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Energy transitioning school buildings in Peninsula Malaysia: A case study on the potential of photovoltaic power

N M Alwi[1, *], J-F Flor[1], N H Anuar[1], N N H Hanafi[1], N H Muhammad[1], M H K M Zain[1] and M R M Nasir[1]

[1] Architectural Technology and Management Research Group, Department of Architecture, Faculty of Architecture & Ekistics, Universiti Malaysia Kelantan, Bachok Campus, 16310 Bachok, Kelantan, Malaysia
*Corresponding author: najah.ma@umk.edu.my

Abstract. This study builds on the ways design modifications can improve the integration of solar electric generation in Malaysian educational buildings. The study suggests the benefit of a solar installation at a standard school as both an educational and economic opportunity for a photovoltaic (PV) system can bring together classroom learning and energy supply. In analysing the existing design details of selected case study schools, this study aims to determine how the integration of this technology in the building design can be applied to the most basic education buildings in Malaysia. The existing design patterns of school classrooms with and without PV systems were logged and examined through a series of post-occupancy evaluation studies on selected schools. Basic energy requirements were summarized, and specific design modifications for the existing case study schools were proposed to adapt to the newer, modern classrooms. The results of this conceptual evaluation, coupled with energy simulations to model a reference case energy usage, provided the basis to predict PV outputs and future energy use for a modified classroom. Positive results from the solar analysis provided additional evidence about how alternative energy sources are beneficial in long term future-proofing schools.

1. Introduction

Why Green Technology in schools? There are strong reasons to believe that learning environment are one of the best places to start accomplishing sustainable development goals, such as the implementation of renewable energies. This study looks specifically at the potential of photovoltaic (PV) and aligns with the Malaysian government target of achieving 20% power generation capacity for renewable energy by 2025. Schools and educational buildings are prime places for renewable energy transition as they will continue to form a significant part of the local community while also representing powerful sources of transformation for an open mindset towards green technology. For these reasons, it is imperative that to achieve the wider aims of the Sustainable Development Goals, the continuous upgrading, renovation, and refurbishment of the local school is recognised as also being vital in rebuilding and generating communities towards a climate-responsive living [1,2,3].

As schools and education systems shift towards technological advancement of the 4th Industrial Revolution, it is implied that instead of traditional classrooms, there will be more flexible use of space to incorporate workstations-cum-computer laboratories -cum-self-study areas in a single classroom. Information technology introduced into schools promotes individual learning and a closer link with the community [4]. However, we must ask how ready are current classroom designs in Malaysia for

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integrating technology within the learning environment, and how are we going to power them? Depending on the capacity of users and allocated numbers of computers within a classroom. This development does however create greater dependence on electricity. Furthermore, electronic equipment will emit heat, which in tropical climates, only adds to existing problems of thermal discomfort. Based on [5] a set of equipment, including computers, projectors, lights, and fans, used for a typical day in a classroom leads to an estimated energy demand of 2311.18 kWh per year for a single classroom. Being a country with abundant sunshine, a high amount of diffused solar radiation is easily attained in Malaysia. Previous research estimated an energy output for ideally orientated grid-connected PV systems of around I200-1300 kWh/kWp annually [6]; meaning that renewable energy could significantly contribute to the required energy demand for the technological upgrading of Malaysian schools, and with more efficient state-of-the art PV panels even become a power generating hub for the local community [7].

Efforts such as Green Schools Campaign by the Association of Independent Power Producers in Malaysia (Penjana Bebas), with its partner Ministry of Energy, Green Technology and Water (KeTTHA) from years between 2009-2014 have had thirty-eight schools all around Malaysia equipped with PV Panels. However, official reports that the focus had remained only on selected grid-connected schools due to the PV system being supplied consisted of only 5 kW systems. This incentive still excludes most schools just outside urban grids, and even discriminating for more in the poorer, rural areas where education is difficult. Energy poverty in relation to learning performance under uncomfortable thermal conditions is another issue to be cited to underpin the importance of powering schools with renewable energies [8,9].

