps in determining the grain size distribution of both fine and coarse aggregates. As per the recommendation of IS: 2386 (Part I) – 1963.

To determine the suitability of aggregate for making Lime Mortar. Aggregates to be used for making Lime Mortar should be of a known gradation so that good compact Lime Mortar can be made Sieve analysis is one of the important tests conducted while performing design of Lime Mortar mix Indian standard test sieve of different sizes. Weigh balance capable of weight within 0, 1% of weight of specimen. The sieve analysis on fine aggregates is done according to IS: 2386 (part 1)-1963. The zone of the fine aggregates is determined by plotting the graph of the values obtained and is represented in Table 1 and also in the form of graphical representation shown in Graph 1.

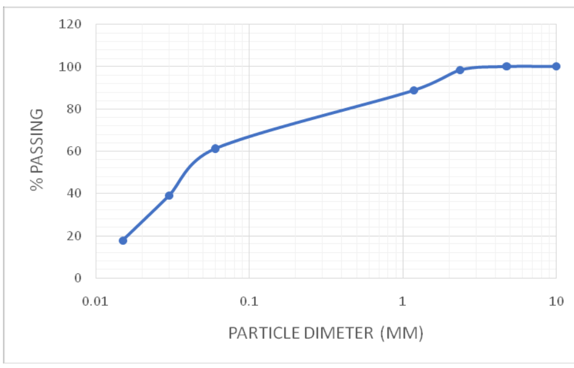
Observation:

- Weight of dry sample = 1000 g

Table 1. Sieve analysis

Size of the sieve (mm)	Soil Retained (g)	cumulative weight retained	Soil Retained (%)	Soil Passing (%)
10.00	0	0.0	0.0	0
4.75	0	0.0	0.0	100.0
2.36	16	16.0	1.6	98.4
1.18	96	112.0	11.2	88.8
0.06	276	388.0	38.8	61.2
0.03	222	610.0	61.0	39.0
0.015	211	821.0	82.1	17.9
PAN	179	1000.0	100.0	0.0
TOTAL:	**1000**		**327.8**	

Graphical representation



Graph 1. Sieve analysis graphical representation

Result: The fine aggregate belongs to **ZONE III.**

Fineness Modulus (FM) of sand:

$$\frac{\text{Sum of cumulative \% wt. retained}}{100} = \mathbf{2.94}$$

4.2 Surkhi

4.2.1 Specific Gravity Test on Surkhi

Specific gravity of Surkhi is the ratio of the Wt. of given volume of aggregates to the weight of equal volume of water used. The test is conducted according to IS: 2386 (part 3) -1963.

$$\text{Specific Gravity} = \frac{\text{wt. of given volume of aggregates}}{\text{wt. of equal volume of water}}$$

Specific Gravity determination is one of the most important tests to be conducted. There are particles which are lighter or heavier than aggregates, tracking of Specific gravity can help us identify if the aggregates are up to the standards or if there are any possible contaminations. Contaminations can be dangerous for the Lime Mortar mixture. The specific gravity of Surkhi is considered to be around 2.7.

Observation and calculation

Wt. of empty bottle (W_1)	=	615 g
Wt. of empty bottle and cement (W_2)	=	1050 g
Wt. of empty bottle, sand and water (W_3)	=	1743 g
Wt. of empty bottle and water (W_4)	=	1469 g

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

$$= \frac{1050 - 615}{(1469 - 615) - (1743 - 1050)}$$

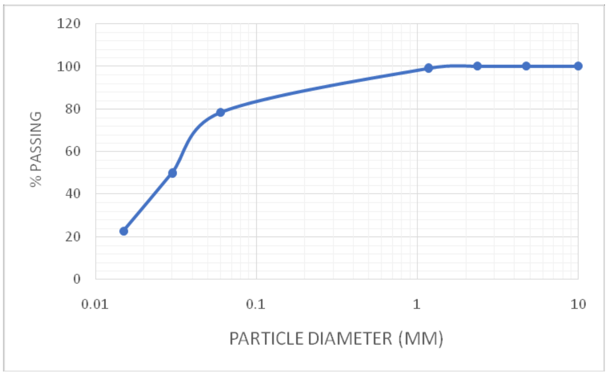
$$\text{Specific gravity} = 2.70$$

Results: The specific gravity of the fine aggregates is **2.70.**

4.2.2 Sieve Analysis of Surkhi

To determine the suitability of aggregate for preparing concrete. Aggregates to be used for making concrete should be of a known gradation so that good compact concrete can be made Sieve analysis is one of the important tests conducted while performing design of concrete mix Indian standard test sieve of different sizes. Weigh balance capable of weight within 0, 1% of weight of specimen. The sieve analysis on fine aggregates is done according to IS: 2386 (part 1)-1963. The zone of the fine aggregates is determined by plotting the graph of the values obtained are represented in Table 2 and also in the form of graphical representation shown in Graph 2.

Graphical representation



Graph 2. Sieve analysis graphical representation

Result: The fine aggregate belongs to **ZONE III.**

Fineness Modulus (FM):

$$\frac{\text{sum of cumulative \%wt. retained}}{100} = \mathbf{2.5}$$

4.3 Lime

Fineness test for Lime

The Fineness Test of lime is done by conducting the sieve analysis for lime sample through standard IS sieves of different sizes recommended by IS 6932(Part IV) -1973.

$$\text{Fineness (\%)} = \frac{\text{Residual lime on sieve in g} \times 100}{\text{Initial taken sample}}$$

$$= \frac{5 \times 100}{100}$$

$$= 5\%$$

Percentage of fineness of lime is 5%.

Observation:

Weight of dry sample = 1000 g

Table 2. Sieve analysis for Surkhi

Size of the sieve (mm)	Soil Retained (g)	cumulative weight retained	Soil Retained (%)	Soil Passing (%)
10.00	0	0.0	0.0	0
4.75	0	0.0	0.0	0
2.36	0	0.0	0.0	0
1.18	9	9.0	0.9	99.1
0.06	208	217.0	21.7	78.3
0.03	284	501.0	50.1	49.9
0.015	273	774.0	77.4	22.6
PAN	226	1000.0	100.0	0.0
TOTAL:	**1000**		**327.8**	

5. Results and Discussions

5.1 Workability Test

The Lime slump test measures the consistency of fresh lime before it sets. It's miles achieved to check the workability of freshly made lime, and consequently the convenience with which lime flows. It may also be used as a trademark of an improperly mixed batch. Inside the case of hydrated lime, the lime putty will be organized by means of thoroughly blending the hydrated lime with an identical mass of easy water at a temperature of 27 + 2'C, 24 hours earlier than the following operations. A convenient quantity of hydrated lime to be taken for this cause shall be 500 g. At the expiry of 24 hours the soaked fabric shall be thoroughly combined and knocked up to provide a plastic putty. A mixer of the sort given in IS 1625.1971 shall be used for the knocking up the cloth being passed two times through this mixer. The lime putty organized will be adjusted to traditional plastering consistency, which will be that indicated by way of an average spread of the decrease part of the lime putty to 11 cm with a permissible deviation of now not extra than zero.1 cm, while subjected to one bump on the standard flow table.

Size of the mould: Top diameter = 40 mm
Bottom diameter = 65 mm
Length = 90 mm

Results: The average spread of 11 cm is obtained at the water content of 180 mL.

5.2 Determination of Initial Setting Time

Initial setting time is regarded as the time elapsed between the moments that the water is added to the lime, to the time that the paste starts losing its plasticity. Place the test block prepared in accordance with 3.2.4 of IS: 6932 (Part-8)-1973. Under the rod bearing the needle (C), lower the needle gently in contact with the surface of the test block and quickly release, allowing it to penetrate into the test block. In the beginning, the needle will completely pierce the test block. Repeat this procedure until the needle, when brought in contact with the test block and released as described above, fails to pierce the block by 5 +0.5 mm measured from the bottom of the mould. The period elapsing between the time when water is added to the lime and the time a: which the needle fails to pierce the test block by 5 +0.5 mm shall be the initial setting time. (After achieving 11 cm spread as done in workability, lime mortar is set for initial setting).

5.3 Determination of Final Setting Time

The final setting time is the time elapsed along the moment the water is introduced to the lime, and the time when the paste has absolutely misplaced its plasticity and has attained sufficient firmness to resist certain particular stress. Determination of final setting Time - replace the needle (C) of the Vicat equipment by the needle with an annular attachment (F). The lime shall be considered as ultimately set when, upon making use of the needle gently to the surface of test block, the needle makes an impression on the surface of test block even as the attachment fails to accomplish that shall be the very last setting time. Within the event of a scum forming at the surface of the check block, use the bottom of the block for the determination. The results obtained after the test conduct are represented in Table 3 with respect to time consideration.

Table 3. IST and FST in Minutes

Sl. No	Reading	Time in minutes
1.	5mm from bottom	1680
2.	0	4320

5.4 Compressive Test

While hydrated lime is used, 500 g or the sample will be very well mixed with 60 to 65 percent of water for five minutes, and the resulting putty shall be surpassed twice through a mixer of the kind given in IS: 1625-1971 and used right away for preparing the standard mortar. Blend 350 g of the putty with an amount of standard sand equal to a few times the mass of the dry hydrate contained in it, this is, 636 g to 656 g. The balance of the putty shall be discarded. The lime putty and sand will be thoroughly combined for 10 mins continuously, so one can form a uniform plastic mortar. Twelve cubes with 50 mm width-0 cm will be prepared from standard lime-sand mortar. The specimens will be taken out of the moulds and located inside the air inside the laboratory for four days, while 7 days old, the specimens will be immersed in clean water and left there until simply previous to trying out for its strength in the testing machine. After 7 days of storage in water of the cubes will be taken out of water, wiped surface-dry and examined for compressive power in a compression testing machine. This offers the strength at 14 days. The final 6 test specimens shall be taken out after 28 days and in addition tested accordingly determining the compressive strength at 28 days. The load will be step by step and uniformly implemented, starting from zero growing on the charge of 15 kg/min. (IS 6932 (part XI) –

1973). Size of the cube: 50 × 50 × 50 mm. Cast cubes were tested for 14 and 28 days curing period and the results were tabulated in Table 4 & Table 5.

Table 4. Compressive Strength of Concrete for 14 Days Curing

Sl.no	Material	No of Days	Area of cube (cm^3)	Compressive Load (kN)	Compressive Strength	
					N/mm^2	Kg/cm^2
1	LIME	14	25	2.5	1.0	10
2		14	25	2.8	1.1	11
3		14	25	2.5	1.0	10
4		14	25	2.3	0.9	9
5		14	25	2.8	1.1	11
6		14	25	2.5	1.0	10

Size of the cube: 50 × 50 × 50mm

Table 5. Compressive Strength of Concrete for 28 Days Curing

Sl.no	**Material**	**No of Days**	**Area of cube (cm3)**	**Compressive Load (KN)**	**Compressive Strength**	
					N/mm2	**Kg/cm2**
1	LIME	28	25	3.8	1.5	15
2		28	25	3.5	1.4	14
3		28	25	3.8	1.5	15
4		28	25	3.8	1.5	15
5		28	25	3.8	1.5	15
6		28	25	3.5	1.4	14

Result: The compressive strength of Lime Mortar at 14 days is 1.01N/mm^2.

