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# THERMAL BEHAVIOUR OF RESIDENTIAL BUILDINGS IN SOUTH-EAST ASIA THROUGH DYNAMIC SIMULATION

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**ABSTRACT:** Dynamic simulation to determine the thermal behavior of buildings is a helpful tool for design and transient analysis. Due to the fact of geographical location, buildings in Malaysia act like energy storage facilities. This leads to discomfort and a massive deployment of air-conditioning facilities. The current work aims to describe how the cooling load of residential buildings is to be predicted by utilizing a software Energy-Plus. The simulation focuses on the influences of the environment as well as the geographical location on the buildings. In this simulation, simple constructional changes and insulation appliances are applied on two different designs of residential houses. They showed a up to 50% lower cooling load. Results have also indicated a positive impact on the consumption of electrical power. Hence, building simulation is a supportive application and useful for energy efficient design in the pre-design stage, as well as for identifying the energy optimization potentials of existing residential buildings.

**Keyword:** Buildings, Design, Cooling Load, Simulation, Tropical climate

## 1. INTRODUCTION

The ever-growing demand for the development of sustainable products (goods and services) has resulted in a number of new technologies and strategies in design of buildings with respect to a variety of performance considerations, such as energy, comfort, cost, aesthetics, and environmental impact. Numerous studies have shown the positive impact of simulations in these areas. They allow architects and engineers to test ideas and designs before they are carried out to see the impact of their decisions on the energy consumption and the environment (Strand et al, 2004).

Malaysia is a tropical country residing at 2° 30'N latitude and 112° 30'E longitude. It possesses a climate with uniformly high temperatures, high humidity and abundant rainfall throughout the year. Private companies mostly develop residential buildings in Malaysia. Based on statement in the governmental program Vision 2020, Malaysia will have an increased demand in living space in the next 14 years. Statistic analysis has shown that a big portion of the Malaysian population lives in so called terrace houses (RPSR, 2005). This type of residential building is widely used by land developing companies. To give low to moderate priced living space to the inhabitants of Malaysia the house are not designed to the optimum in terms of cooling load. Mostly they rely on a combination of cross ventilation and mechanical ventilation by fans to achieve thermal comfort. However, the climate condition of Malaysia might have negative impact on the comfort of the occupants. Thus to improve the thermal environment, more and more occupants install air conditioners for their homes. The most obvious side effect is the dramatic rise of the energy consumption in domestic sector (Wong, 2005).

The Malaysian government is addressing the increased demand for energy with the Malaysian Industrial Energy Efficiency Improvement Project (MIEEIP) to enhance its efficient usage. An analysis of the given situation in the industry has shown that average factory management sees no reason to reduce energy consumption or improve its efficiency for several reasons (PTM, 2006):

- Energy price is relatively low because of government subsidy;

- Absence of incentives to encourage energy efficiency;
- Lack of support system to undertake greener measures;
- Regulations do not address energy efficiency.

Although for the industrial sector, these facts can be applied in the domestic sector as well, especially when it comes to the utilization of comfort in residential buildings and leads to a dilemma between comfort and environment, thus a challenge of the mindset. With this background, the motivation of this research work is to show the energy performance and energy saving potentials of residential houses in Malaysia. The objective of this project is to show trends where energy efficient design enhances building performance and decreases the cooling load. To do so, two different house designs are subjected to a building simulation and different influences on the energy performance are investigated. It is not explicitly bound to certain research objects but takes "real world" examples and subjects them to different selected scenarios, which might occur in reality as well.

## 2. SIMULATION SETUP

The simulation program, which is used to run the test models, is EnergyPlus (or $E^+$) (DOE, 2005). $E^+$ is a building energy simulation program for modelling building heating, cooling, lighting, ventilating, and other energy flows (Witte, 2004). It is based on the most popular features and capabilities of BLAST (Building Loads Analysis and System Thermodynamics) (Building Systems Laboratory, 1999) and DOE-2 (LBNL, 2005; Crawley, 2005). $E^+$ provides the simulation engine but only rudimentary graphical user interface features. The Development team has opened up their code and left it to third party developers to provide user friendly interfaces which make it easier to interact with $E^+$ according to Figure 1.

