Evaluation of the Passive Cooling Strategies for Pei Min Sport Complex

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Abstract. This paper presents a modelling study on the evaluation of the passive cooling strategies for Pei Min sport complex at Miri. The squash centre has experienced excessively high temperature during peak hours that results in complains from the users. We discussed several passive cooling mechanisms and proposed four strategies for the sport centre. Thermal energy simulations were performed on these strategies using OpenStudio to evaluate their impact on the hourly temperature profile within the building. It was found that the peak temperature during the noon was significantly reduced when conductive material was applied at the lower surface of the roof, and the top of the roof was coated with white paint. However, insulating the roof also leads to weaker heat dispersion from the building which lower the rate of temperature drop in the late afternoon. Partitioning the roof was found to have similar effect as insulating roof. Air infiltration is essential for promoting air movement and regulating the temperature within the building. It was found the complex already have sufficient opening for the full effect of air infiltration.

1. Introduction
In today’s worldwide trend towards green energy, there is an increasing demand on the new or existing buildings in the commercial, industrial and residential sectors to be energy efficient. While new buildings can be designed to be energy efficient, meeting this requirement for old buildings is more challenging due to the building design constraints. For this reason, retrofitting or refurbishing existing buildings in order to minimize the building’s energy consumption is becoming increasingly common these day. Numerous study has reported significant reduction in energy consumption and added environmental benefit through proper retrofitting [6-8]. Invariably, refurbishing and retrofitting building has seen intensive research recently that result in numerous development of effective modelling approaches [e.g. 1-3], and strategy, as summarised in these recently published review articles [4-5].

The main challenge faced in retrofitting of existing buildings are the numerous uncertainties that needs to be considered, such as the building design, climate change, human behaviour change, government policy change, etc. In addition, large building generally has extended layout design with a complex network of subsystems that are highly interactive. Dealing with the uncertainties and theses system interaction causes the selection of retrofit technologies becomes very complex. On top of the technical challenge, there are the financial limitations and payback period that needs to be considered. Consequently, in the early stages of a retrofitting studies, integrated approach that can combine the all

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essential components of a building (building information, energy balance, and economical analysis) is increasingly becoming a necessity in order to effectively size the influence of various refurbishing measures [e.g. 9-10]. There is already various modelling software of this kind been developed. The assessment on the pros and cons of these software was conducted recently [11]. OpenStudio is one of the few building simulation software that is open-source, and is capable of performing energy simulation, and design optimisation [12]. It is employed here to evaluate the performance of the proposed passive cooling strategies in reducing the heat problem experienced at Pei Min Squash Court in Miri.

2. Problem Statement
The squash centre in Miri have a gross area of (25000 × 45000) mm². Inside the complex, it has nine squash courts, one admin room, one activity room, two toilets and one sports equipment. Each squash court that includes a wall partition had a dimension of (10000 × 6600) mm². The material of the roof is corrugated sheet made from galvanized steel, and the wall is brick concrete. The unusual high temperature inside the squash court during the afternoon period have led to constant complains from the players. There are several factors that contribute to the overheating in the centre:

- Miri experiences hot and humid weather annually, especially during the dry season that happens from March to September where the volume of rainfall is significantly lower, as shown in Fig. 1.
- The high sunlight intensity during dry season that increases the radiation heat on the surface of sport complex, coupled with the conduction and convection of heat into building environment cause the increase of the temperature
- The lack of proper and efficient ventilation results in heat being trapped inside the complex.

The management had proposed to installed two air-conditions in two enclosed squash court for competition usage. However, the remaining squash court without air-conditioners will require alternative low-budget solutions. The solution should effectively reduce the temperature within the centre which will increase the thermal comfort of the players. The ease of the implementation is another important factor that needs to be considered. Complex equipment generally leads to higher implementation cost.

