International Journal of Engineering

Journal Homepage: www.ije.ir

Enhancing Comfort in Tropical Institutional Buildings: Integrating Thermal, Acoustic and Visual Performance with a Unified Index

S. Yarramsetty*, MVN. Siva Kumar, P. Anand Raj

Department of Civil Engineering, NIT Warangal, Telangana State, India

PAPER INFO

Paper history:
Received 11 July 2023
Received in revised form 22 August 2023
Accepted 23 August 2023

Keywords:
Combined Comfort
Thermal Index
Auditory Index
Illumination Index
Institutional Building Performance Index

ABSTRACT

This study explores the relationship between a country's level of development and its educational standards, emphasizing the significance of well-equipped universities in ensuring high-quality education. While research on comfort in educational buildings has often focused on individual parameters, such as thermal, acoustic, and visual elements, this paper proposes a new metric that integrates these factors to assess environmental comfort. The research was conducted in six hostel rooms at the National Institute of Technology Warangal (NITW) campus in India, utilizing both objective measurements and subjective surveys. Three single measures were introduced: a thermo-hygrometric index, an audio comfort index, and a visual illumination index, each normalized within a 0-1 range denoting comfort and discomfort conditions. A final total comfort index for each room was established by assigning appropriate weights to the three factors. The findings were compared to the questionnaire responses, evaluating the effectiveness of the proposed methodology. The results indicate a comprehensive assessment of indoor environmental comfort, with acoustic factors showing the least impact on overall comfort conditions. The study recommends equal weighting for thermal, acoustic, and lighting parameters when computing the combined comfort index. The building achieved an overall comfort rating of 0.64 out of 1, indicating a comfortable environment. The study also shows that there is a strong correlation between the new combined comfort index and the results from the questionnaire. This research contributes a straightforward and integrated approach to gauge comfort levels in educational buildings and lays the groundwork for further assessments of institutional building performance.

doi*: 10.5829/ije.2023.36.12c.15*

1. INTRODUCTION

There are over one million five hundred sixty-nine thousand educational institutions in India, including several public and a significant number of privately held structures [1]. Government structures significantly contribute to greenhouse gas emissions (GHG). As a result, it is critical to assess the actual performance of university facilities. It has been discovered that the utilization phase of the created environment consumes a significant amount of energy [2, 3]. Nistratov et al. [4] innovated a method employing composite waste as environmentally-friendly building materials, cutting landfill waste costs and reducing production expenses by substituting primary materials. Significant energy savings and CO_2 emission reductions can be realized during the use phase of buildings [5-7]. Occupants spend a large portion of their lives indoors, in built-up environments. Throughout their undergraduate or graduate studies, students in the age range of 18-26 spend the majority of their time (87%) inside buildings. Hence, interior spaces should include the elements that provide a stimulating atmosphere to advance students' learning and analytical thinking [8, 9].

The building sector in India consumes around 35% of the total energy, with an annual increase of 8%. Various techniques and methods are being developed to address this issue [10-12]. The structure's use phase, which includes all amenities for the users' maximum

*Corresponding Author: email: sraoystp@student.nitw.ac.in (S. Yarramsetty)

Please cite this article as: S. Yarramsetty, MVN. Siva Kumar, P. Anand Raj, Enhancing Comfort in Tropical Institutional Buildings: Integrating Thermal, Acoustic and Visual Performance with a Unified Index, ***International Journal of Engineering, Transactions C: Aspects,*** Vol. 36, No. 12, (2023), 2253-2263

comfort, accounts for approximately 73% of total building energy [13-16]. In order to maintain thermal comfort, educational buildings consume a sizable quantity of energy. The overall energy consumption in the Indian educational building stock reaches 4,832 GWh, according to the Energy use in COmmercial buildings (ECO-III) study [17]. Thermal comfort can have a significant impact on the learning process and on the motivation to engage in academic pursuits [18-22] . Haverinen-Shaughnessy et al. [19] discovered strong correlations between good math and reading, exam results and interior temperature, ventilation rate, and cleanliness of high contact surfaces. Lee et al. [21] reported similar findings in four university classes in Hong Kong, demonstrating high correlations between votes and total indoor environmental quality, particularly for auditory components. Toyinbo et al. [22] discovered a link between poorer mathematics exam scores in school buildings and non-recommended ventilation rates. Yang et al. [18] attempted to assess the influence of classroom characteristics on student happiness and performance. According to Wargocki and Wyon [20], poor indoor environmental quality affects learning performance by 30%. Doi [23] and Musa et al. [24] examined how passive cooling technologies can regulate urban development's impact on thermal comfort.

A recent review conducted by Zomorodian et al. [25] identified 48 studies on thermal comfort in educational buildings published in past decades. Among these studies, 25% focused on elementary and middle schools, 34% on secondary and high schools, and the remaining 41% on universities. Recent field investigations in primary and secondary schools have highlighted that children, due to their higher metabolism, experience thermal comfort differently than adults [26-30]. Notably, the neutral comfort temperature was found to be 23.1 °C in primary schools, 23.8 °C in secondary and high schools, and 25.1 °C in universities [25]. These findings emphasize the importance of considering different age groups' thermal comfort requirements in educational buildings. Furthermore, the acoustical characteristics of primary, secondary, and tertiary-level classrooms as well as their impact on pupil success were studied. Yang and Bradley [31] conducted speech tests on elementary school pupils and adults and discovered that the intelligibility of speech for young children is influenced by reverberation time (RT), which is lower than the signal-to-noise ratio. According to Klatte et al. [32] background noise has a greater negative impact on children's speech perception and listening comprehension than it does on adults. Hodgson [33] demonstrated that the British Columbia University's classrooms had severe reverberation, low speech volumes, particularly at the rear of the rooms, and extremely noisy ventilation systems. They also created a questionnaire to assess perception of the listening environment. likewise Zannin and Marcon [34] learned that a Brazilian public school had inadequate acoustics [35].

Finally yet importantly, it is understood that having comfortable visual environments in classrooms is essential for learning and benefits the educational process. Michael and Heracleous [36] looked into how well a typical educational institution in Cyprus utilized natural lighting and suggested improvements to enhance visual comfort in classes. For the purpose of meeting the needs of the students in Athens' south-facing classrooms, Meresi [37] developed a particular light shelf for shade and light redirection as well as semitransparent, adjustable exterior shutters. Through the use of simulations and questionnaires, Korsavi et al. [38] examined a typical high school in Kashan, Iran. The results of the questionnaire revealed a wider range of sunlight acceptability, and the simulation results revealed a more upbeat approach [39].

