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A Review of the Roof Design and its Influence on the Thermal Performance of Buildings in Equator Area with Warm Humid Climate

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ABSTRACT

In equator area, roof is building element that plays a role in protecting the building from solar radiation because the sun traverses almost perpendicular. The character of warm humid climate is not only high radiation but also high humidity and rainfall. The roof design in the past has a large roof shape, the use of local materials and ventilation existed to get a good thermal performance. Roof designs of modern building mostly have a variation on the roof shape, materials and construction that may affect the thermal performance. This study provides a review of research on the roof design and its influence on the thermal performance of building in warm humid climate. For this purpose, all papers are categorized in two main groups namely pitched-roof and flat-roof. This study shows that the variety of roof shape, materials and construction on modern roof design causes each roof design has the different strategy to improve thermal performance. Roof designs of modern building rely on insulation material to reduce heat transfer. The strategy to reduce radiant heat transfer on pitched-roof depends on kind of insulation and its placement. The strategy to reduce conduction heat transfer on flat-roof depends on kind of insulation and air gap thickness. Combination of insulation material and cool paint on both roof designs is not only reduces heat flux but also lowers surface temperature so that contributes to reduce heat dispersion to the surrounding air. Natural ventilation is still required on certain roof designs to help improve the thermal performance of buildings.

Keywords: Roof Design, Thermal Performance, Heat Transfer, Roof Shape, Insulation Material, Cool Paint, Warm Humid Climate

I. INTRODUCTION

In the past, the roof was characteristic that determines the building shape and the appearance of settlements of a climate region. The difference in appearance was a manifestation of its environmental conditions that utilized to get comfort and health [1]. The roof is the main source of heat gain on buildings in equator area with warm humid climate [2]; [3]; [4]; [5]. The area of warm humid climate is located geographically at latitude between 15° N - 15° S. The character of its climate has the monthly temperatures about 20°-30°C with little diurnal range. Humidity through the year above 60% with maximum about 90-100%. The annual rainfall exceeds 1000 mm. The high temperature and high humidity cause excessive evaporation that can not be easily removed [4]. Heat can be removed by ventilation in small differences between indoor and outdoor temperature. On a large temperature difference due to the solar radiation on the roof has caused the high of mass radiation temperature on the ceiling. Therefore, the roof is building element that important to note [5]. The building envelope keeps the heat transfer into the buildings most of the day. Improving thermal performance of building is an attempt to reduce thermal load, that means reducing energy consumption for cooling [7]. In warm humid climate, the roof must be designed to minimize solar heat gain and promote ventilation. Roof shape with sharp slope angle creating the volume of air as cavity. Ventilation existed to remove unwanted heat. This kind of roof is not only to form a large volume of air as cavity but also to drain off rain water promptly because of the high rainfall in the area [13, 14].

1.1 Heat transfer in a roof

The second law of thermodynamics states that heat transfer takes place spontaneously in one direction only from a higher to a lower grade state [5]. Heat transfer in buildings occurs due to the difference in temperature between outside and inside the building or vice versa.

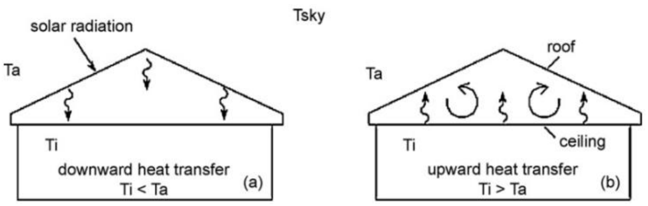

Figure 1: Kind of heat transfer in a roof [8]

On the figure 1 showed the difference heat transfer between downward and upward in a roof. In daytime, downward heat transfer occurs because Ta (ambient temperature) is higher than Ti (indoor temperature). Solar radiation increases roof surface. Heat transfer moves from the roof to the ceiling. Otherwise at night, upward heat transfer occurs because Ti is higher than Ta. Heat transfer back to the sky is trapped under the roof [8]. The downward heat transfer mechanism is as follows heat (in short wave length) received by the roof will be absorbed and reflected. A part of heat is lost by convection and emitted (in long wave length). A part of heat left on the roof is transmitted in radiation to the attic. Heat received by the ceiling will be absorbed and reflected. A part of heat is lost by convection. A part of heat left on the ceiling transmitted in radiation to the room [9].

