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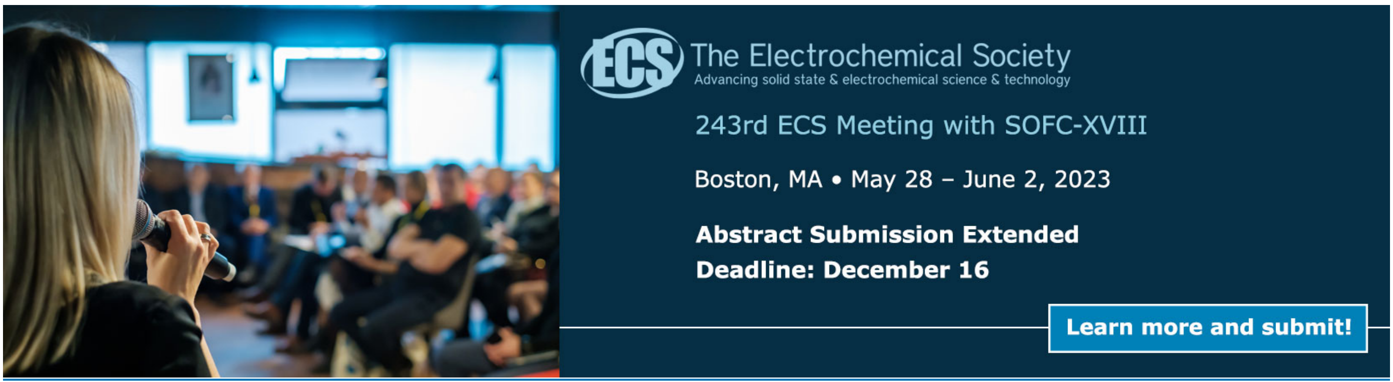

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Retrofitting measures for climate resilience: Enhancing the solar performance of Malaysian school buildings with passive design concepts

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Abstract. Climate-sensitive school buildings can enhance students' learning performance and reduce the building's overall energy consumption. This paper reports on a post-occupancy study of contemporary school buildings in Malaysia, assessing problems of solar heat gain. The research aims to propose retrofitting measures based on passive design principles adapted specifically for the Malaysian tropical climate to strengthen the resilience of local school buildings in a global climate emergency. On-site measurements in two different schools provided the empirical basis for the design modifications. The monitoring procedure included site observations, extended temperature and humidity measurements, and daylight analysis. A virtual classroom model was generated based on the on-site measurements, and a parametric simulation study was conducted to evaluate the proposed retrofit measures' effectiveness. The model variables were evaluated and compared to identify the passive design elements that significantly impact heat gains and thermal comfort. The results showed that increasing roof overhangs to 1500 mm for additional shading, sensitive selection of roof materials and colours of white-painted zinc roof, and reduction of window-to-wall ratio by 30% to the operable windows helps to reduce solar gains by 6% to improve comfort conditions within the classrooms. Overall, the study provided evidence of how passive solar building design would benefit the climate resilience of Malaysian schools.

1. Introduction

This study investigates the nature of Malaysian school design and the initiatives for embedding sustainability in its development. Arguments presented in the study is intended to evaluate quality of standardised design schemes for existing classrooms and review retrofitting measures that can improve thermal performance without adding increase to energy consumption levels.

The classroom being the basic and most important unit in a school building is easily the primary space for thermal comfort and energy consumption. Classrooms are unique and different from other designed spaces for schools, due to higher occupancy and prolonged periods of use. Special attention is needed when addressing aspects of ventilation and comfort for effective learning environments [1].

Bingler et al. [2] suggests that schools should be designed to make the most of existing natural resources. The environment the school is in will be a part of a child’s development, especially in a hot and humid climate these external factors will influence the level of energy consumption needed for the design to perform its function, mostly aiming to provide the level of comfort for efficient learning. The

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high humidity level and diurnal temperature all year long will require specific design approaches in both passive and active [2].

