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Post Occupancy Evaluation of Residential College Building with Bioclimatic Design Strategies in Tropical Climate Condition of Malaysia

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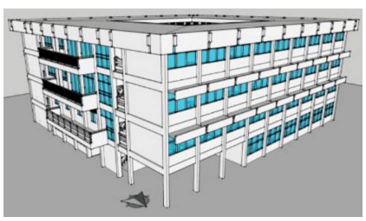
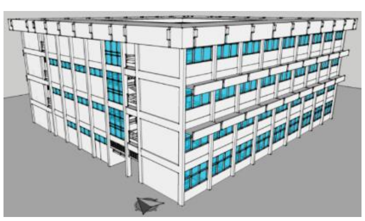
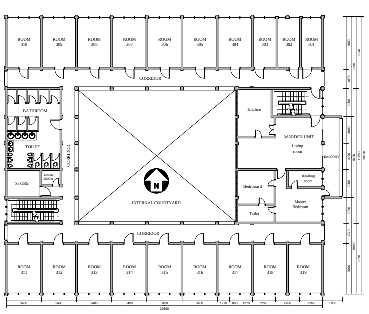
Graphical abstract







Abstract

The evaluation through a set of questionnaire and field measurement with the use of climatic devices was conducted in an old residential college building with the best practice of bioclimatic design strategies, particularly on the implementation of daylighting and natural ventilation. Initially, the implementation of these strategies has a significantly positive impact on the satisfaction level of the residents. Temperature and relative humidity range that is accepted as thermally comfortable by university students are 29-30°C and 72-77%, respectively. The comfort level was successfully maintained with a good adaptation of living behaviour including the activity in the room, garment dressed, usage of room opening and electronic devices. Unfortunately, further improvements on natural daylighting are still required based on the negative feedbacks given by the majority of respondents.

Keywords: Bioclimatic design, likert scale, living behavior, post occupancy evaluation (POE), residential college building

Abstrak

Penilaian menggunakan satu set soal selidik dan pengukuran di lapangan menggunakan peranti berkaitan iklim telah dijalankan di sebuah bangunan kolej kediaman lama dengan amalan terbaik strategi reka bentuk bioiklim, terutamanya pada perlaksanaan pencahayaan siang dan pengudaraan semulajadi. Pada asasnya, pelaksanaan strategi ini mempunyai kesan positif yang ketara kepada tahap kepuasan penduduk. Julat suhu dan kelembapan relatif yang diterima sebagai selesa oleh mahasiswa adalah 29-30 °C dan 72-77%. Tahap keselesaan telah berjaya dikekalkan dengan pengadaptasian terbaik tingkah laku kehidupan termasuklah aktiviti di dalam bilik, pemakaian, penggunaan pembukaan bilik dan peranti elektronik. Walaubagaimanapun, penambahbaikan pencahayaan siang masih diperlukan berdasarkan kepada maklum balas negatif yang diberikan oleh majoriti responden.

Kata kunci: Reka bentuk bioiklim, skala likert, tingkah laku kehidupan, post occupancy evaluation (POE), bangunan kolej kediaman

1.0 INTRODUCTION

Bioclimatic design strategies integrate the disciplines of human physiology, climatology and building physics [1], [2]. As the key factor for the implementation, these strategies help to eliminate negative environmental impact completely through skilful and sensitive designs [3]. As the consequence, some positive outcomes include better use of building resources, significant operational savings and increased workplace productivity [4], [5]. The implementation of these strategies entails the careful assessment of economic feasibility, benefits for the environment and human comfort. For that reason, the Post Occupancy Evaluation (POE) is recognised as a proper process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time towards sustainable environment [6].

POE is an effective examination of occupied design environments for human users [7] to determine the building defects that would lead to increased maintenance and operating costs [8].It recommends ways of improving the building environment and performance necessary to accommodate user needs [9]. Thus, successful design features can be repeated in future development, and any redundant or unnecessary building features will be eliminated to ensure that the building continues to deliver appropriate levels of satisfaction to the end-user [10]. The POE should not be a one-off process to confirm that a new building has fulfilled its criteria [11], but it should carry out throughout the entire building delivery cycle [6].

The implementation of the POE is frustrated by the factors of ownership, liability, lack of knowledge and progress especially on the acceptance and consistency of agreed-upon protocols, measures and procedures which make comparison difficult to be done holistically [10], [12]-[17]. In addition, Riley *et al*. [18] also highlight culture as a barrier to the POE process where the occupants may feel that moving into a new working environment is disruptive. In Malaysia, the aspects of evaluating building performance have not been emphasized widely and as it is, the term of POE itself is still new [19].

Basically, there are three levels of effort in the POE process [6], [20] which are clearly visualised in Figure 1.