The compressive strength of Lime Mortar at 28 days is 1.46N/mm^2.

5.5 Experimental Procedure

5.5.1 Batching

The quantity of materials was batched accordingly to the results obtained from the code book IS 2250-1981. This ensures the usage of required quantity of materials. Weigh batching is the proper and preferred method of measuring concrete ingredients which leads to more uniform proportioning. Weigh batching system allows simplicity, flexibility and accuracy. Exclusive varieties of weigh batchers available in the marketplace and it depends upon the form of task. Manual weigh batching, in manual batching weighing of all lime mortar ingredients is done manually. This system may be used for small jobs. For the project manual weigh batching was adapted as shown in the Figure 2. Weigh batching has a great advantage as it gives good quality of lime mortar and providing more accurate and consistent mixture.

Figure 2. Weigh Batching Lime

5.5.2 Mixing

Complete blending of the materials which are required for the production of a homogeneous lime mortar. This can vary from hand to machine mixing. The materials were mixed using hand mixing to ensure the uniform mix of lime, Sand, Surkhi, Jaggery, Soap Nut, Egg and water was added to the mix.

5.5.3 Placing of Lime Mortar

The uniform blend obtained from the mixer was placed in the moulds manually. Oil was applied to the mould in order to ease the demoulding process. The Lime mortar was placed in layers and then compacted using thumb to ensure good compaction and uniform texture. After finishing manually, it was found hand compaction gave better results as shown in Figure 3.

Figure 3. PLACING

5.5.4 Finishing

The top of the mould i.e. the bottom of the lime mortar cube was finished evenly using a trowel to get a smooth and level bottom surface. This ensures the lime mortar cube to be in a levelled surface in order to have a levelled surface after placing as represented in Figure 4.

Figure 4. Finished Lime Mortar

5.5.5 Demoulding and Curing

The cube from the moulds were demoulded after 3 Days of casting. The lime mortar cube was kept in laboratory for 4 days, reaming days it is kept for curing and maximum gains in strengths are secured in the first 14 to 28 days of curing. These cubes were immersed in curing tanks for 21 days (or 7 days) for curing shown in Figure 5.

Figure 5. Demoulding and kept For Curing

5.6 Tests on Jointing Material Used for Restoration

The following are the tests conducted on Jointing Materials and as follows:

a) Compressive Strength

b) Consistency of Masonry Mortar

In addition to above tests Non-Destructive Test and Scanning Electron Microscopic test are also carried out.

5.7 Test Conducted for Lime Masonry Mortar at Site

The Compressive Strength of Lime Masonry Mortar used at Site as given in below Table 6:

5.8 Test Conducted in Laboratory- Compressive Test (Testing on Jointing Materials)

Lime is typically strong compression but much less than concrete and in real construction, the concrete is used in compression. Lime except strong in compression is likewise appropriate in different characteristics. Higher the compressive strength higher is the durability. Bond strength additionally improves with the boom in compressive strength.

The Classical method by crushing specimens within the compressive testing device the compressive strength is obtained as the take a look at results. Consequently, its miles a right away test technique that's globally standardized. Collectively with the modulus of elasticity, the compressive energy is the most important belongings of Lime mortar. Cube strength will be laid out in terms of 14 days and 28 day's compressive strength. Individual cube strength shall now not be less than 85 percentage of specified strength. The required common compressive strengths of different grades of paver blocks are given in desk 1 of IS 712 -1981 as shown in Figure 6.

Figure 6. Compressive Strength Testing Equipment

Table 6. Compressive Strength of Lime Masonry Mortar used at Site

Block Number	No of Days	Length in mm	Breadth in mm	Area in mm^2	Ultimate Load (KN)	Compressive Strength (Mpa)
1	28	50	50	2500	4	1.62
2	28	50	50	2500	4	1.60
3	28	50	50	2500	4	1.62

Result: The Compressive Strength of lime masonry mortar at site is 1.61 Mpa.

Compression Test Results

The compressive strength test results were shown in below Table 7.

5.9 Grade of Masonary Mortar

Masonry mortars shall otherwise be specific via the grade in terms of their minimal compressive strength as given in Table1 (IS 2250-1981). Masonry mortars in terms of mix proportion which gives the range of compressive strength (at the age of 28 days) values are also given in Table 1 for guidance.

Criteria for Selection of Masonry Mortars

In the case of masonry exposed often to rains and where there may be similarly safety by means of manner of plastering or rendering or other finishes, the grade of mortar shall no longer be much less than MM 0.7 but shall rather be of grade MM 2. In which no protection is supplied, the grade of mortar for outside partitions shall insurrection is less than MM 2 which is represented in Table 8.

For MM2 Grade Masonry Mortars take 1 component Cement, 2 a part of Lime and nine part of sand (1:2:9).

In the case of masonry exposed often to rains and where there may be further protection by way of way of plastering or rendering or other finishes, the grade of mortar shall now not be much less than MM 0.7 however shall otherwise be of grade MM 2. Wherein no protection is furnished, the grade of mortar for external partitions shall not be less than MM 2. For MM2 Grade Masonry Mortars take 1 Part Cement, 2 Part of Lime and 9 part of sand (1:2:9) shown in Figure 7.

5.10 Scanning Electron Microscope Test

A scanning electron microscope (SEM) is a sort of electron microscope that produces images of a sample by scanning the surface with a cantered beam of electrons. The electrons interact with atoms in the pattern, producing numerous alerts that incorporate information approximately the surface topography and composition of the pattern. The electron beam is scanned in a raster scan pattern, and the location of the beam is mixed with the intensity of the detected signal to produce an image. In the maximum not unusual SEM mode, secondary electrons emitted by atoms excited by means of the electron beam are detected the usage of a secondary electron detector (Everhart-Thornley detector). The wide variety of secondary electrons that can be detected, and as a result the signal intensity, depends, among different things, on specimen topography. Some SEMs can gain resolutions better than 1nanometer.

Table 7. Compression test results

Block No.	No of Days	Length (mm)	Breadth (mm)	Area (mm^2)	Ultimate load (KN)	Compressive strength (Mpa)
1	28	50	50	2500	4	1.60
2	28	50	50	2500	4	1.60
3	28	50	50	2500	4	1.60

Result: The compressive strength of the masonry mortar is 1.6 Mpa referring Table 7.

Table 8. Compression strength of MM2 Grade Masonry Mortar

Block No.	No of Days	Length (mm)	Breadth (mm)	Area (mm^2)	Ultimate load (KN)	Compressive strength (Mpa)
1	28	50	50	2500	8	3.20
2	28	50	50	2500	8.2	3.28
3	28	50	50	2500	8	3.20

Result: The compressive strength of the Masonry Mortar is 3.2 Mpa referring Table 8.

IS : 2250 - 1981

TABLE 1 GRADE OF MASONRY MORTARS

(*Clauses* 0.3.1, 5.3.2 *and* 6.1)

Sl No.	Grade	Mortar Mix (by Loose Volume)					Compressive Strength at 28 Days
		Cement	Lime	Pozzolana	Lime Pozzolana Mixture	Sand	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) N/mm²
1	MM 0·5	0	1 B or E	0	0	3	0·5 to 0·7
2		0	0	0	1 (LP-7)	1·25	
3		0	1 C or D	1	0	2	
4	MM 0·7	0	0	0	1 (LP-20)	1·5	0·7 to 1·5
5		0	0	0	1 (LP-40)	2·25	
6		1	3 C or D	0	0	12	
7		1	0	0	0	8	
8		1	0	0·4*	0	10	
9	MM 1·5	0	0	0	1 (LP-20)	1·25	1·5 to 2
10		0	0	0	1 (LP-40)	2	
11		1	0	0	0	7	
12		1	0	0·4*	0	8·75	
13		0	1A	0	0	3	
14	MM 2	0	1A	0	0	2	2 to 3
15		0	1C or D	3*	0	0	
16		1	2C or D	0	0	9	
17		0	0	0	1 (LP-20)	1	
18		0	0	0	1 (LP-40)	1·75	

Figure 7. Grade of masonry mortars as per IS: 2250-1981

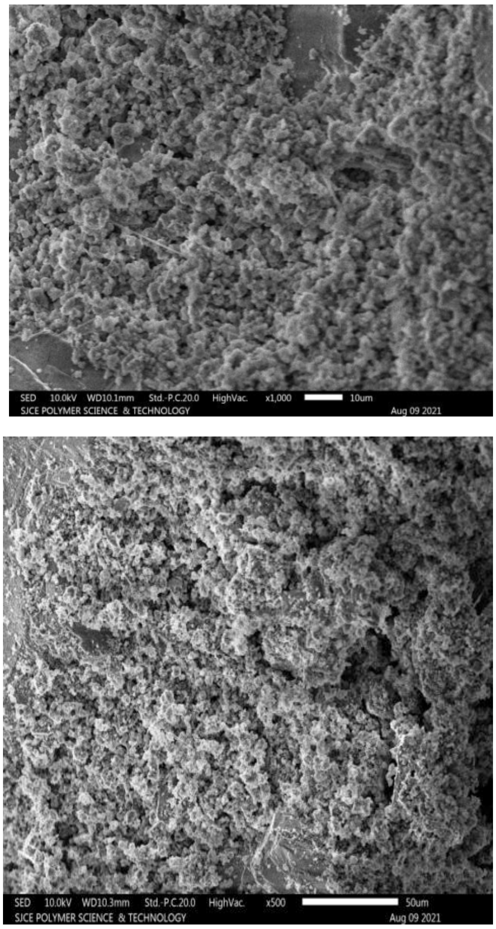


Figure 8. Lime Mortar

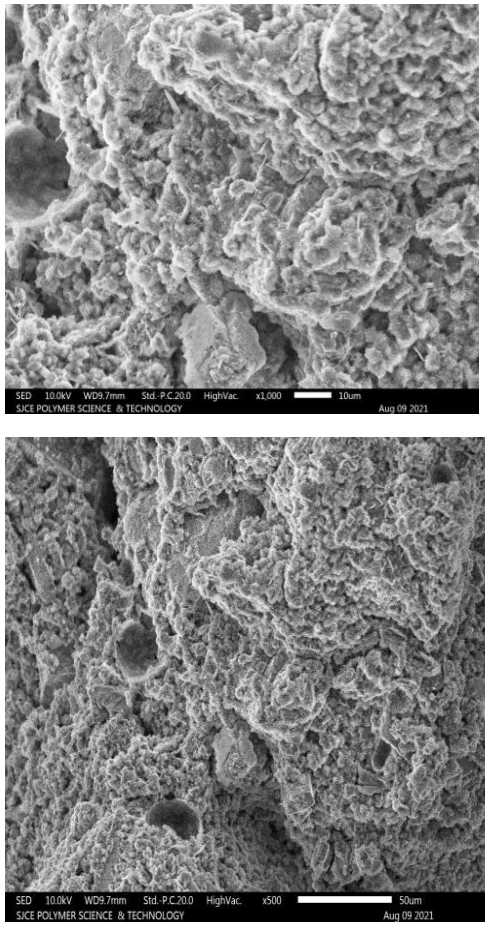


Figure 9. MM2 Grade Masonry Mortar

Result: SEM analysis shows that the mortar prepared at the site which is found with maximum voids when compare to MM2 grade masonry mortar shown in Figure 8 and Figure 9.

