Survey on the Empirical Method to Evaluate the Thermal Performance of Roof Assembly

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Abstract. Roof constitutes as one of the largest surfaces in a building that receives high amount of heat through radiation, conduction and convection. The amount of heat received by a roof depends greatly on climate condition and roof design configurations. In a hot climate, roof is designed as a barrier to the hot sun, while in cold climate, roof is an amplifier that magnifies the amount of heat gains into building envelope. As Malaysia is in tropical climate, roofs in Malaysia must be able to curb heat from the sun. Latest insertion of Malaysia Standard MS1525 requirement to the Universal Building By Law (UBBL) mandate for authority approval on the achievable thermal transmittance (U-value) not greater than 0.4W/m²K for light weight roof and 0.6W/m²K for heavy weight roof. The lower the U-value, the better the roof as a barrier to the external heat. Based on a survey study done in Malaysia, only 43.18% of building practitioners are aware on the requirement, and the current implementation of the regulation involves submission of U-value numerical calculation for total roof assembly during Building Plan (BP) submission. The result of this study suggests a need for an empirical method to measure roof performance. Computer Controlled Solar Simulator (CCSS) is suggested as a platform to ensure effective implementation of MS1525 and certify that housing design in Malaysia complies with the thermal comfort requirement.

1. Introduction
Over the years, rapid economic development has led to vast changes in building construction which contributed to thermal discomfort in residential home. Modern residential housings in Malaysia are constructed on the ground using brick and concrete which are less responsive to the tropical climate compared to the traditional housing design. Study conducted to 94 units single storey terrace house in Malaysia revealed that indoor temperature inside these houses exceeded the recommended indoor temperature for thermal comfort of 28 degree and the indoor temperature was consistently higher than the outside temperature [1]. Studies showed that 76% solar heat gain of single storey terrace in Malaysia are from roof, and the amount of heat gain through roof reduced to 55% for double storey house and 27% for eight storey apartment due to lower roof surfaces compared to wall surfaces [2]. Therefore, careful consideration of roof design is important to ensure that the desired thermal comfort is achieved.
2. Implementation of MS 1525
A survey has been conducted to building practitioners in Malaysia to evaluate level of awareness and understanding on MS 1525 implementation. The survey was conducted from January 2018 to March 2018 through online and manual questionnaires to 60 respondents and received 44 replies (73.33% reply rate). Based on the replies received, majority of the respondents are registered and graduate architect with a total of 54.17%. Details of the respondents’ profession are as per Figure 1. The surveyrevealed that 43.18% from the respondents are aware on the Implementation of MS 1525 in the UBBL Section 38 (A)-2 in Malaysia, and 56.82% respondents are unaware on the regulation (Refer Figure 2).

![Figure 1. Percentage of respondents (based on profession).](image1)

![Figure 2. Percentage of respondents’ awareness on the implementation of MS 1525 in the UBBL Section 38(A)-2.](image2)

Based on the survey, 33.33% of the respondents are in opinion that the regulation should be implemented through submission of calculation on U-value of the whole roof assembly during Building Plan submission to local authority. Details of the respondent’s opinion on the implementation of the regulation is illustrated in Figure 3. The survey also shows that only 39.58% of the respondents understand that currently the implementation of MS1525 regulation is by providing detail calculation.
of the U-value of the whole roof system while 35.42% of the respondents believe that the current implementation is through submission of manufacturer data of the U-value for insulation material.

3. Roof Design Configuration

The U-value of a roof greatly depends on the material, angle, and color of the roof. Studies show that 85% of roofing materials in Malaysia is made from concrete roof tiles, 10% from clay roof and 5% from metal deck [3]. Layers of materials in between the roof and ceiling such as insulation materials influence the roof performance [4]. Hence, the complexity of the roof design with different roof angle, materials and colors will lead to the difficulty to obtain the accurate measurement of U-value for the whole roof assembly.

In Malaysia, material with less conductivity and low emissivity is favorable as roofing material. As 90% of heat in Malaysia is transferred through radiant heat transfer [5], the use of low emissivity material such as aluminium foil and metal deck are advisable. Material with high embodied energy such as concrete is unfavorable as the concrete stores heat and emit long wave infrared radiation at night [6]. To reduce the U-value of a roof, the outer skin of the roof can be paired with insulation materials. The material, position and thickness of the insulation material will influence the U-value of the whole roof assembly. For slope roof, test conducted on reflective aluminium foil showed that the reflective material is less effective when positioned on top the ceiling plaster board with dusts accumulated and reduces emissivity of the insulation material [7]. As for the flat roof, the expanded polystyrene insulation must be located on top to avoid heat from being absorbed into the concrete roof slab. However, over the years, this may lead to leakage problem to the roof, aging of the insulation material and reduce the heat resistance ability [8].