In emerging economies of tropical countries, cooling for the building is one of the prominent concepts and fast-growing in waste-energy for buildings to minimise power consumption. Over the last few decades, electricity usage for cooling in buildings across the region has increased drastically. Although not inclusive to all areas, until now, only 15% of households in Southeast Asia have air conditioners, showing the remarkable ability for further growth in major markets. Studies predict that by 2040, the future of cooling in Southeast Asia will investigate the increase in demand in energy consumption, peak electricity demand and CO2 emission, and lays an alternative scenario that policy drives industry transformation to produce more efficient air conditioners. A sustainable development scenario and more robust policies can address the efficiency of cooling equipment and buildings, which can lead to as much as 110 TWh savings by 2040 [10]. However, whatever the scenario is, it will likely include the integration and repowering of existing building stock with solar electricity generating technologies [11]. Schools may play an important part in that development.

Therefore, this research study asks: is it possible to use renewable energy as a source for school buildings to supply the basic energy demands for a modern classroom and comfortable learning environment? This study hypothesises that most existing schools can be retrofitted with modern green technologies. However, infrastructure criteria must be met, and simulation must show comparable data about energy usage in the current and the future predicted consumption of energy. Consequently, the objective of this study is to evaluate the materials, layout and tropical architectural features of existing standard national school buildings and their capacity to adapt to future energy and climate demands. This can be achieved by developing a basic classroom model with modifying elements of PV design schemes with appropriate sizing through software simulation.

2. Methods

The methods used in this study include empirical and theoretical approaches. Firstly, a post occupancy evaluation (POE) [12] was conducted to identify internal and external elements of existing architecture and the surrounding built environment that might have a direct influence on implementing PV. Then the results of the POE Observation on design and conditions were modelled to predict with simulation tools its daily energy usage, changes of heat loss and gain throughout the day. From this base-model, other model variants were generated and used to test the effect of selected design elements. The process of analysis consisted of the following steps:

- Empirical and observational data collection.
- Formulating base classroom and selected variables for the simulation process.
- Determination of parameters of interest, simulation tools, and simulation outputs.

The analysis of a photovoltaic system implementation tested on simulation program will determine if the integration of this technology as part of the building design is sufficient to assist with supplying future energy requirements. Inferences and conclusions will be made upon the possible design enhancements and modification that could be applied to Malaysian standard design schemes of future schools. A workflow diagram is shown below in Figure 1:

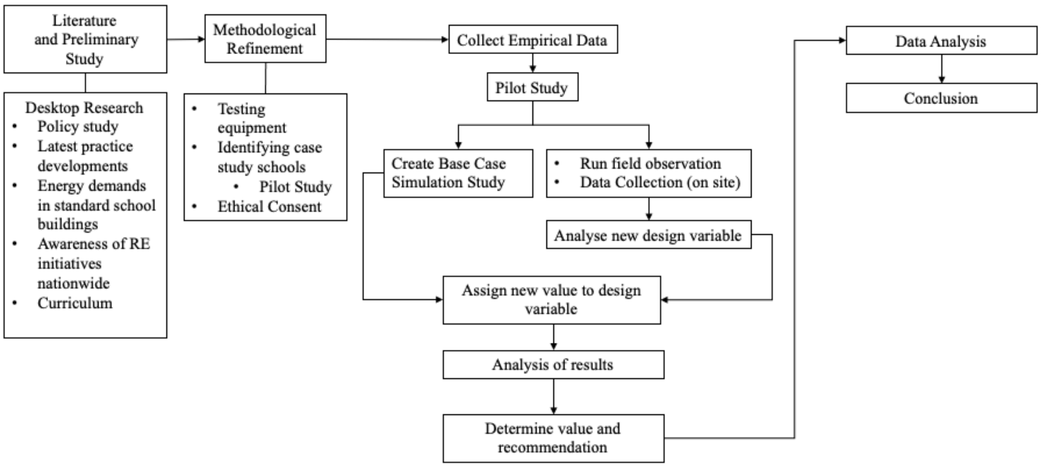


Figure 1. Workflow diagram of applied methods.