6. Conclusions

The following were the conclusions of the present investigation and as follows:

- The fineness, workability, initial setting time, final setting and compressive strength of lime found to be 5%, 180 mL, 1680 mints, 4320 mints and 1.46 N/mm^2 respectively.
- The specific gravity and zone of fine aggregate pertaining to 2.65 and Zone III respectively.
- The specific gravity and zone of Surkhi pertaining to 2.70 and Zone III respectively.
- The compressive strength of the jointing material used at the site was found to be 1.6 N/mm^2.
- The compressive strength of the MM2 grade masonry mortar was found to be 3.2 N/mm^2.
- SEM analysis shows that the mortar prepared at the site which is found with maximum voids when compare to MM2 grade masonry mortar.
- During the inspection of the site, it was observed that – the NDT tests on structure before and after restoration does not show any variations. Because, when we are selecting the points – we need to select on stone columns only.
- Based on the obtained test results and SEM analysis, it can be predicted that the use MM2 grade mortar will help the structure to be durable for longer period.

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Conflict of Interest

There is no conflict of interest.

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ARTICLE

Study on the Current Situation of Urban Integration of Aboveground Space and Underground Space: Under the Background of China's Land Spatial Planning

Yiyang Li* **Luyang Tao***

Faculty of Innovation and Design, City University of Macao, Macao SAR, China

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ABSTRACT

Urban underground public space has a synergistic effect with its surrounding urban aboveground functions or facilities, which reflects the complementarity between underground functions and urban functions. The research analyses the degree of integration through the case study of urban aboveground space and underground space in China. The research method of this paper will give different evaluation criteria to public transport and public space and the influencing factors of space integration. The indicators of public transport include the number of subway lines and underground parking spaces. The evaluation standard of public space is the area of underground space and the number of floors of underground space. The subway entrance and exits are selected as the evaluation index for the aboveground and underground transition space. Through the specific analysis of 7 selected cases, it provides arguments for the research. The average rent in the case is taken as the dependent variable. Through the regression model, the influencing factors of the integration of aboveground and underground space are determined. The purpose of the study is to explore the influencing factors of the integration of aboveground space and underground space, and how to optimize the integration of aboveground and underground space.

1. Introduction

In the 1960s and 1970s, the development of underground space began to be put on the agenda in China. Urban underground space planning is the premise and guarantee for the orderly development of urban underground space [1]. At this time, the utilization of underground space in China is basically in the basic stage. The development of underground space is mainly engineering development, focusing on underground factories and civil air defense projects, which are less used in people's daily life. It is different from the common underground parking lots and underground shopping malls nowadays. However, today

**Corresponding Author:*
Yiyang Li,
Faculty of Innovation and Design, City University of Macao, Macao SAR, China;
Email: yiyangli327@gmail.com
Luyang Tao,
Faculty of Innovation and Design, City University of Macao, Macao SAR, China;
Email: sztaoluyang@163.com

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the construction of urban light rail or subway to alleviate the land traffic congestion in big cities has become a priority choice.

With the emphasis on the utilization of urban underground space, increasingly major cities in China are planning or developing urban underground space on a large scale. Although the construction scale of underground rail and underground municipal infrastructure in Chinese cities is huge [2]. However, the utilization of urban underground public space is still in its infancy. The covered use of urban underground space unable to represent the full development of urban underground public space. A large amount of urban underground spaces is still used as ancillary functions of ground buildings, such as parking, civil air defense and commercial operation. Only a few areas of big cities such as Beijing and Shanghai have the tendency of pedestrian networking of underground public space. Large underground pedestrian network systems composed of underground streets and underground complex nodes have been built in large cities in Europe, America and Japan, such as Manhattan in New York, La Défense in Paris and Sumitomo in Shinjuku.

In management, lack of guidelines and without a comprehensive management agency, China is facing challenges to establish an UUSU (urban underground space utilization) management system that can meet its needs. In technology, further improvements are needed in controlling construction disturbance in complex geological environment [3]. Up to now, cities with a high degree of development in China have successively encountered the "big city disease". The development of central urban areas is gradually saturated. Reduced accessibility, poor environmental quality and other problems emerge in an endless stream, which puts forward new requirements for the development of underground space. In this regard, China's land spatial planning puts forward comprehensive requirements to guide governments and planning units at all levels to comprehensively consider economic population, land use and ecological environment protection to solve the current problems.

The composition of urban underground pedestrian network includes the underground space of urban complex. Although the underground space development of many urban complexes in China has reached a certain scale, and the space quality has gradually deviated from the previous closed and rough design of underground space. The underground space of many urban complexes is still isolated from the city [4]. It is an isolated space that is not systematic in form, there are various defects in its design related to the city or its own functions, resulting in low utilization efficiency and low accessibility, so that the underground space of the urban complex cannot be integrated into the urban underground pedestrian network, and thus cannot assume the function of the urban three-dimensional node.

Combining the requirements of underground space development in the new era and the requirements of China's land spatial planning. Underground space is an important part of urban public space. By promoting the integrated layout of underground metro stations, public service facilities, public space and infrastructure, a comfortable and convenient underground public space system with integration of above ground and underground, underground interconnection and interworking will be formed. At the same time, appropriate underground transportation and large municipal stations can release more ground and shallow underground space, which can effectively improve the urban walking conditions and improve the comprehensive environmental quality of the city.

The integration of above ground space and underground space has many benefits to the sustainable development of the city. The integration of above ground space and underground space can improve the utilization rate of urban space, save land resources in the urban center, shape a better urban landscape, enhance the commercial vitality of underground commercial space, and alleviate the pressure of urban ground space. Meanwhile, the integration of above ground and underground space is also one of the important tasks and goals of China's spatial space planning in the new era. In the "several opinions of the State Council of China on establishing a territorial space planning system and supervising its implementation", it is proposed to "coordinate the comprehensive utilization of aboveground and underground space" and treat space as a resource for protection and development. Therefore, the purpose of the study is to explore the influencing factors of the integration of aboveground space and underground space. And how to optimize the integration of aboveground and underground space.

2. Methodology

Considering the current status of urban development in China, comprehensive underground space development only has construction practice in some large cities. This research case selects 7 typical underground space projects in Chinese cities. Including Underground space of Qianjiang New Town in Hangzhou, the underground space of CBD in Zhujiang New Town in Guangzhou, the underground space of Hongqiao CBD in Shanghai, the underground space of Zhongguancun West District in Beijing, the underground space of Futian business district in Shenzhen, the underground space of Nanjing Xinjiekou central area and the underground space of Chengdu Chunxi Road business district.

The selection principle of the case selected the representative provincial capitals Hangzhou, Guangzhou, Nanjing and Chengdu. The selected cases of representative municipalities directly under the central government, Shanghai, Shenzhen and the capital Beijing, are all representative underground space cases. The CBD and central area of the basic city can clearly describe the most representative underground space development in China. At the same time, the underground space has different scales and construction dates, including the urban characteristics of northern, southern, central and western China, which is of great reference. The research also follows the principle of easy data crawling. There are multiple ways to access the data.

The research method of the article is to collect data, including the number of subway lines and underground parking spaces; the area of underground space ,the number of floors of underground space and the subway entrance and exits. Independent variable rent. Through the regression model to analyze the relationship between dependent variables and independent variables.

The rent well shows the advantages and disadvantages of the above ground and underground space integration in the case. A good above ground and underground space integration can bring a large flow of people, thus increasing the rent of the case. Therefore, the average rent of the store in the case is taken as the dependent variable. The rent data come from the statistics of 15 key business districts of China Index Research Institute in 2021. The indicators of public transport include the number of subway lines and the number of underground parking spaces. The evaluation standard of public space is the quantity of underground construction and the number of floors of underground space. The entrances and exits of underground space in China are often combined with the entrances and exits of the subway, so the transition space above and below the ground is evaluated by the entrances and exits of the subway. According to the rents of different cases and the above evaluation criteria, carry out multiple regression to analyze the impact of the evaluation criteria on the rents obtained by the cases, so as to analyze the construction level of the integration of aboveground and underground space.

3. Research Trends of Underground Space in China under China's Land Spatial Planning

The difficulty in implementing the policy of China's land spatial planning in underground space lies in not taking underground space as a part of land space, and viewing it from a resource perspective. Therefore, it is necessary to reconstruct the planning system and reintegrate underground space into the system of urban planning and design [5].

Underground space planning often appears in urban special planning, such as the engineering planning system. There are problems in the connection between master planning and detailed planning. At the same time there is a lack of legal benefits like the master planning or detailed planning. The lack of unified requirements for underground space planning makes it difficult to find solutions at the same level through different underground space planning when the needs are the same [6].

The construction cost of underground space is tremendous. After a period of development, China's cities have the ability to carry out overall planning and construction of underground space. The benefits of urban underground space development China can be mainly divided into seven categories, including the saving of tangible and intangible resources, contain time or space and all kinds of non-renewable energy; And the improvement of the existing quality of life, including the reaction on the life of traditional space, such as increasing the unit area value of underground space in the combination of aboveground and underground space [7].

The industrial agglomeration effect formed by high-density cities provides a continuous driving force for the economic vitality of cities. The economic benefits obtained are put into the development of underground space. However, even in nowadays highly developed city in China, a huge investment still be required in the development of underground space. For example, the construction of urban comprehensive pipe gallery is only used in a few areas, and the construction of urban subway still needs to be fully evaluated.

Moreover, China's high-density cities have also encountered various problems, such as the shortage of land resources and ecological space. The expanding population requires more space to ease the flow of people. The huge commercial space is moved underground, combined with parking and underground street. These underground spaces free up a large area of pedestrian distribution square on the surface. The seven urban indicators that may affect the development of urban underground space utilization include population density, per capita GDP, the proportion of tertiary industry, industrial density, urbanization rate, real estate development investment and car ownership [8].