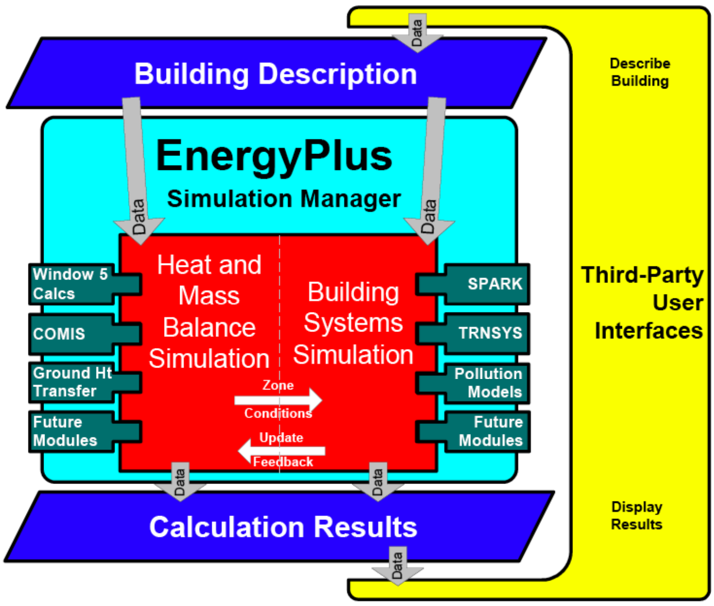


*Figure 1: Data flow in EnergyPlus*

DesignBuilder fills this gap mentioned above with an easy-to-use solid modeller, which allows house and building models to be easily assembled by positioning, stretching and cutting 'blocks' in 3-D space by providing a graphical user interface (GUI) for easy interaction (DBS, 2006). The model then is thermally "zoned" and transferred to the $E^+$ program to do the simulation part; the results are then displayed and evaluated again in DesignBuilder. Data communication between DesignBuilder and $E^+$ is based on the IDF/IFC-files-standard (Bazjanac, 1999).

The reference type of house design for this research is chosen according data of the Valuation & Property Services Department of Malaysia (Finance Ministry of Malaysia, 2005). It states the terrace house holds the biggest fraction of both existing supply and newly planned supply of residential units in Malaysia. The simulation of different setups (for walls, roof etc.) is done on this type of house as "Malaysian standard" and compared to a thermally, high efficient house design as well as to a totally un-insulated setup.

The floor plan of the terrace house used in this project was obtained online (iProperty, 2003). It is a single storey terrace house located in Taman Desa Bayu, Melaka. For the simulation one unit is modelled and then arranged to an array in a way often seen in new land developing projects (see Figure 2). Analysis for this paper was done on the house in the centre of the array; block 6 in Figure 3, because the result of the simulation block can be transferred easily to other 'centre' houses, whereas houses at both ends of the array are considered similar to semi-detached houses.

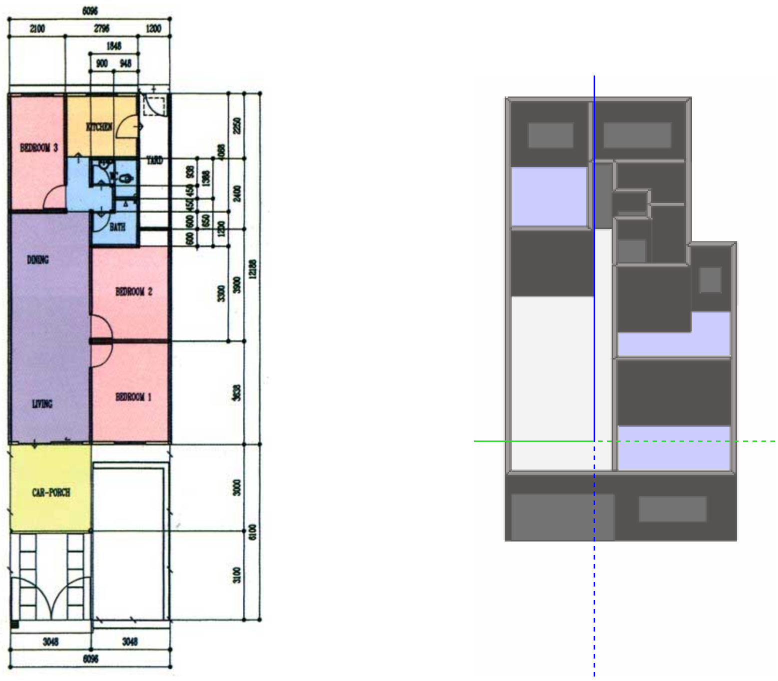

*Figure 2: Floor Plan for Terrace House (left) and the same House transferred to DesignBuilder (right).*