While good lighting conditions with abundant natural sunlight is a basic requirement for productive learning environments, in tropical climates, however, daylight contributes to unwanted heat gain in the classroom [3]. Projection and screens do not like glare or high levels of lighting and is fast becoming part of modern educational tools must also be within the design consideration. There is a need for darker classrooms when these electronic devices are in operation. Keeping daylight out can mean reducing natural ventilation for cooling. The increase of energy consumption within a building is largely due to maintaining a cooling/heated environment to achieve the optimum productivity for the intended space [4, 5].

In Malaysia, school buildings are one of the few building types that have traditionally relied on a combination of cross ventilation and mechanical ventilation by electrical fans to achieve thermal comfort. Climate-sensitive buildings for Malaysia are structures purposely built by integrating features that limit heat build-up, allow natural cooling, and reduce the need for artificial lighting in its use, overall promoting less consumption of energy in building performance [6]. The Sekolah Lestari Environmental Award Program, introduced by the Department of Environment (DOE) Malaysia in 2005, was the first stimulus for recognising a school's potential for promoting environmental stewardship; a programme consisting of management and curriculum initiatives that are consistent with the sustainable development of schools globally [7]. Nevertheless, despite the continued attention of Malaysian legislators and the government, the question still stands as to whether societal Malaysia needs further recognition of climate-responsive architecture to progress beyond a simple "green" concept idea. There are strong reasons to believe that the learning environment is one of the best places to start accomplishing the ideas of environmental sensitivity and responsibility.

The study expects to contribute evidence of design issues in existing methods of planning and construction of classrooms. New buildings are currently designed and executed without consulting the performance of older surviving buildings, its reaction with the environment or how it has managed to cope with ever-changing construction technologies.

2. Methods

This study is concerned with assessing the climatic performance of existing design features used in constructing school classrooms in the Malaysian climate. Two different methods of analysis that involved measuring conditions in existing buildings and predicting the performance of alternative solutions are used in this study. The methodological steps toward achieving the objectives of this study are shown in the flowchart in Figure 1. A detailed description of the individual methods, case study buildings, measurement equipment and simulation tools are presented in sections 2.1 to 2.4.

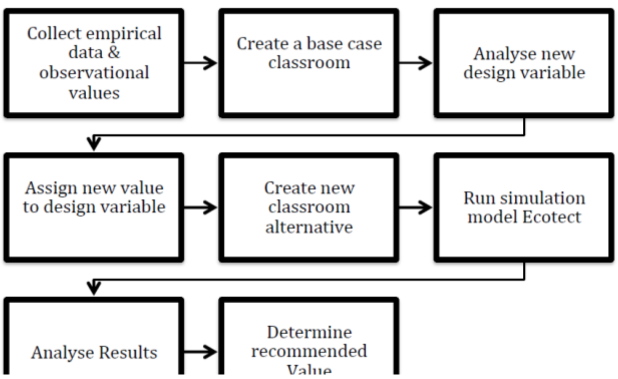

Figure 1. Workflow of the research study.

2.1. Case study selection

The field study was conducted in the state of Selangor (Malaysian West-coast) with two case study schools located in the district of Petaling Jaya. The schools are in a suburban city environment surrounded by housing and industrial developments. Both schools operate as national public schools under the Ministry of Education of Malaysia and are built accordingly to the Public Works Department (PWD) standard plans set in 1960. All selected classrooms were all naturally ventilated rooms with ceiling fans to achieve thermal comfort for occupants. The typical schedule of operational hours extended from 7 am to 6 pm. The details of the assessed schools are presented in Table 1, with the corresponding pictures shown in Figure 2.

Table 1. Case study schools.

Code	School Name	Location / Address
A	Sekolah Menengah Perempuan Sri Aman	SS14, Petaling Jaya, Selangor
B	Sekolah Rendah Kebangsaan Kampung Tunku	SS1/11 Petaling Jaya, Selangor

Figure 2. Photos showing the main building blocks and typical classrooms of the two case study schools A and B

2.2. On-site measurements

All field studies of these four schools were carried out on different days of the week to accommodate the limited time and cost allocated for the study. Field study for schools A & B were carried out approximately for 3-7 days from 24th May to 30th May 2010. All classrooms selected for data measurement in each school was done at the same time as observations were taking place.

