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An innovative roofing system for tropical building interiors: Separating heat from useful visible light

Al-Obaidi K.M., Ismail M., Abdul Rahman A.M.

School of Housing, Building & Planning, Universiti Sains Malaysia, 11800, Minden, Pulau Pinang, Malaysia.

Abstract
Generally it has been known that energy consumption costs are high in temperate countries. In buildings, room spaces are normally designed so as to consume less energy for thermal comfort especially in winter. Passive strategies such large double-glazing windows are to contain heat indoors and also for maximum daylight to reduce dependence on artificial lighting. Thus roof lights are popular building design elements in cold and temperate countries. Unlike in the tropics where it has high temperatures and humidity throughout the year, achieving indoor comfort is a challenge especially with plenty of sunshine and unpredictable wind conditions. This paper explores the possibility of roof light for indoor comfort to be considered as a tropical design element. Initial simulation was carried out before any attempt to do life-sized model for empirical data. By simulation, the hypothesis has been achieved but several factors have to be considered. The solution is not as simple as those achieved in the temperate countries. Comfort can be achieved but permutations of several design factors such as dimensions of room, glazing, reflective materials, blackbody concept and building materials need adjustment to meet the Malaysian Comfort Temperature. With this finding the Tropical Architecture would then be redefined with the introduction of this Innovative Roofing System (IRS) as named by the author.

Keywords: Roof lights; Daylighting; Tropical climate; Innovative roofing system.

1. Introduction
The sun insolation is almost perpendicular to the Earth’s surface, beginning the Tropic of Cancer and the Tropic of Capricorn where there is plenty of sunshine, it is normally referred to as the Tropical zone. As the latitudes get further away from the Equator, both up and down towards the North and South poles respectively, the insolation spreads over a bigger area of the Earth’s surface. That means the amount of daylight received on the ground varies with locations, latitude, climate, inland situation, and air quality affect the intensity and duration of daylight [1]. The amount of daylight is less at upper latitudes also the heat that the sunlight brings along is mild due to lower intensity of rays [2], so people living in the higher latitudes crave for sunshine and this is reflected in the regional architecture and their behavior. Simply, sun bathing is a craze among the Caucasians whereby they flock in droves to the beach during summertime but in some temperate countries such as in the United Kingdom the sun is not intense and not sufficient enough especially between the end of March and the end of September when the sun becomes perpendicular on the earth to produce a good amount of vitamin D [3]. Many weeks during a typical year is cloudy and overcast thus blocking most of the useful daylight from reaching the ground

and buildings. Even when there is sufficient sunlight people spend most of the time working indoors in offices [4]. Therefore for those unable to go to the beaches to sunbathe, they would have it at their own homes that come with a sun deck. Sun deck is part and parcel of the house and is a selling item when it comes to buying and selling of properties. Buildings in temperate and cold regions are designed to reduce the energy consumption by providing daylight systems with low ceiling level and smaller room spaces which are preferred so that heating during winter would be effective. All these strategies used to overcome the increasing of the energy demand, according to the indications that have been recorded in the building sector show greatly increases from 2,912 Mtoe in 2005 to 5,257 Mtoe in 2050 an increase of about 1.3% per year [5].

Daylight strategy is one of the best solutions to overcome the issue of high-energy cost. Daylight normally enters the building from large windows such as the Georgian windows and most times from skylights such as atriums. Temperate climates open up for more flexibility in daylight design due to mild temperature and a variety of seasons [6]. There are several daylight systems in temperate building designs especially for public buildings with roof lights that bring in sunlight during winter and also heat up the interior by long wave radiation. This is very much welcomed by the Europeans. In summertime sunlight is still welcomed and to overcome the heat gain all that is needed is to open the windows to allow natural cross ventilation. The heat is still bearable as it is not as intense as in the tropics. Normally atriums are high above and not easily accessible unless openings are electronically operated. Domestic buildings in the temperate climate also have roof lights and because of the smaller volumes they are designed to be easily accessible to open during summertime. But these strategies cannot be applied simply in tropical region due to the higher intensity and concentration of tropical sun on a smaller surface area.

2. Review of some existing literature

Unlike the temperate and cold climates, Malaysia is a tropical country located at about 3^o N the equator with a important geographical location in the tropical region, it is consider as one of uncomfortable climate zone comparing to moderate and cold climate. The most features recognized it as highly hot temperature ranging from 22°C to 33°C throughout the year, greatly incident level of solar radiation and experiencing higher level of relative humidity during a year [7]. Most feature of this region expressed summer all the time during a typical year which gain highly excessive of heat. Therefore, it is so important to know how to avoid solar radiation from overheating the building fabrics. Malaysia exposed to very high amount of solar insulation, ranging between 1400 to 1900 kWh/m2 [8], with average around 1643 kWh/m2 per year [9] and more than 10 sun hours per day [10]. Furthermore the larger part of population living in the tropic classified as developed nations.

Cooling issue consider as one of the main problem in Malaysian buildings regarding to the thermal performance [11]. Roof is affected by solar incident and especially during clear sky condition when the amount of solar radiation can reach up to 1kW/m2 the absorption can be between 20% to 90% of incident solar radiation in its fabric [12]. Residential Buildings in Malaysia consider as one of the higher demanding of cooling energy due to the problem of heat gain that pass through the building fabrics particularly for low rise buildings where roof elements represent around 70% of the heat gain [13]. In terms of housing types, terrace house represent around 44% of buildings in urban areas as of 2000 [11]. Regarding to Isa [14] more than 1.6 million terrace house are inhabited by more than 7 million people and most of these buildings were built by cement or clay brick for walls and using cement or clay tiles for roof, in addition most of these buildings have no insulation materials have been installed, just there is little modification of a thin layer under the roof tiles. According to the survey that has been done by Allen [15] shows that roof materials of Malaysian buildings in terrace apartment (Concrete tiles 45%, Clay tiles 2.5%), Semi-Detached (Concrete tiles 20%, Clay tiles 2.5%), Cluster House (Concrete tiles 2.55), Bungalow (Concrete tiles 17.5%, Clay tiles 5%, Metal deck 5%). Therefore these houses are suffer from highly transmission of solar radiation make them act like a sauna and creating uncomfortable environment to their occupants. With all these situations mentioned above, poor ventilation and air circulation make the situation more worse, since openings in Malaysian houses just located in facades from front and back, consequently the heat gain inside the building is trapped by rooms, doors and partitions which lead to increase the temperature of internal spaces [14]. According to Kubota [11] shows that especially Malaysia terrace house have problem of night ventilation because the most Malaysian residents open windows during the day but most close them at night which cause trapping of the heat and leading to increase the demanding of energy consumption at night. All these factors lead to increase the energy use for residence in Malaysia. Data recorded by IEA 2009 [16] indicates that 19% of energy supplies go for residential usage, and last study shows that 21% of this portion are using to power the air-conditioning units and another 2% are using to power the mechanical fans. According to Ar Chan [17] shows that in residential sector the number of air-conditioning units owned by Malaysians in 1999 was 493,082. This number increased in 2000 by 6.7% with 528,792 units and it was anticipated to increase around 42% in 2009 with 907,670 units [18].