2.1 Selection of case study schools

The field study took place in two public schools in Petaling Jaya, Malaysian state of Selangor. The dual case study allowed to observe and compare how the design features of standard school design correspond with the different context of climatic and environmental aspects of each location. The schools were selected according to the following criteria:

- Operated and registered as national public schools under the Ministry of Education of Malaysia.
- Built accordingly to the Public Works Department (PWD) standard plans set in 1960.
- All daily classrooms in selected schools are naturally ventilated rooms with ceiling fans to assist achieve thermal comfort for occupants.
- School selected also includes classroom utilised as computer labs for "smart school" learning programme endorsed by the government. This criterion is important to see how widely computers are used within current classrooms.
- Operational schedule from 7.30 am to 6.00 pm with occasional extra curriculum activity.

2.2 Observation and post occupancy evaluation

The field studies were carried out for 1-2 weeks days between January and March. All classrooms selected for data measurement in each school was done at the same time as observations were taking place. This Post Occupancy Evaluation (POE) is concerned only with a focused area of the study which is the classroom measurements. Information such as the floor layout, ceiling height, ceiling. plan and existing locations of the window and door openings, as well as the location of artificial light in classrooms, are recorded. The investigated parameters during the field study are listed in Table 1 showing the outdoor and indoor data collected.

Table 1. Parameters for outdoor and indoor of data collection on case study site visits.

Outdoor Data Collection	Indoor Data Collection
Building orientation	Classroom dimensions
Building Form/Shape	Daylighting features
Percentage of glazing	Artificial lighting
Orientation of openings	Placement & type of light bulbs
Shading solutions	Lighting control, manual/sensor
Colour choice of surfaces	Type of ventilation
Landscaping	Wall materials
Percentage of greenery	Ceiling materials
Materials choice of surfaces	Colours and finishes
Covered and uncovered spaces	Internal climate
Ambient climate	Temperature
Ambient temperature	Humidity
Ambient humidity	Light intensity

2.3 Simulations

As solar energy depends on solar irradiation in a particular zone, correct and accurate information from the sun, seasonal changes of the solar energy and the amount of solar energy received from the sun are necessary to be evaluated and the basic parameters of the solar energy system are needed to be as accurate as possible. Together with the collected site data and detailed climate data a base-case classroom simulation can determine if the integration of this technology as part of the building design was sufficient to assist with supplying future energy requirements for a school in the Malaysian climate.

2.4 Limitation of study

This POE study solely focused on the classroom as a base case to sample standard Malaysian classroom size measurements. The intensity of designing and running simulations with time constraints allowed only for a partial set of design features of the school building to be isolated and analysed by simulation. Ideally, future work would include different types of photovoltaic systems (PVS) and other standard spaces of the school complex (i.e., corridors, the assembly hall) to further investigate the possible integration with renewable technology.

3. Results and discussion

The following sections presents the findings from the POE and discusses the results of the simulations. Subsections further elaborate on how vernacular bio-climatic responsive design, assisted by renewable energies might be a pathway for Malaysia to achieve net-zero buildings in the public sector [13, 14, 15, 16].

3.1 Findings from case-study site analysis

This section presents the findings of the site visits, presenting observations from schools Sekolah Menengah Perempuan Sri Aman and Sekolah Rendah Kebangsaan Kampung Tunku, denominate case study A and B, respectively. Both schools are in Petaling Jaya, Selangor, Malaysia at approximately 3°1'N, 101°6'E. Figure 2 shows the site layout and buildings of the case study schools.

