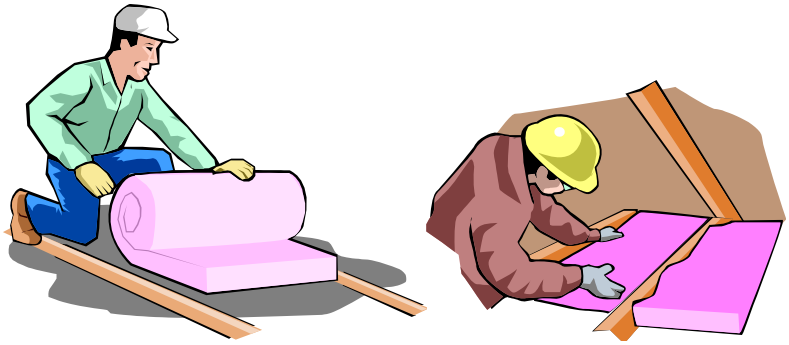
# Chapter 8 – Roof Insulations

*Building Energy Efficiency Technical Guideline for Passive Design (Draft 1)*



**CK Tang & Nic Chin**

## Foreword

This document is produced as part of Component 4, Building Sector Energy Efficiency Program (BSEEP) by CK Tang (ck@gbeet.com) and Nic Chin (nc.environmentology@gmail.com).

The views expressed in this document, which has been produced without formal editing, are those of the authors and do not necessarily reflect the views of neither JKR nor UNDP. Comments and opinions from readers are encouraged and please email it to either ck@gbeet.com or nc.environmentology@gmail.com or comment at our Facebook page: www.facebook.com/bseepc4

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# Table of Contents

# 8 Roof Insulation

## 8.1 Introduction

There are many different types of roofing systems in use in Malaysia. Three commonly practiced roofing systems are concrete flat roof, light-weight pitched roof and light-weight pitched roof over concrete flat roof or ceiling tiles. The energy efficiency behavior of insulation provided on these roof systems is slightly different for each type of roof system and is particularly affected by the different hours of air-conditioning operating hours in the space immediately below the roof.

A typical roof is fully exposed to the entire sky dome and is strongly influence by the received solar radiation and the effective sky temperature. During daytime, radiation heat transfer on the roof is both received and rejected at the same time. The sun (solar radiation) is heating up the external roof surface, while the rest of the sky dome (effective sky temperature, averaging at 20°C) is cooling the external roof surface. The net radiation gain on the roof during daytime is positive and the heated external roof surface will transmit heat into the internal space via conduction through the roof.

During night time, where the average effective sky temperature is 15°C (Chapter 2) and without any solar radiation heat gain, heat is rejected by the roof surface into the sky via radiation heat transfer. Warmer temperature from the internal space immediately below the roof is conducted to the top surface of the roof and rejected to the cold night sky. The provision of insulations in roof reduces the amount of heat conducted between the internal and external surface of the roof. Depending on the hours of operating the air-conditioning system, the provision of insulation in roofing system can be beneficial or detrimental to the energy efficiency of the building.

In this climate zone, it will be ideal to be able to provide insulation in roof during daytime to prevent heat gain, and have the insulation removed during nighttime, to allow the sky to cool the building down naturally. Removable roofing system, water sprinklers system during night time and etc. are some of the methods being explored by researcher worldwide to harness the ‘cooling’ abilities of the night sky.

This chapter provides the potential energy reduction due to the use of insulation in roofing system for these scenarios below the roof space:

1. Air-Conditioning Hours of 8am to 5:30pm (weekend off, for office spaces)
2. Air-Conditioning Hours of 24 hours (weekend same, for hotel, hospital, etc.)
3. Air-Conditioning Hours of 2pm to 10pm (weekend same, for residential kids home from school)
4. Air-Conditioning Hours of 10pm to 6am (weekend same, for residential houses)

In addition, 3 roof types were considered:

1. Flat roof (insulation material – polystyrene foam)
2. Pitch roof with plasterboard ceiling (insulation material – mineral wool)
3. Pitch roof with concrete ceiling (insulation material – mineral wool)

The 3$^{rd}$ roof type was provided for this study because it is becoming common for buildings with concrete flat roof to have a pitch roof over it. This provides additional safety against rain water leakages and also provided additional insulation (2$^{nd}$ roof) to the building.