Regarding to World Population Data Sheet [19] the most people cannot afford the bills of mechanical air-conditioning in their houses due to financial limitations. In addition the using of air- conditioning arises two problems increasing the household's utility bills and the electricity generation from fossil fuels is helping to increase the concentration of greenhouse gases in the environment [7]. This change is leading to increase global warming and climate change.

Many studies in Southeast Asian region shows that using of day lighting strategy in building can decrease the demanding on the energy consumption by 20% and help to overcome the problem of increasing of sensible heat load on air-conditioning [20].

The tropical climate has only two seasons (sunny and rainy seasons) thus apart from large public buildings with long span atriums, domestic building rarely have roof lights simply because it brings in thermal discomfort at human height level. Almost immediate when the sun shines through the glazed roof light in the tropical climate, it heats up the interior quickly and for public buildings air conditioning helps to cool the air mass. In previous years this is the way to overcome thermal discomfort (heat build-up and glare) but with the gradual increase in energy cost glass atriums is no more considered as a tropical design element. Existing buildings in the tropical Malaysia would have a major problem when the electricity cost goes up gradually over the years. Only two locations in Malaysian situation where atriums can be designed without having to air-conditioned the volume are viz., locations by the sea to capture the land and sea breeze phenomenon and the hill slopes where wind is almost prevalent [21].

To brighten the interiors of a domestic building, normally courtyards are incorporated into the design within the building interior. Courtyards have no roofs and so heat is easily dissipated but the inconvenient of unpredictable rainfalls such as squalls that can come suddenly. Smaller size vertical openings are known as air wells that not only allow lights but also assist in stack effect are designed mostly in terraced houses. So the function of courtyards and air wells is to brighten the interior and also allow for natural ventilation via stack effect and that means the space has limited use in everyday living. Land is gradually getting expensive and to have a luxury of courtyards or air wells in the urban areas of Malaysia may not be an attractive element when the space cannot be used for creature comfort apart from only letting natural lights in. Most would construct a roof above and install artificial lights but this initiative may not be good for the indoor environment. The gradual increase of energy cost worldwide is common to all and the Malaysian architecture should address this trend. The definition of Tropical Architecture has to take into consideration the emerging vocabulary of energy efficiency in building design. The cost of energy has now become an integral part of everyday living. To provide natural light inside Malaysian buildings, we should understand all the conditions to provide a comfortable environment to all occupants. According to Kroelinger [6] shows that daylight strategy in hot-humid climate has to reduce the amount of solar radiation and controlled especially from side and top lights to overcome the problem of heat gain by providing shading device and windows should be sized and located to allow for indirect daylight also avoid exposure of the east and west directions. Also the aim of daylighting design in tropic is to know how to control the quality and quantity of daylight generated by all sources at a specific location. Moreover it should be consider the luminance of the sky, the illumination intensity from sunlight and the thickness of the air mass that is passes through it [2].

This paper explores the possibility of brightening up building interiors without the vagaries of the weather and also by installing roof lights without generating heat. It seeks to solve the problem of heat build-up by separating the heat from the sun light to get the useful and visible light for the benefit of those living in the tropics. Malaysians normally spend up to 90% of their lifetime indoors. At its peak the Malaysian sun is very strong and biting and a typical behavior for Malaysian is to use either an umbrella to walkabout outdoors, walk under shade like the covered walkway or stay indoors. Indoor illumination levels are benchmarked by the Green Building Index (GBI) Malaysia (www.greenbuildingindex.org) and also by the Malaysia Uniform Building By-Laws (1986) as shown below [25].

3. Malaysian daylighting benchmarking

According to Zain-Ahmed [22], the Malaysian sky is classified as intermediate mean sky and overcast sky with illumination between 60,000 to 80,000 lux at the noon during the months when solar radiation is highest. This is more than the required amount of sunlight needed for effective day-to-day living. Glare and stifling heat would be a major problem and thus the raw exposure of this amount needs to be tampered and sieved for productive use of the sunlight. What is in abundance in the tropics is more than welcomed in the temperate but not welcomed in the tropics. Therefore some form of regulations or benchmarking of daylight is required for interior building designs. In Malaysia there are two types of benchmarking that are complementary to one another and they are from the Green Building Index and also from The Malaysia Uniform Building By-Law of 1984 as stipulated in italics below. The Green Building Index uses a point-scoring approach so that anything that gets measured is easily managed but not necessarily mandatorily imposed on buildings. The UBBL of Malaysia is a mandatory requirement for any building approvals. Below are excerpts from these two benchmarking references.

3.1 Green Building Index for Residential New Construction (GBI-RNC)[23]

Code: EQ2 Daylighting - REQUIREMENTS:

- 1 point : Demonstrate that ≥ 50% of the habitable rooms has a daylight factor in the range of 1.0 – 3.5% as measured at floor level, OR
- 2 points : Demonstrate that ≥ 75% of the habitable rooms has a daylight factor in the range of 1.0 – 3.5% as measured at floor level.

APPROACH & IMPLEMENTATION: Daylight systems for buildings include window, facade shading/light deflecting devices (e.g. lightshelves), roof lights and atrium spaces. The daylight factor is the ratio of indoor light level measured on the working plane to the outdoor light level during overcast conditions with no direct sun. For a daylit space, the lighting level should be fairly uniform with no great contrast for visual comfort.