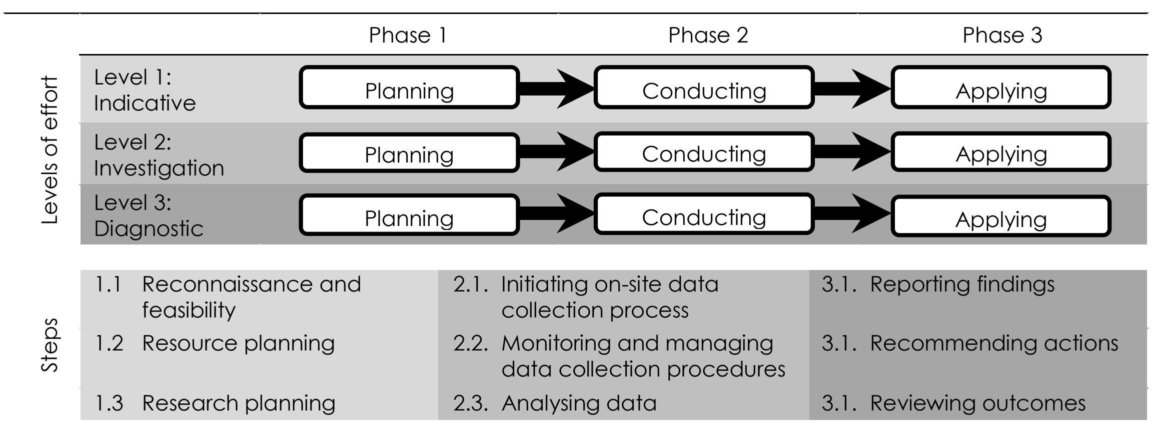


Figure 1 POE process model

The level undertaken will depend on the availability of finance, time, manpower and the required outcome [10]. In the data collection process, there are five categories of the portfolio of techniques that can be considered and utilized namely; audit (quantitative technical assessments), discussion (discursive techniques; i.e. workshops and interviews), questionnaires, process (incorporate feedback in an organized manner), and packages (probes) [12], [21]. The combination of subjective and objective techniques of assessments can enhance the understanding of a building's performance, while giving clear direction for further investigations of key relationships with a more complete and holistic picture of the indoor environment[10], [22]-[23]. The nature and goals of the POE depend on who is asked, as the prospects and hazards of this tool and approaches are seen differently from the standpoint of each stakeholder [13]. Consequently, it is necessary to focus on the most relevant issues rather than attempting to analyse everything and risk an overload of data [12].

The integration of the POE results in the value management process, as an essential component in the organizational learning cycle, where it ensures that the facilities that come with the management decision-making process become increasingly well-informed and are accountable [24]. The residents' perception of the residential environment cannot be ignored in policy, planning, design and implementation levels where the satisfaction with the physical environment of residences is the most powerful predictor of residential satisfaction [8], [13].

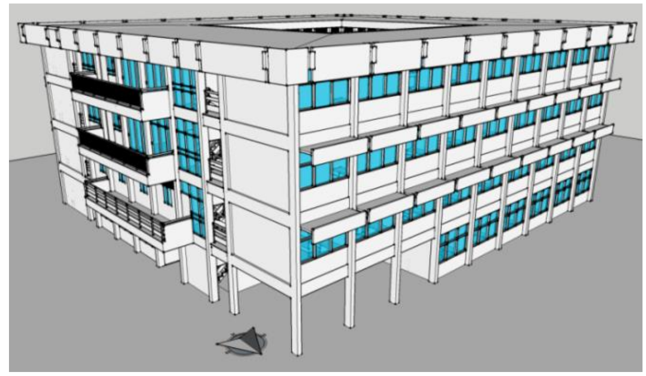
The aim of this study is to evaluate the condition of the building by focusing on the temperature and relative humidity with the purpose of justifying the effectiveness of applying bioclimatic design strategies for residential colleges. Concurrently, the idea is to determine the satisfaction, perception and residential living behaviour in adapting to the recent environment to achieve a state of comfort in the room. With the combination of both subjective and objective evaluations, it gives a more holistic understanding of how to achieve comfortable indoor environments, and to put them into practice where user behaviour and an understanding of the users are taken into account [23]. Residents' adjusting behaviours would serve as concrete and effective information to improve indoor comfort levels [25]. Consequently, this contributes to the establishment of POE protocols, measures and procedures specifically for residential buildings in the tropical climate condition of Malaysia.

2.0 METHODOLOGY

2.1 Building Description

The The Dayasari Residential College (Dayasari RC) established in 1966 is an old multi-residential building which provides accommodation with leisure areas, lounges, meeting rooms and laundry facilities for 847 of the University of Malaya students. Dayasari RC has been acknowledged as the residential college building in campus with the best practice of bioclimatic design strategies, particularly daylighting and natural ventilation [26]. Thus, Dayasari RC has to be among the buildings with the lowest Energy Efficiency Index (34.52 kWh/m^2/year) compared to the other residential colleges; which are in the range of 40 to 125 kWh/m^2/year [27].