The previous studies primarily focus on examining the effects of individual factors on environmental comfort, with limited attempts to comprehensively assess the cumulative impact of various perspectives. In order to gauge students' perceptions of acoustic and lighting comfort, tailored questionnaires were developed. By analyzing the mean responses to questions closely aligned with measured data, six acoustic indices and four visual indicators were formulated. These recommended indices are amalgamated in this study into a unified index that encompasses three distinct attributes: thermal-hygrometric, auditory, and lighting comfort conditions. For each attribute, three specific single indices are initially proposed: the Predicted Mean Vote (PMV) Index for thermal-hygrometric settings, the Sound Index for acoustic comfort, and the Visual Index for lighting conditions. These indices are dimensionless and normalized within the 0 to 1 range, where values nearing 1 indicate favorable comfort conditions, while those nearing 0 signify unfavorable ones. Based on the correlation between questionnaire responses and collected data, each index was computed. Following prior research, equal importance was assigned to lighting, acoustics, and thermos-hygrometry comfort. Consequently, a composite comfort index is recommended and calculated for each classroom using these weighted factors.

The aim of this study by the authors is to investigate how the environment influences occupant comfort, considering aspects of thermal, acoustic, and lighting conditions. These fundamental factors play a vital role in shaping overall comfort conditions and can be managed through a combination of active measures such as utilizing plants and passive strategies like enhancing the building envelope [40].

2. METHODOLOGY

2. 1. Available Data & Case Study The investigation comprised the examination of six hostel rooms situated on the premises of the National Institute of Technology Warangal (NITW) campus. The methodology's visual representation is captured by the flowchart in Figure 1. These particular rooms are located within a hostel complex boasting a total capacity of 1,800 rooms (1.8k hostel/Ultra mega hostel) and are specifically designated as A3-13, B3-50, A7-12, B7-20, and B7-48. The selection of these rooms was guided by factors such as the availability of students for active participation in the investigation and survey activities. A comprehensive consolidation of essential details concerning the hostel rooms, encompassing dimensions and occupancy particulars, is outlined in Table 1. Notably, this study maintained a dedicated focus on single sharing rooms to ensure coherence and uniformity within the analytical framework. Figure 2 depicts the arrangement of single and double sharing. Figures 3 and 4 depict a typical floor plan, ariel view, and front view of the 1.8K hostel. The hostel rooms were studied in terms of thermo-hygrometrical, lighting, and acoustical conditions.

The measurements were taken at a height of 0.75 m to represent the students' usual sitting space, as shown in Figure 5. Experimental measurements of natural ventilated illumination and acoustical conditions were measured with various instruments. Table 2 lists the instruments used to collect the data.

2. 2. Analysis of Questionnaire Data The experimentally measured data are compared to the responses from the questionnaire based on the questions shown in Table 3. To accomplish this, each question is linked to each measured value in order to assess the subjective parameters that are most closely related to the experimental data. Figure 5 depicts the experimental data collection.

2. 3. The Individual Proposed Indexes Individual indexes are evaluated for each parameter under consideration, and by combining individual indexes, a final single index that describes acoustic,

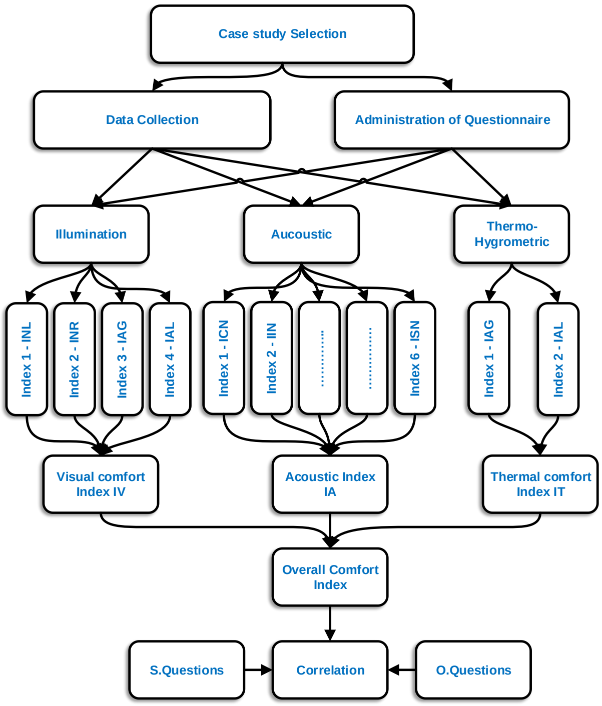


Figure 1. Flowchart showing Methodology

TABLE 1. Characteristics of Hostel rooms

Room type	Sharing	Length (m)	Width (m)	Height (m)	Floor area (m^2)	Volume (m^3)	Door surface (m^2)	Window surface (m^2)
A	1	3.55	3.00	2.80	10.65	29.82	1.99	2.16
B	1	3.64	3.00	2.80	10.92	30.58	1.99	2.16
C	1	3.53	3.00	2.80	10.59	29.65	1.99	2.16
D	1	4.09	3.00	2.80	12.27	34.36	1.99	2.16
E	1	3.18	3.00	2.80	09.54	26.71	1.99	2.16
F	1	3.77	3.00	2.80	11.31	31.67	1.99	2.16
G	2	3.28	4.20	2.80	13.78	38.57	1.99	2.16
H	2	3.78	4.20	2.80	15.88	44.45	1.99	2.16
I	2	3.55	4.20	2.80	14.91	41.75	1.99	2.16
J	2	3.11	4.20	2.80	13.06	36.57	1.99	2.16
K	2	3.50	4.20	2.80	14.70	41.16	1.99	2.16
L	2	3.77	4.20	2.80	15.83	44.33	1.99	2.16