Figure 1. (left) The daily average low (blue) and high (red) temperature. (right) The fraction of days in which various types of precipitation are observed. [15]

3. Passive Cooling Mechanism
3.1 Solar Reflective Insulation
Solar reflective insulation is a barrier material which resists/blocks/reflects radiant heat energy to prevent its transfer through the boundary between two spaces which are at different temperatures. Radiation transfers heat via invisible electromagnetic wave. When sunlight is shined on a roof, the roof absorbs a portion of the radiation heat and reflect the rest back into the atmosphere. Since the roof itself emits radiation heat, the amount of radiation absorbed by the roof depends also on the radiation emittance of the roof. A good reflective material should have high reflection, high emittance and low
absorption rate. Cool Roof Rating councils introduced the following definitions for evaluating the reflective performance of roof:

- Solar absorptance, which refers to proportion of the overall solar radiation incidence that is absorbed by the material.
- Infrared emittance, which refers to emittance of heat of the material in form of infrared.

The level of the absorptance and emittance depends on the colour coating of the external surfaces, surface roughness, and the thermal properties of the material. As shown in Fig. 2, light colour coated material such as the white plaster and white paints have both high reflectance and infrared emissivity. Aluminium foil has high reflector but low emissivity. Dark asphalt has good emissivity but very poor reflectance.

![Figure 2. Spectral characteristics of building materials. [13]](image)

### 3.2 Thermal Conductive Insulation

Thermal insulation involves the use of a material or combination of materials that has low thermal conductivity for reducing the rate of heat flow in and out of a building. These materials are often placed near to the surface of the heat entry. There four type of insulations as shown in Fig. 3. The selection of these materials depends on several factors, i.e. the durability of the material, safety reason, the environment impacts, and the cost to benefit ratio. For instance, fibrous materials such as glass wool fibres may not be an ideal choice for building with high humidity because the thermal conductivity of the material increases when its moisture content increases. On the other hand, organic material such as polyurethane, have low moisture absorption rate, are cheap, and have high thermal resistance, but emits chlorofluorocarbons (CFC) over its life cycles which has detrimental effect on the ozone, and also have higher flammability index.

### 3.3 Air Infiltration / Natural ventilation

Temperature difference between the indoor air and outdoor air causes the pressure difference across the building envelope and moves air in and out from the building through the openings. Depending internal structure of the building, and the climatic condition, air movement can reduce the temperature and moisture level inside the building, and improve the thermal comfortability of the occupants. Ignoring the internal structural resistance, wind speed of 2.5m/s or less can generate an exterior wind pressure of 1 or 2 Pa, and higher speed of 10m/s can generate pressure of 25 Pa or more. In addition to the natural ventilation, the operation of mechanical equipment, ventilation systems, and local exhaust fans further influences the net flow of air into and out of the building.
4. Solution Strategy
The cooling mechanisms discussed in the previous section was employed on the sport complex. Four scenarios were created as listed in Table 1. Case A considers a layer of thermal conductive resistance material (glass wool with thermal conductivity of 0.04 W/mK) overlain with a thin layer of aluminium foil to be installed underneath the roof of the sport complex to reduce the heat transfer from the roof into the building. Three thicknesses in the range of 0.1 to 0.3 m will be considered to evaluate the effect of the thickness. Case B considers white paint (solar absorptance of 0.1) to be included on the roof as the solar radiation reflector, in addition to the installation of the insulation material in Case A. Case C considers the roof to be partitioned using a layer of wooden platform in order to create a closed airspace between the roof and the inner section of the building, as shown in Fig. 5. The airspace functions as thermal insulation in addition to a layer of glass wool on top of the wooden platform. Lastly, Case D considers the size of the openings that exists in the original building to be increased by 25%. The purpose is to investigate whether enhancing the air movement within the building can reduce the temperature in the building.

Table 1. Evaluation of passive cooling strategy for the sport centre

| Scenario | Description |
|----------|-------------|
| Case A   | Insulation materials (glass wool) overlain with aluminium foil are installed underneath the roof. Three thickness are considered, i.e. 0.1m, 0.2m, and 0.3m. |
| Case B   | In addition to the installation of the insulation material (0.1m) underneath the roof, white reflective coating is painted on top of the roof. |
| Case C   | The roof is partitioned by installing thin layer of wood. A layer of insulation material and aluminium foil is placed on top of the partition. |
| Case D   | The opening at the wall is increased by 25% to increase the rate of infiltration. |
5. Thermal-Energy Simulation

The strategy outlined in previous section was evaluated using OpenStudio, a building energy software that is derived from EnergyPlus (released by National Laboratory of the U.S. Department of Energy) for performing thermal and energy balance simulation on buildings. OpenStudio employs heat balance-based solution of radiant, convection and conduction effects to determine the temperature, and thermal comfort of thermal zones prescribed in the buildings. In addition, the solutions take into account the weather effect that includes the solar radiation, daylight illuminance, and precipitation, in addition to the standard parameters of temperature, humidity, pressure, wind speed and direction. Therefore, sub-hourly interaction between the thermal zones and the environment can be modelled.