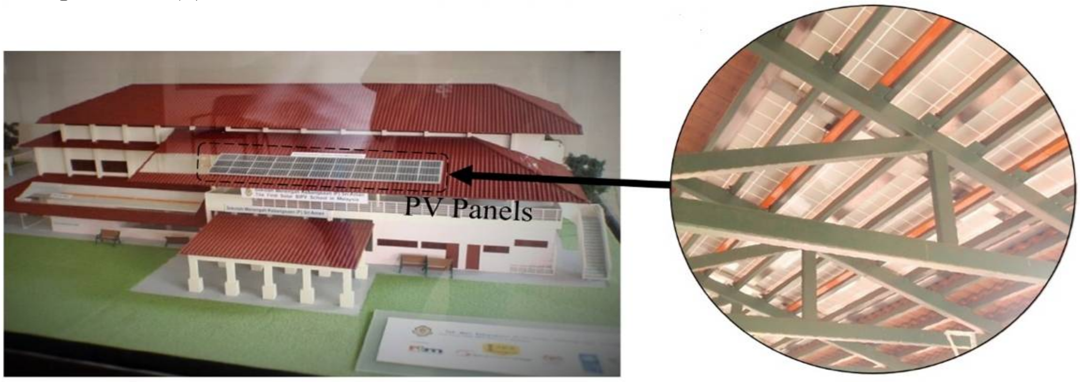
Case study A. Sri Aman Secondary School for girls (Sekolah Menengah Perempuan Sri Aman) was built in August 1971. The school is located within the suburban district area bordering Kampung Tunku and Section 14, in one of the oldest towns in Petaling Jaya, Selangor. At the time of the site visit the built area of the school was approximately 25% of the overall site, with a total site and roof area of approximately 36293 m² and 9279 m², respectively. Approximately one third of the school grounds were covered with shrubs and trees, assisting with keeping school grounds shaded. Landscaping in between the building blocks were good indication of means to control the temperature down from entering the building. Hard and impermeable surfaces were only found in the main school access.

(a) (b)

Figure 2. Case study Schools: (a) Sekolah Menengah Perempuan Sri Aman, (b) Sekolah Rendah Kebangsaan Kampung Tunku.

The building design and layout, comprising both new and old and building structures, retained the rectangular shape approach for most classroom blocks with windows and openings oriented along the North and South axis. The main hall and administration blocks, however, were orientated along the opposite axis, with extended roof overhangs and larger areas of veranda on the east side. Basic measurements showed that both classrooms have a higher internal temperature than outside temperature starting at about 10 am and peaking in the late afternoon.

It is also worth mentioning that this school was one of the first to host a Photovoltaic Roof System in the newly built administration, which was installed in 2008, with currently six panels of 1.2m X 1.5m with 4.5kW of photovoltaic cells mounted on the roof of the administration building. Figure 3 (a) shows a picture of an architectural model of the school with the PV, which were identified during the site visit, shown in picture 3 (b).



(a) (b)

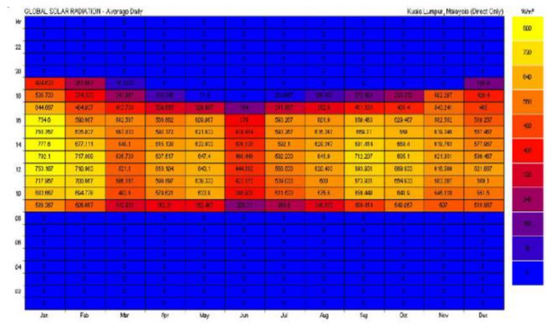
Figure 3. Scale model of a public school in Petaling Jaya (a) with the proposed PV roof, and a close-up picture (b) showing the installed panels on-site [4].

Case study B. Sekolah Rendah Kebangsaan Kampung Tunku is also located in Petaling Jaya, Selangor, in a neighbouring district of case study (a). The school operates with 36 classrooms with an average of 30-40 students per each class and currently runs two-session operational times to accommodate student from a high number of students aged from 7 to 12 years old. The school's total site and roof area is approximately 22489 m² and 4393 m², respectively. Building blocks are laid out according to the set standard plan, keeping the rectangular shape, with the main facades oriented to face north and south with window openings only on both north and south according to the climatic requirements. Only 40% of the building façade were covered with glazing to allow some natural ventilation through the glass louvered shutters.