2.2.1. Data collection. This study combined physical measurement and visual observations to obtain a comprehensive picture of the school buildings' environmental performance. The objective of this observation was to simplify the type of data collected while still comparing the existing classroom design with the simulation models. Therefore, contextual data and information concerning the building fabric such as building orientation, form and shape, window opening, materials and colours, lighting and ventilation features and usage patterns were recorded manually. Environmental factors concerning the climate and solar radiation, such as the ambient temperature, relative humidity, and lighting intensity, were instead measured automatically over a prolonged timeframe with temporarily installed data logger equipment.

2.2.2. Measurement devices. To measure the length and height of classroom space, a Leica DISTO D2 laser meter for distance measurement up to 60 m and accuracy of +/-1.5 mm is utilised. Two types of data loggers were used for recording temperature and humidity in classrooms: 1. The DS100 Data logger with USB with temperature accuracy of +/-1.0 °C from 0 °C to 45 °C, humidity accuracy: +/- 4.5% from 25 % to 85%. 2. Hobo Data Logger U10 with USB Temperature: +/- 0.54 °C from 0 °C - 50 °C, humidity accuracy ± 3.5% from 25% to 85% over the range of 15 ° to 45°. Both pieces of equipment were set to record at hourly intervals. A lux meter was used to measure the luminance level of the selected classroom with and without the artificial lighting. All the equipment was calibrated to ensure accuracy in readings taken during this study. Figure 3 shows the location of the measurement points.

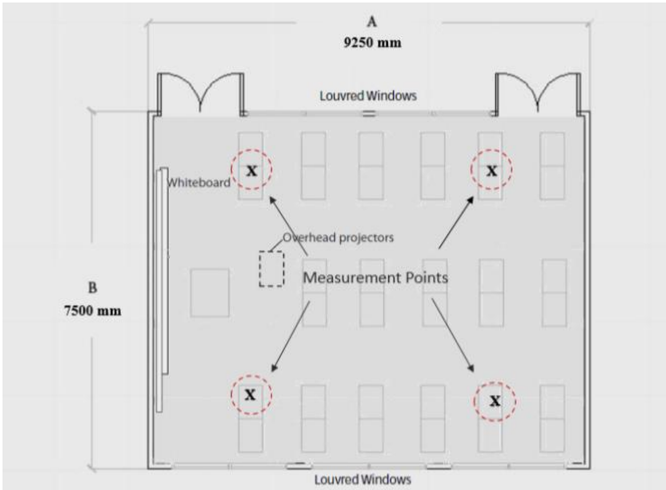

Figure 3. Base classroom floor plan and measurements points

2.3. Simulation

The main concern of this study is to investigate the influences of solar radiation against different building features. Both thermal comfort and insolation modelling was performed on the "base model" created to represent a typical Malaysian classroom that can be compared with the site measurements and allow to evaluate retrofitting measures. For the simulation campaign of this study, Autodesk Ecotect software package was used, which has commonly been used for analysing the environmental performance of buildings during the conceptual stage of the architectural design practice.

2.3.1. Model parameters. A simplified representative three-dimensional classroom base model was created with Autodesk Revit CAD software for all simulation use. The design of the base model is of the predominant type of school building currently in use, added with the specific observations made during the site visits. The fixed dimension for all models is 69.3 square meters (7500 mm x 9250 mm); the average size of a typical common-practice design of classroom surveyed in the preliminary case study, with a ceiling height of 3200mm complying with the Malaysian Unified Building By-Law (UBBL) and the standard building guide for educational school buildings outlined by the Economic Planning Unit Malaysia. The model parameters included window orientation (North, East, South, West), window to wall ratio (0%, 30%, 45%), roof overhang (900 mm, 1500 mm), roof materials (Zinc, Zinc white, Clay tiles, Clay tiles white). Figure 4 shows perspective views of the generated model variations

Figure 4. Simulation models with varying window-to-wall-ratio

2.3.2. Climate data. Weather and climatic data file used for the simulation study was collected from the built-in database of Autodesk Ecotect 2011. The calculated data were obtained for Kuala Lumpur (Latitude: 3.12; Longitude: 101.6; Time zone: +8). According to the Köppen Climate Classification, Kuala Lumpur's climate is hot and humid Tropical Rainforest Climate (Af) with an annual average temperature of 27.8 °C. It is noted that from January onwards much higher temperatures indicate more critical periods of heat rise and less rain with April being the warmest month (avg. 28.3 °C). Lower temperatures between months July-September are due to the monsoon season as heavy rainfalls cool the overall temperature. This annual climate pattern was also considered for the on-site measurement.

