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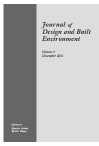

ENERGY PERFORMANCE OF THREE RESIDENTIAL COLLEGE BUILDINGS IN UNIVERSITY OF MALAYA CAMPUS, KUALA LUMPUR

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Abstract

Three residential collegeslocated in Kuala Lumpur, Malaysia, were selected for energy performance analysis in regards to its implementation of bioclimatic design strategies. Specifically, passive design strategies on daylighting and natural ventilation were examined. In Malaysia, the residential college or hostel is a multi-residential building providing accommodation to university students. The three residential colleges in this study, namely C1, C2 and C3, were built in different years with different designs and forms, particularly with regards to enclosure and facade design, solar control devices, passive daylight concepts, and natural ventilation strategies. The building designswere carefully studied and an electric consumption analysis was carried out in each residential college. This study revealed that the wide-scale implementation of bioclimatic design strategies in college C2 help reduced the annual energy consumption. The building bioclimatic design features that are accountable to reduce energy consumption are the internal courtyard and balconies on each unit of floor area, as shown in C3.Results from this study highly recommend internal courtyard and balcony building combinationfor multi residential building design, especially in tropical urban regions.

Keywords: bioclimatic design strategies, daylighting, energy efficiency index (EEI), natural ventilation, residential college

Introduction

In recent times, terms such as sustainable building, green building, eco design building, bioclimatic design building and many more have become popular in the building sector. The terminology and their meanings vary somewhat, but the aim is the same with intents on promoting more efficient use of natural resources, especially energy and water, and using renewable energy in the running of the buildings. Green building practices can significantly reduce or eliminate negative environmental impacts and improve existing unsustainable design, construction and operation practices [1]. However, most of these practices have already been adopted in traditional buildings long ago, for example the utilisation of natural ventilation, day light, solid walls, light exterior surfaces etc. [2, 3], yet have only recently attracted wider attention due to the climate change issues and higher cost of energy.

The building sector was identified as a useful area for studying energy conservation due to it being the third largest energy consumer in Malaysia [4] and its contributions of 40% percentto world total GHG (greenhouse gas) emissions, and up to 80% of emissions in city areas [5]. The commercial and residential sector alone account for about 13% of total energy consumption in addition to 48 percent of electricity consumption in Malaysia. These figures can be decreased by constructing energy efficient buildings in the future, although this will increase construction costs by up to 15 percent compared to conventional designs [6]. However, in the long term, energy efficient buildings can improve indoor and outdoor air quality, social welfare and enhance energy security [7].

Energy conservation in a building can be achieved in many ways, but from a holistic perspective, one should start with the basics: the building design and structure. Building design is one of the factors determining the building's energy performance, beside service design and occupant behaviour [6]; these latter factors are difficult to control and maintain. In tropical regions, there are three main areas related to building services which utilises up to 60-70% of the total energy in non-industrial buildings, are air conditioning, lighting and ventilation [8].

Mechanical cooling loads and usage of electric lightingare commonly substituted with natural ventilation and use of day lighting as design strategies to reduce a building's energy consumption. The peak-cooling load (which determines the maximum demand of energy) and the annual electricity consumption can be reduced substantially by 10% and 13%, respectively, through the application of daylighting [9, 10]. Additionally, about 50% of energy used for ventilation in buildings in warm, humid climates can be saved by carefully determining a building's massing such as length, depth and height. Such energy conservation has been shown by Haase and Amato [11] who revealed that shallow buildings with optimal orientation and a maximum offive floors are more effective in using daylight and exploiting wind for natural ventilation. Efficient day lighting of spaces promotes efficiency of work productivity, and simultaneously increases the sense of well being of inhabitants [8]. The effective control of air movement can save up to 20% on heating and cooling costs while improving comfort for the inhabitants, since air speeds of between 0.5-1.0m per second can make the body feel 2-3ºC cooler in air temperatures of 25ºC [12]. Approximately 43% of energy reduction can be achieved by using combinations of well-established technologies such as appropriately designed glazing, shading, insulation and induced natural ventilation. The early stage of building design must not forgo the climate and characteristics of the site [8]. All these improvements can be achieved by well-planned building strategies considering a variety of aspects. Natural ventilation combined with solar protection is the most efficient building design strategy to achieve thermal comfort without resorting to mechanical cooling [13].

Most of the studies reported in the literature have focused on residential houses, such as single storey, double storey, flat houses and apartments [14,15,16,17], rather than on residential college buildings, which are quite different in terms of building layouts and services provided. In Malaysia, the residential college or hostel is a multi-residential building that provides accommodation to university students. The multi-residential building typically plays a role as student halls of residence, key worker accommodation, care homes and sheltered house,containing catering facilities, lounges, dining rooms, health and leisure areas, offices, meeting rooms and other support areas such as laundry facilities [18].

Consequently, how we design our buildings will determine how much energy they require to run. The intense sunlight, heat and high humidity are the key elements for the Malaysian climate that need to be considered [19]. According to Nugroho et al. [20], a good house design keeps the indoor environment favourable and comfortable during most of the year without the use of any mechanical devices and also guarantees sufficient airflow through the building to allow for dehumidification. The use of daylighting as a passive solar source can contribute to the reduction of energy consumption when effectively used. In the long term, the implementation of passive designs can reduce operating cost, enhance building marketability, reduce potential liability from indoor air quality problems and increase worker productivity [1]. From a residential college perspective, it can help to increase the students' achievements in their studies. Thus, provision for air movement and daylighting must be the most important considerations in building design, however, while the aim is to implement passive and low energy systems and meet sustainability requirements, thermal comfort in the building should be maintained.