Related to the intensity of radiation, Lambert's cosine law states that the intensity of light on a surface is equal to the value of the intensity of the light that fall perpendicular to a surface multiplied by the cosine of angle of incidence. So the more perpendicular the angle of incidence causes the higher the value of the intensity of radiation [10]. In equator area, the sun traverses almost perpendicular to the horizontal surface that causes a roof shape with low slope angle receives radiation higher than a roof with sharp slope.

Two types of roof construction are the lightweight roof with slope and the heavyweight roof. The lightweight roof consist of 1 layer or 2 layers (roof and ceiling) that separated by air cavity. This roof using a light materials such as tile, galvanized steel and aluminum sheet. For ceiling using materials such as plasterboard, fiberboard and gypsum sheet. The main heat is transferred to the ceiling in radiation. The thermal character of this roof influenced by external color, thermal resistance and ventilation. The heavyweight roof consist of 1 layer material which generally use a heavy materials such as concrete. The main heat is transferred to the ceiling in conduction. The thermal character of this roof influenced by external color, thermal resistance and heat capacity [3].

1.2 Thermal character of roof

The character of the envelope that affects the thermal performance namely thermal resistance (R-value) or thermal transmittance (U-value), thermal mass and exterior surface condition. R-value is the rate of steady-state heat transfer of a material property. U-value is the rate of steady-state heat transfer of a construction. A higher R-value or a lower U-value has the capability reducing heat gain [11]. Thermal mass is ability of material to store heat and to delay heat transfer. A useful level of thermal mass is a combination of high heat capacity, high heat density and moderate thermal conductivity. A longer time-lag and smaller decrements factor represents a good thermal mass in stabilizing the indoor temperature [12]. Each material has its own thermal conductivity (k-value). Most metals have a great k-value. The k-value of metal deck is 50 W/m.K, meanwhile tiles: 0.84 W/m.K and concrete slab: 1.13 W/m.K. Materials of insulation have the least k-value compared to other materials [5].

Three types of insulation that affects the thermal performance are reflective, resistive and capasitive insulation. Reflective insulation has shiny characteristic to reflect solar radiation. Resistive insulation has cavity characteristic to resist heat conduction and convection. Capasitive insulation has thermal mass characteristic to longer duration time-lag. Radiant barrier is a shinny metallic surface that has high reflectance and low emittance, usually used in cavity [11]. Radiant barrier can be installed with follow the roof slope angle and applied horizontally on the ceiling. To install horizontally is more efficient 5% than follow the roof slope angle [15, 16].

Radiation for an opaque material has surface qualities: absorptance (a) + reflectance (r) = 1. The material with the lighter color has high reflectance (close to 1) and low absorptance (close to 0). Vice versa for the material with the darker colour. Roof surfaces have three behaviors that respect to radiation i.e. absorptance, reflectance and emittance (e). The emittance is the capacity to emit long-wave radiation compared to a black body. The values of emittance and absorptance are affected by the wave-length. The wave-length in radiation influenced by temperature from the source of radiation. At normal temperature, most building materials have high emittance meanwhile polished materials have low emittance [5]. Cool roof is the character of roof surface that has high solar reflectance and high thermal emittance. Cool roof has high solar reflectance ($r>0.6$) and high infrared emittance ($0.8<e<0.9$). Cool roof contributes to release the accumulation of heat gain in the day through the heat loss in a night sky radiation [17, 18].

The development of technology of construction and materials brings a change in building design including roof design. The roof designs of modern building show the variety of roof shape at slope angle, the choice of materials, the system of construction. The challenge of roof design currently is not only able to reduce thermal load of buildings but also contribute to a broader context such as reducing urban heat island effect and producing alternative energy with technology of solar panel. At this time, the study focus on observing the thermal performance of roof designs in reducing thermal load of building.

II. METHODS AND MATERIAL

This study reviews previous research related topics systematically. The selected study is a research that mainly conducts field measurements and there is an explanation of the location of latitude and climatic conditions. The research that meets criteria then identified and grouped based on the typology of roof namely pitched-roof and flat-roof. Based on the total of paper collected, the area of study includes Indonesia, Malaysia, Thailand, Singapore, Sri Lanka, India, Hong Kong and Brazil.