3.2 Green Building Index for Non Residential New Construction (GBI-NRNC)[24]

Code: EQ8 Daylighting - REQUIREMENTS:

- 1 point: Demonstrate that ≥ 30% of the NLA has a Daylight Factor in the range of 1.0 – 3.5% as measured at the working plane, 800mm from floor level, OR
- 1 points: Demonstrate that ≥ 50% of the NLA has a Daylight Factor in the range of 1.0 – 3.5% as measured at the working plane, 800mm from floor level.

Note: Refer to MS1525:2007 for the description and calculation of Daylight Factor.

APPROACH & IMPLEMENTATION: Daylight system for building includes window, facade shading/light deflecting devices (e.g. lightshelves), roof lights and atrium spaces. The Daylight Factor is the ratio of indoor light level measured on the working plane to the outdoor light level during overcast conditions with no direct sun. For a daylit space, to ensure visual comfort, the lighting level should be fairly uniform with no great contrast.

Code: EQ9 Daylight Glare Control

REQUIREMENTS: Reduce discomfort of glare from natural light. Where blinds or screens are fitted on glazing and atrium as a base building, incorporate provisions to meet the following criteria;

1. Eliminate glare from all direct sun penetration and keep horizontal workspace luminance level below 2000 lux;
2. Eliminate glare from diffused sky radiation for occupant workspace at viewing angles of 15° to 60° from the horizontal at eye level (typically 1.2m from floor level);
3. Control with an automatic monitoring system (for atrium and windows with incident direct sun light only – not applicable for fixed blinds/screens);

3.3 SECTION 4 of Malaysia Uniform Building By-Laws Part III 1984 [25]

39 (1) Every room designed, adapted or used for residential, business or other purposes except hospitals ands schools shall be provided with natural lighting and natural ventilation by means of one or more windows having a total area of not less than 10% of the clear floor area of such room and shall have openings capable of allowing a free uninterrupted passage of air of not less than 5% of such floor area.

(2) Every room used for the accommodation of patients in a hospital shall be provided with natural lighting and natural ventilation by means of one or more windows having a total area of not less than

15% of clear floor area of such room and shall have openings capable of allowing a free uninterrupted passage of air or not less than 10% of such floor area.
(3) Every room used for the purpose of conducting classes in a school shall be provided with natural lighting and natural ventilation by means of one or more windows having a total area of not less than 20% of clear floor area of such rooms and shall have openings capable of allowing a free uninterrupted passage of air of nor less than 10% of such floor area.
(4) Every water closet, latrine, urinal or bathroom shall be provided with natural lighting and natural ventilation by means of one or more openings having a total area of not less than 0.2 square meter per water closet, urinal latrine or bathroom and such openings shall be capable of allowing a free uninterrupted passage of air.
There are many ways to capitalize the available daylight indoors. If these are considered earlier during the planning stage of a new building or renovation, the long term results usually look great and work superbly to brighten up indoors during the day. The daylight design strategies are in the form of roof lights, atria, glazing, transparent insulation, light shelves and reflectors, light pipes and light ducts and shading. This paper explores the roof light strategy as the light being casted over a space in a more uniform way and are unlikely to be obstructed either internally.

4. Method

Initial study requires some computer simulations in order to set some relevant parameters before an actual experiment to be carried out for empirical data. IES-VE (Virtual Environment software) by Integrated Environmental Solutions is a latest development of dynamic building energy simulation software. It allows designers to test different design options, identify best passive solutions in building mass and form, the climate , materials , occupancy, natural resource availability. The IES can draw conclusions on thermal analysis, daylight and light levels, airflow and more [26].
The location of testing area is in Penang, according to the finding of Zain [22], this finding was done at the state of Selangor, that has lower latitude than Penang. This may justify that Penang has less lux due to the higher latitude. Using the IES-VE (Virtual Environment) software, the calculation of CIE clear sky condition was used as the worst-case condition, with limitation of the IES-VE the higher input reaches to more than 50,000 lux.
The basic and minimum size was thought to be the size of a typical room but for this exercise slightly more than the minimum dimensions was simulated. For the first instance the simulation would be done on a roof with skylight and measured for air temperature and illumination at workable area, set at 800mm from ground level, the height of a typical office desk. The findings from the simulations will then be compared with a design of an innovative roofing system (IRS).
This IRS referred to is the roof construction encompassing the attic space as a whole. Several IRS material properties will be tested for conductivity and better distribution of illumination. Technical dimensions of room are shown in Figure 1.
Items 1 to 7 below are fixed items followed by items 8 and 9as variable parameters for performance comparisons. These are the specifications for the simulation based on March 15th considered as one of the hottest days of a typical year;

1. W 4m x L 5m and H 3m with the height at the roof ridge to the horizontal ceiling level as 1 meter and a roof pitch of 30^o.
2. The daylight illuminance at point of entry is set at 50000lux.
3. Both the gable ends face the sun path i.e. the longer façade faces the North-South direction.
4. The glazed roof finish allows sunlight to enter is to be 1m long x 0.5m wide on both sides of the roof.
5. The test bed has no opening from the walls so as not to influence the illumination patterns coming from the roof. It is understood that any openings from the walls would be a bonus and to consider the heat transfer by adjustment of components similar to what this paper is indulging in. This is for future fine-tuning the experiment but for now the experiment is testing on a worst-case condition.
6. The materials used in the simulation are shown in Table 1.
7. The ceiling glazed area is measured at W 2m x L 4m.
8. Test bed without ceiling - Materials used: Normal floating single sheet glass; double-glazing.
9. Test bed with ceiling - Materials used: Double glass glazing, polycarbonate, blackbody, reflective surface, hybrid turbine ventilator (HTV).