The aims of this study were to analyze the energy performance of three residential colleges regarding the existence and current implementation of bioclimatic design strategies, specifically with regards to daylighting and natural ventilation. Thus, the effects of the recent adoption of climatic design strategies in influencing the total energy consumption at residential colleges will be revealed by the evaluation of electricity consumption patterns, which is the most important part of the energy management and the energy conservation programme [21].

Research design and approaches

Building description

Three residential colleges with different configurations, layouts and year of construction were chosen in this study, namely, Tuanku Bahiyah Residential College (C1), Dayasari Residential College (C2), and Ungku Aziz Residential College (C3). The similarity are the building are all made of the same material and similar construction method, which is concrete and brick using post and beam with pitched roof (with slight varying angle). All these residential colleges are located within the University of Malaya campus in the capital city of Kuala Lumpur, Malaysia, and are able to housemore than 2,500 local and international students. C1 is the oldest residential college, established in 1958 and designed with linear arrangement which clearly differs from C2, which was established in 1966 with an internal courtyard arrangement. As the newest residential college, established in 1997, C3 shows some evolution in terms of building design as it has been arranged with an internal courtyard and balcony. Each residential college comprises of one administrative block and four to five residential blocks. All administrative office and block are equipped with air-condition for cooling and fluorescent lamps for lighting whilst all the residential units/ rooms at the residential blocksare not air-conditioned but are installed with a ceiling fans and fluorescent lamps.

Building design studies

The buildings' drawings, which include a site plan, architectural drawings and structure drawings, were the main source of data for the building design studies. Site visits to each residential college were also carried out in order to gauge actual conditions, since most of the drawings were drawn 30 to 40 years ago, and since then, numerous renovations and add-ons have been carried out to increase the residences' capacities. The elements of bioclimatic design (passive mode) introduced by Yeang [22] were adapted as matrixes for assessing the building's design in adapting climatic design concepts, with particular focus on the application of natural ventilation and day lighting.

Performance of electric use

The efficiency of electricity use in each residential college was evaluated by adapting a method from Saidur [23] who estimated energy intensity, EI in kWh/m^2 by using following equation:

$$EI = AEC / TFA$$

where, AEC is annual energy consumption (kWh) and TFA is total floor area (m^2). Basically, Kamaruzzaman and Edwards [24] stated that the energy use per unit floor area can be described as 'Normalised Performance Indicators' (NPI), which is also known as the energy use index or Building Energy Performance (BEP) [25]. Consequently, the term BEP will be used in this study to indicate the performance of electric use at the residential colleges, while Energy Efficiency Index (EEI) will be used to elaborate kWh/m^2/year [26,27]. Referring to Iwaro and Mwasha [28], energy use in residential buildings is usually 10-20 times lower compared to office buildings. Thus, the electricity usage in residential buildings in Malaysia amounts to approximately 10 to 25 kWh/m^2/year if the electricity use in office buildings in Malaysia is in the range of 200 to 250 kWh/m2/year [29].

A five year period beginning from 2005 until 2009 energy consumptions data were collected and analysed, while total floor area was calculated from the building design study. On-site measurements were also carried out for the purpose of obtaining accurate facts, since errors arose from the same sources as mentioned earlier, such as outdated drawings and recent renovations. Further statistical analysis was carried out using SPSS 15.0 computer software package. From there, descriptive statistical analysis was performed to analyse mean, median, mode, standard deviation, variance and range for comparison purposes.

Results and discussion

The characteristic and bioclimatic design strategies demonstrated by the three residential colleges C1, C2 and C3, particularly regarding natural ventilation and daylighting, are presented in Table 1. Some of the points were clearly explained in Figures 1, 3 and 5, presenting typical floor plans of each residential college building. They are also can be visualised through photos that are presented in Figures 2, 4 and 6.

C1 was built as a linear arrangement with adjustable and fixed opening devices at the both end of corridors. As solar control devices, horizontal awnings are implemented along with residential units opening. The built form configuration is not orientated to the sun path, which directly eliminates thermal effects to the buildings, north-south, while the location of openings is not with respect to the wind direction, southwest. Thus, directly it is not persuade natural ventilation in the residential unit.

Then, small fixed opening devices were set up in the staircase area which indirectly promotes daylighting and natural ventilation. Unfortunately, it was not capable to provide adequate air circulation and day light along the corridor area. Therefore, the corridor lamps do need to be continuously switched on, even during day time. Regarding roof design, there is no potential for a rooftop garden whilst this residential college is surrounding by 81.71% of green area. Overall, less bioclimatic design strategies, particularly on natural ventilation and daylight were employed by C1 compared to other two residential colleges.