2.3.3. Simulation parameters. To study the temperature fluctuations within the classroom throughout the day, a grid analysis set at the height of 1 m (desk height) at 9 am, 12 pm and 3 pm on the hottest day was run and recorded. For this study, a schedule of school hours, weekends, and holidays is created based on the Ministry of Education calendar for Malaysian School 2010. Opening and closing of windows are set according to the school operating schedule, from 7 am till 6 pm on weekdays, 8 am to 12 pm on selected weekends, and closed during public and school holidays. This schedule will also contribute to the opening and closing of windows, with 35 students at 100% operational level occupancy.

2.4. Data analysis

Retrofitting measures for thermal comfort in the hot, humid climate were tested on the following six principles: I. Building Orientation, II. Shading of the glazing III. Thermal mass for thermal buffering and heat sinks, IV. Insulation to reduce heat gains and losses, V. Natural ventilation for cooling VI. Zoning of internal spaces to allow different thermal requirements.

The simulation output provides information about the energy gain/loss (Watt-hour/m^2) as a function of the passive strategies mentioned above. For each retrofitting modification, the total heat gains/losses were recorded, and the contribution of each heat transfer mechanism was calculated as a percentage of total heat gain/loss, with the results shown in Watt-hour/m^2.

3. Results and Discussion

This section summarises the obtained results from the on-site measurements and simulation of the classroom model with applied retrofitting measures. The data presented in the following graphs and figures (Figures 5-8) represent only a small, selected portion of the obtained results, highlighting the key findings of the study and demonstrating the effectiveness of the passive design strategies in reducing solar heat gain and improving thermal comfort conditions.

3.1. Measurement results

Figure 5 presents the summary data of the recorded environmental conditions from 24th May to 27th May 2010 for school A (a) and school B (a). The graphs compare indoor and outdoor temperature and relative humidity for classrooms in schools A and B, which share similar features such as occupancy level, sedentary activity, and design layout. Results show that both classrooms have a higher internal temperature of approximately 1 °C than the outside temperature, rising at 10 am and peaking in the late afternoon with a latency of approximately 45 minutes to the external temperatures. The thermal conditions inside the classroom are worse than outdoors, which reconfirms previous concerns about the suitability of current school building designs in the tropics, justifying the evaluation of retrofitting measures.

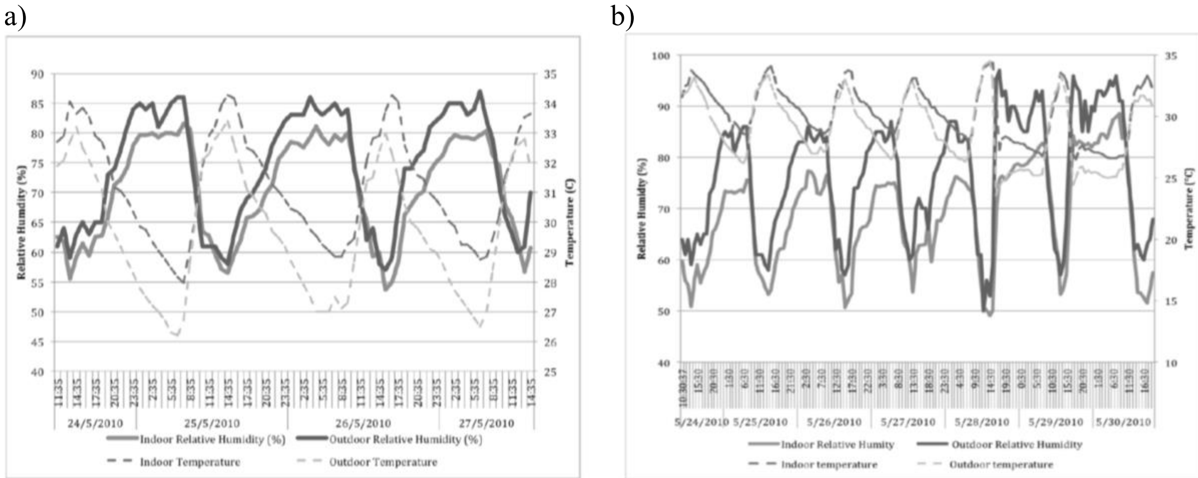

Figure 5. Measurement results of classroom long-term monitoring in schools (a) and (b)