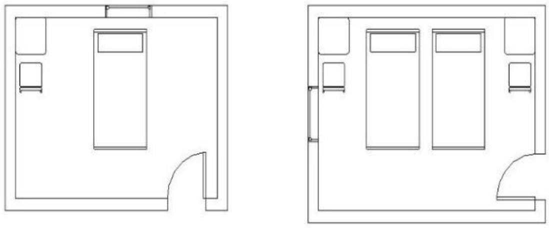
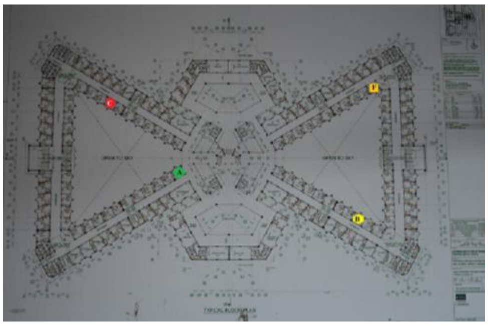
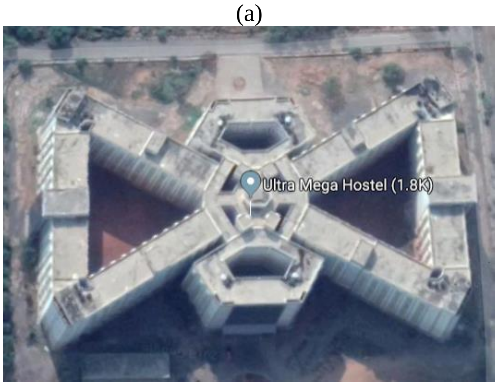


Figure 2. Typical Single and Double sharing arrangement



(a)



(b)

Figure 3. Top view of the building a) Plan view of 7th floor b) Birds eye view

Figure 4. Front view of the 1.8K hostel

Figure 5. Illustrates the aggregation of factual data

lighting, and thermal-hygrometric comfort conditions must be established. Individual indices are calculated by taking into account the various questionnaire survey indexes listed in the corresponding section. Each index is given weight based on the degree of correlation between the perceived and measured values. The average of the answers to the questions is used as the index value, which ranges from 0 to 10. The dimensionless single parameter index is calculated by normalizing the value (0 to 1) and dividing it by 10.

2. 3. 1. Acoustic Index I_A The acoustic index I_A is calculated as follow:

$$I_A = \frac{0.1*(10-ICN)+0.1*IIN+0.4*(10-IDN) +0.2*(10-ION)+0.1*(10-IRN)+0.1*(10-ISN)}{10} \quad (1)$$

where ICN, IIN, IDN, ION, IRN and ISN are explained in Table 3. The weightage for each question is given in proportion to its correlation with the experimental data, with the question that is most correlated with the experimental data receiving the most weightage. ICN is given a 10% weight. IIN receives 10% of the weight, while IDN receives 40% of the weight. ION receives a 20% weightage, IRN receives a 10% weightage, and ISN receives a 10% weightage. It is important to note that an increase in mean votes for the indexes ICN, IDN, ION, IRN, and ISN is detrimental to acoustic comfort; therefore, a complement of 10 was considered in the average.

2. 3. 2. Visual Comfort Index I_V The lighting index I_{vc} is calculated as follow:

$$I_{VC} = \frac{0.46*INL+0.01*INR+0.03*(10-IAG)+0.5*(10-IAL)}{10} \quad (2)$$

TABLE 2. Comfort parameters range, accuracy and resolution

Parameter		Units	Range	Accuracy	Resolution	Instrument system
Air Temperature	Ti	ºC	-50ºC to +70ºC (-58ºF to + 158ºF)	± 1ºC	0.1ºC	HTC-1, Digital Hygrometer Temperature Humidity Meter
Air Relative Humidity	Rh	%RH	10% RH to 99% RH	±5% RH	1%	
Sound	Si	dB	35 dB to 130 dB	1 dB	1dB	Digital Sound Level Meter
Illumination	Li	Lux	0 Lux to 200000 Lux	+ 3%	0.01 Lux	HTC Lux meter LX-103

TABLE 3. Acoustic, Lighting and Thermal questionnaires: selected questions and correspondent indexes

	No.	Question	Index
Acoustic	1	Hostel mates making noise in the corridors	ICN- Corridor Noise Index
	2	Internal noise (fan, phone, etc)	IIN- Internal Noise Index
	3	Noises that disturbs once in a day	IDN- Daily Noise Index
	4	Noises that disturbs occasionally	ION- Occasional Noise Index
	5	Do these noises disturbs you while taking rest	IRN- Rest Noise Index
	6	Do these noises disturbs you while you studying	ISN- Study Noise Index
Lighting	1	Amount of light entering through the windows	INL- Natural Light Index
	2	Experience discomfort due light reflecting from outside	INR- Reflection Light Index
	3	Inside the room, dark patches and too bright locations created by window	IAG- Lighting Annoying Glares Index
	4	How frequently you use artificial lighting in room	IAL- Artificial Light Index
Thermal	1	The heat entering through windows from natural source (sun) in winter	INH- Natural Heat Index
	2	The heat shield by the windows and wall (summer)	IIH- Internal Heat Index

Table 3 defines the terms INL, INR, IAG, and IAL. INL receives 46% of the weightage, INR receives 1%, IAG receives 3%, and IAL receives 50% of the weightage. We used a negative value in the calculations by subtracting the votes from 10. Because an increase in mean votes for the indices IAG and IAL reduces visual comfort.

2. 3. 3. Thermal Comfort Index I_T

The predicted mean value can be used to assess thermal comfort (PMV). The PMV value will range between -3 and +3. I_{PMV}, with a value ranging from 0 to 1, is calculated from PMV using the following formula, taking into account the linear relationship depicted in Figure 6.

$$I_{PMV} = |(|PMV|+1) - (|PMV|*4/3)| \quad (3)$$

When PMV is -3 or +3, IPMV has a value of 0 and has a maximum value of 1 when PMV is 0. The intermediate values will have a linear trend ranging from 0 to 1.

2. 3. 4. The New Overall Comfort Index I_{NCC}

The weighted average values of individual comfort indices are added to calculate the new overall comfort index. The equal weights of three individual comfort indexes, which are normalised to the 0-1 range. The formula for calculating the new combined comfort index is given below:

$$I_{NCC} = 0.33*I_A + 0.33*I_V + 0.33*I_T \quad .(4)$$

3. RESULTS

During the month of October 2018, data was collected for seven days. The information gathered is related to thermal, lighting, and acoustical conditions [41]. Table 4 displays the mean values of the observed data.