Basically, the building arrangement is based on the internal courtyard arrangement with 18,212.51m^2 of the total floor area. The building's orientation to sun path is north-south that reduces the glare and the thermal effect inside the rooms. Only service areas, such as toilets, bathrooms, stores, staircases and balconies are located at the west-east orientation. The typical room's floor area and volume are 16.35m^2 and 45.78m^3, respectively. Each room is able to accommodate two or three residents at one time. There is a wall opening in the room which creates a wind pressure inside the room. Each room was designed with a transom on top of the entrance door and two types of tinted glass windows, a centre pivot and an awning which indirectly form cross-flow/two sided ventilation. The window to wall ratio (WWR) is 0.66, which is not efficient when on the current update, the ASHRAE 90.1 Standards Committee voted 0.24<WWR>0.40 for low-rise buildings [28]. Nevertheless, there are large horizontal overhangs along the window in each room to cast a significant shadow effect to the rooms. This feature is not available at the room on the ground floor which happens to be shaded by the plants with large canopies. Indirectly it also gives a shading effect to the whole building from maximum sunlight penetration especially in the mid-afternoon [29]. The Biotope Area Factor (BAF) is 0.607 and there are 61:39 ratio of soft and hard landscape area. The typical elevation and floor plan of Dayasari RC are presented in Figure 2.



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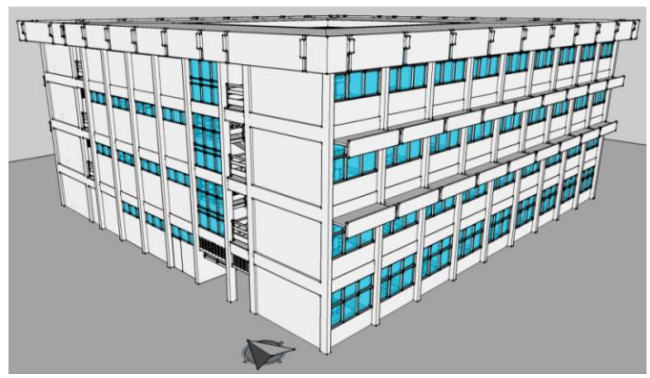

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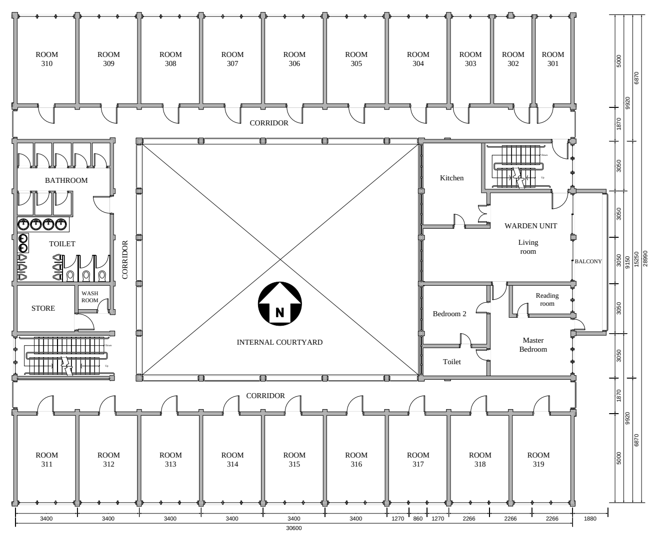

(c)

Figure 2 Typical elevation (a) front isometric elevation (b) rear isometric elevation, and (c) floor plan of Dayasari RC buildings

2.2 Field Measurement

Regarding the lack of data logger, devices and the safety issues; which limit the accessibility to certain residential blocks, field measurement was only done for two weeks at eight rooms that occupied by male students as permitted by the residential college administrators. These rooms are decidedly the most concern the level of radiation and penetration of sunlight into the rooms. Two from eight selected rooms had been chosen to represent two different scenarios. Thus, all eight rooms that representing ten different scenarios are representing the average condition of the whole residential building.