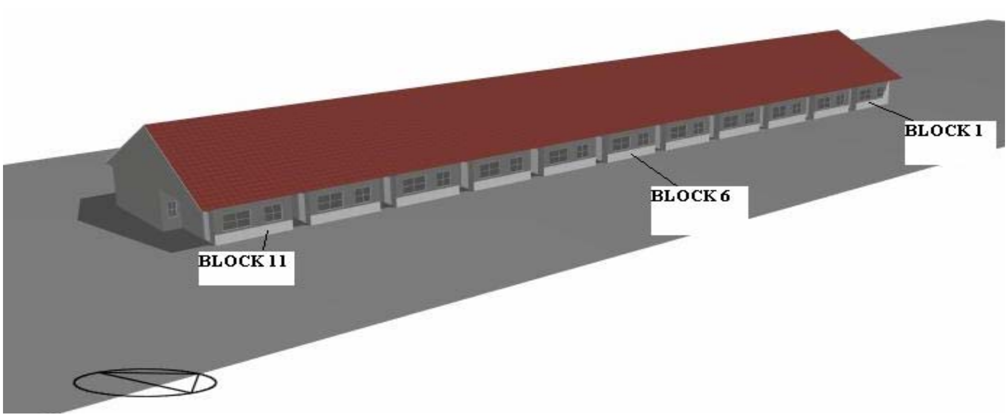


*Figure 3: Visualization of the Terrace House Array with North Point in DesignBuilder.*

The design of the highly efficient residential building is based on the so-called "Cooltek" house, located in Tiara Melaka Golf and Country Club (see Figure 4). This single storey house is build with energy saving and low cooling load characteristic including a solar chimney, two underground cooling chambers, extra insulated walls and floors, and double glazing. The floor plan for this house was obtained from the owners Mr. Harry Boswell and Mrs. Stephanie Bacon.

First, simulations on building design with partially optimized changes in their building structure are done to show how each change will affect the cooling load of a building. The parameters studied are different setups of: walls, doors, roofs, ceilings, and floors.

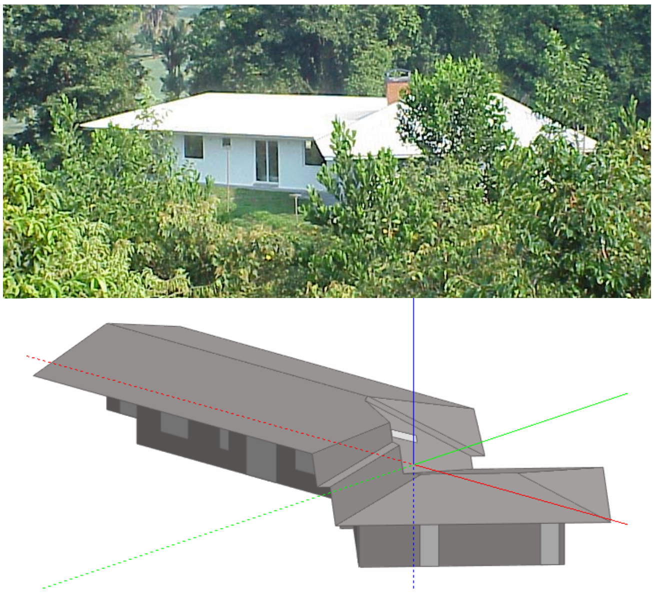

*Figure 4: The Cooltek House and its visualization in DesignBuilder*

The details (constriction layer, material, and *U*-value) for the materials used for walls and roof in this research are as follows:

**Wall**

Malaysian Wall

| | | |
|---|---|---|
| Outermost layer: | Concrete | 0.010 m |
| | Brickwork | 0.120 m |
| Innermost layer: | Concrete | 0.010 m |

*U*-value: 2.962 W/m$^2$K

Cooltek Wall

| | | |
|---|---|---|
| Outermost layer: | External rendering | 0.010 m |
| | Aerated concrete slab | 0.250 m |
| Innermost layer: | Plaster (lightweight) | 0.010 m |

*U*-value: 0.549 W/m$^2$K

**Roof**

Malaysian/Un-insulated Roof

| | | |
|---|---|---|
| Outermost layer: | Clay tiles | 0.025 m |
| | Air gap | 0.020 m |

| | | |
|---|---|---|
| Innermost layer: | Roofing felt | 0.005 m |

*U*-value: 2.790 W/m$^2$K

Cooltek Roof

| | | |
|---|---|---|
| Outermost layer: | Zinc-Aluminium | 0.0005 m |
| Innermost layer | Steel | 0.0048 m |

*U*-value: 6.364 W/m$^2$K

For each simulation cycle of different setups, the following parameters remain constant:

| **Rooms equipped with air conditioner:** | **Bedrooms and Living Hall** |
|---|---|
| Air conditioners cooling capacity for Bedroom 1: | 1.115 kW |
| Air conditioners cooling capacity for Bedroom 2: | 0.474 kW |
| Air conditioners cooling capacity for Bedroom 3: | 0.642 kW |
| Air conditioners cooling capacity for Living Hall: | 2.477 kW |
| Air conditioner temperature set point: | 24 °C |
| Simulation/Design day: | March 21$^{st}$ |
| Location/Weather Data (NCDS, 1981): | Melaka/Kuala Lumpur |