## 8.2 Key Recommendations

These recommendations were made assuming electricity tariff of RM 0.35 per kWh. Please compute again if the electricity tariff is different using the savings shown in kWh/year from the tables below.

In general, the maximum insulation thickness to be provided to buildings in Malaysian climate zone is 100mm of polystyrene foam or mineral wool. Providing thicker insulation than 100mm does not yield much further energy reduction.

### *8.2.1 Concrete Flat Roof*

Concrete flat roof are provided with Polystyrene foam with conductivity value (k-value) of 0.030 W/m-K as insulation materials (lower k-value signify better insulation properties, many manufacturer will meet or surpass this k-value used for polystyrene foam in this study). The total constructed roof U-values with and without insulation are provided in the table below.

| Flat Roof Descriptions | Ashrae U-value ($W/m^2K$) |
|---|---|
| Base Flat Roof | 4.0604 |
| Flat Roof with 25mm Insulation | 0.8898 |
| Flat Roof with 50mm Insulation | 0.5109 |
| Flat Roof with 75mm Insulation | 0.3641 |
| Flat Roof with 100mm Insulation | 0.2794 |
| Flat Roof with 200mm Insulation | 0.1447 |
| Flat Roof with 300mm Insulation | 0.0972 |
| Flat Roof with 400mm Insulation | 0.0736 |
| Flat Roof with 500mm Insulation | 0.0591 |

**Table 8.2.1.1: Ashrae U-value for Flat Roof Used in this Study**

Tables 8.2.1.2 to 8.2.1.5 below provide the budget for flat roof insulation depending on the hours of air-conditioning used. For example, from the table below, for an office building where the air-conditioning hours are 8am to 5:30pm weekdays, the available budget for a 100mm polystyrene insulation foam is RM 67.92 per $m^2$ of roof area with 15 years payback period. If the cost of 100mm polystyrene foam is less than RM 67.92, then it is economically feasible to insulate the roof with 100mm insulation foam. Due to the reason that electricity tariff will continue to increase over the years, the actual payback period will definitely be faster than 15 years as provided by these table below. Users are encourages to create their own table with own electrical tariff assumptions as information becomes available.

| Cases | Flat Roof Descriptions | Building Energy kWh/$m^2$ of roof area per year | kWh/$m^2$ reduction per year | RM/$m^2$ reduction per year | Budget for Insulation with 15 years Payback (RM/$m^2$ of roof area) |
|---|---|---|---|---|---|
| 1 | Base Flat Roof | 135.06 | - | | |
| 2 | Flat Roof with 25mm Insulation | 124.19 | 10.86 | 3.80 | 57.04 |
| 3 | Flat Roof with 50mm Insulation | 122.95 | 12.11 | 4.24 | 63.58 |
| 4 | Flat Roof with 75mm Insulation | 122.42 | 12.64 | 4.42 | 66.36 |
| 5 | Flat Roof with 100mm Insulation | 122.12 | 12.94 | 4.53 | 67.92 |

| | | | | | |
|---|---|---|---|---|---|
| 6 | Flat Roof with 200mm Insulation | 121.63 | 13.43 | 4.70 | 70.49 |
| 7 | Flat Roof with 300mm Insulation | 121.63 | 13.42 | 4.70 | 70.47 |
| 8 | Flat Roof with 400mm Insulation | 121.42 | 13.63 | 4.77 | 71.58 |
| 9 | Flat Roof with 500mm Insulation | 121.39 | 13.66 | 4.78 | 71.74 |

**Table 8.2.1.2: Simulation Results for Flat Roof, Air-Conditioning Hours of 8 am to 5:30 pm weekdays**

| Cases | Flat Roof Descriptions | Building Energy kWh/m² of roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of roof area) |
|---|---|---|---|---|---|
| 1 | Base Flat Roof | 552.08 | - | | |
| 2 | Flat Roof with 25mm Insulation | 522.65 | 29.43 | 10.30 | 154.50 |
| 3 | Flat Roof with 50mm Insulation | 518.42 | 33.66 | 11.78 | 176.71 |
| 4 | Flat Roof with 75mm Insulation | 516.72 | 35.36 | 12.38 | 185.66 |
| 5 | Flat Roof with 100mm Insulation | 515.79 | 36.29 | 12.70 | 190.51 |
| 6 | Flat Roof with 200mm Insulation | 514.31 | 37.77 | 13.22 | 198.29 |
| 7 | Flat Roof with 300mm Insulation | 513.79 | 38.29 | 13.40 | 201.03 |
| 8 | Flat Roof with 400mm Insulation | 513.52 | 38.56 | 13.50 | 202.43 |
| 9 | Flat Roof with 500mm Insulation | 513.36 | 38.72 | 13.55 | 203.28 |