3.2. Simulation Results

This section summarises the main findings from the various simulations with different applied retrofitting measures. Figure 6 shows the effect of window sizes and roof overhangs on internal temperatures for different building orientations. From the results, a reduced window-to-wall ratio of 30% combined with a wide overhang of 1500 mm is the most effective measure to reduce internal temperature by approximately 2 °C from the outdoor conditions. The best choice for the roof material and colour among the evaluated options is a white painted zinc roof (Figure 7), which helps to reduce the solar heat gains by 6% in absorbing less solar radiation while model with clay tiled roof, it was shown that the percentages of heat gain were 9.7%, an effect independent of the building orientation. Figure 8 shows detailed results for the internal temperatures on a spatial grid.

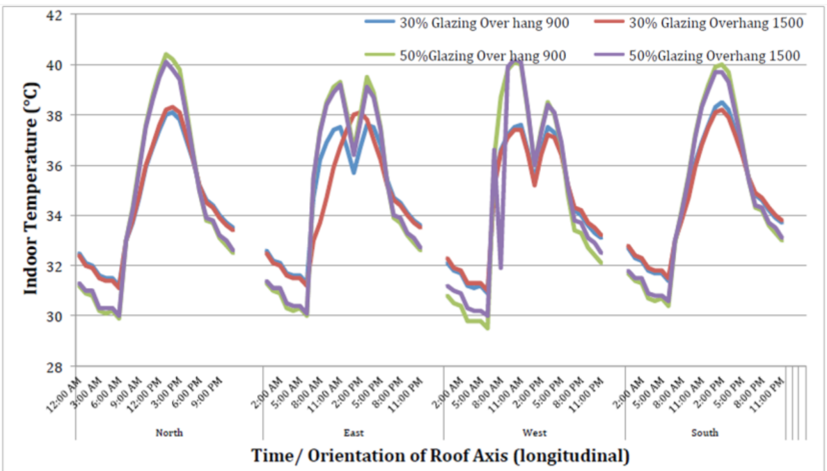

Figure 6. Indoor temperature according to changes in window proportions and overhang dimensions

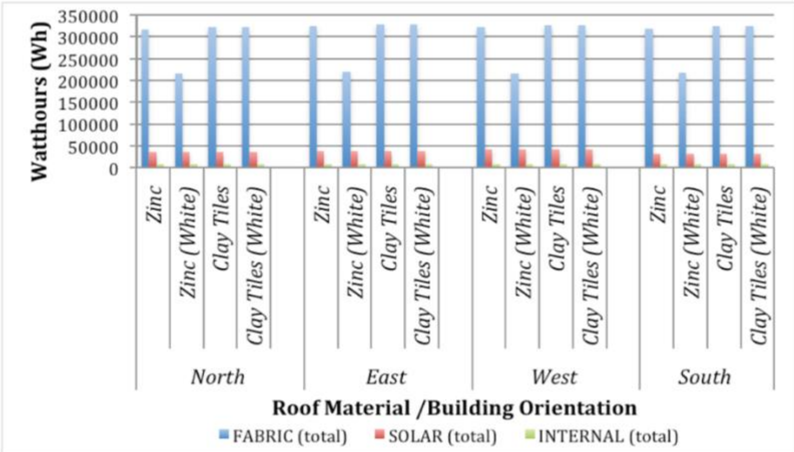

Figure 7. Passive heat gain for different roof materials and building orientation