The review of study is classified in two section i.e.: i) thermal performance of pitched-roof, ii) thermal performance of flat-roof. The classification of the study based on the roof shape because it is an aspect that the first thought out in a design. The sequence of discussion in section begins with pitched-roof which includes traditional building, modern building in small scale and large scale.

III. RESULTS AND DISCUSSION

3.1 Thermal performance of pitched-roof

The roof design in warm humid climate is largely a pitched-roof with lightweight construction. Heat transfer on this roof is predominantly takes place by radiation. In the past, the material used was easy to find in the surrounding environment such as wood, bamboo and foliage. Mappaturi [19] observed the influence of roof shape and materials against the formation of attic temperature on traditional house that shaped stage in Indonesia. See Figure 2. Toraja house, is located on altitude 1.500 m, has a saddle type roof (60° slope) from bamboo material with thickness 70 cm. Bugis house, is located on altitude 100 m, has a saddle type roof (30° slope) from sago palm material. In the cool area, Toraja house has a roof with U-value: 0.32 $W/m^2.K$, time-lag: 4.6 hours and the attic temperature: 23.3°C. In the warm area, Bugis house has a roof with U-value: 1.14 $W/m^2.K$, time-lag of less than 1 hour and the attic temperature: 29.6°C.

Figure 2: The traditional house of Toraja and Bugis [19]

It shows Toraja house has roof shape with a large volume of air as a cavity is an effort to reduce heat transfer into the building during the day. The thickness of roof construction of Toraja house determines in the form a small U-value and a long time-lag, so that has the ability to reduce heat gain and to store heat for a relatively long time It is a appropriate conditions for cool area in forming of comfortable temperature in nighttime. While Bugis house also has roof shape with a large volume of air as cavity is an effort to reduce heat transfer into the building during the day. The light of materials of roof construction of Bugis house determines in the form a small U-value and a short time-lag, so that has the ability to reduce heat gain and to store heat for a relatively short time. It is a suitable conditions for warm area in forming of comfortable temperature in daytime. This is appropriate as described by Lstiburek [11] that a lower U-value has the capability reducing heat gain, and also by --- [12] that a longer time-lag represents a good thermal mass in stabilizing the indoor temperature. The roof of Bugis house shows the ability to reduce heat and the presence of ventilation, as described by Hyde [13, 14] that a roof must be designed to minimize solar heat gain and promote ventilation in warm humid climate.

On the roof model, Samodra [20] observed the influence of roof geometry against the acceptance of irradiation on roof models of village house in Java Island, Indonesia. See Figure 3. Among the models, The roof of Srotongan (slope 45° and 35°) has a small surface area so that has the lowest irradiation than other roof models. The roof surface on the north orientation is the greatest of the total irradiation. Total irradiation on element of 'Gajah' (45° slope) is lower than the element of 'Emper' (35° slope). Total irradiation on element of 'Gajah' with area 71 m^2: 2,042 Wh/m^2 and on element of 'Emper' with area 44 m^2: 2,807 Wh/m^2.

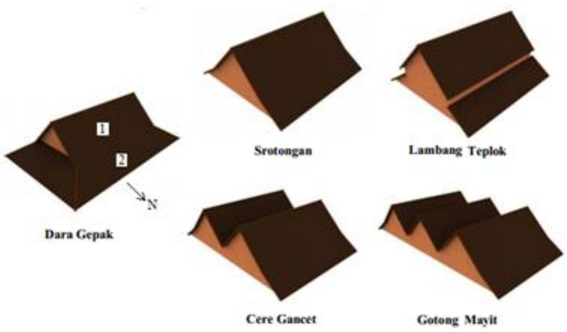

Figure 3: The roof model of Javanese village house (1. Gajah, 2. Emper) [20]

It shows that orientation and roof geometry (surface area, slope angle) determine the number of irradiation received. Orientation and slope angle determine the intensity of irradiation because related to the position of the sun (angle of incidence) while surface area determines total irradiation received. In equator area on the same orientation, a roof with low slope angle receives the greater of intensity of irradiation than a roof with sharp slope angle because sunlight falls more perpendicular. This is in accordance with the principle of angle of incidence from Lambert's cosine law by Taylor [10] that the more perpendicular the angle of incidence causes the higher the value of the intensity of radiation. Therefore, most village house have a roof shape with sharp slope angle in an effort to reduce irradiation.