**Table 8.2.1.3: Simulation Results for Flat Roof, Air-Conditioning Hours of 24 hours daily**

| Cases | Flat Roof Descriptions | Building Energy kWh/m² of roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of roof area) |
|---|---|---|---|---|---|
| 1 | Base Flat Roof | 181.22 | - | | |
| 2 | Flat Roof with 25mm Insulation | 158.32 | 22.91 | 8.02 | 120.26 |
| 3 | Flat Roof with 50mm Insulation | 155.67 | 25.55 | 8.94 | 134.13 |
| 4 | Flat Roof with 75mm Insulation | 154.63 | 26.60 | 9.31 | 139.64 |
| 5 | Flat Roof with 100mm Insulation | 154.06 | 27.17 | 9.51 | 142.62 |
| 6 | Flat Roof with 200mm Insulation | 153.11 | 28.12 | 9.84 | 147.61 |
| 7 | Flat Roof with 300mm Insulation | 152.66 | 28.56 | 10.00 | 149.95 |
| 8 | Flat Roof with 400mm Insulation | 152.58 | 28.64 | 10.03 | 150.38 |
| 9 | Flat Roof with 500mm Insulation | 152.51 | 28.71 | 10.05 | 150.73 |

**Table 8.2.1.4: Simulation Results for Flat Roof, Air-Conditioning Hours of 2pm to 10pm daily**

| Cases | Flat Roof Descriptions | Building Energy kWh/m² of roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of roof area) |
|---|---|---|---|---|---|
| 1 | Base Flat Roof | 152.03 | - | | |
| 2 | Flat Roof with 25mm Insulation | 148.23 | 3.81 | 1.33 | 19.99 |

| | | | | | |
|---|---|---|---|---|---|
| 3 | Flat Roof with 50mm Insulation | 146.76 | 5.28 | 1.85 | 27.71 |
| 4 | Flat Roof with 75mm Insulation | 146.13 | 5.90 | 2.07 | 30.98 |
| 5 | Flat Roof with 100mm Insulation | 145.79 | 6.24 | 2.18 | 32.77 |
| 6 | Flat Roof with 200mm Insulation | 145.25 | 6.79 | 2.38 | 35.63 |
| 7 | Flat Roof with 300mm Insulation | 144.76 | 7.28 | 2.55 | 38.20 |
| 8 | Flat Roof with 400mm Insulation | 144.89 | 7.15 | 2.50 | 37.52 |
| 9 | Flat Roof with 500mm Insulation | 144.79 | 7.25 | 2.54 | 38.04 |

**Table 8.2.1.5: Simulation Results for Flat Roof, Air-Conditioning Hours for 10pm to 6am daily**

### *8.2.2 LIGHT WEIGHT PITCH ROOF WITH PLASTERBOARD CEILING*

Pitch roof are provided with mineral wool with conductivity value (k-value) of 0.035 W/m-K as insulation materials (lower k-value signify better insulation properties, many manufacturer will meet or surpass this k-value used for mineral wool in this study). The total constructed roof U-values of the pitch roof with and without insulation are provided in the table below.

| Pitch Roof Descriptions | Ashrae U-value (W/m²K) (excluding the roof space between the ceiling and pitch roof) | Ashrae U-value (W/m²K) (including the roof space between the ceiling and pitch roof, and plasterboard ceiling) |
|---|---|---|
| Base Pitch Roof | 7.2735 | 2.5479 |
| Pitch Flat Roof with 25mm Insulation | 1.174 | 0.9035 |
| Pitch Flat Roof with 50mm Insulation | 0.6385 | 0.5491 |
| Pitch Flat Roof with 75mm Insulation | 0.4385 | 0.3944 |
| Pitch Flat Roof with 100mm Insulation | 0.3339 | 0.3077 |
| Pitch Flat Roof with 200mm Insulation | 0.1709 | 0.1638 |
| Pitch Flat Roof with 300mm Insulation | 0.1148 | 0.1116 |
| Pitch Flat Roof with 400mm Insulation | 0.0865 | 0.0846 |
| Pitch Flat Roof with 500mm Insulation | 0.0693 | 0.0681 |