At the same time, large cities in China. The contradiction between public resources in the city of personal motor vehicle travel deepens. Therefore, urban rail transit with fast operation speed and large passenger throughput has become the way to solve the problems of large cities, especially the underground rail transit line. In the near future, the development of urban underground space in China has broad prospects, but there are still some institutional and technical obstacles in the development and utilization [9]. From the perspective of underground space cases, the indicators are the number of subway lines and underground parking spaces; building area of underground space.

Combined with the needs of the development of the times. The trend of underground space utilization in Chinese cities has changed. In the past, when the construction of ground facilities could already meet the needs, the construction of underground space was mainly to expand the space, and to transfer some functions of the building to the underground from the perspective of functional zoning, such as computer rooms and parking garages. High-rise buildings need a deep foundation, and the underground space enclosed by the box-type foundation is added for practical use, and the underground space is basically only used for the building itself. At the stage of rail transit network formation, many cities form a huge underground space by connecting underground rail transit stations with the underground floors of surrounding buildings, which not only facilitates people's action between rail transit and buildings, but also sets up shops in the underground space, endowing the underground space with commercial and interactive functions outside the passageway.

4. Case Studies

▪ Underground space of Qianjiang New Town, Hangzhou

As one of the cores of the four major cities in the Yangtze River Delta (Shanghai, Nanjing, Hangzhou and Hefei), Hangzhou has a unique position in the development of urban agglomeration in the Yangtze River Delta. Hangzhou is a part of the ecological functional area in the south of the Yangtze River Delta. With Huangshan and Tianmu Mountains around, it is an important part of the national ecological environment resource area. In the master planning, the development focus of Hangzhou has gradually expanded from the development around the West Lake to the Qiantang River area. As the new core of Hangzhou's planning, Qianjiang new town pays attention to the requirements of protecting the environment and ecology, realizing the combination of green development and protective development, making long-term plans, overall design, reserving the interface between the existing development and subsequent development.

The underground space development scale of Qianjiang new town is 2.58 million square meters (Figure 1). The underground public service places and social places are arranged in combination with subway stations, carriageways and sidewalks and underground parking spaces. Through the extensive use of sunken squares and daylighting wells, sunlight and vegetation are introduced into the underground space.

There are four floors underground in Qianjiang New Town, Hangzhou, passing through Hangzhou Metro Line 2, Line 4, Line 7 and Line 9. The four subways pass through a total of four subway stations in Qianjiang New City, namely Qianjiang Road subway station, Jiangjin Road subway station, Xinye Road subway station and citizen center subway station. According to statistics, there are 37 entrances and exits in the four subway stations. The total development volume of underground space is about 2.3 million m^2. There are 30000 underground parking spaces in the core area, equivalent to an underground parking garage of about 900000 ~ 1200000 square meters [10]. Rent of key business districts in the first half of 2021. The average rent is 711 yuan per square meter per month (China Index Research Institute).

Figure 1. The Underground space of Qianjiang New Town, Hangzhou

▪ The underground space of CBD in Zhujiang New Town in Guangzhou

The underground space of Guangzhou Zhujiang

New Town covers an area of about 440000 square meters (Figure 2). The area spans the main traffic roads. The conventional traffic is developed. The underground space is combined with Guangzhou Metro Line 3, Line 5 and Metro APM Line (Zhujiang New Town Automated People Mover System). Zhujiang New Town is a subway transfer station with 6 entrances and exits, which has four stations and eight entrances and exits in total.

It is one of the important traffic nodes. The Pearl River New Town area includes a wide range of public buildings, commercial office buildings such as Bank of Guangzhou and Evergrande center, cultural buildings such as Guangzhou Library, Guangdong Provincial Museum and Guangzhou second children's palace, entertainment buildings such as Guangzhou Grand Theater, etc. abundant public buildings are equipped with sufficient underground parking space, but on the whole, they serve their own office buildings. A large number of facilities will be moved underground in the Pearl River New Town area, and the aboveground space will be connected with the underground space through the sinking square. There are 7511 parking spaces on the three floors of the underground space in Zhujiang New Town, Guangzhou. The average rent is 1110 yuan per square meter per month.

Figure 2. The underground space of CBD in Zhujiang New Town in Guangzhou

▪ The underground space of Hongqiao CBD in Shanghai

As the gateway area of the Yangtze River Delta, Shanghai has gradually become the core of highly developed economy since the concession era. The extended development axis and one of the four most important urban agglomerations in China have promoted the development of centralized population and economy. The scope of services covers the city and surrounding areas. Shanghai, Nanjing, Hangzhou, Hefei, Ningbo innovative service corridor has been opened to drive the development of coastal areas, areas along the Yangtze River Estuary and Qiantang River Estuary. It is also an important endpoint of the riverside economic belt proposed in December. The planning and construction of Shanghai plays an exemplary role in the economic peak and is a beacon for the future development of many cities.

The underground space of Shanghai Hongqiao CBD (Figure 3) has commercial, cultural and entertainment facilities, dynamic traffic combining underground pedestrian traffic and vehicle traffic, static traffic of underground parking and comprehensive pipe gallery.

Shanghai Hongqiao CBD already has three subway lines: Line 2, Line 10 and Line 17. The main transportation hub of Shanghai Hongqiao CBD is Shanghai Hongqiao Station subway station, with a total of 6 entrances and exits. The underground space development scale is 1.02 million square meters and 11750 static parking spaces [11]. There are three floors underground, and the average rent is 345 yuan per square meter per month.

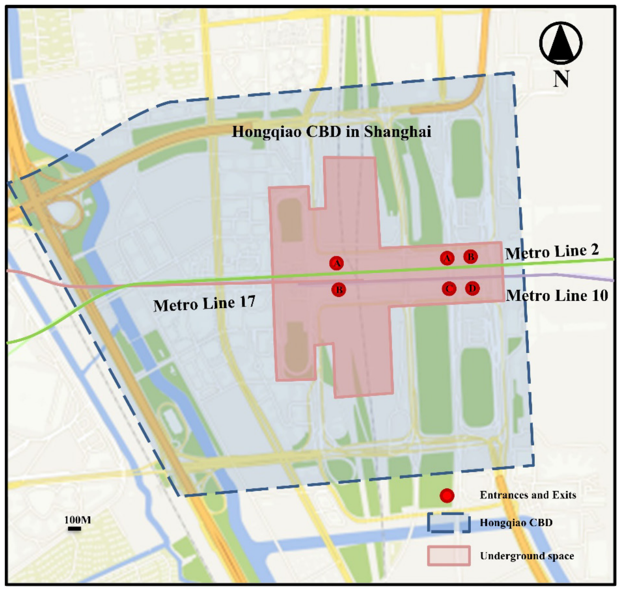

Figure 3. The underground space of Hongqiao CBD in Shanghai

▪ The underground space of Zhongguancun West District in Beijing

As the core of Beijing Tianjin Hebei Urban Agglomeration, Beijing, with the imperial capital of the feudal era as the core, expanded the city outward in a circle through reconstruction, forming the rudiment of today's Beijing urban form. However, in the long-term population agglomeration, cities are gradually overwhelmed and become one of the representative cities of "big city disease" in China. Space resources are tight, and the development of aboveground space is close to saturation. In the goal of ecological sustainability and promoting high-quality development, the development of underground space in Beijing has become one of the links to solve urban problems.

The Western District of Zhongguancun in Beijing (Figure 4): Its underground floor area is 500,000 m^2, and the number of motor vehicle parking is 10,000. This underground space is divided into three floors. It is the largest three-dimensional transportation network in China which is formed by underground space development, utility tunnel and underground round driveway.

The underground and the ground are connected with each other, and the underground facilities serve the ground. The independent buildings on the ground in Zhongguancun are connected in series to realize the three-dimensional development of the above ground and underground.

On account of the lighting and ventilation of the underground space is relatively poor compared with the ground space, at present, even buildings built alone will set the underground space as a parking lot. The parking lot on the ground floor of Zhongguancun in Beijing has four exits and five entrances connected with the ground roads. It connects the underground parking garage of 12 buildings in the area through the underground vehicle system. Compared with the separate underground parking spaces in each building, it integrates the traffic flow. The establishment of commercial catering and service ecology on the second floor of the underground attracts the flow of people from the ground to the underground, which not only brings vitality to the underground space, but also improves the utilization rate of the underground space. The engineering system serving the West District of Zhongguancun in Beijing is a centralized integrated pipe gallery, which is located on the third floor underground and goes down to the pipe gallery area through the commercial service area on the second floor.

The underground of Zhongguancun West District in Beijing is Beijing Metro Line 4. The subway station is ZhongGuanCun subway station, with 7 entrances and exits with a development area of 190000 square meters and 1000 parking spaces [12], three floors underground, the average rent is 1368 yuan per square meter per month.

Figure 4. The underground space of Zhongguancun West District in Beijing

▪ The underground space of Futian business district in Shenzhen

Shenzhen Futian business district also accommodates the business population and residential population, develops underground business services and entertainment, and rail transit and car companies enter the underground space to connect the flow of people. The underground development area is 400000 square meters. The underground transportation center will be built with Futian passenger station as the framework, and the underground transportation center will also be built with Futian passenger station as the underground transportation center. At the same time, Shenzhen Futian business district has introduced the concept of ecological construction into the underground, introducing sunshine and vegetation into the underground space, creating a pleasant underground space environment.

Metro lines 1, 2, 3, 4, 11 and 14 are distributed underground in Futian business district, Shenzhen (Figure 5). There are four subway stations in Futian business district, Futian subway station, citizen center subway station, shopping park subway station and exhibition center subway station, with 59 entrances and exits. The underground development area is 400000 square meters. There are three floors underground, 42000 parking spaces, and the average rent is 1734 yuan per square meter per month.