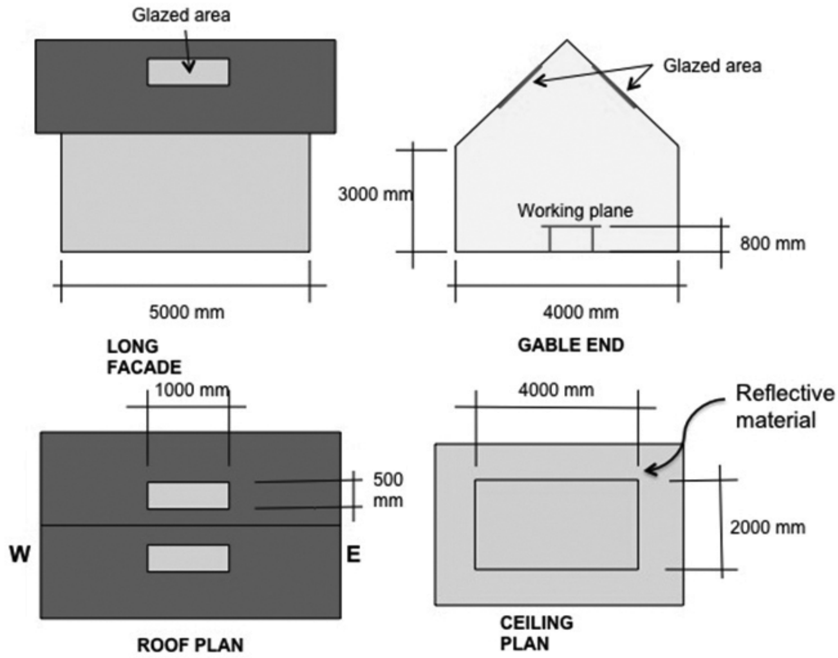


Figure 1. Graphic representation of the test bed: (top left) the long façade (top right) the gable end (bottom left) roof plan and (bottom right) ceiling plan. Dimensions show that they are above the minimum requirements of the UBBL

Table 1. Specification of the test bed to be used for simulation

Building Materials	Materials	Thickness m	Conductivity W/m.k	Density kg/m3	Specific heat capacity	U-Value	R-Value
Wall	Stucco	0.0254	0.721	2659	837	2.1535	0.2944
	Common Brick	0.1016	0.727	1922	837		
	Gypsum/Plaster board	0.0191	0.16	801	837		
Ground	Clay	0.75	1.41	1900	1000	0.7059	0.6747
	Brickwork (Outer Leaf)	0.25	0.84	1700	800		
	Cast concrete	0.1	1.13	2000	1000		
	Screed	0.05	0.41	1200	840		
	Synthetic Carpet	0.01	0.06	160	2500		
Ceiling	Aluminum	0.005	160	2800	896	7.1413	0
Roof	Aluminum	0.005	160	2800	896	7.1413	0

Based on the model as shown in Figure 1 above, several permutations of roof construction system are selected together with carefully selected materials for predicted extreme cases beginning from skylight normal single sheet glass as worst case condition to be used as a base for performance comparison. The follow up of other materials were chosen based on availability, manufacture's specifications and widespread use in the building industry market. The specifications below show the different daylight strategies incorporating the above components as a roofing system.

Skylight/No ceiling - (i) Roof: with clear single sheet glass and
(ii)Roof: with double glazing glass,

Innovative Roofing System/with ceiling - (i) Roof and Ceiling: double-glazing polycarbonate
(ii) Roof: double-glazing glass
Ceiling: double-glazing polycarbonate
(iii) Roof and Ceiling: double-glazing polycarbonate

The above specifications is graphically represented as shown in Figure 2 below and followed by the assessment from the computer simulation findings before building an actual model for empirical data to validate the computer findings.

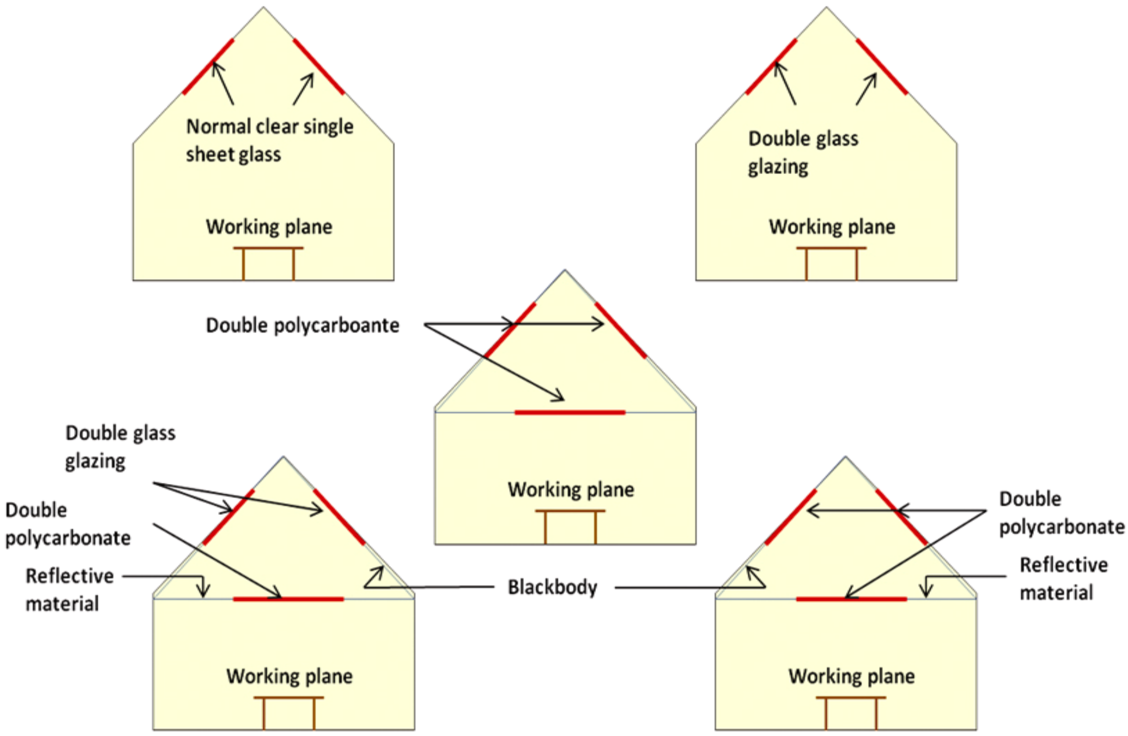


Figure 2. The search for an effective roof daylight system

5. Results and discussion

5.1 Computer modeling – air temperature

The simulated measurements were for the specifications of the above-mentioned test bed. The air temperature figures (Table 2) are the room air temperature but may not be that accurate because in reality the windows are normally opened. These readings are for *worst-case condition*. The relevant data is the temperature difference. The acceptable figures would be the last column of Table 2 below and this is used to compare how other roof systems fare in the thermal performance.