In the brief autumn month of October, the minimum value of mean indoor temperature reaches 30.1°C (room B7-18), corresponding to an outdoor temperature of 31.70°C [8]. Indoor temperatures reach a maximum of 30.56°C. (room A7-12). As a result, there is not much of a temperature difference between the rooms; they are almost all the same temperature. Acoustic results show

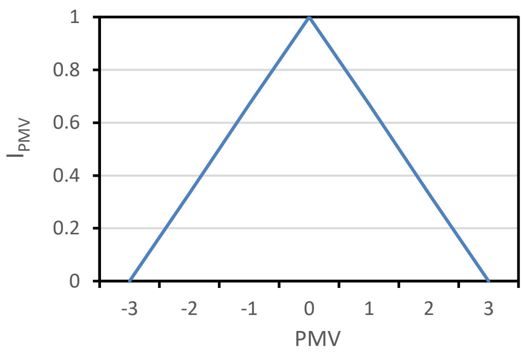


Figure 6. PMV Vs I_{PMV}

TABLE 4. Mean values of observed data of one week

Parameter	Temp Ti_d	Humidity (%)	Sound (dB)	Illuminance (lux)
Out door	31.7	50.05	65.7	494.6
A3-13	30.29	54.64	67.66	183.71
B3-50	30.16	54.67	65.6	284.18
A7-12	30.56	54.45	71.56	483.09
A7-46	30.35	54.95	71.91	294.81
B7-20	30.35	54.95	70.95	465.14
B7-48	30.1	55.56	68.29	178.84

Ti_d – Temp. INDOOR

that sound levels in all rooms exceed 60dB. The maximum sound level was 71.91 dB (room A7-46), which could be attributed to the fact that there were more people in the room most of the time.

3. 1. Acoustic Index IA The acoustic survey results are tabulated in Table 5. Acoustic indices are derived using Equation (1) from the survey responses. Among the rooms, B7-48 exhibits the highest internal noise, while Room A3-13 attains the most favorable value (8.12 for occasional noise). A comparative assessment is presented in Table 5, confirming Room A3-13's superior performance. Upon reviewing the IA values in Table 5, it becomes evident that Room A3-13 excels with an acoustic comfort index of 0.68. Notably, almost all rooms yield an acoustic index above 0.6 (excluding B7-20 with 0.59). The consistent acoustic index values within the 0-1 scale across rooms indicate uniform behavior. Values surpassing 0.6 within the 0-1 range signify satisfactory performance, underscoring good acoustic comfort across all rooms.

3. 2. Visual Parameter Comfort Index– IVC Table 6 lists the illumination comfort index values. Room A7-12 is found to have a high level of visual comfort (0.75), as well as a high illumination value of 483.18 lux and low annoying glare formation from natural light. All rooms with a visual comfort index greater than 0.5 are considered visually comfortable. Because of higher glare formation due to natural lighting, rooms A3-13 and B7-48 have a lower visual comfort index (0.56).

TABLE 5. Acoustic Index (I_A) based on questionnaire

	Room	A3-13	B3-50	A7-12	A7-46	B7-20	B7-48
Acoustic Index	10-ICN	6.37	5.73	6.71	5.87	5.68	6.18
	IIN	5.81	5.50	6.00	4.35	4.23	3.36
	10-IDN	6.75	6.41	6.67	6.26	6.23	7.23
	10-ION	8.12	6.5	7.52	7.78	6.27	6.77
	10-IRN	7.12	6.55	6.86	7.00	6.32	6.64
	10-ISN	5.69	5.18	5.38	6.17	5.27	6.45
	I_A	**0.68**	0.62	0.67	0.64	0.59	0.65

TABLE 6. Visual comfort index I_V based on questionnaire

	Room	A3-13	B3-50	A7-12	A7-46	B7-20	B7-48
Visual comfort index	INR	7.31	5.68	7.19	6.52	5.41	5.09
	10-IAG	5.25	4.95	5.71	5.65	5.36	6.32
	10-IAL	5.06	6.45	6.86	4.96	5.64	4.45
	IVC	0.56	0.66	**0.75**	0.61	0.62	0.56

3. 3. Thermal Comfort Index IT The thermal sensation is evaluated on a 10-point scale (0-10), which is then converted into the traditional Fanger scale (7–value). Because this survey is taking place during the brief autumn month of October, and all average measured temperatures are above 30 degrees Celsius, the scale is converted to the warm side (0 to 3) of the Fahrenheit scale. If the response is 10, PMV is set to 0 and IPMV is set to 1, which is more comfortable. If the response is 0, it indicates that the occupant is more dissatisfied, resulting in a -3 on the fanger scale and an I_{PMV} of 0. Many factors influence thermal comfort, including metabolism, clothing resistance, air velocity, mean radiant temperature, and relative humidity. Due to the lack of equipment, the only factors considered in this thermal comfort evaluation are temperature and relative humidity. Table 7 contains the PMV and IPMV. Room A has good thermal comfort (I_{PMV} = 0.81) while Room D has I_{PMV} = 0.74. The remaining space has an index of around 0.6.

3. 4. The New Overall Comfort Index I_{NCC} By substituting the individual indices in Equation (4), the new combined overall comfort index is calculated. The total index value of the rooms is furnished in Table 8. The new combined comfort index is measured on a scale of 0 to 1, with 0 being the worst and 1 being the best. More than 0.65 is considered comfortable shwon by smile face. Neutral is 0.45 to 0.65 shown by emotionless face, and Uncomfortable is lessthan 0.45 shown by sad face. According to this classification, rooms A3-13, A7-12, and A7-46 are comfortable, while the remaining rooms have a comfort index of less than 0.6 and fall into the neutral category. The NCC for all

TABLE 7. PMV & I_{PMV} values

Room	PMV	I_{PMV}
A	0.57	0.81
B	1.41	0.53
C	1.17	0.61
D	0.77	0.74
E	1.25	0.58
F	1.23	0.59

TABLE 8. New combined comfort index value of rooms

Index	A3-13	B3-50	A7-12	A7-46	B7-20	B7-48
I_A	0.68	0.62	0.67	0.64	0.59	0.65
I_V	0.56	0.66	0.75	0.61	0.62	0.56
I_T	0.81	0.53	0.61	0.74	0.58	0.59
I_{NCC}	**0.68**	0.60	**0.67**	**0.66**	0.59	0.59

observed rooms is plotted in Figure 7, and it is observed that rooms B3-50, B7-20, and B7-48 have low thermal index values because their windows face the Sun for a longer period of time than the remaining rooms.