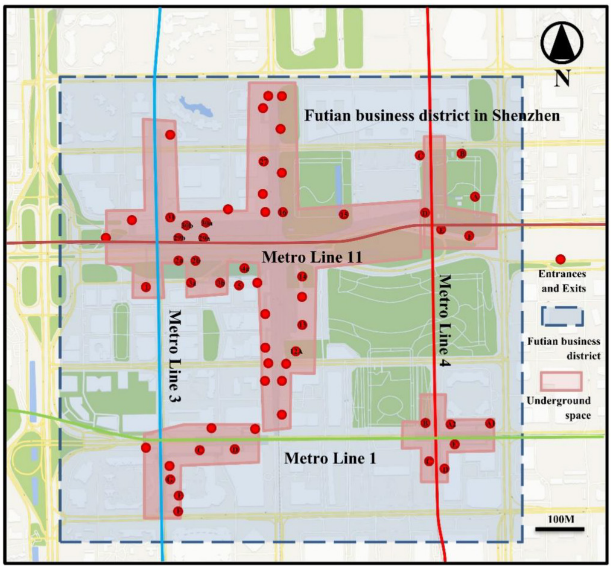

Figure 5. The underground space of Futian business district in Shenzhen

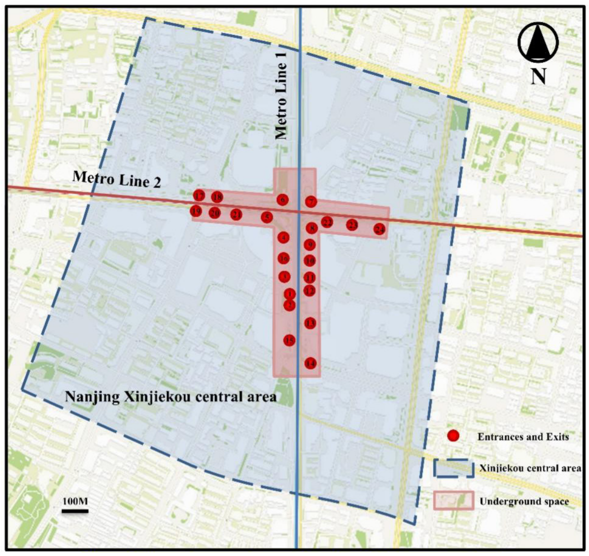

Figure 6. The underground space of Nanjing Xinjiekou central area

▪Underground space of Nanjing Xinjiekou central area

Nanjing Xinjiekou is positioned as a comprehensive commercial and commercial center with international influence (Figure 6). Xinjiekou is a renovation area for upgrading the underground space in the renewal of the old city of Nanjing. The current situation of Xinjiekou central area has formed a relatively large-scale urban underground space, especially the underground commerce and underground parking, which are mature and belong to the leading level in Nanjing and even in China. The underground mall has attracted a large number of tourists. It has established a connection with Xinjiekou station and evacuated the passengers arriving by subway in time, laying a foundation for building a three-dimensional business district in Xinjiekou. The underground parking lot provides a large number of parking spaces for the central area. Combined with the ground parking and the parking building, it forms a three-dimensional parking system, which relieves the parking pressure and ensures the daily operation of the city. There are 2900 parking spaces in the underground space of Xinjiekou central area. The total amount of existing underground space construction is about 1.4 million square meters. There are five floors underground, two subway lines, Line 1 and Line 2. The subway station is a Xinjiekou transfer station with 24 entrances and exits. The average rent is 1089 yuan per square meter per month.

▪Underground space of Chengdu Chunxi Road business district

In the corridor from Chunxi Road to IFS underground commerce, there is a small number of subsidiary commercial layout. The business type is mainly retail and catering, and there are few cultural and entertainment stores. The distribution of commercial space is highly guiding. The shops are arranged along the channel from the subway exit. The area of the shops is uniform, which has become a good connection between the traffic space and the commercial space. It not only introduces commercial functions, but also retains the traffic efficiency and guidance of the traffic space [13].

Chengdu Chunxi Road station is the transfer station of Chengdu metro Lines 2 and 3, with 6 entrances and exits (Figure 7). The surrounding commercial and cultural resources are sufficient and public service facilities are perfect, which provides passenger flow and service facilities for the development of underground commerce in the metro station. The underground commercial space of Chunxi Road studied in this paper includes the underground commercial space at the south end of Chunxi Road subway station and the ocean taikooli underground commercial space at the northwest end. The underground of Chunxi Road has a connecting corridor with the surrounding mature commercial bodies, through which the hall of Chunxi Road station and the surrounding mature underground commercial system are combined into a complete commercial whole. Chengdu Chunxi Road business district has an underground development area of 11983 square meters, three floors underground, 910 underground parking spaces around the business district, and the average monthly rent is 1107 yuan.

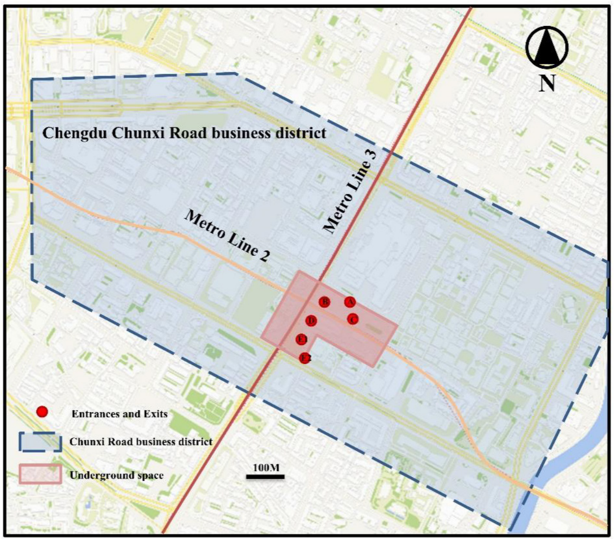

Figure 7. Underground space of Chengdu Chunxi Road business district

5. Data Analyses

According to statistics (Table 1), among the seven selected cases, the highest rent is 1734 yuan per square meter per month in Futian business district, Shenzhen, and the lowest rent is 345 yuan per square meter per month in Hongqiao CBD, Shanghai. In the case, the largest underground development area is 2300000 square meters in the core area of Qianjiang New Town in Hangzhou, and the smallest development volume is 11983 square meters in the underground space of Chunxi Road business district in Chengdu. The largest number of parking lots is 42000 underground in Futian Business District of Shenzhen, and the smallest number is 910 underground in Chunxi Road Business District of Chengdu. There are six subway entrances and exits in the underground of Futian business district in Shenzhen, the CBD of Zhujiang New Town in Guangzhou, the CBD of Hongqiao in Shanghai and the underground space of Chunxi Road business district in Chengdu. It can be seen from the data that the newly-built underground space, such as the underground of the core area of Qianjiang New City in Hangzhou, has reserved a large amount of space in consideration of many factors. The volume is huge, and there are many parking spaces and entrances and exits. The underground of Hongqiao CBD in Shanghai and Futian business district in Shenzhen shoulder the function of connecting high-speed railway stations, so a large number of entrances and exits are arranged to evacuate people, as well as a large number of underground parking spaces. The underground space in Nanjing Xinjiekou central area and Chengdu Chunxi Road Business District, where the underground space business is developed, shows that there are few parking spaces, but the rent is high.

Table 1. Indicators of 7 cases

Cases	Indicators					
	Rent	Area	Metro lines	Underground parking spaces	Underground floors	Number of Metro entrances and exits
The underground space of Qianjiang New Town in Hangzhou	711	2300000	4	30000	4	37
The underground space of CBD in Zhujiang New Town in Guangzhou	1110	440000	3	7511	3	14
The underground space of Hongqiao CBD in Shanghai	345	1020000	3	11750	3	6
The underground space of Zhongguancun West District in Beijing	1368	190000	1	1000	3	7
The underground space of Futian business district in Shenzhen	1734	400000	6	42000	3	59
Underground space of Nanjing Xinjiekou central area	1089	1400000	2	2900	5	24
Underground space of Chengdu Chunxi Road business district	1107	11983	2	910	3	6

To sum up, the seven case spaces can be divided into three categories. The first type is the underground space where CBD types gather comprehensive functions, such as the underground of the core area of Qianjiang New Town in Hangzhou, the underground of Zhongguancun West District in Beijing, and the underground of the CBD of Zhujiang New Town in Guangzhou. The second type is the underground space connecting the high-speed railway station as the transportation hub, such as the underground of Hongqiao CBD in Shanghai and the underground of Futian business district in Shenzhen. The third category is the underground space of Xinjiekou central area in Nanjing and the underground space of Chunxi Road business district in Chengdu, which are mainly underground pedestrian streets and have developed underground commerce. These three types basically include the types of underground space development in China.

In this part of the regression model, rent is taken as the dependent variable (Table 2). The indicators of public transport include the number of subway lines and underground parking spaces. The evaluation standard of public space is the quantity of underground construction and the number of floors of underground space. The transition space above and below the ground is evaluated by the entrance and exit of the subway. Through the regression of 7 cases of different types, this paper analyzes the factors affecting the integration of above ground and underground space, and whether the integration of above ground and underground space will be affected by public transport, public space and transition space.

The regression coefficient (Coef.) represents the parameter of the influence of the independent variable x on the dependent variable y in the regression equation. The larger the regression coefficient is, the greater the influence of x on y is. The positive regression coefficient means that y increases with the increase of x, and the negative regression coefficient means that y decreases with the increase of x. R-squared is the determination coefficient, or goodness of fit, which is the square of the correlation coefficient and the part of the independent variable interpretation in the total deviation of Y. P value is used to explain the significance of regression coefficient. Generally speaking, P value <0.1 (*) means that the 10% significant level is significant, P value <0.05 (**) means that the 5% significant level is significant, and P value <0.01 (***) means that the 1% significant level is significant. St.Err. It is the regression standard error, which reflects the average difference between the actual values of dependent variables and their estimated values.

It is found that the construction area of underground space(8.39e-06) and the entrances and exits of underground space (67.8611) will have a positive impact on the rent, while the construction area of underground space (–0.0536711), the number of floors of underground space (–573.8478) and the number of subway lines (–192.6692) will have a negative impact on the rent. The R2 of the model is 1, showing a high goodness of fit. The P values of the construction area (0.522) of underground space, the number of subway lines (0.011), the number of underground parking spaces (0.013), the number of floors (0.012) of underground space and the number of entrances and exits (0.006) were <0.05, showing a high significance. The data show that more parking spaces, floors and entrances and exits of underground space will enhance the value of underground space.

Table 2. Results of regression model t-statistics in parentheses

Rent	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Area	8.39e-06	9.00e-06	0.93	0.522	–0.0001059	0.0001227	
Metrolines	–192.6692	3.349695	–57.52	0.011	–235.231	–150.107	**
Parking spaces	–0.0536711	0.0010755	–49.90	0.013	–0.0673369	–0.0400053	**
Floors	–573.8478	11.02809	–52.04	0.012	–713.9729	–433.7227	**
Entrances and exits	67.8611	0.6608375	102.69	0.006	59.46437	76.25784	***
Constant	2858.219	28.03848	101.94	0.006	2501.957	3214.482	***
Mean dependent var	1066.286		SD dependent var		444.867		
R-squared	1.000		Number of obs		7		
F-test	18790.363		Prob > F		0.006		
Akaike crit. (AIC)	36.001		Bayesian crit. (BIC)		35.677		
**** p<.01, ** p<.05, * p<.1*							

6. Conclusions

It is found that the number of subway lines, underground parking spaces, underground construction, underground space and subway entrances and exits in the case will affect the rent, and the rent also confirms the flow of people in the underground space and the integration of above ground and underground space. In the context of China's territorial spatial planning, major cities have accelerated the construction of underground space. At the same time, they are also vigorously promoting the integration of aboveground space and underground space to create a comprehensive underground space of transportation hubs, parking lots and commercial space. The limited urban ground space has been gradually integrated with the underground space, and more use space has been developed. However, as reflected in previous studies, the new underground space such as the core area of Qianjiang New Town in Hangzhou and Futian business district in Shenzhen has a large underground area, while the underground space built in the old urban area such as Chunxi Road business district in Chengdu has a small underground space, which is difficult to meet the growing space demand.