But when considering on slope angle and color together, will get a different result. Al-Obaidi et al. [21] observed the influence of roof slope angle and color variation against the formation of indoor temperature on saddle type roof models in Malaysia situation. Roof model with low slope angle on white surface has surface temperature lower than roof model with sharp slope angle. Roof model with low slope angle on black surface has surface temperature higher than roof model with sharp slope angle. The difference of indoor temperature due to the difference of color between white and black surface (> 5°C) is greater than due to slope angle difference between 0° and 60° (< 1°C). It is said that the difference of color more decisive in the reduction of indoor temperature rather than the difference of slope angle. The difference of the results between Samodra [20] and Al-Obaidi et al. [21] occurs due to the difference observations of light source. Samodra [20] observed the influence of the direct radiation so that the angle of incidence on the surface which is the concern. While Al-Obaidi [21] observed the influence of the diffuse radiation so that the quality of the surface which is the concern.

Insulation materials play a role in addressing the problems of building heat in the roof design of modern building. Harimi et al. [22] observed the influence of the addition of insulation material against the lowering of ceiling temperature on a low cost house with galvanized steel-roof in Malaysia. The addition of the thickness of mass insulation (fiberglass) of 50 mm into 100-150 mm just lowering ceiling temperature with differences of less than 0.5°C. Fiberglass insulation reduces ceiling temperature lower than aluminum foil insulation. Ceiling temperature of roof with insulation is higher than the roof without insulation in nighttime, giving ventilation can help to reduce heat flux. It shows that fiberglass insulation is greater in lowering the ceiling temperature of galvanized steel-roof than the roof with aluminum foil insulation. The steel material has k-value:

45 W/m.K so that ceiling temperature easier to rise, the addition of fiberglass insulation with a thickness can reduce and stabilize temperature rise. Insulation having high heat capacity is needed to cope the rapidly radiant heat transfer, as described by Lstiburek [11] that capasitive insulation has thermal mass characteristic to longer duration time-lag, and also by --- [12] that a longer time-lag represents a good thermal mass in stabilizing the indoor temperature. While natural ventilation helps to remove heat accumulation in nighttime because there is heat flow back to the sky trapped that must be removed.

Chirarattananon & Vu [23] observed the influence of placement of reflective insulation (radiant barrier) against the reduction of heat flux on a model of concrete tile roof (30° slope) in Thailand situation. The heat flux of roof model with radiant barrier (k-value: 0.232 W/m.K) on the ceiling is lower than roof model with radiant barrier under the roof, in forced ventilation conditions. A comprehensive study conducted by Kiet et al. [25] that evaluated the influence of roof material, insulation material and placement of insulation against the reduction of the mean radiant temperature on three construction systems of pitched-roof in Malaysia. With or without insulation material, mean radiant temperature on clay tile roof is the lowest followed by concrete tile roof and metal deck roof. On its roofs with reflective insulation (double sided aluminum foil) reduces the mean radiant temperature greater than the roofs with mass insulation (rockwool) 50 mm. Placement of double sided aluminum insulation on the ceiling reduces temperature 3°C lower than the placement it under the roof. It shows that reflective insulation such as double sided aluminum can be applied not only on clay tile roof and concrete tile roof but also metal deck roof. Insulation having high heat reflection is needed to cope radiant heat transfer, as described by Lstiburek [11] that reflective insulation has shiny characteristic to reflect solar radiation.

Chirarattananon & Vu [23] and Kiet et al. [24] both show that placing a reflective insulation on the ceiling better in reducing heat flux than placing a reflective insulation under the roof. As described by Medina [15]; Medina & Young [16] that to install radiant barrier horizontally is more efficient 5% than follow the roof slope. Kiet et al. [24] reported on clay tile roof with insulation or no insulation is the most good reduce temperature followed by concrete tile roof and metal roof deck because the material of clay has smaller k-value than concrete and metal materials.