Correlating the Indoor Comfort Combined Index (INCC) with mean votes from occupants on thermal, acoustic, and lighting aspects (calculated as the arithmetic average of the three votes). Mean votes for specific questions (with refering to Table 3, mean votes of Aucoustic:Q2, Lightning:Q1 and Thermal:Q1) are categorized as Mean values of simple questions (Mean S.Q), while mean votes for all questions are categorized as Mean values of Overall Questions (Mean O.Q). The approach evaluates the suitability of INCC for describing room comfort comprehensively. Outcomes are presented in Table 9, showing good correspondence between rooms and INCC for various comfort conditions using both Mean S.Q and Mean O.Q. Specific rooms (B7-20 and B7-40) are rated neutral with INCC 0.59, aligning with occupants' mean votes. Discrepancies arise, such as in room A7-46, where INCC doesn't fully match occupants' votes on acoustic and visual comfort. Reasonable correlation coefficients of 0.67 and 0.79, for Mean S.Q and Mean O.Q respectively, indicate a solid link between INCC and occupant votes.

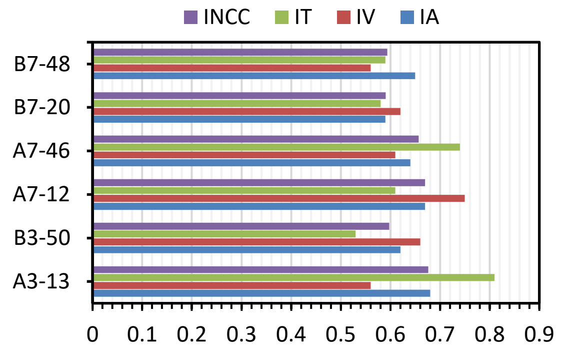


Figure 7. Comparison of indices of rooms

TABLE 9. Comparison between INCC and mean votes

Room	Comfort			Mean Vote		INCC
	Acoustic	Visual	Thermal	S.Q	O.Q	
A3-13	🙂	😐	🙂	7.11	7.06	0.68
B3-50	😐	🙂	😐	6.10	6.52	0.60
A7-12	🙂	🙂	😐	8.56	7.65	0.67
A7-46	😐	😐	🙂	8.11	7.27	0.66
B7-20	😐	😐	😐	4.10	5.13	0.59
B7-48	🙂	😐	😐	6.17	5.49	0.59

4. DISCUSSION

This study has examined a novel composite comfort index that integrates thermal, acoustic, and lighting aspects within an educational building. A comprehensive analysis was conducted by cross-referencing the responses obtained from Table 3's questionnaire with empirical measurements. Each question was matched with corresponding measurements, facilitating an assessment of the questionnaire's key subjective elements in relation to real-world data. The subsequent section delves into the correlation between the combined comfort index (INCC) and the average occupant ratings for heat, noise, and lighting factors (Figure 8). This investigation aims to establish whether the newly proposed INCC indicators effectively characterize the collective comfort conditions within the room. The findings in Table 9 underscore that rooms A3-13, A7-12, and A7-46 exhibit notably improved comfort conditions in comparison to other spaces. Room A3-13 demonstrates a heightened thermal comfort index (IT = 0.81) but a relatively lower visual comfort index (IV = 0.56), contrasting with room B3-50's lower thermal comfort (IT = 0.53) and elevated visual comfort (IV = 0.66). The compromised state of the thermo-hygrometric dimension is likely to additionally, Table 10 presents the relative weights assigned to acoustic, thermal, and lighting parameters for overall indoor environmental comfort, as gleaned from prior field studies. This facilitates parameter-level comparisons to provide comprehensive insights. While study data from various geographical regions can't be directly correlated, it's noteworthy that acoustics had the least influence on the overall indoor environmental comfort conditions among the three parameters examined. Field studies did not yield conclusive trends in comfort parameter weighting. Buratti [50] suggests that acoustic, thermal, and illumination factors hold nearly equal importance, which aligns with the findings of this study.

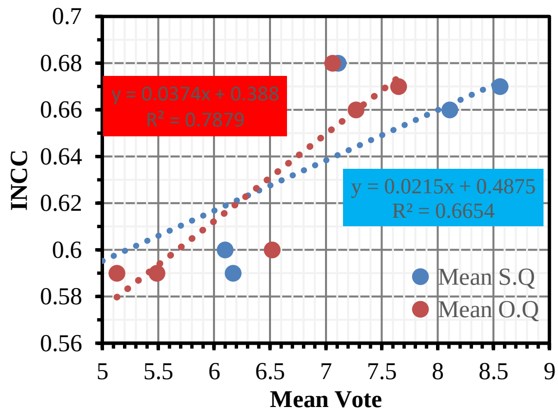


Figure 8. Correlation of INCC with Mean Vote

TABLE 10. Summarization of previous studies based on indoor environmental comfort

Comfort Parameter weightage			Sample size	Type of analysis	Reference
Acoustical	Thermal	Illumination			
0.11	0.10	0.46	1000 denizens (US)	Pearson Product-moment correlations	[42]
0.20	0.21	0.16	12 advisors (Taiwan)	AHP	[43]
0.5	0.28	0.25	852 secondary school students (Italy)	Pearson coefficient	[44]
4.74	6.09	3.70	293 denizens (Hong Kong)	Multivariate regression	[45]
0.22	0.32	0.17	500 denizens (Beijing & Shanghai)	Multivariate regression	[46]
0.18	0.30	0.16	68 denizens (UK)	Multivariate regression	[47]
0.16	0.17	0.15	Standard code - EN15251	Relative weightage vector	[48]
0.18	0.33	0.30	17 denizens (Italy)	Multivariate regression	[49]
0.36	0.34	0.30	928 denizens	Questionnaires	[50]

The INCC indicators exhibit a notable alignment with the three distinct comfort conditions, as observed through Mean S.Q and Mean O.Q measurements (refer Table 9). Classrooms B7-20 and B7-40 are assessed as neutral with an INCC value of 0.59, which resonates with occupants' average votes of 5.13 and 5.49 (Mean O.Q). The potential influence of poor thermo-hygrometric conditions on these rooms is plausible. For room A7-46, the INCC value does not closely mirror the occupants' mean vote (neutral for acoustic and visual comfort). It is conceivable that students attributed more significance to the thermal aspect. A noteworthy correlation was identified between the mean votes assigned to the rooms and the INCC, established for both S.Q and O.Q metrics. The obtained R^2 values from this analysis are substantial, registering 0.67 and 0.79, respectively. This consistency aligns with the efficacy of the composite thermal, acoustic, and visual comfort indicator formulation. Conducting a broader experimental campaign with the new questionnaire could provide valuable validation of the newly proposed index. This approach involves calculating the index using data distinct from those used to develop the methodology, thereby augmenting its robustness.