In practice, it is relatively difficult to integrate the completed plots, especially the medium-scale multi block integration project. In China, many underground corridors are used to connect the built underground space, but the difference between the post construction connection project and the original integration project is that the post construction connection project does not consider the overall flow of people, and the necessity of the post construction connection channel is in doubt if the connection of the connected facilities is not considered in the design. In addition, when connecting, the space under the crossing road is often affected by the pipeline, the reserved openings of adjacent facilities are difficult to adapt, and the fire protection specifications are not met. In view of the cost and development cycle of underground space development, a unified standard should be established when considering the interconnection of underground space. Even if the construction cannot be carried out due to cost control, the space should be reserved according to the unified standard.

From the perspective of economic benefits, people tend to move on the shallow surface, while Zhongguancun in Beijing is parking on the first floor underground and the second floor underground is for people's commercial catering. In fact, the transformation activities in the future were not envisaged at the beginning of construction. In the planning of Beijing CBD, according to the traffic planning of Beijing Central Business District and the comprehensive planning, the underground first floor of Beijing CBD is mainly a pedestrian system, and the underground garages of adjacent construction land on the underground second floor are interconnected as much as possible, which is different from Zhongguancun. Based on the irreversible nature of underground space development, planning and construction activities should be ahead of schedule.

Conflict of Interest

There is no conflict of interest.

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ARTICLE

Evaluation and Simulation of the Effect of the Types of Glazing and the Choice of Materials on the Energy Efficiency of a Building

Sami Yaich[1] **Malek Jedidi**[1,2*]

1. Higher Institute of Technological Studies of Sfax, Department of Civil Engineering, Sfax, Tunisia
2. University of Tunis El Manar, National Engineering School of Tunis, Civil Engineering Laboratory, Tunis, Tunisia

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ABSTRACT

Tunisia is one of the pioneering developing countries in terms of energy efficiency policy initiated since the mid-1980s. Indeed, energy efficiency has become one of the main pillars of the country's energy strategy, especially with the increase in energy prices. The main objective of this work is to give an idea of the impact that certain choices made during the design of a building can have on its energy balance, namely the orientation of the facades, the types of glazing and their surfaces, the choice of materials, etc. The calculation of the building's energy requirement was determined using the transient systems simulation program TRNSYS (version 18) with a modular structure.

1. Introduction

Energy efficiency is often considered the most important source of energy for a country. All scenarios that make projections, whether at regional, national or global level, by betting on large shares of non-fossil energy sources in the global energy mix are based on considerable reductions in primary energy demand in final energy consumption [1,2].

All sectors need to improve their energy efficiency, otherwise it will not be possible to decouple economic growth from energy demand and greenhouse gas emissions.

Buildings are the largest individual consumers of energy in the world, but they also offer the greatest individual potential for saving energy. Buildings must meet the user's need for comfort and maintain an acceptable level of interior comfort, day and night, all year round [3]. Low-

**Corresponding Author:*
Malek Jedidi,
Higher Institute of Technological Studies of Sfax, Department of Civil Engineering, Sfax, Tunisia; University of Tunis El Manar, National Engineering School of Tunis, Civil Engineering Laboratory, Tunis, Tunisia;
Email: malekjedidi@yahoo.fr

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energy buildings are of crucial importance for the future evolution of greenhouse gas emissions because, if they are not, population growth and the growing demands of the population for energy will household energy consumption will reach enormous quantities. During the past years, the average and specific energy consumption per household has increased in most regions of the world. Recently, this increase has been due to the growth of emerging economies such as China, India and South East Asia where more and more people can afford to use electrical household equipment and heating installations. In industrial countries, household energy consumption has increased for the following two reasons:

- The average household size has fallen, so that the number of households has increased and the number of basic household appliances has followed this trend;
- The average size of houses and apartments has grown, leading to an increase in heating, air conditioning and lighting needs and thirdly, the number of electrical appliances per household has itself increased.

Improving the energy efficiency of buildings is an important source of energy savings in developing countries, given the share that buildings represent in the demand for commercial energy in these countries (about 30% of the total electricity consumption in West Africa). Managers often consider energy expenditure as a fixed cost over which they have no control. However, appropriate techniques for the use and control of energy make it possible to achieve annual savings of around 10 to 15% in buildings in the tertiary sectors [4].

Tunisia has accelerated its action in terms of energy efficiency since the early 2000s by undertaking a diversification of its energy mix. This diversification aims to cope with the widening of the national energy deficit, which exceeded 4 Mtoe (million tonnes of oil equivalent) in 2015, reaching a rate of 56% [5]. The main characteristics of the energy sector in Tunisia are as follows [5]:

- A sharp increase in the demand for electricity and the great importance given to carbon energies by the national authorities;
- Continued construction of new gas-fired power plants (97% of current electricity production) to meet growing demand and save the country from power outages;
- Quasi-monopoly of electricity production by the public sector (81%).

Several studies have been carried out on buildings to determine the influence of several parameters on the energy balance [6-11].

Depending on the outdoor conditions and glazing size, windows are responsible for around 10% to 25% of the total heat loss [12]. Therefore, adjusting the window to wall ratio can lead to a considerable impact on energy compared with adjusting the external walls' thickness [13,14]. There are other parameters that considerably affect energy building performance such as the glazing type, the choice of materials and use of shading. The results of the study conducted by Cesari and Khoukhi [15,16] indicated that retrofitting may have a major influence on the building's energy pattern as well as the cost of the energy consumption.

The energy diagnosis of a building constitutes the realization of a complete assessment of the energy situation of the building. It pursues three objectives:

- Optimization of energy consumption;
- Identification of opportunities for using renewable energies locally;
- Improved occupant comfort.

In this context, this work consists in giving an idea of the impact that certain choices made during the design of a building can have on its energy balance by using dynamic thermal simulation using the transient systems simulation program TRNSYS (version 18) [17].

2. Impact of Building Form on the Energy Efficiency of Residential Buildings

Residential buildings have a different occupancy pattern and the daytime energy consumption is lower compared to non-residential buildings. Several studies have been carried out to identify the effect of orientation, shape, and window to wall ratio in residential buildings. In their experimental study, Hachem et al. [18] demonstrated that the number of shading facades and the ratio between the shading to shaded facade significantly affect the solar radiation on non-convex shapes. The study was based on residential buildings in cold climate including seven different shapes (square, rectangle, trapezoid, L, U, H and T). Bichiou and Krarti [19] conducted a research on single-family homes in the USA including five different locations. This research considered the building shape, window to wall ratio and orientation as important parameters for the optimisation. Three optimisation algorithms were considered and the optimal design reduced the life cycle cost by 10%-25% depending on the type of homes and climate.

3. Experimental Study

3.1 Simulation Software

There is a large number of software dedicated to energy simulation. The existing software differ from each other by the algorithms they use, by their user interface and by their vocations and their fields of application. The software used in this study is TRNSYS version 16 able to:

- perform dynamic simulations based on a modular approach;
- create new models in addition to those in the library of models of thermal systems and auxiliary components (weather data, histograms, …);
- solve systems of equations.

The TRNSYS software has been parameterized with the characteristic data of the base case using the TRNBUILD (Type 56) as well as the meteorological data of the city of Tunis. The calculation was made by fixing the calculation step at one hour for each iteration. A simulation was carried out to obtain the evolution of the average air temperature inside each zone as well as the energy needs for heating and air conditioning in useful energy.

3.2 Presentation of the Building

The building is located in the city of Tunis (Figure 1a) in the RT2 region at a latitude of 36°50'N, longitude of 10°14'E and an altitude of 3.00 m.

The hot season in Tunis lasts for three months, from June to September, with an average daily high temperature above 31 °C. The hottest month of the year in Tunis is August, with an average high of 34 °C and low of 22 °C. The cool season lasts for four months, from November to March, with an average daily high temperature below 18 °C. The coldest month of the year in Tunis is January, with an average minimum temperature of 8 °C and maximum of 16 °C.

The outside air temperature T_a (°C) and the solar radiation G_h (KWh) have a huge influence on the heating and cooling demand. These data are presented in Table 1.

Table 1. Daily average weather data for the Tunis region

Month	T_a (°C)		Gh (KWh)
	Max	min	
January	16	8	2.6
February	17	8	3.6
March	20	9	4.9
April	22	11	6.2
May	26	15	7.1
June	31	19	7.7
July	34	22	7.9
August	34	22	6.9
September	31	20	5.4
October	27	17	4.0
November	21	12	2.9
December	17	9	2.4
Average	24.6	14.3	5.1

The building can be described as follows :

- The floor area is 80 m² for a volume of 240 m^3. The ceiling height is 3.00 m. It consists of two rooms, living room, kitchen, toilet and hall. The entrance to the building faces north as shown in Figure 1b.
- Glazed surfaces represent 10% of the floor surface (which represents approximately 6.67% glazed surface per facade). Single-glazed windows have a heat transfert coefficient U = 6.32 W/m².K and a solar factor g = 0.85 [20].
- Number of occupants is 5 persons.
- The building is a rectangular shape with overall heat transfer coefficient (U) of 1.57W/m².K and 1.85W/m².K for external wall and internal wall, respectively.

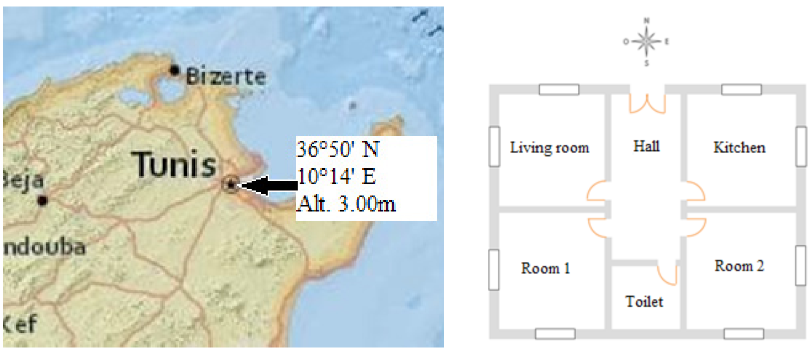


Figure 1. (a) : Topographic map of Tunisia showing the location of Tunis. (b) : Plan and orientation of the building located in the region of Tunis

- Comfort temperatures for heating and cooling are 24 °C and 20 °C respectively where the relative humidity is set 50% for cooling and 30% for heating.