C2 is the leading residential college in energy performance due to the design of its residential unit that allows for the best utilisation of natural ventilation and daylighting. The building layout that is based on a courtyard arrangement allows the wing walls on top of the entrance door and wall to fully function in inducing air circulation and bringing daylight to the interior of the residential units. As a result the corridor lamps need not to be switched on during day time. Additionally, the building's orientation to the sun path is north-south, which massively reduces the thermal gain into the residential units create better thermal comfort. Only the services areas, such as the toilet, bathroom, store, staircase and balcony, are located at a west-east orientation. The positive side of arranging the toilets and bathroom in this orientation, help keep humidity level lower due to the high sun penetration, which in a way eliminates any risk of mould and mildew growth, which is a major contributor to unhealthy buildings and poor indoor air quality. Regarding the enclosure and facade design, C2 was designed with special features such as glare protection and adjustable natural ventilation options. The two types of windows, centre pivot and awnings, which are tinted, offered the

Table 1: The characteristic and bioclimatic design strategies demonstrated at C1, C2 and C3

		RESIDENTIAL COLLEGE AND YEAR ESTABLISHED		
INTERNAL SYSTEMS	**CHATACTERISTIC**	**C1** *1958*	**C2** *1966*	**C3** *1997*
		Low-rise	Low-rise	Low-rise
BUILT-FORM	**Form of building**	Linear arrangement	Courtyard arrangement	Courtyard arrangement
CONFIGURATION,	**Building layout**	N - S	N - S	N - S & W - E
ORIENTATION,	**Orientation to sun path**	Rectangle	Rectangle	L-shape
SITE LAYOUT	**Shape of the building's floor plate**	SW	SW	SW
PLANNING &	**Wind direction of the locality**	Different altitude	Different altitude	Same altitude
ENERGY INDEX	**Building location on the ground**	3	3	3
	Floor level (excluding GF)	11,224.71	18,212.51	34,305.32
	Total floor area (m^2)			
		5.0 x 3.5 x 2.9	5.0 x 3.4 x 2.77	5.0 x 4.0 x 2.87
RESIDENTIAL	**Typical room dimension (l) x (w) x (h)**	17.50	17.00	20.00
UNIT - FORM	**Typical room's floor area (m^2)**	50.75	47.09	57.40
CONFIGURATION	**Typical room volume (m^3)**	1.52	1.87	1.6
& PLANNING	**Typical of corridor width (m)**			
ENCLOSURAL	**Design**	Glare protection &	Glare protection &	Glare protection &
AND FAÇADE		adjustable natural	adjustable natural	adjustable natural
DESIGN	**Window area (m^2)**	ventilation option	ventilation option	ventilation option
	Window to wall ratio	4.31	6.46	Type A: 1.65 / Type B: 4.12
	Operable window area (m^2)	0.42	0.69	Type A: 0.14 / Type B: 0.36
	Operable window to wall ratio	2.39	4.07	Type A: 1.10 / Type B: 2.75
	Window design	0.24	0.43	Type A: 0.1 / Type B: 0.24
	Location	Louver/Jalousie	Centre pivot & awning	Casement & Turn window
		N - S	N - S	N - S & W - E
SOLAR CONTROL DEVICES	**Horizontal overhangs along the wall with windows**	✓	✓	×
	Vertical overhangs along the wall with windows	×	×	×
	Tinted window glass	×	✓	✓
	Balconies/Verandah	×	×	✓
	Deep recesses	×	✓	✓
PASSIVE DAYLIGHT	**Skycourts/Internal courtyard**	×	✓	✓
CONCEPTS	**Articulated light shelves**	✓	✓	×
	Light pipes	×	×	×
	Skycourts/Internal courtyard	×	✓	✓
WIND AND NATURAL	**Balconies/Verandah**	×	×	✓
VENTILATION	**Window opening with horizontal adjustable/ closing devices**	✓	✓	×
	Window opening with vertical adjustable/closing devices	×	✓	✓
	High level fixed/adjustable exhaust opening	✓	✓	×
	Low level fixed/adjustable exhaust opening	×	×	×
	Horizontal/vertical wing walls above residential unit entrance door & wall	✓	✓	×
	Wall opening (create wind pressure inside room)	×	✓	×
	Balconies/Verandah	×	×	✓
	Internal courtyard	×	✓	✓
	Location of opening with respect to wind direction	×	×	×
LANDSCAPING	**Potential for rooftop garden**	×	✓	×
	Green area (%)	81.71	60.70	57.97
OTHERS	**Corridor**	Adjustable & fixed opening devices at the both end of corridor	Open corridor (facing to internal courtyard)	Open corridor (facing to internal courtyard)
	Staircase area	An expanse of fixed opening devices	Open staircase area	Open staircase area

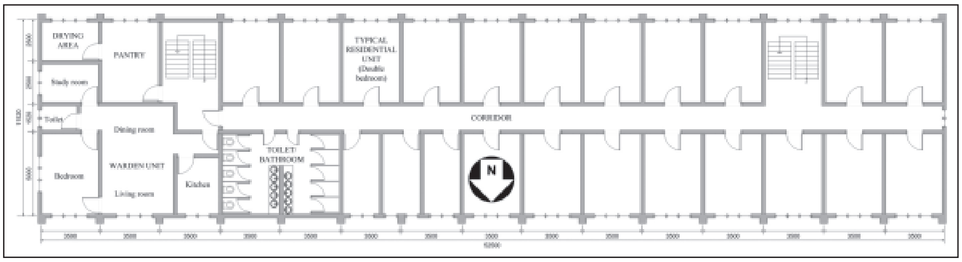

Figure 1: Typical floor plan of C1

Figure 2: The characteristic and bioclimatic design strategies demonstrated at C1

(a). Louver window/Jalousie window design & large horizontal overhangs along the wall with windows, **(b).** High level fixed exhaust opening & articulated light shelves, **(c).** Large fixed horizontal wing walls above residential units' entrance door and wall, **(d).** The roof designs that denying the potential of rooftop garden, **(e).** Open ended corridor with adjustable & fixed opening devices, **(f).** Staircase with fixed opening devices - creates wind pressure effects.