The extremes of the five roof systems would be from columns B and F, and from between 9.30 am to 16.30 pm, The temperature difference shows a minimum of 2.48^{0}C (30.26 – 27.78) and a maximum of 7.22^{0}C (41.31 – 34.09). Comparing the other strategies with column F the temperature difference would be as follows;(i)B-F = Max 7.22 Min 2.48; (ii) C-F = Max 6.76 Min 2.36; (iii) D-F = Max 1.02 Min 0.52; (iv) E-F = Max 0.13 Min 0.04. This confirms that column B with clear glass is not a reliable tropical roof design, as it brings discomfort. The IRS (double polycarbonate for roof and ceiling, blackbody and reflective material as shown in column F) is the most promising roofing construction system to reduce heat in the overall structure. Graph A below confirmed this discovery. This is the temperature performance within the room for skylight and as for IRS the space below the ceiling.

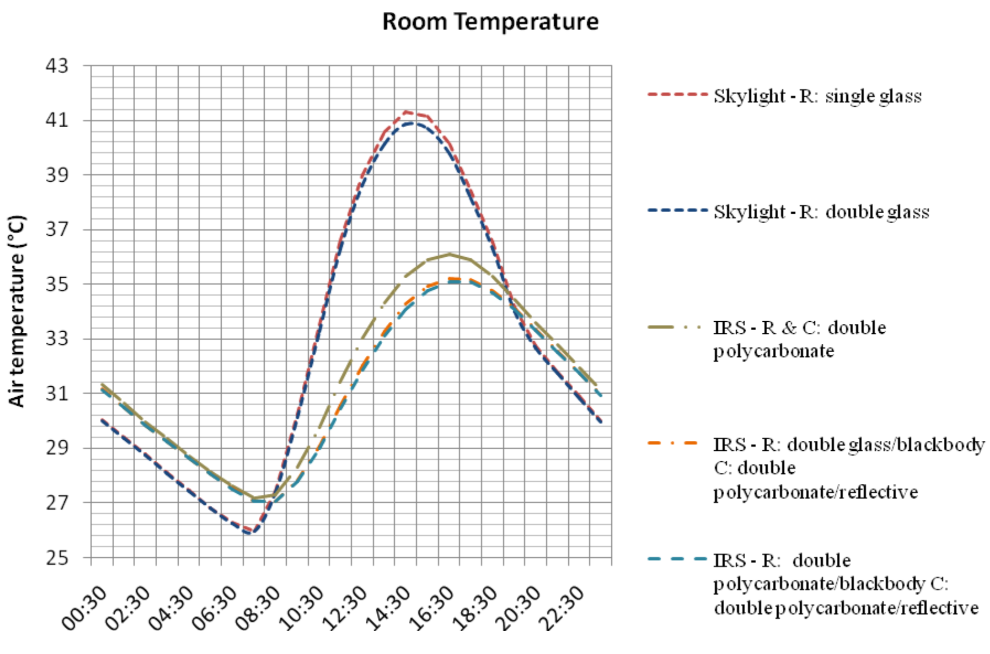
In Table 3 the simulated measurements were for the specifications of three different types of attic spaces. The air temperature figures shown are almost accurate because in reality the attic spaces are normally partially enclosed or enclosed altogether. Again the acceptable figures would be the last column F of Table 3 because of the comparatively lower temperatures. This table confirms that addition of a blackbody and a reflective material does help to reduce further the air temperature inside the attic.

See also Graph B for visual comparison.

The difference between the figures in columns E and F is very slight. This means that the first line of defense in preventing the heat from dissipating and radiating into the room space below the ceiling has been successful where the heat is trapped within the attic space by the placing the aluminium as a reflective surface just above the ceiling to reflect the heat and a blackbody surface to absorb the infrared along the underside of the roof trusses.

Table 2. Indoor temperature (^{o}C) of the room space for the skylight and IRS from the five strategies

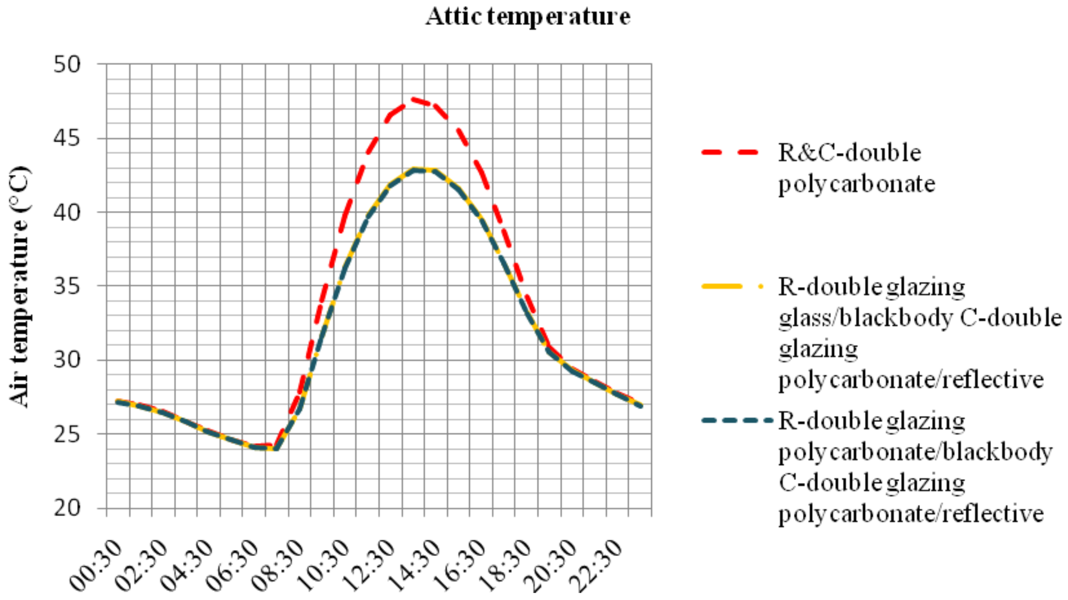
A	B	C	D	E	F
	SKYLIGHT		**INNOVATIVE ROOFING SYSTEM (IRS)**		
Time	Normal single sheet glass	Normal double glazing glass	Roof : Double glazing polycarbonate Ceiling: Double glazing polycarbonate No Blackbody No Reflective Surface	Roof : Double glazing glass Ceiling: Double glazing polycarbonate Blackbody Reflective Surface	Roof : Double glazing polycarbonate Ceiling: Double glazing polycarbonate Blackbody Reflective Surface
0:30	30.05	30.01	31.32	31.18	31.15
1:30	29.41	29.37	30.63	30.50	30.47
2:30	28.79	28.76	29.98	29.86	29.85
3:30	28.11	28.08	29.34	29.24	29.22
4:30	27.45	27.42	28.73	28.63	28.62
5:30	26.83	26.81	28.16	28.06	28.05
6:30	26.28	26.26	27.61	27.53	27.52
7:30	25.97	25.95	27.16	27.07	27.05
8:30	27.42	27.37	27.30	27.07	27.05
9:30	30.26	30.14	28.30	27.82	27.78
10:30	33.50	33.29	29.78	29.06	28.99
11:30	36.61	36.30	31.44	30.55	30.43
12:30	39.01	38.62	33.01	32.01	31.86
13:30	40.59	40.14	34.33	33.28	33.12
14:30	41.31	40.85	35.30	34.26	34.09
15:30	41.12	40.69	35.90	34.91	34.75
16:30	40.12	39.75	36.11	35.22	35.09
17:30	38.43	38.14	35.90	35.17	35.07
18:30	36.52	36.31	35.29	34.76	34.69
19:30	34.14	34.00	34.46	34.11	34.07
20:30	32.76	32.66	33.60	33.34	33.31
21:30	31.79	31.72	32.77	32.56	32.52
22:30	30.88	30.81	31.94	31.75	31.72
23:30	30.01	29.95	31.14	30.97	30.95