**Table 8.2.2.1: Ashrae U-value for Pitch Roof Used in this Study**

| Cases | Pitch Roof Descriptions | Building Energy kWh/m² of pitch roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of pitch roof area) |
|---|---|---|---|---|---|
| 1 | Base Pitch Roof | 137.40 | - | | |
| 2 | Pitch Flat Roof with 25mm Insulation | 134.55 | 2.85 | 1.00 | 14.97 |
| 3 | Pitch Flat Roof with 50mm Insulation | 133.85 | 3.55 | 1.24 | 18.64 |
| 4 | Pitch Flat Roof with 75mm Insulation | 133.55 | 3.85 | 1.35 | 20.24 |
| 5 | Pitch Flat Roof with 100mm Insulation | 133.37 | 4.03 | 1.41 | 21.14 |
| 6 | Pitch Flat Roof with 200mm Insulation | 133.09 | 4.31 | 1.51 | 22.64 |
| 7 | Pitch Flat Roof with 300mm Insulation | 132.99 | 4.41 | 1.54 | 23.17 |
| 8 | Pitch Flat Roof with 400mm Insulation | 132.94 | 4.47 | 1.56 | 23.45 |
| 9 | Pitch Flat Roof with 500mm Insulation | 132.90 | 4.50 | 1.58 | 23.63 |

**Table 8.2.2.2: Simulation Results for Pitch Roof, Air-Conditioning Hours of 8 am to 5:30 pm weekdays**

| Cases | Pitch Roof Descriptions | Building Energy kWh/m² of pitch roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of pitch roof area) |
|---|---|---|---|---|---|
| 1 | Base Pitch Roof | 520.70 | - | | |
| 2 | Pitch Flat Roof with 25mm Insulation | 509.89 | 10.80 | 3.78 | 56.73 |
| 3 | Pitch Flat Roof with 50mm Insulation | 507.24 | 13.46 | 4.71 | 70.64 |
| 4 | Pitch Flat Roof with 75mm Insulation | 506.09 | 14.61 | 5.11 | 76.69 |
| 5 | Pitch Flat Roof with 100mm Insulation | 505.44 | 15.26 | 5.34 | 80.11 |
| 6 | Pitch Flat Roof with 200mm Insulation | 504.36 | 16.34 | 5.72 | 85.80 |
| 7 | Pitch Flat Roof with 300mm Insulation | 503.97 | 16.72 | 5.85 | 87.80 |
| 8 | Pitch Flat Roof with 400mm Insulation | 503.77 | 16.92 | 5.92 | 88.86 |
| 9 | Pitch Flat Roof with 500mm Insulation | 503.64 | 17.06 | 5.97 | 89.55 |

**Table 8.2.2.3: Simulation Results for Pitch Roof, Air-Conditioning Hours of 24 hours daily**

| Cases | Pitch Roof Descriptions | Building Energy kWh/m² of pitch roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of pitch roof area) |
|---|---|---|---|---|---|
| 1 | Base Pitch Roof | 160.23 | - | | |
| 2 | Pitch Flat Roof with 25mm Insulation | 153.75 | 6.48 | 2.27 | 34.03 |
| 3 | Pitch Flat Roof with 50mm Insulation | 152.39 | 7.84 | 2.74 | 41.16 |
| 4 | Pitch Flat Roof with 75mm Insulation | 151.58 | 8.65 | 3.03 | 45.42 |
| 5 | Pitch Flat Roof with 100mm Insulation | 151.13 | 9.10 | 3.19 | 47.78 |
| 6 | Pitch Flat Roof with 200mm Insulation | 150.38 | 9.86 | 3.45 | 51.75 |
| 7 | Pitch Flat Roof with 300mm Insulation | 149.97 | 10.26 | 3.59 | 53.88 |
| 8 | Pitch Flat Roof with 400mm Insulation | 149.65 | 10.58 | 3.70 | 55.55 |
| 9 | Pitch Flat Roof with 500mm Insulation | 149.45 | 10.78 | 3.77 | 56.59 |