The development of technology of constructions and building materials also create a wide span structure for spacious buildings. The amount of heat flux on the roof and using air conditioning require more expensive to handle the thermal load of building. Han et al. [25] observed the influence of insulation materials and colors of paint against the reduction of heat flux and the cooling load on the wide span roof construction with LASRS (lightweight aluminum standing seam roofing system) system in Hong Kong. Heat flux on roof with polyurethane insulation 150 mm is smaller than glasswool 75 mm + polyurethane 75 mm insulation. Compare to black painted roof, LASRS roof with white painted reduces cooling load by 9.3%. LASRS roof with white painted and polyurethane insulation can reduce cooling loads up to 20%. It shows LASRS roof with white painted has a character that reflects most of the heat radiation and only a small portion is absorbed so that be able to reduce heat, as described by [5] that the material with the lighter color has high reflectance and low absorptance. While polyurethane insulation significant reduce cooling load rather than glasswool insulation because polyurethane has smaller k-value than glasswool. Therefore, a combination of white painted and polyurethane insulation represents the best in reducing cooling load related to air conditioning used in building.

The similar study carried out by Filho & Santos [26] who observed the suitability of the use of thermal insulation and painting on the metal deck wide span roof construction in Manaus, Brazil. Compare to the conventional metal deck roof (without coating: $\varepsilon_{e,ir} = \rho_{e,s} = 0.30$), metal deck roof with polyurethane insulation and painting (selective coating: $\varepsilon_{e,ir} = \rho_{e,s} = 0.90$) produces a larger reduction in the average annual daily heat flux and the external surface temperature than metal deck roof with polyurethane insulation and painting (white painted: $\varepsilon_{e,ir} = 0.75$, $\rho_{e,s} = 0.90$). The reductions of annual daily value on the combination polyurethane and selective coating are heat flux: 98.08 W/m^2 and surface temperature: 11.26^{o} C. The reductions of annual daily value on the combination polyurethane and white painted are heat flux: 97.42 W/m^2 and surface temperature: 2.95^{o} C. It shows that reduction in heat flux is not much different because using the same insulation but reduction in surface temperature is big enough due to differences in the types of painting. A selective coating significantly decreases the surface temperature on the metal deck roof and also helps reduce heat flux a little.

The study of Han et al. [25] and Filho & Santos [26] shows the similarities in the use of combination of polyurethane insulation and painting on the wide span roof construction. Han et al. [25] conduct a combination of polyurethane insulation and white painted in reducing heat flux only. While Filho & Santos [26] conduct a combination of polyurethane insulation and selective coating in reducing heat flux and lowering surface temperature of roof. For wide span roof construction above, the addition of insulation polyurethane insulation with a thickness can reduce and stabilize temperature rise. Insulation having high heat capacity is needed to cope the rapidly radiant heat transfer because the use of aluminum and metal materials, as described by Lstiburek [11] that capasitive insulation has thermal mass characteristic to longer duration time-lag, and also by --- [12] that a longer time-lag represents a good thermal mass in stabilizing the indoor temperature. Roof with selective coating reflects more radiation and releases the heat slowly is a roof called cool roof. This is appropriate as described by Synnefa & Santamouris [17] and Synnefa et al. [18] that cool roof is the character of roof surface that has high solar reflectance and high thermal emittance.

Study of special color paint on pitched roof performed by Uemoto et al. [27], who investigated the thermal performance of a special paint color (cool colored acrylic paints) and conventional paint color (colored acrylic paints), which applied on corrugated fiber cement sheet in Brazil. The value of reflectance of near infrared reflectance (NIR) is higher than VIS (visible) and UV (ultra violet). The value of reflectance of NIR on a special paint colors of cool white, cool yellow and cool brown was 80.1%, 76.2%, and 72.9%, whereas in conventional paint colors of white, yellow and brown is 63.8%, 44.4%, and 32.8%. Surface temperature on fiber cement roof with a special paint color is more than 10°C lower than fiber cement roof with conventional paint color. Compare to the unpainted roof, the reduction of heat flux on the roof with a special paint color reaches 37%. It shows in general the lighter color has a high reflection value than the darker colors both on conventional paint color and special paint color. The high value of NIR of special paint color has greater reduction of heat flux and lower of surface temperature than conventional. Roof with a special paint color reflects more radiation and releases the heat slowly is a roof called cool roof. This is appropriate as described by Synnefa & Santamouris [17] and Synnefa et al. [18] that cool roof is the character of roof surface that has high solar reflectance and high thermal emittance. With high solar reflectance, cool roof contributes to reduce heat flux. With high thermal emittance, cool roof contributes to release heat accumulation through heat loss in nighttime so that keep lower surface temperature, which ultimately can reduces heat dispersion to the surrounding air.