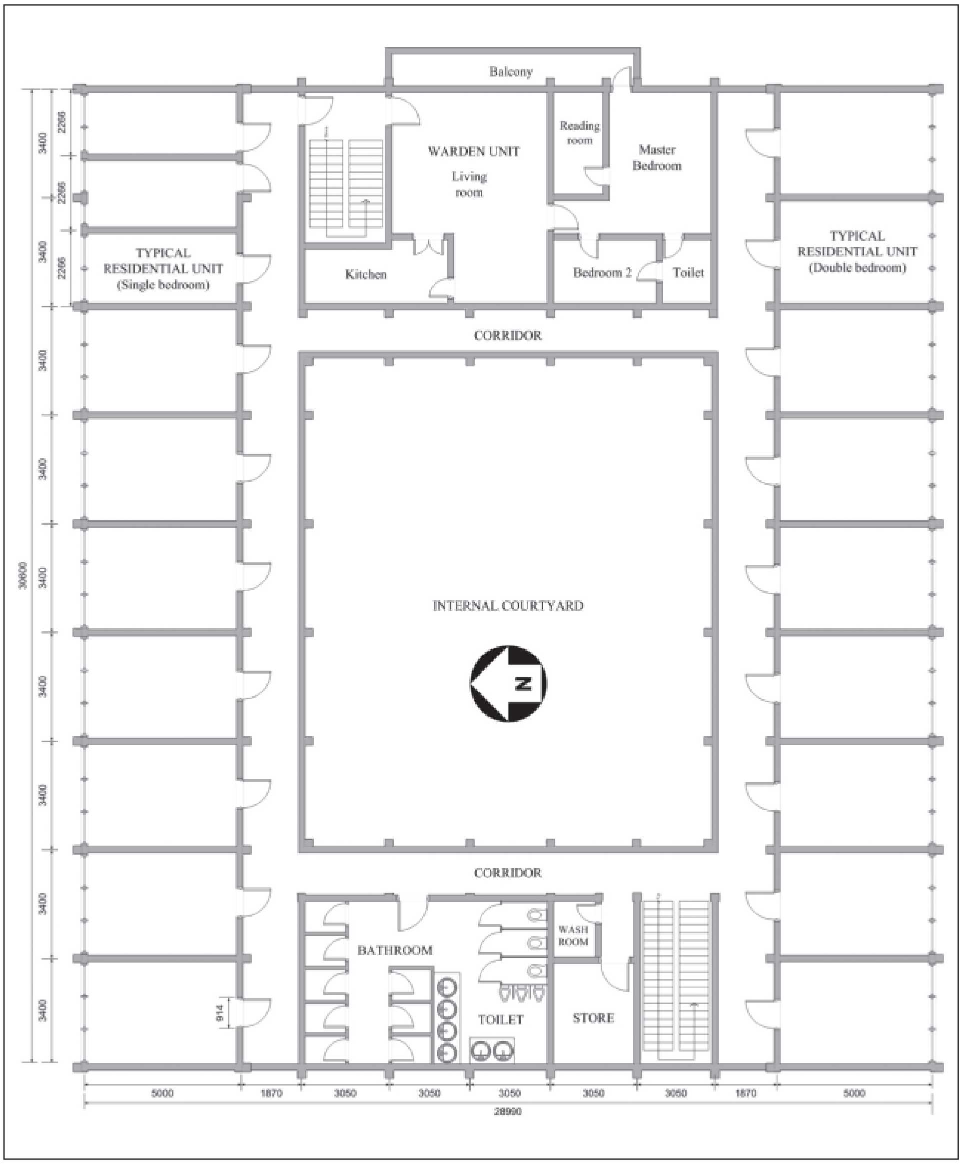

Figure 3: Typical floor plan of C2

occupancies the possibility to channel the outside air/wind, although the position of the windows and the building orientation are not in accordance with the prevailing wind flow direction, southwest. Moreover, the amounts of daylight penetration can be controlled even though each residential unit stated the biggest window to wall ratio. The awning windows that are located above

Figure 4: The characteristic and bioclimatic design strategies demonstrated at C2

(a). Centre pivot & awning window design with tinted glass and high level adjustable exhaust opening with articulated light shelves, **(b).** Large horizontal overhangs along the wall with windows, **(c).** Large fixed vertical wing walls above residential units' entrance door and wall, **(d).** The roofs design that encourage the implementation of rooftop garden, **(e).** Large open corridor facesto internal courtyard, **(f).** Open staircase area.