Graph A. The temperature performance of five different roof specifications

Table 3. IRS indoor room temperature (^oC) only for space below the ceiling from the five strategies

	D	E	F
	IRS - ATTIC AIR TEMPERATURE		
Time	Roof : Double glazing polycarbonate Ceiling: Double glazing polycarbonate **No** Blackbody **No** Reflective Surface	Roof : Double glazing glass Ceiling: Double glazing polycarbonate Blackbody Reflective Surface	Roof : Double glazing polycarbonate Ceiling: Double glazing polycarbonate Blackbody Reflective Surface
0:30	27.27	27.20	27.19
1:30	26.96	26.91	26.90
2:30	26.54	26.49	26.48
3:30	25.87	25.83	25.82
4:30	25.22	25.19	25.18
5:30	24.64	24.61	24.60
6:30	24.17	24.13	24.12
7:30	24.24	24.05	24.04
8:30	27.82	26.71	26.70
9:30	34.07	31.62	31.60
10:30	39.81	36.26	36.20
11:30	44.06	39.77	39.68
12:30	46.59	41.92	41.80
13:30	47.59	42.94	42.81
14:30	47.24	42.85	42.72
15:30	45.57	41.66	41.54
16:30	42.69	39.56	39.46
17:30	38.75	36.6	36.54
18:30	34.32	33.21	33.18
19:30	30.94	30.59	30.57
20:30	29.42	29.29	29.26
21:30	28.59	28.48	28.46
22:30	27.8	27.71	27.69
23:30	27.03	26.95	26.93



Graph B. The temperature performance of three different types of IRS attic spaces

5.2 Computer modeling – illumination

Simulations were done at four one-hourly specific times starting from 12.00 noon, 1.00 pm, 2.00 pm and 3.00 pm because these were times of abundance in solar radiation that brings in heat and light with it. Observations were made for four roof systems to compare the contrasting illumination. And out of the four hours it was observed that the most extreme is the reading taken at 1.30 pm. Due to the large amount of information generated, this paper only reports the two extreme conditions which is the readings taken at 1.30 pm. It was found that at 1.00 pm all the readings were high in illumination. The comparison is between the skylight for normal single sheet glass and the IRS with double polycarbonate (Figure 3).

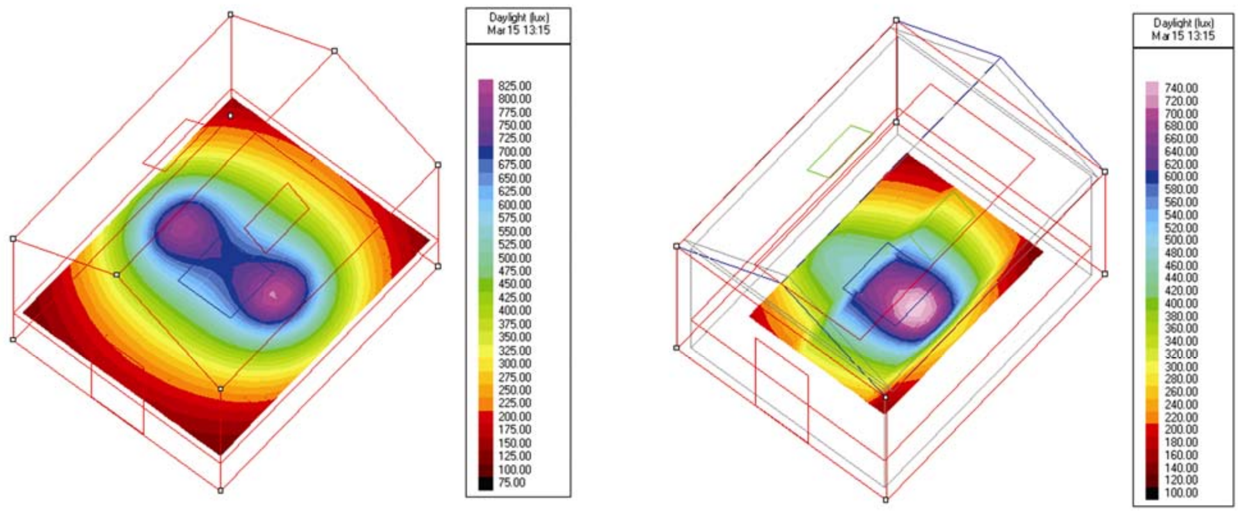
For both the configurations, the concentration of illumination is obviously in the centre of the room space because of the central glazing at the roof and ceiling levels. The legends in Figure 3 show the gradation of illumination from minimum (bottom) and maximum (above) and the recorded illumination for Skylight (clear glass) is a minimum of 100 lux and a maximum of 900 lux. The IRS (double polycarbonate) receives a minimum of 125 lux and a maximum of 800 lux was recorded. This proves that the IRS Double Polycarbonate is able to provide ample day lighting with reduced heat from the tropical sun. The IRS also met with the daylight glare control below 2000 lux. And all of this rely only on the passive design elements meaning that there are no mechanical aids or opened windows to cool the air temperature.