As an example, in the study of different walls, the house has Malaysian standard roof, Malaysian standard ceilings and Malaysian standard floors with wooden doors, while different setups of walls are applied. The comparison of resulting data gives a broad outlook at how each setup modifies the cooling load of both house designs. Scenarios with both air conditioners turned on and off are done to figure out the influence on how much electrical energy is needed for cooling. For classification the influence of the setups and their characteristic *U*-values on the cooling load is given.

In a second step, different kinds of insulation templates are wholly applied to the two house designs. Hereby a possible extrapolation on the asset of residential houses can be drawn.

## 3. SIMULATION RESULTS AND DISCUSSION

### 3.1 Different Walls

From Figure 5, we observe that lower insulation standard leads to bigger temperature amplitude of indoor air temperature within the day. The reason for this is to see in the energy gain. The better-insulated walls (i.e. Cooltek walls) show low amplitude while walls with decreased insulation (Malaysian walls), although they loose energy in the morning and night, gain an over proportional amount of energy in the afternoon which leads to increased inside temperature.

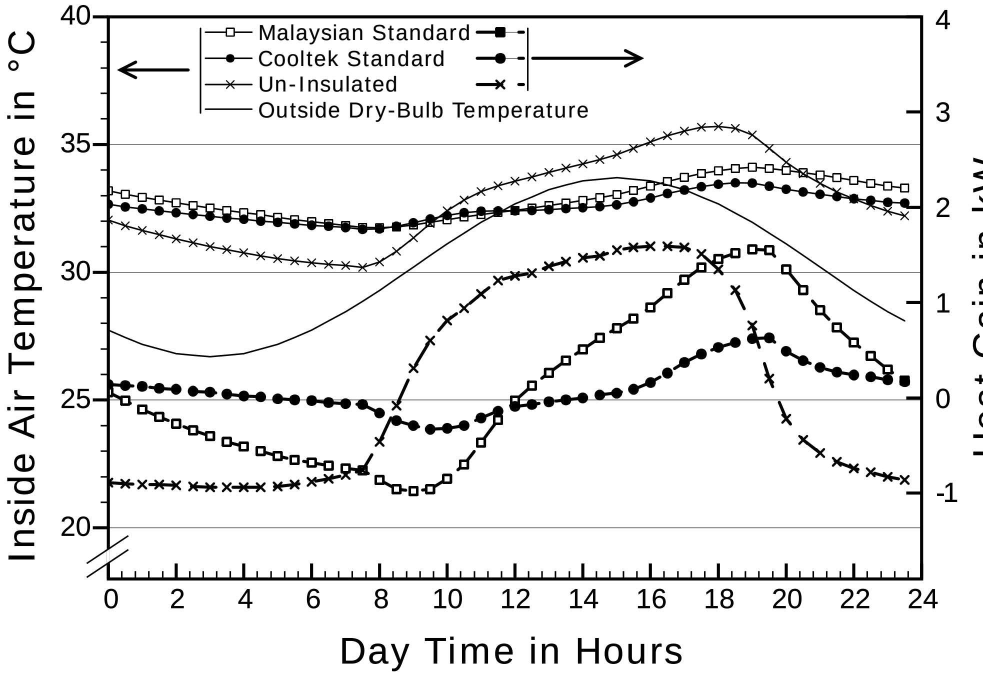


*Figure 5: Indoor Temperature and Heat gain through Walls vs. Time for Terrace house with different wall setups; A/C OFF*

It is easy for a house equipped with air conditioning to maintain comfort temperature of approximately 24°C (Szokolay, 2004). This behaviour is the same for the terrace house design as well as for the Cooltek design. Significant differences however are seen in energy consumption. The terrace house with applied Cooltek standard for walls needs a cooling requirement of 4.12 kWh lower than the same design with Malaysian standard setup. Even more energy is needed if a house design has no insulation setup at all. For comparison: electrical energy needed for cooling such a setup is double to the Cooltek setup. Due to the capability of insulated walls of keeping off the hot outside air from the colder inside air, the air conditioning is running at lower capacity.

It is also noted that less fluctuation of temperature may lead to less maintenance as extreme high and low temperature may cause fatigue to materials.