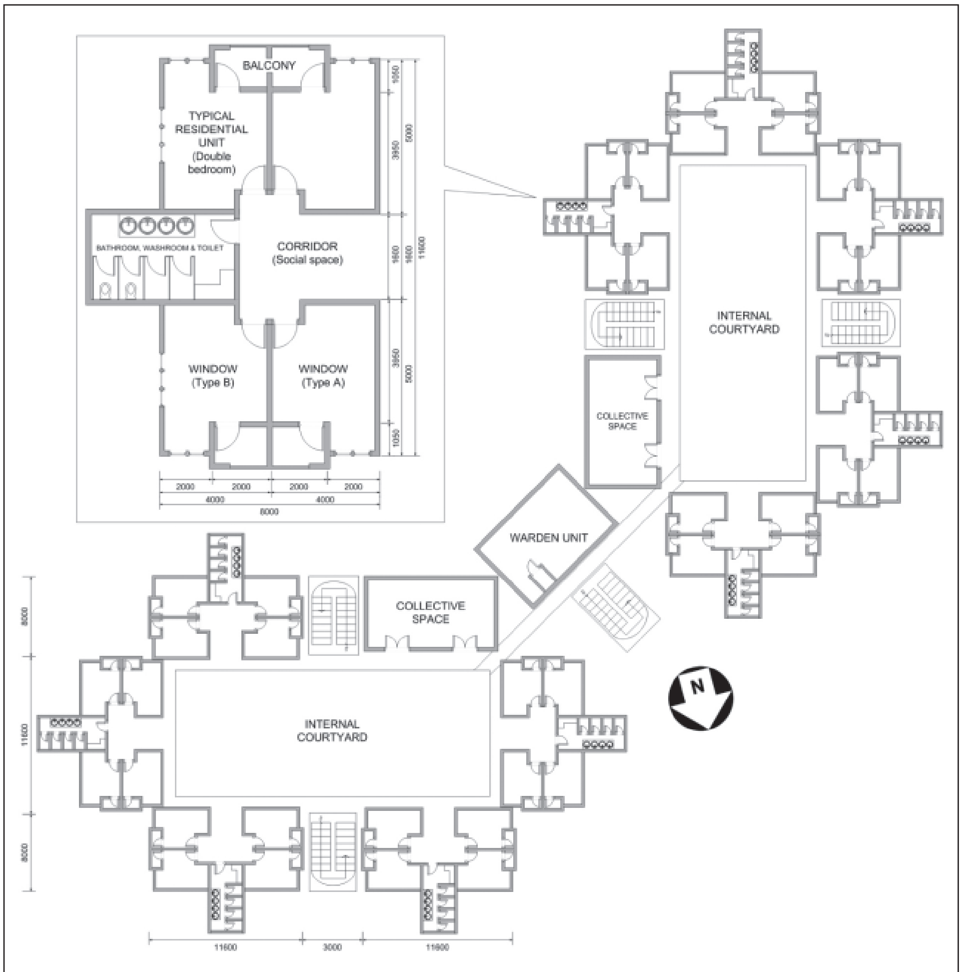

Figure 5: Typical floor plan of C3

the centre pivot directly play a role as high level exhaust opening. The flat roof design offers a big potential for the creation of a rooftop garden in the future, which would directly help to decrease the heat penetration through the roof.

Similar to C2, C3 also has a layout with a courtyard arrangement but not directly facing the residential unit. With the L-shape of the building's floor plate, the residential buildings are orientated towards north-south and west-east. There are four residential units/rooms, with their entrance doors facing each other, creating a cubicle. Each cubicle is connected by an open corridor that faces the internal courtyard, the corridor lamps do not need to be continuously switched on during day time. The presence of wall openings creates wind pressure in the cubicle, which provides air circulation indirectly into the residential unit. The