**Table 8.2.2.4: Simulation Results for Pitch Roof, Air-Conditioning Hours of 2pm to 10pm daily**

| Cases | Pitch Roof Descriptions | Building Energy kWh/m² of pitch roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of pitch roof area) |
|---|---|---|---|---|---|
| 1 | Base Pitch Roof | 136.03 | - | | |
| 2 | Pitch Flat Roof with 25mm Insulation | 138.25 | (2.22) | (0.78) | (11.66) |
| 3 | Pitch Flat Roof with 50mm Insulation | 138.97 | (2.95) | (1.03) | (15.48) |
| 4 | Pitch Flat Roof with 75mm Insulation | 139.19 | (3.16) | (1.11) | (16.61) |
| 5 | Pitch Flat Roof with 100mm Insulation | 139.32 | (3.30) | (1.15) | (17.32) |
| 6 | Pitch Flat Roof with 200mm Insulation | 139.65 | (3.63) | (1.27) | (19.04) |
| 7 | Pitch Flat Roof with 300mm Insulation | 139.88 | (3.85) | (1.35) | (20.22) |
| 8 | Pitch Flat Roof with 400mm Insulation | 139.98 | (3.95) | (1.38) | (20.75) |

| | | | | | |
|---|---|---|---|---|---|
| 9 | Pitch Flat Roof with 500mm Insulation | 139.96 | (3.94) | (1.38) | (20.67) |

**Table 8.2.2.5: Simulation Results for Pitch Roof, Air-Conditioning Hours of 10pm to 6am daily**

### *8.2.3 LIGHT WEIGHT PITCH ROOF WITH CONCRETE CEILING*

Pitch roof were provided with mineral wool with conductivity value (k-value) of 0.035 W/m-K as insulation materials. The total constructed roof U-values of the pitch roof with and without insulation are provided in the table 8.2.3.1 below.

| Pitch Roof Descriptions | Ashrae U-value (W/m²K) (excluding the ceiling, roof space between the ceiling and pitch roof) | Ashrae U-value (W/m²K) (including the ceiling, roof space between the ceiling and pitch roof, and concrete ceiling) |
|---|---|---|
| Base Pitch Roof | 7.2735 | 2.5713 |
| Pitch Flat Roof with 25mm Insulation | 1.174 | 0.9065 |
| Pitch Flat Roof with 50mm Insulation | 0.6385 | 0.5502 |
| Pitch Flat Roof with 75mm Insulation | 0.4385 | 0.3950 |
| Pitch Flat Roof with 100mm Insulation | 0.3339 | 0.3081 |
| Pitch Flat Roof with 200mm Insulation | 0.1709 | 0.1638 |
| Pitch Flat Roof with 300mm Insulation | 0.1148 | 0.1116 |
| Pitch Flat Roof with 400mm Insulation | 0.0865 | 0.0846 |
| Pitch Flat Roof with 500mm Insulation | 0.0693 | 0.0681 |

**Table 8.2.3.1: Ashrae U-value for Pitch Roof Used in this Study**

| Cases | Pitch Roof Descriptions | Building Energy kWh/m² of pitch roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of pitch roof area) |
|---|---|---|---|---|---|
| 1 | Base Pitch Roof with concrete slab | 124.54 | - | | |
| 2 | Pitch Flat Roof with concrete slab & 25mm Insulation | 121.07 | 3.47 | 1.21 | 18.21 |
| 3 | Pitch Flat Roof with concrete slab & 50mm Insulation | 120.19 | 4.35 | 1.52 | 22.83 |
| 4 | Pitch Flat Roof with concrete slab & 75mm Insulation | 119.90 | 4.64 | 1.62 | 24.37 |
| 5 | Pitch Flat Roof with concrete slab & 100mm Insulation | 119.73 | 4.81 | 1.68 | 25.26 |
| 6 | Pitch Flat Roof with concrete slab & 200mm Insulation | 119.44 | 5.10 | 1.78 | 26.77 |
| 7 | Pitch Flat Roof with concrete slab & 300mm Insulation | 119.36 | 5.18 | 1.81 | 27.22 |
| 8 | Pitch Flat Roof with concrete slab & 400mm Insulation | 119.34 | 5.21 | 1.82 | 27.33 |
| 9 | Pitch Flat Roof with concrete slab & 500mm Insulation | 119.33 | 5.21 | 1.82 | 27.37 |