### 3.2 Different Setups for Doors, Roof, Ceilings, and Floors

The temperature difference resulting from the application of different setups of doors for the different house designs is comparably small. One reason is the surface doors are covering which is small compared to the total surface of the walls. The resulting energy gain is insignificant. If a house has applied air conditioning, the cooling design requirements have shown marginal differences (approximately 5%) between best practise and un-insulated setup as seen in Figure 7.

Thus, it can be concluded that if a house does not have air conditioning, the type of doors used has no big influence on energy consumption. If the however air conditioning is applied, a tight locking PVC + PU door is recommended. With applied air conditioning in only one room, the PVC + PU door is the best choice as door for this particular room. Even for life span considerations such a door bears advantages. Other considerations done for the choice of doors are non-measurable like the feature of the door, the security level provided, and pest protection before the door is selected.

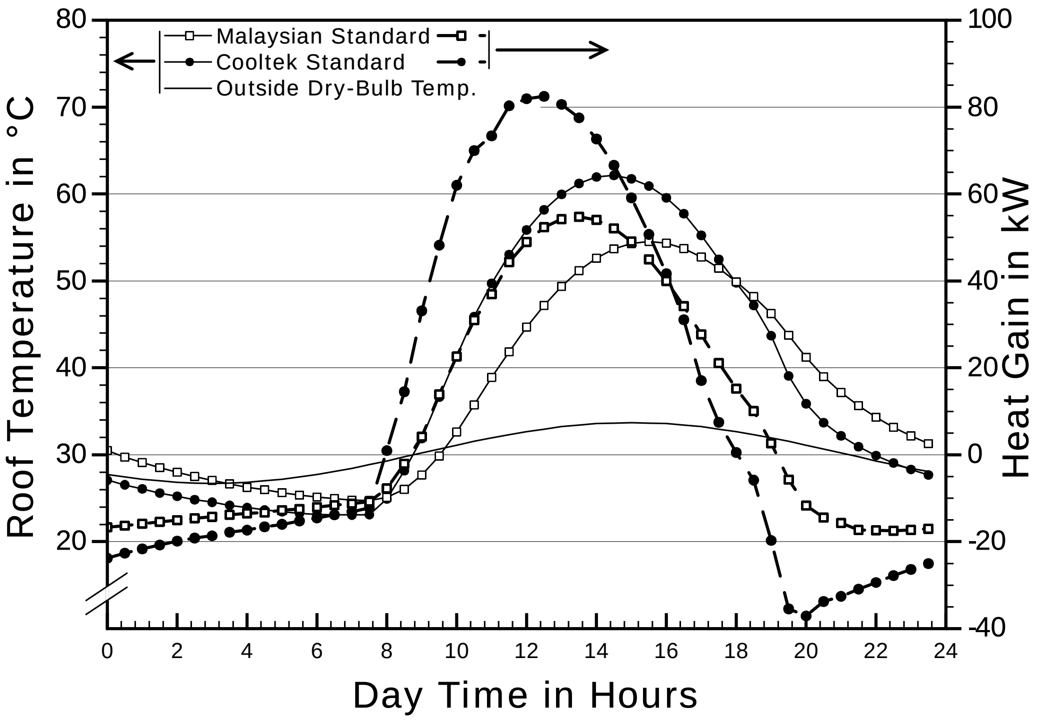


*Figure 6: Temperature and Heat Gain of Roof Space for different Setups for Terrace house design; A/C OFF*

The roof according to Cooltek standard is made of metals sheets and can be considered a good heat conductor with a high *U*-value of $U = 6.364$ W/m$^2$K. It heats up the fastest but can also cools down fastest among the roofs used in the simulation. In Figure 6 this behaviour can be observed. However, the comparison amongst all roof setups shows a significant temperature differences for peak temperatures of roof space, it only plays a minor role in influencing the inside temperature, see Figure 7. Here the influence on the cooling requirement of an un-insulated roof and a roof according to Cooltek standard are compared. Due to the effect that warm air raises it barely touches the underlying ceilings of the living area and only minor part is conducted towards the living space. The difference in inside temperature between highly insulated and un-insulated ceilings is $\Delta\theta_{\text{ceiling,max}} = 5.3$ °C. Resulting in cooling requirement regarding the different setups of $\Delta Q_{\text{ceiling,max}} = 40$ Wh.