All the ten identified scenarios are based on grounded theories according to previous studies done particularly in the tropical region [2], [4], [30]-[34]; that theoretically represent the condition of the whole building. The ten identified scenarios are;

i. North orientation: *Receiving reflected heat radiation and penetration either from the west or east. Meanwhile, it is not influenced by direct heat radiation and penetration by man-made surface either on top or on the ground*.
ii. East orientation: *Receiving direct heat radiation and penetration from the east. Meanwhile, it is not affected by direct heat radiation and penetration of man-made surface either on top or on the ground*.
iii. South orientation: *Receiving reflected heat radiation and penetration either from the west or east. Meanwhile, it is not influenced with direct heat radiation and penetration by man-made surface either on top or the ground*.
iv. West orientation: *Receiving direct heat radiation and penetration from the west, while, not affected by direct heat radiation and penetration of man-made surface either on top or on the ground*.
v. Avoiding direct contact with man-made surfaces on the top: *Not receiving direct heat radiation and penetration from man-made surfaces on the top, i.e. roof, wall etc. and with the north-south building orientation*.
vi. Direct contact with man-made surfaces on the top: *Solely receiving direct heat radiation and penetration from man-made surfaces on the top, i.e. roof, wall etc. and with north-south building orientation*.
vii. Avoiding direct contact with man-made surfaces on the ground: *Not receiving direct heat radiation and penetration from man-made surfaces on the ground, i.e. tarmac, court etc. Also, direct heat radiation and penetration neither comes from the east nor the west*.
viii. Direct contact with man-made surfaces on the ground: *Solely Receiving direct heat radiation and penetration from man-made surfaces on the ground, i.e. tarmac, court etc., while not affected by directing heat radiation and penetration either from the east or west.*
ix. Shaded: *Shaded by landscape or trees or adjacent buildings and with the north-south building orientation. Not affected somehow by direct heat radiation and penetration of man-made surfaces either from the top or on the ground*.

excellent rooms to represent ten scenarios which

x. Exposed: *Exposed to open spaces and with the north-south building orientation. Not affected somehow by direct heat radiation and penetration of man-made surfaces either from the top or ground*.

One ONSET HOBO U12-012 data logger for indoor climate measurements was fixed on the centre of the room at the height of 1.10m above the floor [35]. This height is acknowledged as the typical human body level. The same device was also fixed outside the selected student rooms to examine the climate outside of the rooms, specifically at the corridor area. There are two parameters collected - air temperature (°C) and relative humidity (%). This microclimatic measurement set was to cover a 24-hour period with one-hour intervals between measurements [36]. The data on the microclimate were taken from the UM weather station, which is located in the campus and managed by the Malaysian Meteorological Department. The UM weather station is located in the range 500m from Dayasari RC, at 3°07' N latitude, 101°39'E and at the height of 104.0m above mean sea level.

All the collected data were initially analysed by using the Hoboware pro software and a statistical computer software package, IBM SPSS Statistics Version 23 was used for further statistical analysis.

2.3 Satisfaction and Perception Survey

The study done by Jamaludin *et al*. [37] on the satisfaction and perception of residents towards bioclimatic design strategies at a residential college building was adapted to restructure the questionnaire. The questionnaire had been simplified by focusing on seven performance indicator to avoid respondents from losing their attention and getting apathetic in filling in the same questionnaire for three times a day during the course of the research (for two weeks). Each time a day is assigned to different periods which are morning (6 a.m. - 12 p.m.), afternoon (12 p.m. - 6 p.m.) and evening (6 p.m. - 12 a.m.); as the occupants need to attend lectures at their faculty and attend their own off-campus activities. Thus, the residents were able to give their responses in a long time frame.

The Likert Scale format was used in the questionnaire where each number generally responses to a specific scale as listed below,

- -2: too dark/still air/very poor/too hot/very uncomfortable/much decreased,
- -1: dark/inconspicuous, still air/poor/hot/ uncomfortable/decreased
- 0: neither/nor/neutral/no changes,
- +1: bright/breezy/good/cool/comfortable/ increased, and
- +2: too bright/very breezy/very good/cold/very comfortable/much increased.

Concurrently, all the male residents in these eight selected rooms were asked to record the garments worn, activity, weather, condition of openings, and electrical appliances that were used including the ceiling fan and lamps. Thus, it was possible to recognize the times when the room conditions had reached the desired comfort level for residents and the regular changes made in the room by the occupants to obtain an optimum comfort level [38]. Indirectly, this will show the residents' pattern of living behaviour at the residential college buildings with respect to the internal space arrangement. The statistical computer software package, IBM SPSS Statistics Version 23 was used for further comprehensive analysis and the correlation between the performance indicators had been drawn.

3.0 RESULTS AND DISCUSSION

The mean values of the climate's condition that includes the indoor, corridor and microclimate during three different time periods are statistically presented in Table 1, while the general daily patterns of the temperature and relative humidity of the selected residential building are given in Figure 3.

Table 1 The mean values of the climate's condition according to three different time periods

Climate	Parameter	Time		
		Morning	Afternoon	Evening
Indoor	Temperature (°C)	29 (25-31)*	30 (26-34)*	30 (26-33)*
	Relative humidity (%)	77 (61-90)*	72 (54-88)*	74 (57-90)*
Corridor	Temperature (°C)	28 (24-32)*	30 (25-35)*	29 (25-34)*
	Relative humidity (%)	81 (61-94)*	69 (48-93)*	77 (50-94)*
Microclimate	Temperature (°C)	27 (25-30)*	30 (26-33)*	28 (24-31)*
	Relative humidity (%)	84 (62-95)*	67 (56-90)*	81 (59-95)*
	Total rain duration (min)	0 min	105 min	200 min
	Total rain amount (mm)	0 mm	6.1 mm	45.4 mm

* Minimum and maximum value
Morning: 6 a.m. – 12 p.m.; Afternoon: 12 p.m. – 6 p.m.; Evening: 6 p.m. – 12 a.m.