Graph C shows that the temperature in the attic is much higher than the room temperature for all the three designs (a, b and c) of IRS. A heated attic space would heat up the ceiling surface there by radiated infrared heat to the space below the ceiling. To further improved on the condition within the attic space it was suggested to introduce some form of air circulation to rid of the heated air mass in the attic.

In Malaysian climatic condition natural wind is unpredictable in its direction and also air velocity [27] So some form of device is needed to induce air to move out of the attic space. To rely solely on the existing turbine ventilator commonly found on roofs is not effective enough due to the characteristics of the Malaysian natural wind, i.e. the Malaysian wind is unpredictable, multi-directional and erratic in its air velocity. A Hybrid Turbine Ventilator (HTV) (Figure 4) is a concoction of a solar panel, turbine ventilator and an extractor fan would be more promising in aiding to reduce the air temperature of the attic [28]. A relatively cooler attic would logically lower the ceiling surface temperature thence the temperature of the room.

5.3 Proposed construction of the Innovative Roofing System

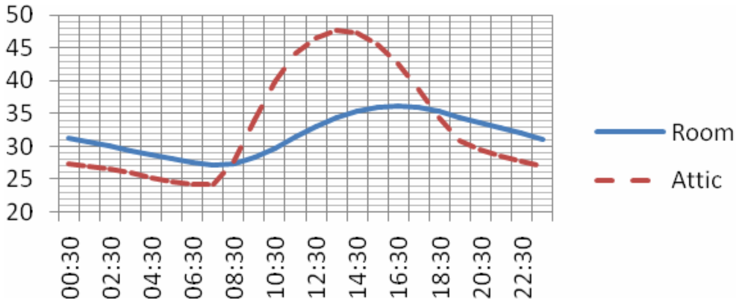
Finally the Innovative Roofing System (Figure 5) is the answer to utilize full daylight from the roof for tropical buildings. The attic space helps to trap the hot air and be dissipated with the help of the HTV and the visible light can now be useful to the people of the tropics.



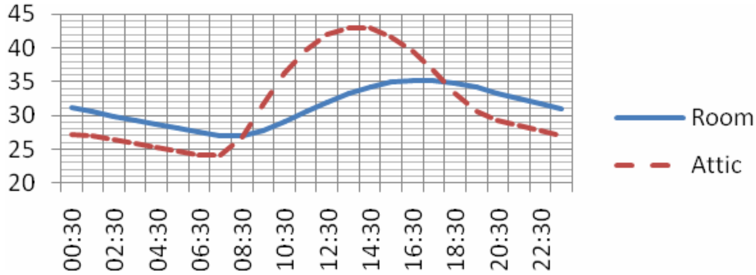
(a) Skylight: clear single glass
Legend: Bottom 75lux Middle 500lux Top 825lux

(b) IRS: all double polycarbonate
Legend: Bottom 100lux Middle 400 lux Top 740lux

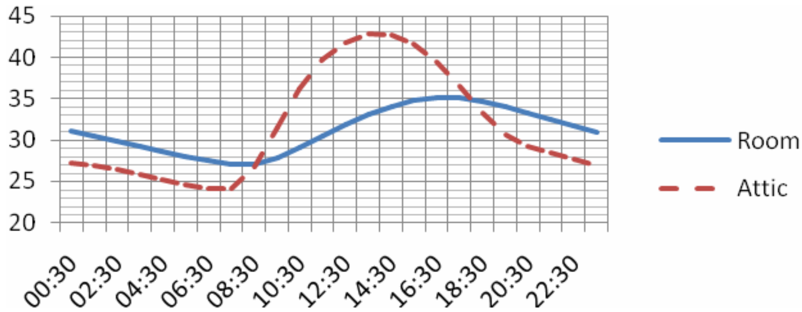
Figure 3. Illuminations at 50000 lux: (a) skylight - clear glass (b) IRS- all double polycarbonate



(a) IRS Attic – Roof (double polycarbonate)/Ceiling (double polycarbonate)/**No** Blackbody/**No** Reflective Material



(b) IRS Attic – Roof (double glass)/Ceiling (double polycarbonate)/ Blackbody / Reflective Material



(c) IRS Attic – Roof (double polycarbonate)/Ceiling (double polycarbonate)/ Blackbody / Reflective Material

Graph C. Comparison between room (single line) and attic (broken line) Temperatures (^oC) under three different IRS designs

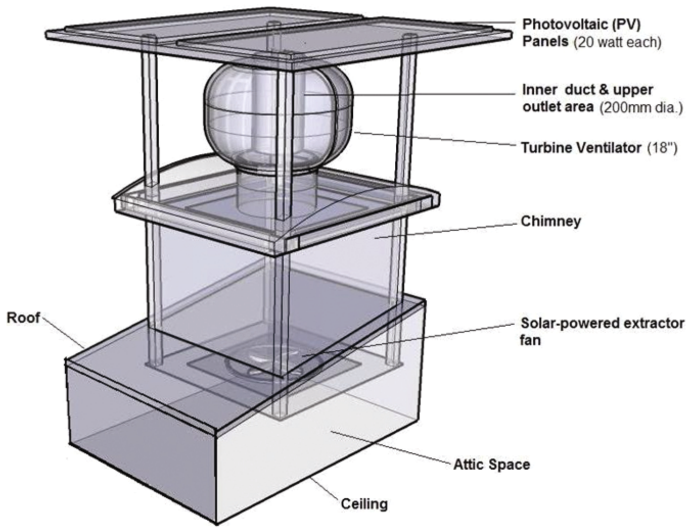


Figure 4. A Hybrid Turbine Ventilator (HTV)