5. CONCLUSION

This study introduces a pioneering approach to comprehensively assess the comfort levels within institutional buildings, unveiling a newly devised combined comfort index. Through an intricate analysis of thermal, acoustic, and visual comfort factors in six university hostel rooms, this research formulates a comprehensive model for evaluating comfort that goes beyond conventional parameters. The distinctive aspect lies in its ability to holistically measure comfort through a user-friendly questionnaire. The significance of each question aligns with its correlation to real-world data, leading to higher weighting for questions closely connected to actual experiences.

Building upon this framework, distinct equations are crafted for each comfort parameter (thermal, acoustic, and lighting). These parameters are subsequently normalized within a 0–1 range, where enhancements in comfort elevate dimensionless values from 0 to 1. Drawing from preceding research, equal importance is assigned to the three comfort-related indexes -IT (Thermal Index), IA (Acoustic Index), and IV (Illumination Index) -to establish the equation for the New Combined Comfort Index. By amalgamating individual indexes with uniform weights, a consolidated index emerges as the ultimate metric. The building's overall comfort achieves a rating of 0.64 out of 1, characterizing it as a comfortably conducive environment. Notably, a robust correlation emerges between room-specific mean votes and the INCC, substantiated through both S.Q and O.Q metrics. The ensuing R^2 values, 0.67 and 0.79 respectively, underscore the statistical robustness of this association.

This study not only introduces a fresh paradigm for evaluating comprehensive comfort but also demonstrates its practicality by devising the New Combined Comfort Index. Such insights open avenues for advanced strategies in designing and enhancing comfort conditions in built spaces.

6. REFERENCES

1. MHRD, D. “Educational Institutions Statistics India 2016.” Retrieved June 10, 2019, from http://dise.in/ and http://mhrd.gov.in/statist
2. Nässén, J., Holmberg, J., Wadeskog, A., and Nyman, M. “Direct

and indirect energy use and carbon emissions in the production phase of buildings: An input-output analysis." ***Energy***, Vol. 32, No. 9, (2007), 1593-1602. https://doi.org/10.1016/j.energy.2007.01.002

3. Yohanis, Y. G., and Norton, B. "Life-cycle operational and embodied energy for a generic single-storey office building in the UK." ***Energy***, Vol. 27, No. 1, (2002), 77-92. https://doi.org/10.1016/S0360-5442(01)00061-5

4. Nistratov, A. V., Klimenko, N. N., Pustynnikov, I. V., and Vu, L. K. "Thermal Regeneration and Reuse of Carbon and Glass Fibers from Waste Composites." ***Emerging Science Journal***, Vol. 6, No. 5, (2022), 967-984. https://doi.org/10.28991/ESJ-2022-06-05-04

5. Airaksinen, M., and Matilainen, P. "A Carbon footprint of an office building." ***Energies***, Vol. 4, No. 8, (2011), 1197-1210. https://doi.org/10.3390/en4081197

6. Wu, H. J., Yuan, Z. W., Zhang, L., and Bi, J. "Life cycle energy consumption and CO_2 emission of an office building in China." ***The International Journal of Life Cycle Assessment***, Vol. 17, No. 2, (2012), 105-118. https://doi.org/10.1007/s11367-011-0342-2

7. Yarramsetty, S., Rohullah, M. S., and Anand, M. V. N. S. "An investigation on energy consumption in residential building with different orientation : a BIM approach." ***Asian Journal of Civil Engineering***, No. 0123456789, (2019). https://doi.org/10.1007/s42107-019-00189-z

8. Thapa, S., Bansal, A. K., and Panda, G. K. "Thermal comfort in naturally ventilated office buildings in cold and cloudy climate of Darjeeling, India - An adaptive approach." ***Energy and Buildings***, Vol. 160, (2018), 44-60. https://doi.org/10.1016/j.enbuild.2017.12.026

9. Dear, R. De, Kim, J., Candido, C., Deuble, M., Dear, R. De, Kim, J., Candido, C., and Deuble, M. "classrooms Adaptive thermal comfort in Australian school classrooms," No. May, (2015), 37-41. https://doi.org/10.1080/09613218.2015.991627

10. BEE. "Energy benchmarks for Commercial Buildings Bureau of Energy Efficiency 4 th Floor, Sewa Bhawan, R.K. Puram, New Delhi-110066 Website : www.beenet.in." Retrieved January 21, 2023, from http://eecbindia.com/

11. Bangia, T., and Raskar, R. "Cohesive Methodology in Construction of Enclosure for 3.6m Devasthal Optical Telescope." ***HighTech and Innovation Journal***, Vol. 3, No. 2, (2022), 162-174. https://doi.org/10.28991/HIJ-2022-03-02-05

12. Barreca, F., Arcuri, N., Cardinali, G. D., Fazio, S. Di, Rollo, A., and Tirella, V. "A Highly Sustainable Timber-Cork Modular System for Lightweight Temporary Housing." ***Civil Engineering Journal (Iran)***, Vol. 8, No. 10, (2022), 2336-2352. https://doi.org/10.28991/CEJ-2022-08-10-020

13. BEE. *Energy Conservation Building Code 2017*.

14. Rawal, R., Vaidya, P., Ghatti, V., Ward, A., Group, T. W., Seth, S., Jain, A., and Parthasarathy, T. "Energy Code Enforcement for Beginners : A Tiered Approach to Energy Code in India," No. Cbre 2011, (2012), 313-324.