Other than that, roof angle also contributes to the U-value of the total roof assembly. The roof angle allows air cavity in between the skin of the roof and the ceiling. Widen the width of the air cavity will lower the U-value, hence improve the thermal performance of a roof [9]. In addition to that, the air cavity also induces air movement, hence reduces the heat gain into a building. The U-value of the air cavity in a slope roof is only able to be measured using experimental setup which is unable to be obtained through numerical calculation method. In addition to that, roof color also influences the U-value of the whole roof system.
value of the whole roof assembly. A high reflective roof surface enhances the solar reflectance and reduces amount of heat that absorbs into a building. However, the application of cool paint to improve roof U-value can only be measured through experimental setup and not through numerical calculation.

4. Method of Evaluating Roof Thermal Performance

As there are many parameters that influence the U-value of a roof assembly, it is important to determine the best method of implementation for MS1525 in the UBBL Section 38(A)-2 regulation in Malaysia. Based on literature review, there are three methods other than numerical calculation method to evaluate the thermal performance of a roof assembly i.e. laboratory testing, field testing and computer simulation methods. Each of the method has their own advantages and disadvantages. Laboratory testing method allow experimentation to be conducted in a controlled weather condition and modification to be done with low cost implication. Many parameters which are unable to be measured through numerical calculation method can be measured through laboratory testing method such as the impact of varies location and thickness of the insulation materials, the width of the air cavity and roof color. Based on synthesis of literature review as illustrated in Table 1, laboratory testing method allows experimentation to be done to variety type of roof assembly. For the field testing method as illustrated in Table 2, the method provide an accurate measurement of the U-value for the whole roof assembly but is cost intensive as it allow less modification to the design parameters. Prototypes needed to be assembled at the same time to ensure the consistency of weather measurement. The computer simulation method on the other hand is not commonly used by researchers to measure U-value of a whole roof assembly as illustrated in Table 3. The method is frequently used with laboratory testing method and field testing method when further exploration are requires in the study.
Table 1. Synthesis on laboratory testing method.

| Method | Ref | Climate | Heat Flow Direction | Research Equipment | Full Roof Assembly/Single Material | Roof Profile (Slope/Flat) | Type of Roof Assembly | Type of Insulation Material Single/ Hybrid | Parameter |
|--------|-----|---------|---------------------|--------------------|-----------------------------------|--------------------------|----------------------|---------------------------------------------|------------|
|        | (7) | Maritime| Downward/Upward     | 1. Heat flux meter 2. Thermocouple | Full roof assembly                  | Slope roof               | 1. Concrete tile 2. Ventilated cavity 3. Insulation underlay 4. Mineral fibre insulation 5. Non-ventilated cavity 6. Gypsum board | Hybrid (Insulation underlay + mineral fibre insulation) | Emissivity of insulation material |
|        | (10)| Tropical| Downward            | 1. Single needle sensor – thermal conductivity of insulation paint 2. Air probe 3. Surface temperature sensor 4. E-data logger | Full roof assembly                  | Slope roof               | 1. Cool paint/normal paint 2. Metal roofing sheet 3. Moving air cavity/ no moving air cavity 3. Open attic inlet/ close attic inlet 4. Ceiling | Not applicable | 1. Insulation Material 2. Cool Paint 3. Air gap |
|        | (9) | Tropical and sub-tropical | Downward | 1. Thermocouple 2. Thermograph – measure air temperature 3. Heat flux meter 4. Anemograph 5. Weather station | Full roof assembly                  | Slope roof               | 1. Steel wave plate 2. Reinforced concrete slab (both structures are inclination angle) | Aluminium foil | 1. Ventilation 2. Width of air gap 3. Location of radiant barrier |
|        | (6) | Tropical | Downward | 1. Thermocouple 2. Heat flux meter | Full Roof Assembly                  | Flat roof                | 1. Reflector (Aluminium, galvanized steel) - flat, sinusoidal, triangular 2. Insulation 3. Concrete slab | 1. Single (polystyrene) 2. Single (polyurethane foam) 3. Single (polyethylene) | 1. Type of reflector 2. Shape of reflector 3. Type of insulation 4. Thickness of insulation |
### Table 2. Synthesis on field testing method.