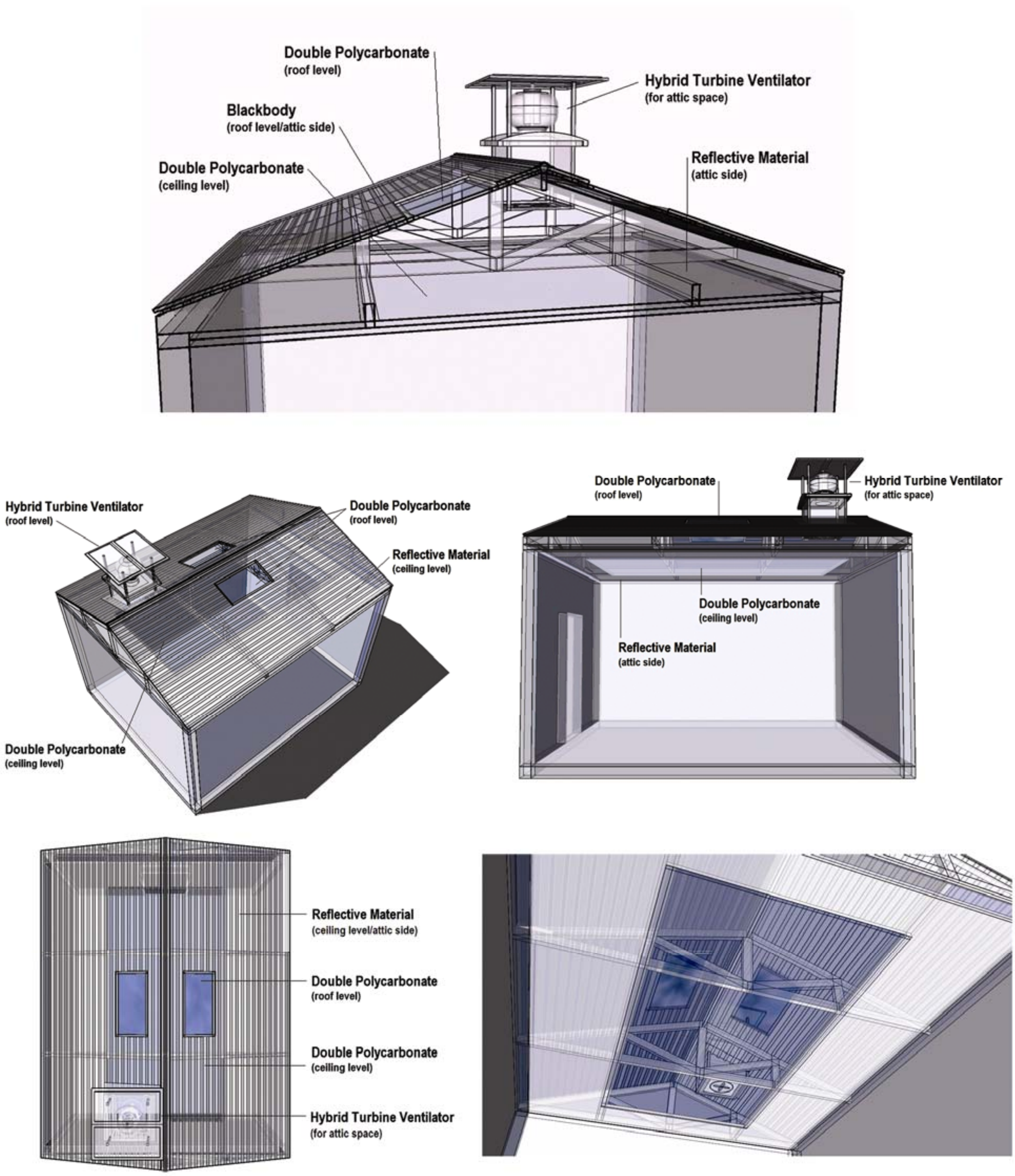


Figure 5. The Innovative Roof Structure (IRS) that separates heat from useful visible light

6. Conclusion

The above research findings show that it is possible to introduce generous and uniform amount of daylight from the roof as experienced in countries from the temperate climates except that some modifications have to be done on the construction of the roof, attic and ceiling. Getting natural light from above means that deep planning of interiors are now possible, commonly found in hospital designs where long and wide corridors, lobbies and waiting areas are presently artificially lit. Separating the heat from useful visible light was done within the attic space by using double polycarbonate for roof finish as well as for ceiling finish but requires reflective materials such as shiny aluminium or white paint and the concept of the blackbody for heat absorption of the infrared rays. To make the extracting of heat more effective installing the hybrid turbine ventilator helps to catalyse the heated air mass flow out of the attic

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space. The test bed nine specifications stipulated in section 4 are opportunities to be explored further by making adjustments to suit design conditions in order to achieve maximum results. As technology of glazed materials improved the design of the IRS can be simplified but for the moment this experiment has proven to be innovative for the tropical climate. This will also revolutionize the way architects design the tropical roof, externally as well as internally.

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Al-Obaidi K.M. received his Bachelor's Degree in Architectural Engineering at University of Sana'a in 2008. In 2011 he received Master's Degree in Building Technology from Universiti Sains Malaysia. Currently he is pursuing Doctoral Degree in Sustainable Architecture from Universiti Sains Malaysia. His research focuses on Climatic Architecture, Energy Efficient Design, Daylighting systems and Thermal analysis of construction materials.
E-mail address: karam_arc@yahoo.com

Ismail M. is a lecturer in Architecture at the School of HBP, Universiti Sains Malaysia (USM), Penang. He received his B.Sc (HBP), Bachelors in Architecture, M.Sc in Housing and Ph.D in Architecture (Energy Efficient Design) from USM. His main research interests are climatic responsive architecture, low energy ventilation technologies and thermal comfort studies in tropical building.
E-mail address: mazran@usm.my

Abdul Rahman A.M is an Associate Professor at the School of Housing, Building & Planning, Universiti Sains Malaysia, Penang. He received his B.A (Arch) (South Bank Polytechnic, London) 1980, B. Arch (University of Melbourne, Australia) 1984 and PhD Environment (University of Wales) 1995. He is also a Registererd Architect with the Board of Architects Malaysia (BAM), a corporate member of the Malaysian Institute of Architects (MIA) and a member of the Malaysian Green Building Confederation (MGBC) as a Green Building Index Facilitator. He has produced four books all pertaining to energy efficiency building designs for tropical climate and the main interest in research is in green building..
E-mail address: malik@usm.my