15. Rincon, L., Castell, A., Perez, G., Sole, C., Boer, D., and Cabeza, L. F. "Evaluation of the environmental impact of experimental buildings with different constructive systems using Material Flow Analysis and Life Cycle Assessment." ***Applied Energy***, Vol. 109, (2013), 544-552. https://doi.org/10.1016/j.apenergy.2013.02.038

16. Taherkhani, R., Alviri, M., Panahi, P., and Hashempour, N. "Low Embodied Carbon and Energy Materials in Building Systems: A Case Study of Reinforcing Clay Houses in Desert Regions." ***International Journal of Engineering, Transactions B: Applications***, Vol. 36, No. 8, (2023), 1409-1428. https://doi.org/10.5829/ije.2023.36.08b.02

17. Kumar, S. *USAID ECO - III Project Energy Use in commercial buildings - Key findings from the national benchmarking study*. Retrieved from USAID - INDIA

18. Yang, Z., Becerik-gerber, B., and Mino, L. "A study on student perceptions of higher education classrooms : Impact of classroom attributes on student satisfaction and performance." ***Building and Environment***, Vol. 70, (2013), 171-188. https://doi.org/10.1016/j.buildenv.2013.08.030

19. Ulla, Haverinen-shaughnessy; Shaughnessy, Richard J; Cole, Eugene C; Toyinbo, O., and Moschandreas, D. J. "An assessment of indoor environmental quality in schools and its association with health and performance." ***Building and Environment***, Vol. 93, (2015), 35-40. https://doi.org/10.1016/j.buildenv.2015.03.006

20. Wargocki, P., and Wyon, D. P. "Providing better thermal and air quality conditions in school classrooms would be cost-effective." ***Building and Environment***, Vol. 59, , (2013), 581-589. https://doi.org/10.1016/j.buildenv.2012.10.007

21. Lee, M. C., Mui, K. W., Wong, L. T., Chan, W. Y., Lee, E. W. M., and Cheung, C. T. "Student learning performance and indoor environmental quality (IEQ) in air-conditioned university teaching rooms." ***Building and Environment***, Vol. 49, No. 1, (2012), 238-244. https://doi.org/10.1016/j.buildenv.2011.10.001

22. Toyinbo, O., Shaughnessy, R., Turunen, M., Putus, T., Metsamuuronen, J., Kurnitski, J., and Haverinen-Shaughnessy, U. "Building characteristics , indoor environmental quality , and mathematics achievement in Finnish elementary schools." ***Building and Environment***, Vol. 104, (2016), 114-121. https://doi.org/10.1016/j.buildenv.2016.04.030

23. Doi, R. "Are New Residential Areas Cooler than Older Ones?" ***Emerging Science Journal***, Vol. 6, No. 6, (2022), 1346-1357. https://doi.org/10.28991/ESJ-2022-06-06-08

24. Musa, H. H., Hussein, A. M., Hanoon, A. N., Hason, M. M., and Abdulhameed, A. A. "Phases of Urban Development Impact on the Assessment of Thermal Comfort: A Comparative Environmental Study." ***Civil Engineering Journal (Iran)***, Vol. 8, No. 5, (2022), 951-966. https://doi.org/10.28991/CEJ-2022-08-05-08

25. Zomorodian, Z. S., Tahsildoost, M., and Hafezi, M. "Thermal comfort in educational buildings: A review article." ***Renewable and Sustainable Energy Reviews***, Vol. 59, , (2016), 895-906. https://doi.org/https://doi.org/10.1016/j.rser.2016.01.033

26. Nam, I., Yang, J., Lee, D., Park, E., and Sohn, J.-R. "A study on the thermal comfort and clothing insulation characteristics of preschool children in Korea." ***Building and Environment***, Vol. 92, (2015), 724-733. https://doi.org/https://doi.org/10.1016/j.buildenv.2015.05.041

27. Teli, D., Jentsch, M. F., and James, P. A. B. "The role of a building's thermal properties on pupils' thermal comfort in junior school classrooms as determined in field studies." ***Building and Environment***, Vol. 82, (2014), 640-654. https://doi.org/https://doi.org/10.1016/j.buildenv.2014.10.005

28. Almeida, R. M. S. F., Ramos, N. M. M., and de Freitas, V. P. "Thermal comfort models and pupils' perception in free-running school buildings of a mild climate country." ***Energy and Buildings***, Vol. 111, (2016), 64-75. https://doi.org/https://doi.org/10.1016/j.enbuild.2015.09.066

29. Trebilcock, M., Soto-Muñoz, J., Yañez, M., and Figueroa-San Martin, R. "The right to comfort: A field study on adaptive thermal comfort in free-running primary schools in Chile." ***Building and Environment***, Vol. 114, (2017), 455-469. https://doi.org/https://doi.org/10.1016/j.buildenv.2016.12.036

30. Wang, D., Jiang, J., Liu, Y., Wang, Y., Xu, Y., and Liu, J. "Student responses to classroom thermal environments in rural primary and secondary schools in winter." ***Building and Environment***, Vol. 115, (2017), 104-117.

https://doi.org/https://doi.org/10.1016/j.buildenv.2017.01.006

31. Yang, W., and Bradley, J. S. "Effects of room acoustics on the intelligibility of speech in classrooms for young children." ***The Journal of the Acoustical Society of America***, Vol. 125, No. 2, (2009), 922-933. https://doi.org/10.1121/1.3058900

32. Klatte, M., Lachmann, T., and Meis, M. "Effects of noise and reverberation on speech perception and listening comprehension of children and adults in a classroom-like setting." ***Noise and Health***, Vol. 12, No. 49, (2010), 270-282. https://doi.org/10.4103/1463-1741.70506

33. Hodgson, M. "Rating, ranking, and understanding acoustical quality in university classrooms." ***The Journal of the Acoustical Society of America***, Vol. 112, No. 2, (2002), 568-575. https://doi.org/10.1121/1.1490363

34. Zannin, P. H. T., and Marcon, C. R. "Objective and subjective evaluation of the acoustic comfort in classrooms." ***Applied Ergonomics***, Vol. 38, No. 5, (2007), 675-680. https://doi.org/10.1016/j.apergo.2006.10.001

35. Khalvati, F., and Omidvar, A. "Prediction of Noise Transmission Loss and Acoustic Comfort Assessment of a Ventilated Window using Statistical Energy Analysis." ***International Journal of Engineering, Transactions C: Aspects***, Vol. 32, No. 3, (2019), 451-459. https://doi.org/10.5829/ije.2019.32.03c.14

36. Michael, A., and Heracleous, C. "Assessment of natural lighting performance and visual comfort of educational architecture in Southern Europe: The case of typical educational school premises in Cyprus." ***Energy and Buildings***, Vol. 140, (2017), 443-457. https://doi.org/10.1016/j.enbuild.2016.12.087

37. Meresi, A. "Evaluating daylight performance of light shelves combined with external blinds in south-facing classrooms in Athens, Greece." ***Energy and Buildings***, Vol. 116, (2016), 190-205. https://doi.org/10.1016/j.enbuild.2016.01.009