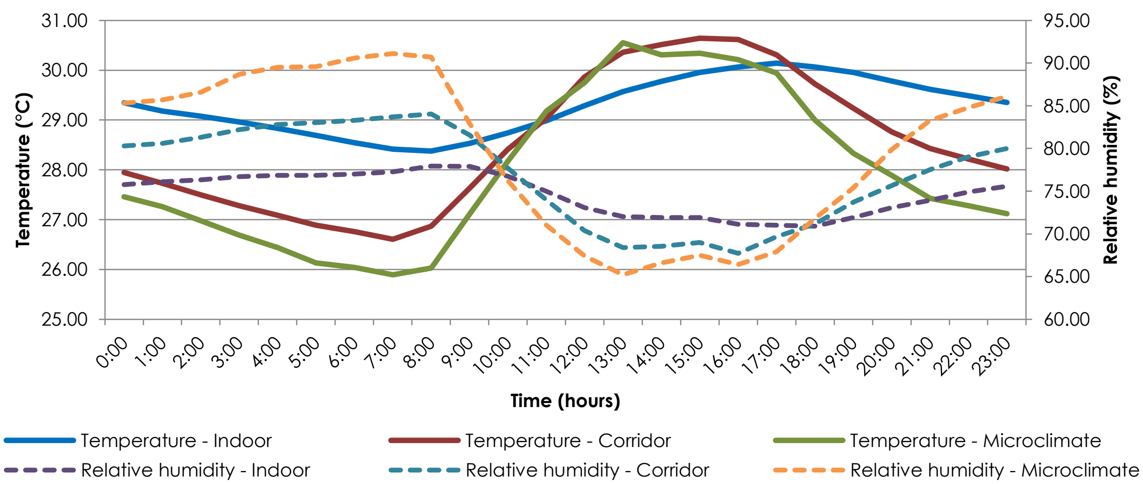

Figure 3 The general daily patterns of temperature and relative humidity.

Statistically, the microclimate has a better condition as compared to the corridor climate and the latter was better than the former, in terms of the lowest mean temperature with the highest mean percentage of relative humidity, as shown in Table 1. This is clearly seen during the period of 6 a.m. - 12 p.m. (morning) and 6 p.m. - 12 a.m. (evening) when there was a difference of up to 1°C of the mean temperature with 7% of relative humidity. The temperature was drastically increased in the afternoon and slightly decreased in the evening.

The indoor mean temperature in the evening was maintained as in the afternoon with a small increment of relative humidity percentage; which was about 2%. In the corridor and the microclimate, the percentage of relative humidity had considerably increased with the reduction of the temperature values; in the range of 8 to 14%. The largest amount of total rain with the longest rain duration was recorded in the evening; 200 minutes and 45.4 mm respectively. Thus, this influences the percentage of relative humidity especially in the microclimate. Only 6.1 mm of total rain amounts and 105 minutes of total rain duration were recorded in the afternoon and there was coincidentally no rain in the morning from 6 a.m. to 12 p.m. during the time of the research.

Referring to Figure 3, 11 a.m. and 17 p.m. are recognised as the transition times. In the morning, higher indoor mean temperatures were recorded as compared to the corridor and microclimate. However, the mean temperature values of the corridor and microclimate drastically increased at 11 a.m. and automatically overcoming the indoor value; which also recorded some increment but only in a small range of 1-2°C. At 17 p.m., the pattern of the temperature was back to normal as in the morning, where the indoor temperature was the highest, followed by the corridor and microclimate. The same pattern was also revealed by the relative humidity values.

The residents were well adapted with the significant increase of temperature in the afternoon, which was up to 3°C. It was assumed that the residents performed light tasks such as reading while sedentary (1.0 Met) to reduce the metabolic heat production. Light clothes with the cloth insulation value in the range of 0.06 to 1.03 clo; with the mean value up to 0.20 clo, were worn at most times. This value is much lower than the suitable cloth insulation value of tropical clothing; 0.55 clo, which was reported by Nughoro *et al*. [35]. The activity, the garment worn, usage of room opening and electronic devices by the residents according to different time periods are all presented in Table 2.