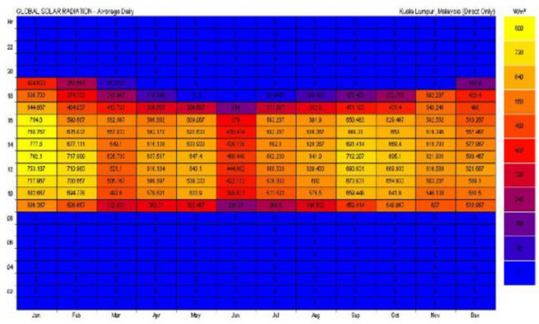
Similarly, to case study (a), this school also demonstrated unsatisfying thermal comfort conditions regardless of where classroom where situated. Internal temperature continued were much higher than the outdoor temperatures. In addition, school (b) has no special architectural features installed to assist with passive cooling. Despite allocated areas for water features in the middle of the three main school blocks and towards the rear exit, none of those were used or maintained to its potential to assist with cooling the environment. It was observed, however, that the shrubs and trees alongside the East and West side of the schools provide some shading.

3.2 *Solar radiation exposure*

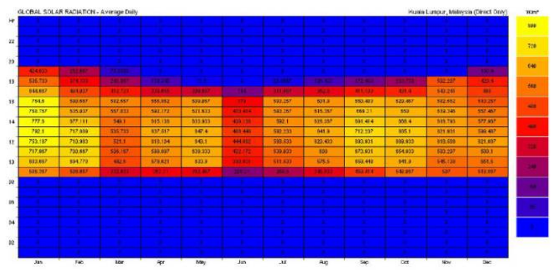
To estimate the potential for powering the schools with solar energy, available solar radiation was estimated through plotting daily average global solar radiation for different roof orientations. Meteorological data for Kuala Lumpur, under clear sky conditions was used for this calculation. The results showed that, in the equatorial belt where Malaysia is located, if the roof pitch of the buildings does not exceed 45 degrees, the global incidence level for roof surface for each orientation will not differ very much as illustrated in solar radiation analysis below. However, the direct solar incident radiation, is slightly more prominent in the East and West orientation. This can be seen in Figure 4 (a), (b), (c) and (d).



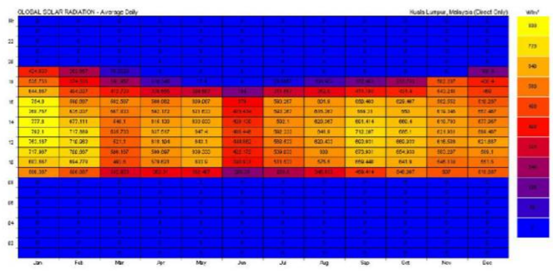
(a)



(b)



(c)



(d)

Figure 4. Global solar radiation charts showing in (a) North orientation, (b) South orientation, (c) West orientation, and (d) East orientation.

3.3 *Photovoltaic potential*

A simple estimation for the required energy for the base classroom is illustrated in the calculation below evaluating the base model's potential for harnessing solar power and generate enough to sustain its daily required needs. The minimum PV area obtained from the calculation was the fitted onto the simulation model to test effect of orientation roof axis in all four directions. The assumed values for the calculation are listed below in Table 2:

Table 2. Assumed parameters for calculating minimum PV area.

PV Module Size [m^2]	PV Peak Power [kWp]	PV Energy Output [kWh]	Av.Solar Radiation [kWh]	Energy Demand [kWh]
1.277	0.185	0.9435	5.1	6.332

**Note: The assumptions are based on a 1.58 x 0.808 m PV module from Rigin (SCO155) ET M572185 with Pmax of 185 Watt-peak (Wp) normal operating cell temp. of 44.4°C +- 2°C*

The calculation for the minimum PV area and number of modules require to meet the power requirement for a single classroom was done using equation (1) below:

$$Power\ Requirement = \frac{Estimated\ Usage\ in\ a\ Day\ (kWh)}{Estimated\ Energy\ Output\ PV\ (kWh)} \quad (1)$$

Where the power requirement for each classroom equals the estimated electrical power usage per day in kilo Watt hours divided by the estimated energy output of a single PV module. The result showed that a minimum of seven panels, equalling 8.93 m^2 of roof coverage, is required as per the above assumption in Table 2 to power a basic classroom with the expected loads for a future proof learning environment.