The thermal performance of windows is evaluated mainly using the heat transfert coefficient U and the solar factor g. The combination of these characteristics makes it possible to obtain very interesting performances to minimize heating costs in winter and cooling costs in summer. In addition, the installation of mobile solar protection and closures acts on summer comfort and winter comfort. U-value translates the capacity of the window to maintain the interior temperature. The lower U, the more the window is insulating.

The solar factor reflects the ability of the window to transmit the heat of the sun. It is the ratio between the total energy transmitted through the bay, and the incident solar energy. The higher the solar factor, the greater the transmitted heat gains. In winter, this will help minimize heating consumption through free solar gain. In summer, on the contrary, the solar factor should be low, in order to limit the entry of heat through the windows, thus limiting the interior temperature.

The heat transfert coefficient U of a wall expresses the intensity of the heat flux which crosses a square meter of wall for a temperature difference of one degree between the inside and the outside. The lower this coefficient, the more the wall performs thermally. The heat transfer coefficient of a wall was calculated using the following formula (Equation 1):

$$U = \frac{1}{R_{si} + \sum_{i=1}^{n} \frac{e_i}{\lambda_i} + R_{se}} \tag{1}$$

where U is the heat transfer coefficient (W/m².K), R_{si} is the internal surface thermal resistance (m².K/W), R_{se} is the external surface thermal resistance (m².K/W), e_i is thickness of the layer of the corresponding material (m), λ is thermal conductivity of of the corresponding material, (W/m.K).

The lighting requirements for a residential building can not be easily generalised as it heavily depends on the occupant behaviour and the specific requirements. The average illuminance levels for various spaces (living, kitchen, rooms and bathroom) of single-family houses varies from 100 lux to 200 lux [21], and except for the kitchen, all the other zones require 100 lux ~ 150 lux illuminance level.

The dimensions of the different parts of the building are given in Table 2.

Table 2. Dimensions of the different parts of the building

Parts of the building	Length (m)	Width (m)	Height (m)	Area (m²)	Volume (m³)
Room1	4.00	4.00	3.00	16.00	48.00
Room2	4.00	4.00	3.00	16.00	48.00
Living room	4.00	4.00	3.00	16.00	48.00
Kitchen	4.00	4.00	3.00	16.00	48.00
Hall	6.00	2.00	3.00	12.00	36.00
Toilet	2.00	2.00	3.00	4.00	12.00
Total				80.00	240.00

3.3 Thermal Characteristics of Materials

The non-insulated exterior walls are made of hollow brick 15 cm thick with an exterior plaster of cement mortar and the interior of plaster. The internal walls are made of 10 cm hollow brick with a plaster coating on both sides. The ground consists of a layer of stone 20 cm thick followed by 10 cm of concrete, covered with tiles. The roof is made of concrete-slab with a thickness of 20 cm and a cement mortar screed and an interior plaster coating. Table 3 presents the thermal characteristics of the materials used in the building.

Table 3. Thermal characteristics of the materials

	Layers	Thermal conductivity λ (W/m.K)	Thermal capacity (KJ/Kg.K)	Density (Kg/m³)	Thickness (mm)	Total U Value (W/m².K)
External Wall	External plaster	1.15	1.34	1800	10	1.57
	Hollow brick	0.34	0.84	1920	150	
	Plaster	0.57	1.34	720	10	
Internal wall	Plaster	0.57	1.34	720	10	1.85
	Hollow brick	0.35	0.84	1920	100	
	Plaster	0.57	1.34	720	10	
Ground	Concrete screed	1.30	1.15	2200	50	0.85
	Stone	1.75	1.00	2350	200	
	Concrete	0.80	0.84	2240	100	
Roof	Concrete-slab	2.30	0.84	2240	40	054
	Slab	0.60	0.88	1000	160	
	Plaster	0.57	1.34	720	10	

3.4 Determination of Energy Requirement

The annual energy requirement of the building is shown in Figure 2. The values are around 9300 (KWH) for heating and 11180 (KWH) for air conditioning. The total annual requirement is therefore 20480 (KWH).

For our building with a total area of 80 m², the energy performance is around 256 KWH/m². This result is obtained if we consider that the air conditioning system has a coefficient of performance COP = 4 and the efficiency of the heating system is η =0.6.

The Coefficient of Performance (COP) is the ratio between the heat produced and the energy consumed. The higher the COP, the less energy the air conditioner will use to heat the space.

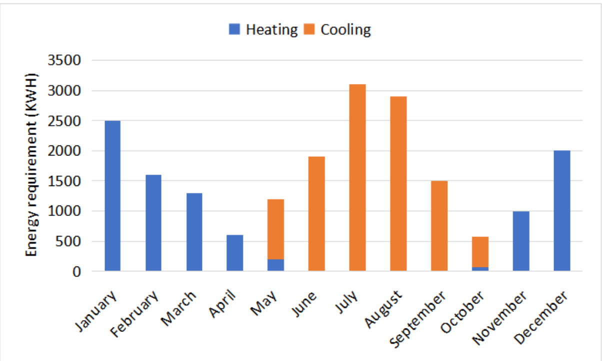


Figure 2. Monthly evolution of energy requirement

4. Energy Efficiency Measures

4.1 Orientation

The initial building oriented North-South has been modified and oriented East-West as shown in Figure 3.

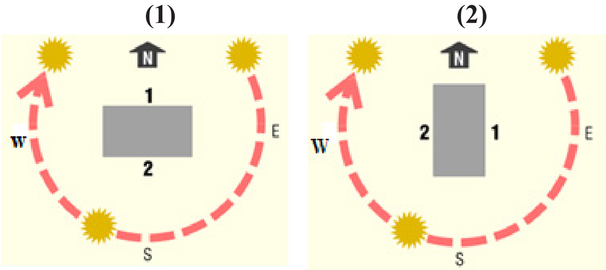


Figure 3. Orientation of the building. (1): North-South. (2): East-West

Figure 4 gives the results of the influence of the orientation of the building on its energy balance. We note that the demand for heating and cooling has been increased by 5% and 11% respectively for a total increase in thermal consumption of 3%. Indeed, for the facade facing north, it receives a little sunshine in the morning and evening. In the modified situation, it is oriented to the East and it receives solar gain only in the morning, but more significantly. We should therefore heat less in winter but cool more in summer.

For the facade facing south, it receives significant solar gain in the middle of the day. In the modified situation, the facade is oriented to the West and the sunshine occurs later. It is therefore necessary to heat more in winter. In summer, the end-of-day supplies will be stored in the building overnight and returned in the morning, so additional cooling will also be required.

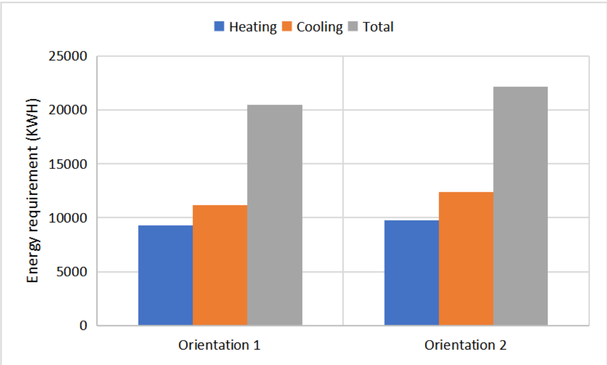


Figure 4. Annual energy requirement according to the building orientation

4.2 Glazed Surfaces

Figure 5 presents the results of the annual energy requirement for heating and cooling as a function of the percentage of glass surfaces in the building. According to the results, we note that the use of single glazing with a heat loss coefficient U=6.32W/m².K did not give an energy gain for all the facades, including that of the South.

For double-glazed windows, we note that it is absolutely necessary to avoid arranging them on the North facade under penalty of seeing its energy needs explode simultaneously with the increase in the glazed surface. For the other facades, an energy gain in heating was recorded in proportion to the increase in glazed surfaces, especially for the south facade where the gain is significant and stabilizes beyond half the surface of the facade. For the East and West facades the gain increased slowly to reach its maximum for a percentage of 40%.

For low-emission double glazing, we note a heating gain of 22.64% for the south facade. For the other three facades, the gain was 1% on average for 20% more glazed surface.

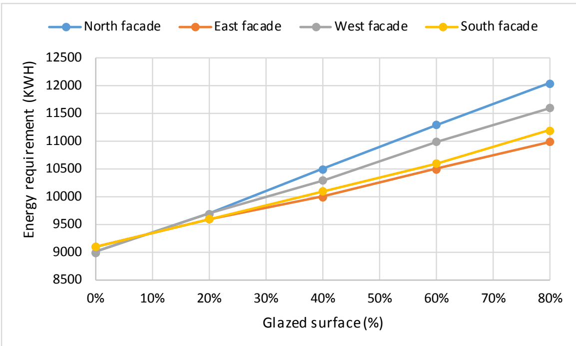
According to the results, we also notice that a window placed to the south can improve the heating balance. Indeed, in winter, since the sun remains low on the horizon, only windows facing south and without shade can really contribute to heating provided that their glazing is very insulating and fairly transparent to the radiation of the sun. In summer, on the other hand, the sun reaches all the facades, and the building can overheat if it is not equipped with solar protection.

We also note that windows facing east and west are more difficult to keep in the shade, because the sun reaches them at a lower angle on the horizon than windows facing south. Thus, it is advisable not to exceed:

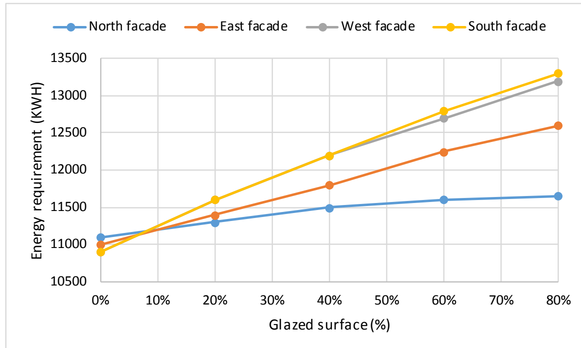
- 50% glazing on the south facades (a good compromise to take advantage of solar energy in winter without suffering too much overheating in summer).
- 20% glazing on the east and west facades (to avoid losses in winter and overheating in summer).
- 10% glazing on the north facades (to avoid heat loss in winter while still receiving light).