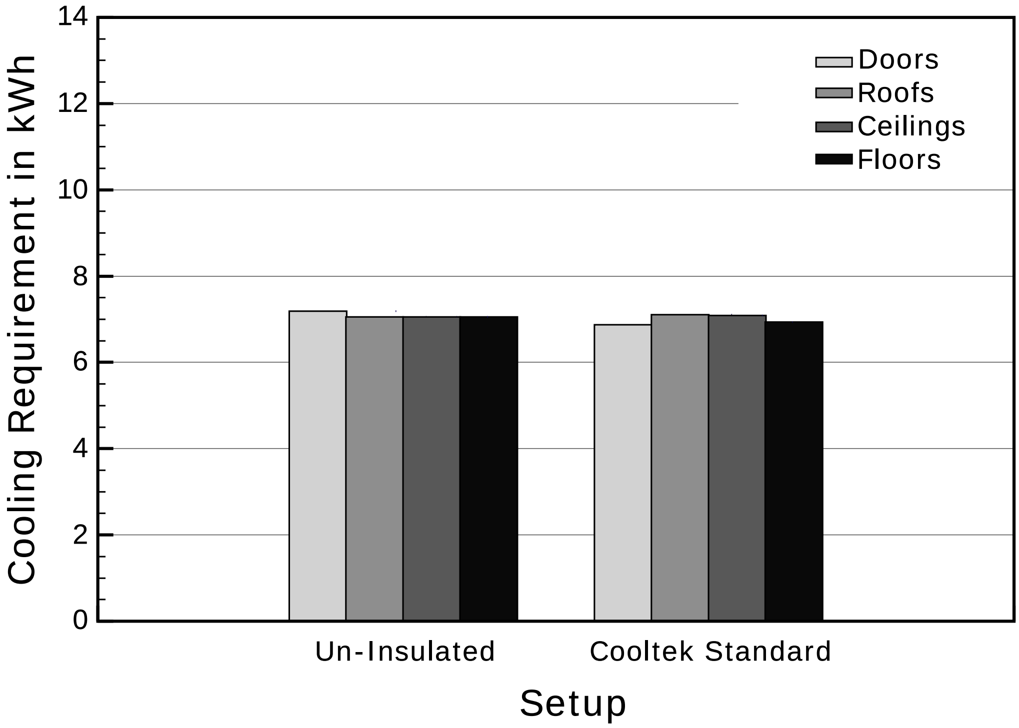


*Figure 7: Cooling Requirement for different Setups (Doors, Roofs, Ceilings, and Floors) in kWh for Terrace House design; A/C OFF*

Floors are divided into the floor and its insulation as seen in Figure 8. Calculations have shown that different floor types (carpet, wooden and ceramic floors) do not affect significant differences on the inside temperature of the house, because of its low height (≈ 10 mm), resulting in low thermal resistance. On the other hand it can be seen that different insulation layer results in a small difference of cooling requirement according to the differences in *U*-value.


*Figure 8: Floor Setup Scheme*

Floor insulations are also applicable for two-storey houses. If rooms at the second storey are air conditioned (≈ 24 °C), the temperature potential between the ground of this floor and the ceiling side of the first storey (here: not air conditioned; ≈ 33 °C) is large and thus energy is lost through the ceiling. The application of an insulated ceiling would contribute to a better overall effect than insulating the ground of the first floor as the ground temperature locally is relatively high, 25 °C, and the air temperature in a air-conditioned room is approximately 24 °C. So low heat gain may be expected.

Figure 9 shows clearly the influence of the different setups shown above on the cooling requirement. The Walls have the highest influence. Reason for this is their covered surface area thus their exposure to the sun and the surrounding environment. The setups of doors, roofs, ceilings, and floors play only minor role. Thus future research has to focus on how walls of buildings can be optimized regarding local conditions to lower the cooling load of different house designs.