Table 2 The activity, garment dressed, usage of room opening and electronic devices by the residents according to different time periods

The performance indicator		Time & Percentages of usage			Overall
		Morning	Afternoon	Evening	%
Activity	Reclining (0.8 Met)	17.2	4.1	3.7	8.3
	Seating relaxing (1.0 Met)	59.3	70.7	65.9	65.0
	Sedentary activity (1.2 Met)	20.7	21.1	27.4	23.4
	Standing relaxed (1.2 Met)	0.0	0.0	0.6	0.3
	Domestic work (1.7 Met)	2.1	2.4	1.8	2.1
	Walking on 5 km (3.4 Met)	0.7	1.7	0.6	0.9
Garment dressed	Mean value (clo)	0.18 (0.06-1.03)*	0.20 (0.06-1.03)*	0.19 (0.06-0.83)*	0.19 (0.06-1.03)*
Windows	Open	18.0	26.5	42.0	29.6
	Close	82.0	73.5	58.0	70.4
Curtain	Open	50.6	49.3	64.4	55.4
	Close	49.4	50.7	35.6	44.6
Ceiling Fan	On	98.8	96.7	99.5	96.7
	Off	1.2	9.3	0.5	3.3
Ceiling Fan speed	0	1.2	8.6	0.6	3.1
	1	0.0	0.6	0.0	0.3
	2	3.5	2.0	2.6	2.7
	3	30.2	6.0	8.9	11.8
	4	15.0	12.6	18.8	15.7
	5	60.1	70.2	69.1	66.4
Ceiling lamp	On	20.8	21.9	90.1	46.8
	Off	79.2	78.1	9.9	53.2
Study lamp	On	15.7	16.6	71.7	36.8
	Off	84.3	83.4	28.3	63.2
Computer	On	42.4	43.7	71.7	53.7
	Off	57.6	56.3	28.3	46.3
Mobile phone charger	On	18.0	22.5	46.8	30.0
	Off	82.0	77.5	53.2	70.0

* Minimum and maximum value
Morning: 6 a.m. – 12 p.m.; Afternoon: 12 p.m. – 6 p.m.; Evening: 6 p.m. – 12 a.m.

Referring to Table 2, higher mean value of clo was recorded in the afternoon when most of the residents were dressed with proper apparel for the classes at the faculties.

The ceiling fan has been used at full speed at all times by the majority of the residents to maintain the air circulation and movement in the room when the windows had been closed most of the time. Indirectly, this condition did not restrict the natural ventilation inside the room that indirectly influences the indoor climate. The curtains were fully utilised in the afternoon by half of the residents to control the amount of daylight into the room to reduce the glare and the heat caused by the daylight penetration [39]. In fulfilling the needs for privacy, the curtains had been overused; especially for those who are living on the ground floor or facing the adjacent residential block occupied by students of opposite gender [37]. These deny the daylighting in the room and spontaneously force the residents to switch on the artificial light, although there is abundance of of natural daylight outside the room. Through the observation, most of the residents who have a class on the daytime will leave the rooms with the windows and curtains completely closed due to the same reasons, namely privacy and security purposes. The privacy, personal space, territoriality, security and protection from various external effects are the basic needs of people [40], [41]. Therefore, the fixed external venetian blinds which are placed on all bedroom windows should be highly considered as this device is very effective in providing privacy and security needs' while allowing users to control sunlight penetration without denying the role of opening/windows in providing natural ventilation inside the room [42].

The basic electrical appliances in the room such as ceiling lamp, study lamp and computer were fully utilised in the evening when the room happened to be fully occupied. Hence, there were internal thermal loads produced by people and electrical appliances [42]. This explains the retaining of high temperature in the room while the temperature in the corridor and the microclimate was drastically reduced after 6 p.m. (Table 1), besides the effects of building thermal mass when the building acts as a heat sink; absorbing the heat gains during the day and releasing heat in the night time [43], [44]. Referring to Table 2, the majority of residents were assumed to tend to charge their mobile phones from 12 a.m. to 6 a.m. when the majority of residents were not used the mobile phone charger within three recognised of time periods. Thus, the mobile phone charger is not the major contributor to the internal thermal loads as compared to other electrical appliances.

The changes of the microclimate influence the room conditions and have a strong relation to recent outdoor temperatures [31], [45]. However, the thermal internal loads and the inefficiency of natural ventilation approaches due to the privacy and security purposes denies the reduction of the indoor temperature in the evening. Fortunately, with the good adaptation through the changes of living behaviour; which includes the activity of the residents in the room, garment dressed, usage of room opening and electronic devices, the comfort level of the room was successfully maintained [46]. This has been proven through the satisfaction and perception survey of the room condition according to three different periods (Table 3), which has been done concurrently with the field measurement of the climate condition as presented before in Table 1. The majority of the residents felt that there were no changes in the quality of lighting, indoor ventilation, and thermal comfort with regards to the three different time periods. Most of them voted 'neither/nor' for the quality of lighting and indoor ventilation, whereas neutral for thermal comfort. Thus, the overall comfort level was 'neutral' and there were 'no changes' on their work productivity. In order to improve the thermal comfort of the room, the application of the night ventilation at the residential building provided better thermal comfort due to high humidity conditions that reached 70-80% of indoor relative humidity and decreased the indoor surface temperatures by up to 3.9°C; as compared to other ventilation approaches [47]. A shallow building with optimal orientation and a maximum of five floors is more applicable for exploiting wind for natural ventilation [48].