Table 1: Summary studies on pitched-roof

Reference	Results
Mappaturi [19]	In the cool area, Toraja house has a large roof with U-value: 0.32 W/m^2.K, time-lag: 4.6 hours and the attic temperature: 23.3°C. In the warm area, Bugis house has a large roof with U-value: 1.14 W/m^2.K, time-lag of less than 1 hour and the attic temperature: 29.6°C.
Harimi et al. [22]	Surface ceiling temperature on galvanized steel roof with 50 mm fiberglass insulation lower than with aluminum foil. The addition of fiberglass thickness from 50 mm to 2-3 times does not significantly lower the ceiling temperature.
Chiraratta nanon & Vu [23]	Heat flux on concrete roof tile model (slope 30°) with the placement of radiant barrier on the ceiling is lower than roof model with the placement of radiant barrier under the roof, both in ventilation conditions.
Kiet et al. [24]	Mean radiant temperature on clay tile roof with or without insulation is lower than concrete tile roof and metal deck roof. The roof with the placement of double-sided aluminum insulation on the ceiling is lower 3°C than insulation placement under the roof.
Han et al. [25]	Compared to roof with black painted, LASRS roof with white painted reduces cooling load by 9.3%. The addition of polyurethane insulation on LASRS with white painted can reduce cooling load by up to 20%.
Filho & Santos [26]	Reduction of annual daily heat flux and external surface temperature on metal deck roof with polyurethane insulation and selective coating (98.08% and 11.26%) larger than metal roof deck with polyurethane insulation and white painted (97.42% and 2.95%).
Uetomo et al. [27]	Surface temperature on fiber cement roof with a special paint is more than 10°C lower than fiber cement roof with conventional paint. Compare to the unpainted roof, the reduction of heat flux on roof with a special paint color reaches 37%.

The study of Han et al. [25], Filho & Santos [26] and Uemoto et al. [27] shows the importance of the use of the painting on roof surface. The results of their studies are similarly associated with building energy savings for large building. The use of white painted by [25] only reduce heat flux of roof meanwhile the use of selective coating by [26] and the use of a special paint colors by [27] reduce heat flux and lower surface temperature of roof so that contribute to reduce heat dispersion to the surrounding air.

From the table 1 above shows that roof design of traditional house reflects the ability to adapt to climatic and environmental conditions to overcome radiant heat transfer. Roof shape with sharp slope angle, the construction of roof with a small U-value and natural ventilation existed are a parameter design that is considered [19]. Roof designs on modern building with pitched-roof overcome radiant heat transfer by relying on the use of insulation materials. Clay tile roof and concrete tile roof using reflection insulation with the effective placement on the ceiling rather than under the roof slope [23]; [24]. Metal deck roof using capasitive insulation with the effective placement under the roof slope [22]; [25]. Combination of insulation material and selective coating or special paint color on the roof reduces heat flux and lowers surface temperature [26]; [27]. Natural ventilation still be used to help remove heat on small building with pitched-roof [22]; [23].

3.2 Thermal performance of flat-roof

The design of flat-roof generally is a roof type of heavy construction with material of concrete. Heat transfer on this roof is predominantly takes place in conduction. Halwataru & Jayasinghe [28] observed the influence of addition of insulation material against the lowering of soffit temperature on concrete flat roof (slab 125 mm) in Sri Lanka. The addition of the thickness of resistive insulation (polyethylene) from 25 mm to 50 mm less significantly in lowering soffit temperature. Concrete flat-roof with polyethylene 25 mm (U-value: 1.01 $W/m^2.K$) is more efficient in lowering soffit temperature than the roof without insulation (U-value: 4.0 $W/m^2.K$). It shows that the addition of insulation thickness does not result an improvement in reducing heat flux. There is one significant thickness in lowering soffit temperature. Concrete flat-roof with 25 mm polyethylene insulation is an effective to improve the roof performance with reducing U-value up to a quarter of U-value (the roof without insulation). Insulation having high heat resisting with the placement on the roof surface is needed to cope conduction heat transfer, as described by Lstiburek [11] that resistive insulation has cavity characteristic to resist heat conduction and convection.