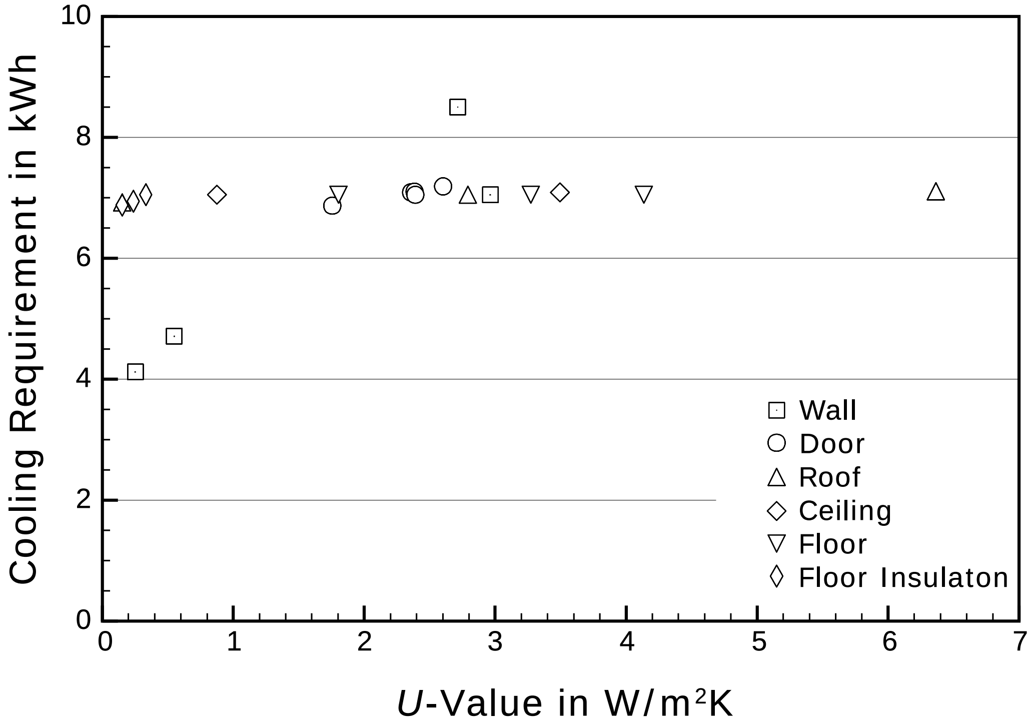


*Figure 9: Influence of U-Value of different Setups on Cooling Requirement for Terrace house design; A/C OFF*

### 3.3 Different Insulation Templates

Figure 10a) shows the house with higher insulation standard (Cooltek) has lowest temperature when no air-conditioning is applied. Based on inverse greenhouse effect, the characteristic of insulating against heat also prevents the heat from leaving the house. From Figure 10b), it can be observed exactly this behaviour: the terrace house with highest insulation standard applied has lowest cooling requirement, 3.85 kWh lower compared to a terrace house design with applied un-insulated template. The influence of the shape of the house on the energy consumption for cooling becomes even more obvious for the house in Cooltek design. The difference is up to 7.6 kWh between un-insulated setup and Cooltek setup applied on the same design. On the other hand, the Cooltek insulation standard seems to be that high, it is invariant to the underlying design, say: architectural application, it is applied on. Difference in cooling load between the Malaysian terrace house and the Cooltek house is 1.5%. Further investigations have to show how this insulation standard has positive impact on other house designs as well as bigger (office) buildings.

In conclusion, reasonable combinations of applied insulation setups show significant advantages regarding the consumption of electrical energy compared to houses without proper setup. As an example shows, a house setup according to Cooltek standard requires only RM 1.25 per day to keep it a 24°C temperature level, a un-insulated house requires RM3.20 to keep it on the same temperature level, based on the actual price for one kilowatt-hour of electrical energy.