38. Korsavi, S. S., Zomorodian, Z. S., and Tahsildoost, M. "Visual comfort assessment of daylit and sunlit areas: A longitudinal field survey in classrooms in Kashan, Iran." ***Energy and Buildings***, Vol. 128, (2016), 305-318. https://doi.org/10.1016/j.enbuild.2016.06.091

39. Rahman, N. A. A., Kamaruzzaman, S. N., and Akashah, F. W. "A Review of Optimization Techniques Application for Building Performance Analysis." ***Civil Engineering Journal (Iran)***, Vol. 8, No. 4, (2022), 823-842. https://doi.org/10.28991/CEJ-2022-08-04-014

40. Kharazi, B. A., Alvanchi, A., and Taghaddos, H. "A Novel Building Information Modeling-based Method for Improving Cost and Energy Performance of the Building Envelope." ***International Journal of Engineering, Transactions B: Applications***, Vol. 33, No. 11, (2020), 2162-2173. https://doi.org/10.5829/ije.2020.33.11b.06

41. Sutarja, I. N., Ardana, M. D. W., and Putra, I. D. G. A. D. "The post-disaster house: Simple instant house using lightweight steel structure, bracing, and local wood wall." ***International Journal of Engineering, Transactions B: Applications***, Vol. 34, No. 2, (2021), 348-354. https://doi.org/10.5829/IJE.2021.34.02B.06

42. Marans, R. W., and Yan, X. "Lighting quality and environmental satisfaction in open and enclosed offices." ***The Journal of Architectural and Planning Research***, (1989), 118-131. https://doi.org/www.jstor.org/stable/43028916

43. Chiang, C. M., and Lai, C. M. "A study on the comprehensive indicator of indoor environment assessment for occupants' health in Taiwan." ***Building and Environment***, Vol. 37, No. 4, (2002), 387-392. https://doi.org/10.1016/S0360-1323(01)00034-8

44. Astolfi, A., and Pellerey, F. "Subjective and objective assessment of acoustical and overall environmental quality in secondary school classrooms." ***The Journal of the Acoustical Society of America***, Vol. 123, No. 1, (2008), 163-173. https://doi.org/10.1121/1.2816563

45. Wong, L. T., Mui, K. W., and Hui, P. S. "A multivariate-logistic model for acceptance of indoor environmental quality (IEQ) in offices." ***Building and Environment***, Vol. 43, No. 1, (2008), 1-6. https://doi.org/10.1016/j.buildenv.2007.01.001

46. Cao, B., Ouyang, Q., Zhu, Y., Huang, L., Hu, H., and Deng, G. "Development of a multivariate regression model for overall satisfaction in public buildings based on field studies in Beijing and Shanghai." ***Building and Environment***, Vol. 47, No. 1, (2012), 394-399. https://doi.org/10.1016/j.buildenv.2011.06.022

47. Ncube, M., and Riffat, S. "Developing an indoor environment quality tool for assessment of mechanically ventilated office buildings in the UK - A preliminary study." ***Building and Environment***, Vol. 53, (2012), 26-33. https://doi.org/10.1016/j.buildenv.2012.01.003

48. Marino, C., Nucara, A., and Pietrafesa, M. "Proposal of comfort classification indexes suitable for both single environments and whole buildings." ***Building and Environment***, Vol. 57, No. December 2002, (2012), 58-67. https://doi.org/10.1016/j.buildenv.2012.04.012

49. Fassio, F., Fanchiotti, A., and de Lieto Vollaro, R. "Linear, non-linear and alternative algorithms in the correlation of IEQ factors with global comfort: A case study." ***Sustainability (Switzerland)***, Vol. 6, No. 11, (2014), 8113-8127. https://doi.org/10.3390/su6118113

50. Buratti, C., Belloni, E., Merli, F., and Ricciardi, P. "A new index combining thermal, acoustic, and visual comfort of moderate environments in temperate climates." ***Building and Environment***, Vol. 139, No. April, (2018), 27-37. https://doi.org/10.1016/j.buildenv.2018.04.038

Persian Abstract

چکیده

این مطالعه رابطه بین سطح توسعه یک کشور و استانداردهای آموزشی آن را بررسی می‌کند و بر اهمیت دانشگاه‌های مجهز در تضمین آموزش با کیفیت بالا تأکید می‌کند. در حالی که تحقیقات در مورد راحتی در ساختمان‌های آموزشی اغلب بر پارامترهای فردی مانند عناصر حرارتی، صوتی و بصری متمرکز شده است، این مقاله معیار جدیدی را پیشنهاد می‌کند که این عوامل را برای ارزیابی آسایش محیطی ادغام می‌کند. این تحقیق در شش اتاق خوابگاه در پردیس موسسه ملی فناوری Warangal (NITW) در هند، با استفاده از اندازه‌گیری‌های عینی و نظرسنجی‌های ذهنی انجام شد. سه معیار منفرد معرفی شد: یک شاخص گرما- رطوبت سنجی، یک شاخص راحتی صوتی، و یک شاخص روشنایی بصری، که هر کدام در محدوده ۰-۱ نرمال شده اند که نشان دهنده شرایط راحتی و ناراحتی است. یک شاخص نهایی آسایش کلی برای هر اتاق با تخصیص وزن های مناسب به سه عامل ایجاد گردید. یافته ها با پاسخ های پرسشنامه مقایسه شد و اثربخشی روش پیشنهادی ارزیابی شد. نتایج نشان‌دهنده یک ارزیابی جامع از راحتی محیط داخلی است، با عوامل صوتی که کمترین تأثیر را بر شرایط کلی آسایش نشان می‌دهند. این مطالعه وزن برابر برای پارامترهای حرارتی، صوتی و روشنایی را هنگام محاسبه شاخص راحتی ترکیبی توصیه می‌کند. این ساختمان امتیاز کلی آسایش ۰.٦٤ از ۱ را به دست آورد که نشان دهنده یک محیط راحت است. این مطالعه همچنین نشان می دهد که همبستگی قوی بین شاخص آسایش ترکیبی جدید و نتایج حاصل از پرسشنامه وجود دارد. این تحقیق یک رویکرد ساده و یکپارچه برای سنجش سطوح آسایش در ساختمان‌های آموزشی ارائه می‌کند و زمینه را برای ارزیابی‌های بیشتر عملکرد ساختمان‌های سازمانی فراهم می‌کند.