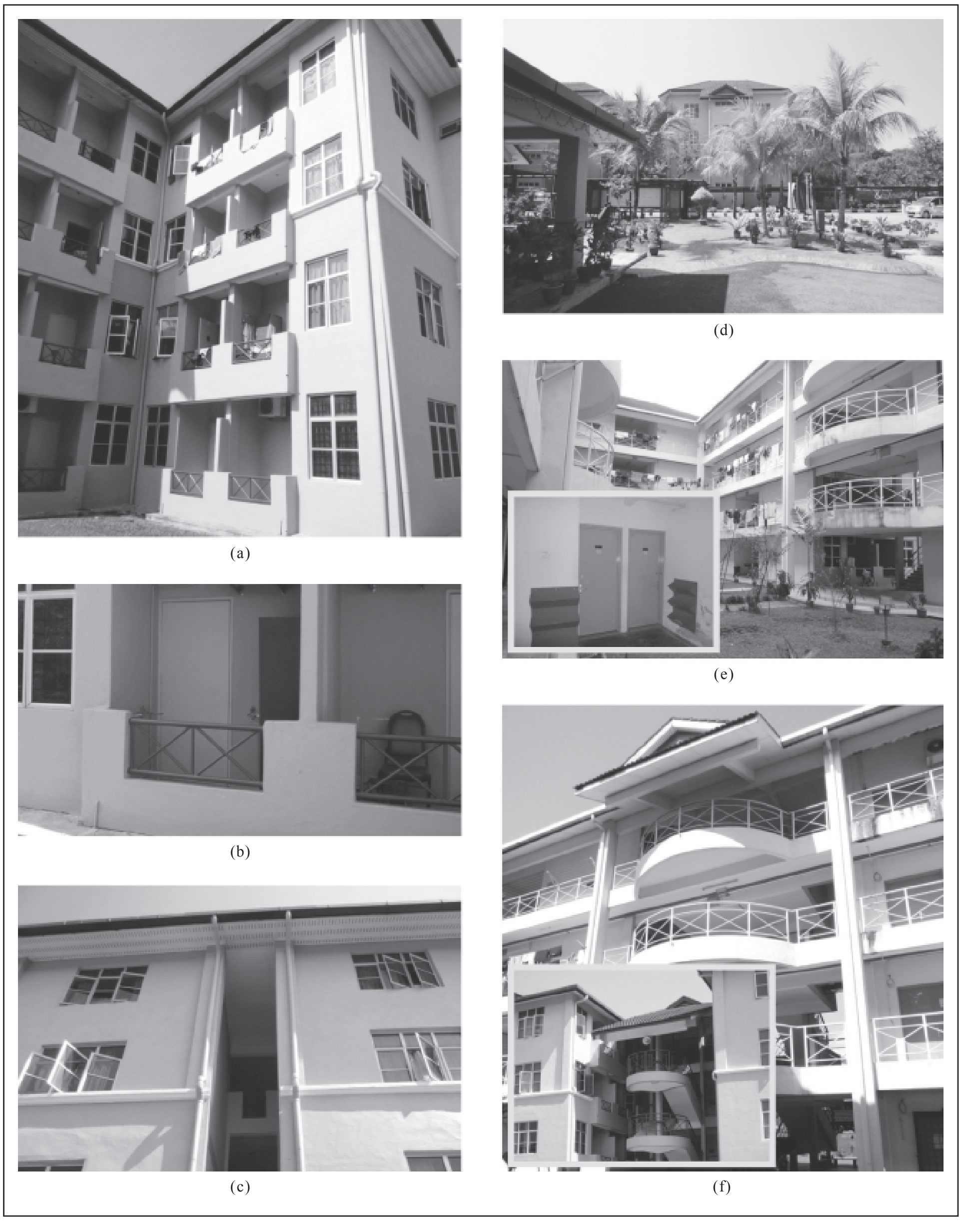

Figure 6: The characteristic and bioclimatic design strategies demonstrated at C3

(a). Casement and turn window design with tinted glass, **(b).** Large balcony at each residential unit faces to outside area, **(c).** Wall opening - create wind pressure in the cubicle, **(d).** The roofs design that denying the potential of rooftop garden, **(e).** Open corridors face internal courtyard with lightlyvegetated, No opening/ fixed vertical wing walls above residential units' entrance door and wall (small picture in the box), **(f).** Open staircase area (view from inside and outside) - creates wind pressure effects residential unit included the largest floor area and volume, 20.0m^2 and 57.40m^3, of the three residential colleges. In general, more bioclimatic design strategies were adopted in C3 compared to C1. From the observation, the balcony at each residential unit and the tinted window glass allows the residents full control of the day light distribution and air circulation into the residential unit. Additionally, the casement and turn window help the residents channel air/wind that flows from southwest, even though the building orientation becomes an obstruction.

For the purpose of this study the three residential colleges are rankedby their bioclimatic design strategies implementations, it was found to be in following order, C2>C3>C1. The residential building with internal courtyard provides higher potential of bioclimatic design strategies implementation compared to linear arrangement. Then, residential colleges building with north-south orientation is the main element in reducing heat penetration either from morning or afternoon sunlight penetration particularly in equatorial region, which indirectly can influences the electricity consumption for cooling purpose. Whilst, in certain condition where the residential college buildings are need to built in west-east orientation, the balcony can be an alternative aid that should be highly considered.

The electricity use and the total floor area (TFA) at the three residential colleges are presented in Table 2. C3 had the largest TFA, 34,305.32m^2, followed by C2 with 18,212.51m^2, while C1 as the oldest residential college was the smallest among these three with 11,224.71m^2 of TFA.

Statistically, C3 achieved the best result regarding electricity usage as it attained the lowest mean of Energy Efficiency Index (EEI), 24.23 kWh/m^2/year, compared to the other two case studies, C1 (61.80 kWh/m^2/year) and C2 (34.52 kWh/m^2/year). Referring to the range value, there is extreme usage of electricity stated at C2 which exceeded 152,408 kWh. This happened when there were a lot of students' activities in April 2006 and most of the students were stay overnight for final exam preparation. The ranking of electricity consumption in these three residential colleges was found to be in following order C3<C2<C1. Regarding the Building Energy Performance (BEP), C3 stated the lowest kWh per unit of floor area, 2.020 kWh/m^2, followed by C2 (2.877 kWh/m^2) and C1 (5.150 kWh/m^2), which means that C1 still remains the highest user of electricity in 5 years of duration.

Conclusions

This study illustrated how the implementation of bioclimatic design strategies, particularly with regards to daylighting and natural ventilation, can influence the energy performance of residential colleges. The adoption of appropriate bioclimatic design strategies, including enclosure and facade design, solar control devices, passive daylight concepts, wind and natural ventilation and landscaping, as realised in C2 and C3, clearly helped to reduce the electricity consumption per annum, while the combination of internal courtyard and balcony in the building design additionally help reduce electricity usage per unit of