Single glazing

(a)

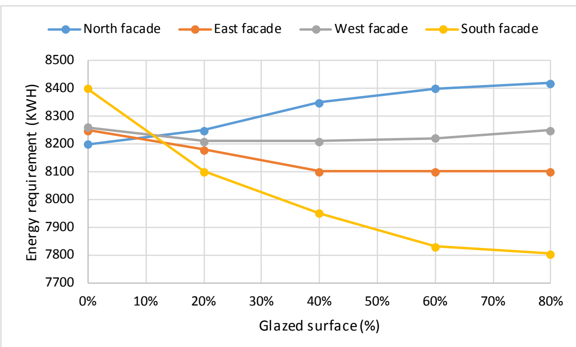


(b)



Double glazing

(a)



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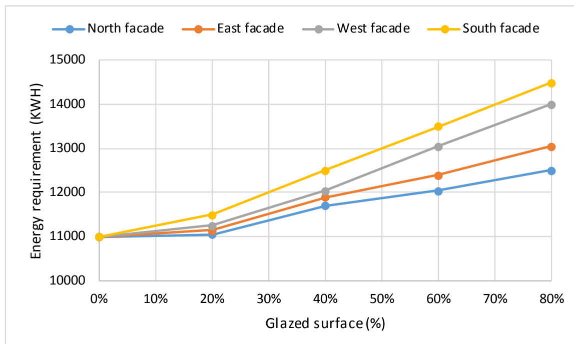
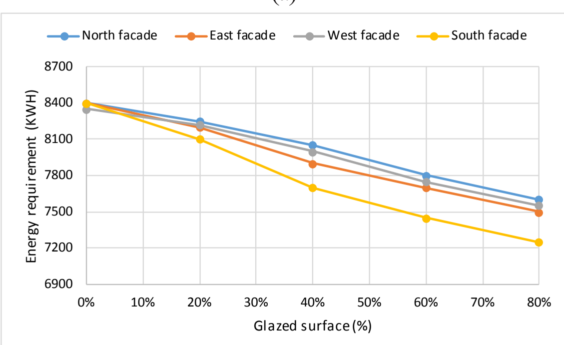


Low-emission double glazing

(a)



(b)

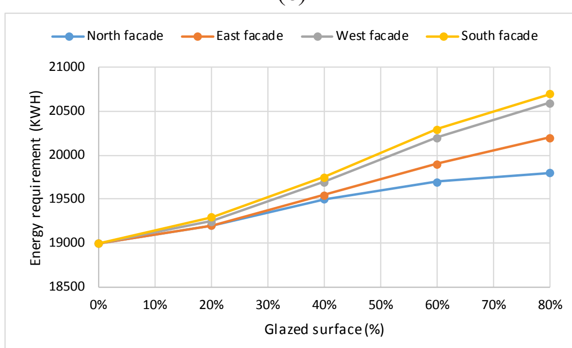


Figure 5. Annual energy requirement according to glazed surfaces.
(a): Heating requirement. (b): Cooling requirement

4.3 Movable Sun Protection

Solar protection reduces energy consumption by reducing summer solar gains. It limits air conditioning consumption while maintaining a stable and comfortable interior temperature. The exterior solar protection will block the heat before it enters the building. The dynamic nature of solar protection and the choice of the appropriate opening coefficient make it possible to maintain sufficient natural light intake to limit the use of artificial light and therefore energy consumption.

The solar protection chosen is that of external canvas roller blinds, with a solar factor of 0.2 determined according to NF EN 13363-2 standards [22]. The solar factor indicates the proportion of heat that enters the interior of a room of a building compared to the incident solar energy. The lower the coefficient, the higher the thermal comfort.

The external blinds are placed on the east, south and west facades, and are regulated facade by facade according to the minimum temperature of the rooms overlooking these facades.

According to the results presented in Table 4, we note that the annual solar contributions are thus reduced by 20%, which results in a reduction in the demand for cold by 30% but also by an increase in the demand for heat by 7%. This increase is probably due to less heat storage in the mass of the building.

Table 4. Annual energy requirement of the building with movable window sun protection

Energy requirement (KWH)	Without sun protection	With sun protection	Compared to the original building
Heating	9300	9985	7%
Cooling	11180	7830	-30%
Total	20480	17815	13%

4.4 Types of Glazing

Table 5 presents the different characteristics of the glazing to be installed in order to see their influence on the energy needs of the building.

Table 5. Glazing characteristics

Type of glazing	Dimension (m)	U (W/m².K)	Solar factor	Solar reflectance	Solar transmittance
Single glazing	0.80 x 1.00	6.32	0.85	0.08	0.83
Double glazing	0.80 x 1.00	3.24	0.75	0.15	0.73
Triple glazing	0.80 x 1.00	2.17	0.70	0.20	0.63
Low-emission double glazing	0.80 x 1.00	1.76	0.60	0.12	0.53

The results of the annual energy requirement according to the type of windows in the building are shown in Figure 6. We note that the quality of the glazing has a huge influence on the total energy requirement of the building. Indeed, the use of low-emission double-glazed windows brought an energy gain of 5.46%, while the use of triple glazing brought a gain of 4.97%. Consequently, the energy gain is not proportional to the number of glazing that constitutes the window but rather to its thermal quality.

We also note that the use of a window with a loss coefficient (U=1.76 W/m².K) three times lower than that of single-glazed windows (U=6.32 W/m².K) has brought a gain very modest compared to the investment cost, however the low-emission double-glazed window will be retained as the optimal case for our building.

Generally, the annual energy saving of a window depends on several factors: the two parameters specific to the window (U-value and g-value), its orientation, the climatic conditions and the parameters of the building [23].

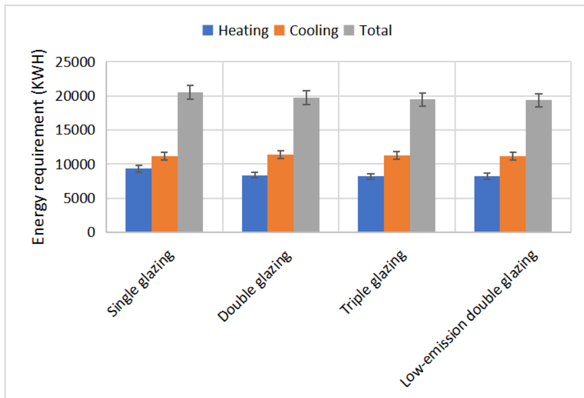


Figure 6. Annual energy requirement according to window types

4.5 Types of Building Materials

The building envelope plays a role of thermal separation between the interior and exterior atmosphere. It ensures the storage of heat in the building and then distributes it to the indoor and outdoor air [24-26].

Figure 7 gives the energy requirement of the building for some building materials. We note that the use of a double partition 30 cm thick allows a gain of 22% while the replacement of the hollow brick wall (e = 15 cm) by another hollow brick wall but of different thickness (e = 10 cm) allows a drop in energy performance of 11.20%. For a stone wall 45 cm thick, there is a reduction in energy consumption which can reach 11.70%.

The results also show that the energy requirement for air conditioning is greater than that for heating, which leads us to choose materials that allow passive cooling and lower the need for heating.

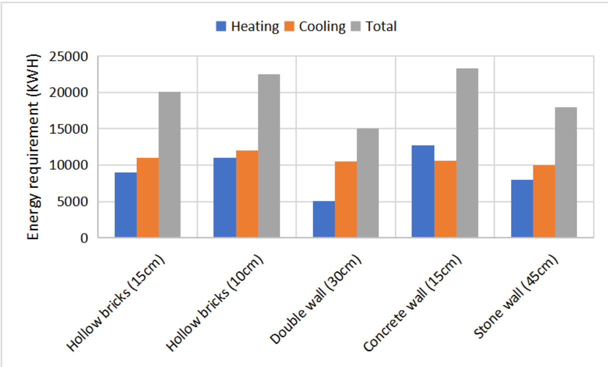


Figure 7. Annual energy requirement according to the type of building materials

4.6 Wall Insulation

Figure 8 gives the values of the building's energy requirements when using thermal insulation of the expanded polystyrene type with thermal conductivity λ = 0.042 W/m.K. We note that the insulation of the exterior walls and the roof with a thickness of 7 cm of polystyrene gave a reduction rate in energy consumption of 21% and 35% respectively. This difference is explained by the fact that the insulation of the roof allows the reduction of the energy need for heating and air conditioning, on the other hand the insulation of the exterior walls only allows the reduction of the need for heating.

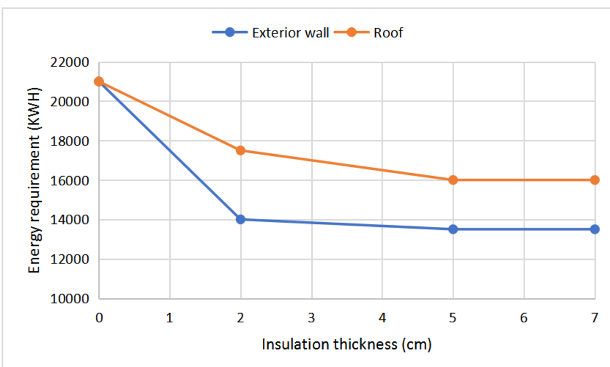


Figure 8. Annual energy requirement according to insulation thickness

5. Conclusions

This paper presented the impact that certain choices made during the design of a building can have on its energy balance. The following results can be deduced:

- Changing the North-South orientation of the building to East-West increased the demand for heating and air conditioning respectively by 5% and 11% for a total increase in consumption of 3%.
- The replacement of single-glazed windows with low-emission double-glazed windows brought an energy gain of 5.46%.
- The energy gain is not proportional to the number of glazing that constitutes a window but rather to the thermal quality of the window itself.
- The use of single glazing with a heat transfer coefficient U=6.32W/m².K did not result in an energy gain for all the facades, including the southern one. For double-glazed windows, it is absolutely necessary to avoid arranging them on the north facade, otherwise the energy needs will explode simultaneously with the increase in the glazed surface.
- The study of permanent solar protection showed that the energy requirement for heating increased inversely to air conditioning, which recorded a drop of more than 30%, ultimately arriving at a total energy gain of more than 13%.
- The building envelope has a significant impact on energy consumption. However, the replacement of the hollow brick wall (e = 15cm) by a double partition (e = 30 cm) resulted in a 22% drop in energy consumption.
- Insulation of the roof using expanded polystyrene 7 cm thick resulted in a 35% reduction in energy consumption. On the other hand, the insulation of the wall is not too profitable for a conditioned building.

The energy efficiency measures have brought an energy gain but in different proportions, this is how it is necessary to distinguish the order of priority according to the objective assigned and the financial means devoted. The effect of the equipment was excluded from the simulation since the objective of the study was to reduce the building's energy needs and not its consumption (final energy), this approach made it possible to distinguish the impact of the measures without it being altered by the operation of the equipment.

Conflict of Interest

There is no conflict of interest.

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