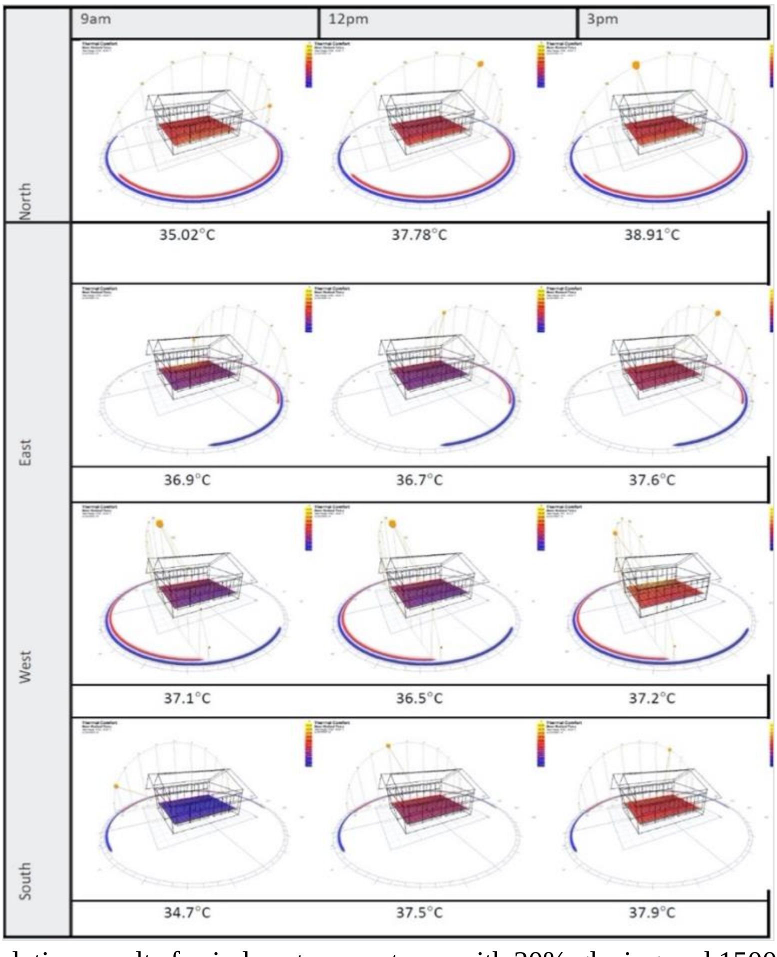

Figure 8. Simulation results for indoor temperatures with 30% glazing and 1500 mm overhang

3.3. *Why then are climate responsive schools important in Malaysia?* Architecture for the "greener good" involves an overall understanding of a design approach's immediate and future environmental implications. Malaysia is in a privileged region with great diversity and energy availability, and other natural resources. However, in terms of energy from conventional fossil fuels, such as oil, coal and gas, these sources are not limitless and will only increase in price. Due to the cost of maintaining comfortable

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habitable structures in a hot and humid environment, Malaysia's economy and society will stand to benefit by implementing "greener good" initiatives that reduce energy and cost inputs.

4. Conclusions

Ultimately, the goal of this study was to present strategies for retrofitting existing operating schools for more climate resilience. By researching the integration of adaptive measures and simultaneously testing the principles of bio-climatic architecture, a few solutions were proposed to meet the demands for thermal comfort and energy efficiency in a changing global climate. The study showed that design factors such as window orientation and proportion, roof material and colour, and roof overhang dimension directly impact the solar heat gains and, therefore, the indoor thermal comfort conditions of public-school buildings in Malaysia. However, the study also showed that the proposed retrofitting measures are insufficient to provide satisfactory thermal comfort levels for learning and teaching environments.

Despite these findings, progress towards passive design and other low energy solutions is a potential path to guarantee future-proof affordable schools. However, there are still sizable challenges in attaining optimal thermal comfort through passive design in Malaysia’s climate. Combination of use and social factors such as high coverage use of air-conditioning in other daily activities (e.g., home, office, transportation) must also be addressed as they have significantly slowed down a shift towards passive design.

Due to the time intensity of designing and running simulations, only a limited set of design features could be isolated and analysed by simulation in this study. Future research might ideally aim to simulate more design features, e.g., louvres or multiple combinations of features to investigate the potential of combining passive with active cooling features to understand the long-term saving costs and added lifespan of older buildings when integrated with renewable technology.

Acknowledgments

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