Table 3 The residents' evaluation of the selected rooms according to different time periods

Performance indicator	Time	Likert scale/residents' responses (%)				
		-2	**-1**	**0**	**+1**	**+2**
Natural daylighting	Morning	2.3	22.0	31.8	41.6	2.3
	Afternoon	2.0	33.1	30.4	32.5	2.0
	Evening	14.0	38.5	30.7	15.6	1.2
	Overall	6.6	31.4	31.0	29.3	1.7
Artificial lighting	Morning	0.0	13.3	64.7	21.4	0.6
	Afternoon	0.0	17.9	57.0	24.5	0.6
	Evening	0.0	24.0	28.0	47.4	0.6
	Overall	0.0	18.6	48.8	32.0	0.6
Quality of lighting	Morning	2.3	12.1	43.4	41.6	0.6
	Afternoon	0.0	17.2	53.0	29.1	0.7
	Evening	0.0	24.5	39.6	35.9	0.0
	Overall	0.8	18.2	44.8	35.9	0.3
Air movement	Morning	14.5	14.0	39.5	32.0	0.0
	Afternoon	14.7	14.0	45.3	26.0	0.0
	Evening	10.9	8.3	38.0	40.1	2.7
	Overall	13.2	11.9	40.7	33.3	0.9
Quality of indoor ventilation	Morning	0.5	11.0	43.4	43.4	1.7
	Afternoon	1.3	10.6	51.0	36.4	0.7
	Evening	0.0	8.3	44.8	43.2	3.7
	Overall	0.6	9.9	46.1	41.3	2.1
Thermal comfort	Morning	0.0	10.4	52.6	37.0	0.0
	Afternoon	1.3	25.8	42.4	29.8	0.7
	Evening	0.0	9.9	50.5	37.0	2.6
	Overall	0.4	14.7	48.8	34.9	1.2
Overall comfort level	Morning	0.0	6.4	50.9	41.6	1.1
	Afternoon	0.7	15.2	49.7	33.1	1.3
	Evening	0.5	6.8	47.4	41.7	3.6
	Overall	0.5	9.1	49.2	39.1	2.1
Work productivity	Morning	1.2	10.4	72.3	14.5	1.6
	Afternoon	0.7	16.5	69.5	12.6	0.7
	Evening	0.5	14.1	64.9	17.8	2.7
	Overall	0.9	13.6	68.7	15.1	1.7

Morning: 6 a.m. – 12 p.m.; Afternoon: 12 p.m. – 6 p.m.; Evening: 6 p.m. – 12 a.m.

There are some changes in the perceptions on the natural daylighting, artificial lighting and air movement according to the three different time periods. Most of the residents claimed that the quality of natural daylighting was 'neither/nor' in the morning, while it was 'dark' in the afternoon and evening. These typically happened due to the overused curtains in the rooms and the overwhelmingly efficient solar protection and shades [49]. According to the findings by Dahlan [50], the occupants were less concern with their daylighting and glare when means of controlling these two conditions, i.e. using window curtain and switching on the artificial lights were available within their reach.

Meanwhile, the quality of artificial lighting was 'bright' in the evening when 90.1% and 71.7% of the residents who were on behalf of the majority had switched on the ceiling lamp and study lamp, respectively. With the reduction of the outdoor mean temperature and the increasing relative humidity at both indoor and microclimate, most of the residents Thus, it demonstrates the effectiveness of the internal courtyard in encouraging air circulation and movement inside the room through the fixed transom on the top of the entrance door and the wall, whereas the majority of the residents had kept the windows closed in all periods.

The internal courtyards within the building can offer a substantial potential for indoor thermal comfort as the ability of a courtyard is to act as cool sink for the surrounding built spaces [30]. The internal courtyards create different pressure fields along the wind-flow axis and thus, making the building an air funnel which promotes cross-ventilation, assists the stack effect by the thermal buoyancy and Venturi effects, and felt 'breezy' with the air movement in their rooms. removes warm air away from the courtyards [51]. Indirectly, it also promotes natural ventilation when the air flow effect encourages the cooling of occupants, structural cooling, overheating control and the removal of solar heat out of the building interior. These can be enhanced through the introduction of semi-enclosed courtyard that functions as an air funnel that regulates the heat transfer between the courtyard, its adjacent servant spaces and the outdoor environment [51].