Table 2: The electric use at C1, C2 and C3

Year	Month	The performance of electricity consumption - Monthly & Annually (kWh), BEP and EEI at C1, C2 and C3											
		C1 TFA : 11,224.71 m^2				C2 TFA : 18,212.51 m^2				C3 TFA : 34,305.32 m^2			
		Monthly	Annually	BEP	EEI	Monthly	Annually	BEP	EEI	Monthly	Annually	BEP	EEI
2005	Jan	60,466		5.39		85,490		4.69		57,144		1.67	
	Feb	61,741		5.50		88,685		4.87		58,214		1.70	
	Mar	70,406		6.27		107,161		5.88		72,144		2.10	
	Apr	54,383		4.84		60,742		3.34		38,250		1.11	
	Mei	55,301		4.93		65,696		3.61		42,847		1.25	
	June	59,084		5.26		59,840		3.29		70,364		2.05	
	July	57,754		5.15		98,741		5.42		67,673		1.97	
	Aug	83,054		7.40		95,119		5.22		66,248		1.93	
	Sept	67,252		5.99		76,440		4.20		66,641		1.94	
	Oct	69,747		6.21		79,290		4.35		64,702		1.89	
	Nov	74,428		6.63		69,971		3.84		46,289		1.35	
	Dec	61,218	774,834	5.45	69.03	70,932	958,107	3.89	52.61	84,006	734,522	2.45	21.41
2006	Jan	59,555		5.31		57,398		3.15		47,832		1.39	
	Feb	53,293		4.75		69,532		3.82		64,196		1.87	
	Mar	50,351		4.49		74,881		4.11		62,814		1.83	
	Apr	73,284		6.53		169,827		9.32		60,412		1.76	
	Mei	27,449		2.45		86,806		4.77		37,482		1.09	
	June	32,685		2.91		93,350		5.13		31,418		0.92	
	July	30,434		2.71		77,368		4.25		63,867		1.86	
	Aug	67,857		6.05		76,552		4.20		59,879		1.75	
	Sept	49,689		4.43		82,518		4.53		75,232		2.19	
	Oct	75,052		6.69		86,600		4.75		78,670		2.29	
	Nov	41,294		3.68		52,766		2.90		41,271		1.20	
	Dec	39,646	600,589	3.53	53.51	53,712	981,310	2.95	53.88	68,875	691,948	2.01	20.17
2007	Jan	57,030		5.08		53,014		2.91		95,176		2.77	
	Feb	57,532		5.13		37,427		2.06		77,697		2.26	
	Mar	51,312		4.57		41,281		2.27		75,096		2.19	
	Apr	65,025		5.79		41,313		2.27		75,253		2.19	
	Mei	56,820		5.06		35,087		1.93		54,188		1.58	
	June	38,932		3.47		17,720		0.97		38,712		1.13	
	July	44,603		3.97		34,836		1.91		64,529		1.88	
	Aug	69,057		6.15		35,616		1.96		66,187		1.93	
	Sept	62,934		5.61		47,663		2.62		91,775		2.68	
	Oct	67,960		6.05		34,108		1.87		77,621		2.26	
	Nov	54,266		4.83		36,534		2.01		84,598		2.47	
	Dec	45,015	670,486	4.01	59.73	20,844	435,443	1.14	23.91	66,180	867,012	1.93	25.27
2008	Jan	53,441		4.76		38,243		2.10		82,199		2.40	
	Feb	63,288		5.64		32,143		1.76		72,710		2.12	
	Mar	54,191		4.83		34,608		1.90		72,734		2.12	
	Apr	85,050		7.58		42,677		2.34		98,011		2.86	
	Mei	50,519		4.50		29,495		1.62		73,881		2.15	
	June	36,056		3.21		19,519		1.07		67,895		1.98	
	July	72,893		6.49		33,357		1.83		86,659		2.53	
	Aug	24,573		2.19		28,653		1.57		77,169		2.25	
	Sept	96,096		8.56		35,776		1.96		100,892		2.94	
	Oct	74,797		6.66		32,046		1.76		79,905		2.33	
	Nov	64,464		5.74		27,223		1.49		65,277		1.90	
	Dec	67,792	743,160	6.04	66.21	25,193	378,933	1.38	20.81	78,335	955,667	2.28	27.86
2009	Jan	45,852		4.08		27,366		1.50		70,678		2.06	
	Feb	52,383		4.67		24,577		1.35		57,984		1.69	
	Mar	72,697		6.48		33,848		1.86		86,072		2.51	
	Apr	69,782		6.22		43,145		2.37		103,154		3.01	
	Mei	46,383		4.13		25,920		1.42		59,653		1.74	
	June	63,926		5.70		17,419		0.96		54,651		1.59	
	July	63,231		5.63		40,505		2.22		100,647		2.93	
	Aug	53,927		4.80		32,661		1.79		80,018		2.33	
	Sept	58,577		5.22		28,188		1.55		68,360		1.99	
	Oct	57,106		5.09		36,369		2.00		87,701		2.56	
	Nov	56,417		5.03		36,369		2.00		60,161		1.75	
	Dec	38,805	679,086	3.46	60.50	43,601	389,968	2.39	21.41	78,663	907,742	2.29	26.46
	Mean	57,803	693,631	5.150	**61.795**	52,396	628,752	2.877	**34.523**	69,282	831,378	2.020	**24.235**
	Median	57,643	679,086	5.135	**60.499**	41,297	435,443	2.268	**23.909**	68,618	867,012	2.000	**25.273**
	Std Deviation	14,129.77	67,917.43	1.259	**6.051**	28,418.22	312,076.74	1.560	**17.135**	16,321.82	113,325.65	0.476	**3.303**
	Variance	2E+08	4.613E+09	1.585	**36.611**	8.08E+08	9.739E+10	2.435	**293.618**	2.66E+08	1.284E+10	0.226	**10.913**
	Range	71,523	174,245	6.372	**15.523**	152,408	602,377	8.368	**33.075**	71,736	263,719	2.091	**7.687**
	Max	96,096	774,834	8.561	**69.029**	169,827	981,310	9.325	**53.881**	103,154	955,667	3.007	**27.858**
	Min	24,573	600,589	2.189	**53.506**	17,419	378,933	0.956	**20.806**	31,418	691,948	0.916	**20.170**

Note:

TFA : Total Floor Area (m^2)

BEP : Building Energy Performance (kWh/m^2)

EEI : Energy Efficiency Index ($kWh/m^2/year$)

floor area as shown in C3. The open ended corridor at both end of the building layout with the linear arrangement is not useful for optimising the benefit of day lighting and natural ventilation for energy usage reduction in residential college buildings, as can be seen from C1, which consumed triple the amount of electricity than the average residential buildings in Malaysia, 10 to 25 kWh/m^2/year.