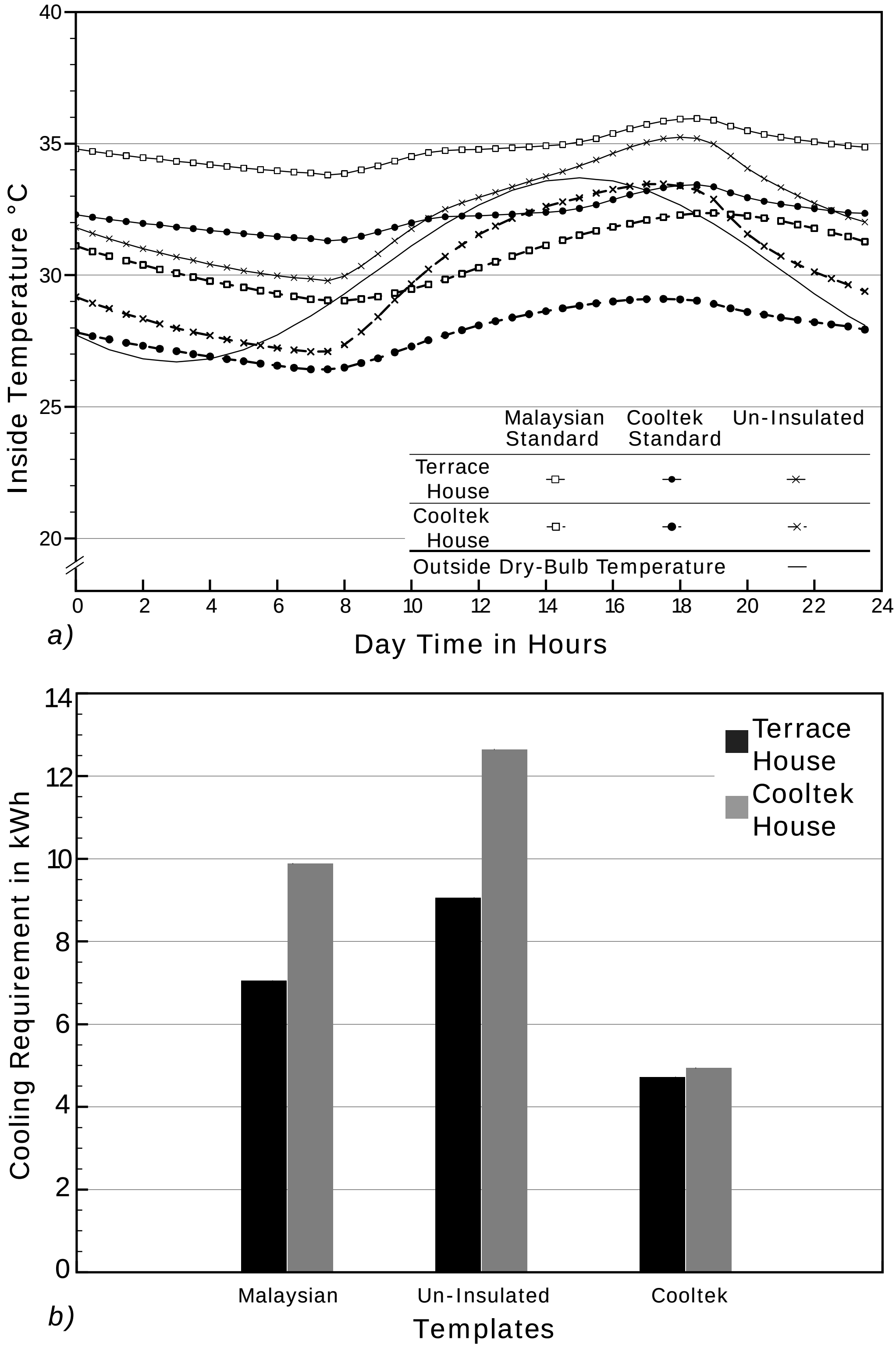


*Figure 10: (a) Indoor Temperature and (b) Total Cooling Design Requirement for Terrace house design and Cooltek design with different insulating templates; A/C OFF*

## 4. CONCLUSIONS

During this research work, two house designs, a terrace house and the Cooltek house were subjected to different setups regarding walls, roof, doors, ceilings, and floors to determine their cooling load by help of building simulation. This was done for the geographical location of Malaysia. It was shown that walls with higher insulation standard have highest impact on the cooling load where as the influence of roof, ceilings, doors, and floors tend to play minor role in designing a energy efficient house in the here given case of study. The design of a highly efficient residential house, the Cooltek design, combined with the highest insulation standard investigated has given the lowest cooling requirement to keep the living space at a comfort temperature of 24 °C. Thus besides the insulation setup, the architecture also plays a major role in designing energy efficient residential houses. In this case cooling load was about 50% of the load of a Malaysian terrace house with un-insulated setup.

By lowering the cooling load for a single Malaysian terrace house design with applied Cooltek template used for this project the cooling requirement is decreased by 2.33 kWh of electrical energy per design day (Malaysian insulation standard - Cooltek insulation standard). Extrapolated on one year, the savings result to 850 kWh of electrical energy. Since a terrace house normally is arranged in array form, an array of 50 of this terrace house designs may save 45.5 MWh of electrical energy. Burning fossil fuels like crude oil and natural gas liquids predominantly does the supply of electrical energy in Malaysia (EarthTrends, 2003). The thermal efficiency of a modern crude oil-fuelled power plant is 35–44% (AES, 2005; Herrmann, 2005). With an average value of 40%, 2.5 kWh of thermal energy has to be used to produce 1 kWh of electrical energy (transportation losses are neglected). For the example of the terrace house array, 45 MWh in electrical energy would equal to 112.5 MWh in thermal energy. With an energy content of 11.63 kWh per kilogram crude oil, this would equal to 9.7 metric tons of crude oil, which could be saved. Expressed in saved $CO_2$ emissions this is equal to 30 metric tons $CO_2$, with an emission factor for carbon dioxide of 0.27 $kgCO_2/kWh_{Oil}$ (Thames Valley Energy, 2006), calculated on a conservative basis. This example shows that even a small contribution per day and per house leads to a large impact when applied on a larger number of houses and for a longer time frame.

Further research will be done on the influence of house orientation, glazing and HVAC control. An automized approach in finding optimal combinations of design and setup will be investigated in applying a method of multi-dimensional variable analysis and the results from the residential houses will be applied on public and office buildings as well as bigger residential buildings like condominiums to find out their optimization potential.

## 5. ACKNOWLEDGEMENTS

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