The Pearson correlation was used to correlate between each performance indicator and the overall comfort, as well as the work productivity with regards to the residents' satisfaction and perception (Table 4).

Table 4 Correlation of residents' evaluation with overall comfort, work productivity and performance indicator

		Natural daylighting	Artificial lighting	Quality of lighting	Air movement	Quality of indoor ventilation	Thermal comfort
Overall comfort	Pearson correlation	-0.075	0.190**	0.030	0.223**	0.540**	0.705**
	Sig. (2-tailed)	0.089	0.000	0.502	0.000	0.000	0.000
Work productivity	Pearson correlation	-0.064	0.045	0.037	0.070	0.308**	0.345**
	Sig. (2-tailed)	0.145	0.304	0.397	0.112	0.000	0.000

* correlation is significant at the 0.05 level (2-tailed), ** correlation is significant at the 0.01 level (2-tailed)

Overall, there is a significant positive relationship of satisfaction and perception levels with all criteria, except natural daylighting which show a negative relationship with the overall comfort and work productivity. Only the quality of indoor ventilation and thermal comfort show a strong relationship with the overall comfort. Consequently, these two criteria are more influential in the overall comfort of residents at Dayasari RC. The occupants who were satisfied with the temperature and air in the building were more likely to report that their health and productivity had been improved [52]. According to Li *et al*. [53], the thermal environment in the university dormitories affects not only the students' comfort and health, but also their learning's productivity and quality of lives.

Referring to the climatic condition and the results of the satisfaction and perception survey in Tables 1 and 3, the ranges of comfort for residents at Dayasari RC are 29-30°C of the mean temperature with 72-77% of relative humidity. These values are much higher as compared to the values set by both international and local standards. Globally, the American Society of Heating, Refrigerating and Air Conditioning Engineers - ASHRAE has set the temperature and relative humidity in the range of 23-25°C and 20-60% respectively, which is quite low compared to the local standard; Standards and Industrial Research Institute of Malaysia – SIRIM MS 1525, which is 22-26°C and 30-70% [54].However, the values are quite similar to the various studies on the range of comfort for Malaysians which have previously been done by Abdulmalik [55] who gives a range of 25.5-29.5°C and 45-90%; AbdulRahman [56]with 23.4-28°C and 54-76%; and Zain-Ahmed *et al*. [57]who establish 24.5-28°C and ~73%. According to Malkoc and Ozkan [41], the bioclimatic comfort value is the combination of a temperature value of 21-27.5°C and relative humidity of 30-65%.

4.0 CONCLUSION

The microclimate with the range of 27-30°C of the mean temperature and 67-84% of the relative humidity shows off a better condition as compared to the corridor's climate. The corridor's climate; with 28-30°C and 69-81% of the mean temperature and relative humidity correspondingly, was better than the indoor climate which recorded higher mean temperature with the lower mean percentage of relative humidity; in the range of 29-30°C and 72-77% respectively. This was obviously recognised during the periods of 6 a.m. - 12 p.m. (morning) and 6 p.m. - 12 a.m. (evening) as the mean temperature was drastically increased in the afternoon and slightly decreased in the evening. Conversely, the indoor mean temperature in the evening was maintained as in the afternoon; 30°C with a small increment of relative humidity percentage; 2% due to the higher total rain amount.

The comfort level of the room was successfully maintained with a good adaptation through the changes of living behaviour. This includes the activity of the residents in the room, garment dressed, usage of room opening and electronic devices. The residents only did a light activity which was seated in a relaxed mode (1.0 Met) most of the time to reduce the metabolic heat production. The light clothes with the cloth insulation value in the range of 0.06 to 1.03 clo; with the mean value up to 0.20 clo, were worn most of the time too. The ceiling fan has been used at full speed at all times by the majority of the residents to maintain the air circulation and movement in the room when the windows have been closed due to privacy and security purposes. The curtains were fully utilised in the afternoon by half the number of the residents to control the amount of daylight into the room to reduce the glare and the heat caused by the daylight penetration. As the room was fully occupied in the evening, there were internal thermal loads of people and electrical appliances in addition to the effects of building thermal mass. Thus, retaining the high temperature was retained in the room while the temperature in the corridor and the microclimate were drastically reduced after 6 p.m.

The implementation of bioclimatic design strategies at residential college building has a significant positive impact on the overall comfort, except for natural daylighting. More attention should be given to natural daylighting to increase illuminance and improve the uniformity, while minimise its negative effect on visual comfort and reduce the building's cooling load by reducing heat gain [4]. Shading system like louver, blind, light shelf and prismatic panel, is ideal structural strategies to be implemented when it able to block direct sun light and admit diffuse light [58].

Finally, the combination of both subjective and objective evaluations points to the fact that the ranges of comfort for residents at Dayasari RC are 29-30°C of the mean temperature with 72-77% of relative humidity.

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