| Method | Ref | Climate | Heat Flow Direction | Research Equipment | Full Roof Assembly /Single Material | Roof Profile (Slope/Flat) | Type of Roof Assembly | Type of Insulation Material (Hybrid/Single) | Parameters |
|--------|-----|---------|---------------------|--------------------|-------------------------------------|--------------------------|----------------------|---------------------------------------------|------------|
|         | (10) | Sub-tropical | Downward/Upward | 1. Heat flux meter 2. Thermocouple | Full roof assembly | Slope roof | 1. Roof tile, waterproofing, wood fibre panel, timber plasterboard. 2. Roof tile, water proofing, polyurethane panel, extruded polystyrene foam, plasterboard | 1. Hybrid (wood fibre + timber fibreboard) 2. Hybrid (polystyrene + polyurethane panels) | Insulation material |
|         | (14) | Temperate maritime | Downward/Upward | 1. Heat flux meter 2. Thermocouple | Full roof assembly | Slope roof | Concrete tile, ventilated cavity, insulation underlay, mineral fibre insulation, non-ventilated cavity, gypsum board | Hybrid (insulation underlay + mineral fibre insulation) | Emissivity of insulation material |
|         | (8) | Tropical | Downward | 1. Resistance temperature detector 2. Albedo meter 3. Solar spectrum meter 4. Emissometer | Full roof assembly | Flat roof | 1. Ferrocement slab, ventilated air gap, concrete slab, cement plaster. 2. Cool paint, ferrocement slab, ventilated air gap, concrete slab, cement plaster. | Single (expanded polystyrene and radiant barrier) | 1. Insulation material 2. Cool paint 3. Air gap |
|         | (15) | Tropical | Downward | 1. Thermocouple 2. Solarimeter 3. Wind anemometer | Full roof assembly | Slope roof | 1. Concrete tile/ metal deck 2. Air gap in attic roof 3. Aluminium foil glued to rockwool (location differ) 4. Cement board | Hybrid (Aluminium foil + rockwool) | 1. Position of aluminium foil + rockwool 2. Roof surface material 3. Ventilation |
|         | (16) | Tropical | Downward | Thermocouple | Full roof assembly | Slope roof | 1. Screed 2. Wyre mesh 3. Insulation 4. Waterproofing layer 5. Concrete slab | Single (expanded cellular polyethylene) | Insulation thickness |
|         | (17) | Temperate monsoon | Downward/Upward | 1. Heat flux meter 2. Temperature difference | Full roof assembly | Flat roof | 1. Without reflective coating 2. Phase change layer 3. Mortar 4. Waterproof 5. Glass fibre cement polystyrene core | Single (Phase change material) | Insulation material |
|         | (18) | Sub-tropical | Downward | 1. Thermocouple 2. Digital thermometer | Full roof assembly | Flat roof | 1. Reinforced concrete slab 2. Fly ash pieces 3. PVC sheet 4. Earth 5. Brick tiles 6. Cement and waterproof layer | Single (Fly ash pieces) | Insulation material |

### Table 3. Synthesis on computer simulation method.

| Method | Ref | Climate | Heat Flow Direction | Research Equipment | Full Roof Assembly/Single Insulation Material | Roof Profile (Slope/Flat) | Parameter |
|--------|-----|---------|---------------------|--------------------|---------------------------------------------|--------------------------|------------|
| Computer Simulation | (11) | Sub-tropical | Downward | Carrier’s Hourly Analysis Program | Full roof assembly | Not stated | Thickness insulation material |
|         | (12) | Sub-tropical | Downward | Design Builder | Full roof assembly | Flat roof | Thickness insulation material |
|         | (13) | Moderate oceanic | Downward/Upward | COMSOL 4.4 | Full roof assembly | Slope roof | Thermal resistance (R-Value) of insulation material |
5. **Empirical Testing using Computer Controlled Solar Simulator**

Based on the complexity of roof design configurations, it is apparent that the implementation of MS 1525 will require more than just submission of U-value calculation to the authority. While data from laboratory testing method and field testing method are reliable, the cost to conduct the experimentation is high. Hence, a Computer Controlled Solar Simulator (CCSS) has been designed as a novel platform to conduct testing and determine the U-value of a roof. All sensors for the CCSS will be integrated and link to the Programmable Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA) System for data logging and monitoring. All data will be logged into the SCADA system when the boundary conditions such as weather, temperature, and wind velocity reach “steady state” where the boundary conditions is consistent for a few seconds.

The set-up of the CCSS is based on laboratory experimentation but differ through its unique data logging and monitoring system. It comprises of motor jacks, metal halide lamps to simulate actual solar radiation up to 1000W/m², thermocouple, pyranometer, heat flux transducer, air velocity sensor and programmable computer control box. The system has a capability of angle tilting ranges from 0 to 90 degree to cater for the whole roof assembly. The size of the roof assembly will be 1.8m width × 3.2m length. This experimental setup will emulate the outdoor environment as the solar radiation can be regulated from 500 to 1000 W/m2 to cover different weather conditions. The system also will allow different type of roofing materials and insulation materials to be installed and tested.

![Computer Controlled Solar Simulator (CCSS).](image)

6. **Conclusion**

As conclusion, the implementation on of MS 1525 requirement to the Universal Building By Law (UBBL) in Malaysia to achieve the thermal transmittance (U-value) not greater than 0.4W/m2K for light weight roof and 0.6W/m²K for heavy weight roof is currently not effective. Level of awareness among building practitioners on the implementation of the regulation are low with only 43.18% of respondents are aware on the implementation of MS 1525. Current practice on the submission for numerical calculation of the U-value for whole roof assembly to the local authority is questionable as U-value of a roof is affected by various parameters of roof configuration which can only be measured through empirical method. CCSS is able to measure the roof U-value and allow testing to be done on various roof design parameters. Future study to be conducted to test the effectiveness of CCSS on measuring the roof U-value. With the use of the CCSS as an empirical method, it is possible for the future residents in Malaysia to enjoy the desired thermal comfort in their home without a use of air-condition system.
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