3.4 Integration of photovoltaic in school buildings

The results of the building simulation integrating PV modules provide evidence that solar availability under Malaysia's climate condition is sufficient to generate enough electricity to meet demands of a basic classroom model. The required minimum PV panel area of 8.93 m^2 represents only 7% of the total 133 m^2 of roof area of the investigated base model, of which half, 67 m^2, could be theoretically equipped with a much larger PV system, for as in practice, a typical school block will have several levels of classroom underneath the same size roof. By integrating these panels onto the roof, it also effectively shades the roof underneath the PV area, reducing solar heat gains. Figure 5 (a-d) shows the simulation results for a minimum area of PV coverage for different roof orientations.

4. Conclusions

This paper investigated the potential of photovoltaics as a strategy for retrofitting public schools in Malaysia with renewable energy to power the electricity demand of state-of-the-art learning environments. The study found that minimal adaptations to roof structures and to correct selection of roof orientation can provide the conditions to install enough PV modules to supply the required demand of standard classrooms. The study also found that installed PV contribute to shading the roof and reducing solar gains, which ultimately help to improve thermal comfort conditions of internal spaces. Factors related to cost for construction adaptation and PV panels are pinpointed as important barriers, along with the lack of awareness of the benefits of passive design and renewable energy and how current prevailing construction methods fail to address sustainability. A growing number of electrical devices in modern classrooms was also highlighted as a factor that increases energy demand. Although energy-consuming devices such as laptops, monitors, and lights are more energy efficient, the real challenge is to compose a design for a self-sustaining learning environment that is flexible for future challenges.

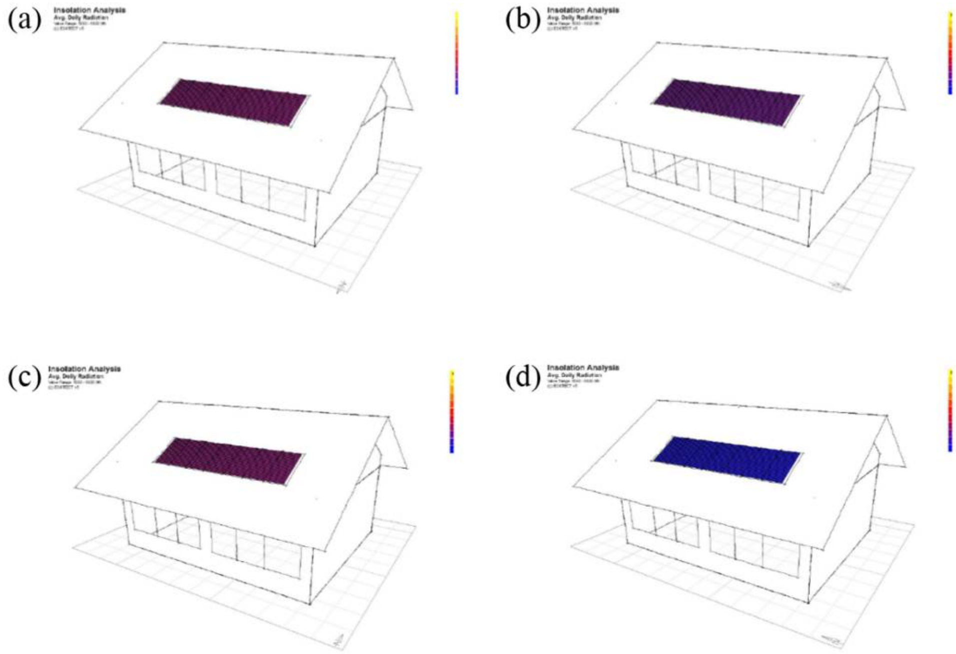


Figure 5. Average hourly solar radiation for (a) PV on North axis, (b) PV on East axis, (c) PV on South axis, and (d) PV on West axis.

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