Thus, the element of internal courtyard and balcony should be seriously considered in the multi residential building design due to its potential for energy efficiency strategies. The abundant daylight, which is available at a consistent rate all year long in the tropical regions, should be optimised in a way to guarantee a balance between energy efficiency and occupant comfort levels.

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References

[1] P. Tiyok, Towards Indonesia's Sustainable future: Green building council Indonesia, FuturArc 14 (2009) 116-119.

[2] C. Tantasavasdi, J. Srebric, Q. Chen, Natural ventilation design for houses in Thailand, Energ.Bldg. 33 (2001) 815-24.

[3] N. Lechner, Heating, cooling, lighting: Sustainable design methods for architects, John Wiley & Sons, New Jersey, 2009.

[4] Economic Planning Unit, Prime Minister's Department, Ninth Malaysia Plan 2006-2010, Prime Minister's Department, Putrajaya, 2006.

[5] M. Atkinson, Building a fast, deep, low-cost climate change solution, FuturArc 14 (2009) 41.

[6] A. Al-Mofleh, S. Taib, M.A. Mujeebu, W. Salah, Analysis of sectoral energy conservation in Malaysia, Energy 34 (2009) 733-739.

[7] M. Levine, D. Ürge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. MongameliMehlwana, S. Mirasgedis, A. Novikova, J. Rilling, H. Yoshino. Residential and commercial buildings, in: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, USA, 2007, pp. 387-446.

[8] A.M. Omer, Renewable building energy systems and passive human comfort solutions. Renewable and Sustainable Energy Reviews 12 (2008) 1562-1587.

[9] D.H.W. Li, J.C. Lam, S.L. Wong, Daylighting and its implication to overall thermal transfer value (OTTV) determinations, Energy 27 (2002) 991-1008.

[10] A. Zain-Ahmed, K. Sopian, M.Y.H. Othman, A.M.M. Sayigh, P.N. Surendran, Daylighting as a passive solar design in tropical buildings: a case study of Malaysia, Energ. Conv. Manage. 43 (2002) 1725-36.

[11] M. Hasse, A. Amato, Sustainable façade design for zero energy buildings in the tropics, Proceedings of The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, September, 2006.

[12] Sustainable Energy Authority Victoria, Energy smart housing manual, State of Victoria, Australia, 2002.

[13] C. Candido, Richard de Dear, R. Lamberts, L. Bittencourt, Natural ventilation and thermal comfort: air movement acceptability inside naturally ventilated buildings in Brazilian hot humid zone. Paper presented at Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Windsor, London; 2008, July 27-29.

[14] N.H. Wong, D.K.W. Cheong, H. Yan, J. Soh, C.L. Ong, A. Sia, The effects of rooftop garden on energy consumption of a commercial building in Singapore, Energ, Bldg. 35 (2003) 353-364.

[15] E. Ghisi, R.F. Massignani, Thermal performance of bedrooms in multi-storey residential building in southern Brazil, Bldg. Environ. 42 (2007) 730-742.

[16] M. Indraganti, Adaptive use of natural ventilation for thermal comfort in Indian apartments, Bldg. Environ. 45 (2010) 1490-1507.

[17] A.M. Mohit, M. Ibrahim, Y.R. Rashid, Assessment of residential satisfaction in newly designed public low-cost housing in Kuala Lumpur, Malaysia, Habit International 34 (2010) 18-27.

[18] Building Research Establishment Environment Assessment Method-BREEAM [Internet], BREEAM Multi-residential. [updated 2009; cited 2010 Feb 12]. Available from http://www.breeam.org/page.jsp?id=2

[19] C.S. Aun, Preview of green building index Malaysia (residential), Proceedings of Green Design Forum, Kuala Lumpur Convention Centre, Kuala Lumpur, 2009.

[20] A.M. Nugroho, M.H. Ahmad, D.R. Ossen, A preliminary study of thermal comfort in Malaysia’s single storey terraced houses, J. Asian Archit. Build. Eng. 6 (2007) 175-82.

[21] M. Haji-Sapar, S.E. Lee, Establishment of energy management tools for facilities managers in the tropical region, Facilities 23 (2005) 416-25.

[22] K. Yeang, Ecodesign: A manual for ecological design, John Wiley & Son Ltd, London, 2008.

[23] R. Saidur, Energy consumption, energy saving, and emission analysis in Malaysian office buildings, Energy Policy 37 (2009) 4104-4113.

[24] S.N. Kamaruzzaman, R.E. Edwards, Evaluating performance characteristics of electricity use of British historic building in Malaysia, Facilities 24 (2006) 141-152

[25] Electrical and Mechanical Services Department-EMSD, Guidelines on Energy Audit, The Government of the Hong Kong Special Administrative Region, Hong Kong, 2007.

[26] H. Ibrahim, Best practices and innovation of buildings in Malaysia, Paper presented at Seminar on The Promotion on Energy Efficiency and Conservation for Building in Southeast Asia, Singapore; 2008, January.

[27] S.K. Chou, Performance-based standards for energy efficiency building, Paper presented at Seminar on Building Control (Amendment), Singapore; 2004, Feb.

[28] J. Iwaro, A. Mwasha, A review of building energy regulation and policy for energy conservation in developing countries, Energy Policy 38 (2010) 7744-7755.

[29] C.S. Aun, Green Building Index - MS1525: Applying MS1525:2007 Code for Practice on energy efficiency and use of renewable energy for non residential buildings, Paper presented at Continuing Professional Development-CPD Seminar. Kuala Lumpur; 2009.