Chirarattananon & Vu [23] also observed the influence of placement of insulation material against the reduction of heat flux on a model of concrete flat-roof in Thailand situation. The heat flux on the roof with placement of radiant barrier (k-value: 0.023 W/m.K) as the ceiling is lower than cellocrete (k-value: 0.1 W/m.K) or acoustic board (k-value: 0058 W/m.K) as the ceiling, in no ventilation conditions. It shows that the reflective insulation (radiant barrier) is more beneficial as the ceiling than cellocrete or acoustic board because radiant barrier has smaller k-value and thus more able to reduce heat. Its found on flat-roof that there is radiant heat transfer under the roof that flows to the ceiling so that reflective insulation is used to cope heat transfer.

While Madhumathi et al. [29] observed the influence of the type of roof construction and materials against the lowering of indoor thermal comfort on some roof constructions (traditional and modern) in India. Madras terrace roof (U-value: 1.59 $W/m^2.K$) and Sloped RC (reinforced concrete) roof shading with clay tile and air space in between (U-value: 1.37 $W/m^2.K$) are two roof constructions with a small U-value that approaching to the indoor thermal comfort level. They said possible to lower air temperature 3-6° C in buildings by using passive roof design. To reach the thermal performance of roof construction, a roof is composed of several layers of material that have a difference of character with a k-value as small as possible. It shows that the addition of certain materials (non-insulation) on flat-roof is able to create flat-roof with a small U-value. Madras terrace roof consists of brick plate and mortar line coated terracotta tiles, while slopped RC roof consists of concrete covered with roof tiles plus air gap. Terracota tiles and roof tiles plus air gap are materials that act as an insulation thereby minimizing the U-value, as described by Lstiburek [11] that a lower U-value has the capability reducing heat gain.

The results of studies with similar approach done by Vijaykumar et al. [30] who observed the influence of addition of certain materials against the reduction heat transmission on the RCC (reinforced cement concrete) roof (slab 150 mm) in India. RCC roof with HCT (hollow clay tile) 75 mm in open hole conditions reduces the heat transmission better than the roof with HCT 75 mm in the closed hole conditions. It can conserve energy around 38-63% over RCC roof with weathering course (lime brick mortar 75 mm). It shows that the use of certain material such as hollow clay tile 75 mm on flat-roof is able to reduce heat flux. HCT in open hole conditions is better than HCT in the closed hole conditions due to the open conditions of hole create air gap with ventilation effect. HCT 75 mm is material that act as an insulation thereby minimizing the U-value, as described by Lstiburek [11] that a lower U-value has the capability reducing heat gain.

Similar with the study above, Khan et al [31] also found that the RCC roof with the addition of the certain materials i.e. concrete hollow tile or hollow clay tile is able to lower inside temperature than RCC roof with the addition of other materials. Madhumathi et al. [30], Vijaykumar et al. [30] and Khan et al [31] agree that the addition of certain materials on flat-roof capable in reducing heat flux. The existence of the construction of certain materials that creates air gap thickness on flat-roof is able to lower the U-value effectively. A comprehensive study conducted by Jayasinghe et al. [32] who studied the influence of orientation, insulation materials and roof color against the establishment of indoor comfort temperature on flat-roof of housing in Sri Lanka. They said that the orientation is not significant in favor of indoor comfort temperature. Materials and insulation significant in the form indoor temperature and can be enhanced with the use of bright color on the roof surface. It showed that orientation is not a parameter design that affects the thermal performance of flat roofs in equator area. With a horizontal surface is easier in addition and placement insulation material or certain materials on the surface roof, including to turn of the color becomes brighter. This is in accordance with the explanation by Givoni [3] that thermal character of heavyweight construction influenced not only by heat capacity and thermal resistance but also external color.