The following steps have been taken in the process to obtain the energy consumption and thermal behaviour of the sport complex:

i. A 3D computer model of the sport complex was created using SketchUp according to the dimension given in the layout plan.

ii. The model is then imported into the OpenStudio for the thermal energy balance analysis.

iii. A thermal zone was created for the airspace inside the building. Since all the courts and the majority of the vacant space share the airspace, only one single thermal zone was created.

iv. The thermal properties of the components of building (roof, and wall) and number of occupants was assigned.
v. The weather file of Brunei Seri Begawan (the location nearest to Miri that is available in the database) in 2015 was incorporated into the model. One of the hottest days in 2015 (22-May-2015) was selected. The peak temperature reaches 33°C and the average wind speed was low (7 km/h).

vi. Simulations were performed to predict the hourly temperature profile inside the building. Various cooling strategy discussed was implemented into OpenStudio and the predicted hourly temperature profile was compared.

6. Result & Discussions
Fig. 6(a) shows that the temperature in the original building rises steadily from 6am until it reaches the peak of 34 °C at 2pm on 22 May 2015. The temperature drops thereafter to 30 °C at 8pm. Since the peak usage hours of the sport centre is between 2pm and 8pm, the discussions on the result will be focussed on this period of time.

The result of case A is shown in Fig. 6(a). The installation of thermal insulation under the roof was able to reduce the overall temperature and most importantly, the peak temperature at noon by approximately 1.5 degrees. Unfortunately, the installation of insulation also allows the building to retain the heat better and therefore reduce the rate of temperature drop after the peak at 2pm. As a result, no significant temperature reduction was observed from 2pm to 8pm. Increasing the thickness twice or three times unfortunately does not yield any significant temperature reduction. The insulation of 0.1m is sufficiently thick for maximum conductive insulation.

Fig. 6(b) shows the result of the Case B. By coating the roof with white paint, the temperature is further reduced. The temperature was significantly reduced in the period of 12pm to 4pm, where the peak temperature was decreased by approximately 3 degrees to 31 °C. Similar to Case A, temperature reduction is lesser after 4pm due to the heat retention by the roof insulation. The effect of partitioning the roof into closed airspace insulation produces similar effect as the installation of insulation underneath the roof. As shown in Fig. 6(c), the predicted peak temperature was reduced by approximately two degrees. The temperature reduction also become lesser after 4pm due to heat retention in the roof partition. Since installing roof partition incurs greater cost but does not yield any significant improvement, Case B is more favourable approach.

Lastly, the result on the effect of infiltration was (case D) shown in Fig. 6(d). Opening was shown to be essential for cooling the building. If the opening in the original design was closed, significant temperature rise was predicted. However, the original opening size was sufficient because increasing the opening size by 25% does not yield much difference to the temperature.

7. Conclusion
This work presents a modelling study on evaluating a set of passive cooling approaches for Pei Min sport complex using OpenStudio. The proposed approaches are based on thermal conductive insulation, solar reflective insulation, air space insulation and air infiltration. The following conclusions were made:

1. The effective cooling was achieved when glass wool and aluminium foil was installed at the lower surface of the roof and the top surface of the roof is coated with white paint. The peak temperature was reduced by three degrees using this method. However, insulation also retain heat better which lower the rate of temperature drop in the late noon.
2. Partitioning the roof into closed airspace for thermal insulation yields the same impact as installing thermal insulation at the lower surface of the roof.
3. Air infiltration is essential for regulating the temperature of the building and the air movement within the building. The sport complex already has sufficient opening for the full effect of the air infiltration.
Figure 6. Prediction on the temperature profile within the squash centre with various passive cooling strategies on 22-May-2015 using OpenStudio, (a) Case A, (b) Case B, (c) Case C, (d) Case D.

8. Reference
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