Tong et al. [33] observed the influence of insulation material, coating and ventilation against a heat gain reduction on concrete flat-roof of high-rise building in Singapore. Compare to the roof without ventilation, daily heat gain on the cool paint roof with ventilation reduces by 42% and the cool paint roof with EPS foam 2.5 cm (k-value: 0037 W/m.K) reduces by 68%. Daily heat gain on the cool paint roof with air cavity 22 cm plus radiant barrier (U-value: 2.04 w/m2. K) and ventilation reduces by 84% and the cool paint roof with EPS foam 2.5 cm and ventilation reduces by 73%. It shows that sequentially from the best reduce daily heat gain is the cool paint roof with air cavity 22 cm + radiant barrier + ventilation, followed by the cool paint roof with EPS foam 2.5 cm insulation + ventilation, and the cool paint roof with ventilation. The importance of the use of the cool paint on roof surface can be associated with building energy savings for large building. The addition of the air gap thickness on the ceiling is needed in reducing the great heat flux and can be combined with reflective insulation. The combination of coating, insulation material, air gap thickness and ventilation is the best to reduce heat flux because it produces a small U-values, as described by Lstiburek [11] that a lower U-value has the capability reducing heat gain. While natural ventilation helps to reduce daily heat gain on all combinations.

Table 2: Summary studies on flat-roof

Reference	Results
Halwataru & Jayasinghe [29]	Concrete flat roof with 25 mm polyethylene insulation is the more efficient in lowering soffit temperature of 10°C than the roof without insulation. The addition of insulation thickness from 25 mm to 2 times only decreases the soffit temperature by 1°C
Chirarattana non & Vu [23]	Heat flux on model of concrete flat-roof with radiant barrier as ceiling is lower than the roof with cellocrette or acoustic board as ceiling, no ventilation conditions.
Madhumathi et al. [29]	Madras terrace roof with U-value: 1.59 W/m^2.K and Sloped RC roof with U-value: 1.37 W/m^2.K are the smaller U-value roof than other models, that approaching indoor temperature comfort level.
Vijaykumar et al. [30]	Reduction of heat transmission on RCC roof with addition of 75mm hollow clay tile in open hole conditions is greater than the roof in closed hole conditions. It can save energy up to 63% compared to RCC roof with weathering course (lime brick mortar 75 mm).
Khan et al [31]	Inside temperature on RCC roof with addition of concrete hollow tile and RCC roof with addition of hollow clay tile is lower than the roof with addition of any other materials.
Tong et al. [33]	Daily heat gain on the cool paint roof with ventilation reduces by 42% and the roof with EPS foam 2.5 cm reduces by 68%. Daily heat gain on the cool paint roof with air cavity 22 cm plus

	radiant barrier and ventilation reduces by 84% and the roof with EPS foam 2.5 cm and ventilation reduces by 73%.

From the table 2 above shows that roof design of modern building with flat-roof overcome conduction heat transfer by relying on the use of insulation materials. Kind of insulation used to reduce conduction heat transfer on flat-roof is resistive insulation. The thickness of insulation determines in lowering soffit temperature [28]. The use of reflection insulation to reduce radiant heat transfer on the ceiling [23]; [33]. The addition of certain materials (non insulation) on flat-roof that creates air gap thickness is able to reduce heat transfer [29]; [30]; [31]. The use of cool paint, the addition of air gap thickness and the use of reflective insulation on the ceiling and natural ventilation are a combination that can be applied to reduce heat flux on large scale building with flat-roof [33].

IV. CONCLUSION

This study identifies and describes the roof design and its influence on the thermal performance of building in warm humid climate. This study has found that the variety of roof shape, materials and construction on modern roof design causes each roof design has the different strategy to improve thermal performance. Roof design of modern building rely on the insulation material to reduce heat transfer. The strategy to reduce heat transfer on pitched-roof depends on kind of insulation and its placement. Pitched-roof is appropriate to use a reflective insulation under the roof to reduce radiant heat transfer. On clay tile roof and concrete tile roof are appropriate to use a reflective insulation with effective placement on the ceiling rather than under the roof slope, while metal deck roof is appropriate to use a capasitive insulation under the roof slope.

The strategy to reduce heat transfer on flat-roof depends on kind of insulation, its thickness and air gap thickness. Concrete flat-roof is appropriate to use a resistive insulation on the roof surface to reduce conduction heat transfer. The addition of insulation thickness is not in line with the increased ability to reduce heat flux because there are certain thicknesses that can effectively reduce heat. While the addition of a layer with air gap thickness on the roof or under the roof can improve it significantly.

Combination of insulation material and cool paint on the roof (cool roof) is not only reduces heat flux significantly but also lowers surface temperature so that contributes to reduce heat dispersion to the surrounding air such as reducing urban heat island effect. Natural ventilation is still required on certain roof designs to help improve the thermal performance of buildings.

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