**Table 8.2.3.2: Simulation Results for Pitch Roof, Air-Conditioning Hours of 8 am to 5:30 pm weekdays**

| Cases | Pitch Roof Descriptions | Building Energy | kWh/m² reduction | RM/m² reduction | Budget for Insulation |
|---|---|---|---|---|---|

| | | kWh/m² of pitch roof area per year | per year | per year | with 15 years Payback (RM/m² of pitch roof area) |
|---|---|---|---|---|---|
| 1 | Base Pitch Roof with concrete slab | 521.48 | - | | |
| 2 | Pitch Flat Roof with concrete slab & 25mm Insulation | 510.12 | 11.36 | 3.98 | 59.66 |
| 3 | Pitch Flat Roof with concrete slab & 50mm Insulation | 507.40 | 14.08 | 4.93 | 73.91 |
| 4 | Pitch Flat Roof with concrete slab &75mm Insulation | 506.22 | 15.26 | 5.34 | 80.12 |
| 5 | Pitch Flat Roof with concrete slab &100mm Insulation | 505.55 | 15.93 | 5.58 | 83.64 |
| 6 | Pitch Flat Roof with concrete slab & 200mm Insulation | 504.43 | 17.05 | 5.97 | 89.52 |
| 7 | Pitch Flat Roof with concrete slab &300mm Insulation | 504.02 | 17.46 | 6.11 | 91.64 |
| 8 | Pitch Flat Roof with concrete slab & 400mm Insulation | 503.81 | 17.67 | 6.18 | 92.76 |
| 9 | Pitch Flat Roof with concrete slab & 500mm Insulation | 503.67 | 17.80 | 6.23 | 93.48 |

**Table 8.2.3.3: Simulation Results for Pitch Roof, Air-Conditioning Hours of 24 hours daily**

| Cases | Pitch Roof Descriptions | Building Energy kWh/m² of pitch roof area per year | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of pitch roof area) |
|---|---|---|---|---|---|
| 1 | Base Pitch Roof with concrete slab | 163.26 | - | | |
| 2 | Pitch Flat Roof with concrete slab & 25mm Insulation | 154.84 | 8.42 | 2.95 | 44.21 |
| 3 | Pitch Flat Roof with concrete slab & 50mm Insulation | 152.97 | 10.30 | 3.60 | 54.06 |
| 4 | Pitch Flat Roof with concrete slab &75mm Insulation | 152.21 | 11.06 | 3.87 | 58.05 |
| 5 | Pitch Flat Roof with concrete slab &100mm Insulation | 151.78 | 11.49 | 4.02 | 60.30 |
| 6 | Pitch Flat Roof with concrete slab & 200mm Insulation | 151.03 | 12.23 | 4.28 | 64.22 |
| 7 | Pitch Flat Roof with concrete slab &300mm Insulation | 150.72 | 12.54 | 4.39 | 65.83 |
| 8 | Pitch Flat Roof with concrete slab & 400mm Insulation | 150.58 | 12.69 | 4.44 | 66.60 |
| 9 | Pitch Flat Roof with concrete slab & 500mm Insulation | 150.52 | 12.75 | 4.46 | 66.93 |

**Table 8.2.3.4: Simulation Results for Pitch Roof, Air-Conditioning Hours of 2pm to 10pm daily**

| Cases | Pitch Roof Descriptions | Building Energy kWh/m² of pitch roof area | kWh/m² reduction per year | RM/m² reduction per year | Budget for Insulation with 15 years Payback (RM/m² of |
|---|---|---|---|---|---|

| | | per year | | | pitch roof area) |
|---|---|---|---|---|---|
| 1 | Base Pitch Roof with concrete slab | 147.33 | - | | |
| 2 | Pitch Flat Roof with concrete slab & 25mm Insulation | 144.98 | 2.35 | 0.82 | 12.34 |
| 3 | Pitch Flat Roof with concrete slab & 50mm Insulation | 144.32 | 3.01 | 1.05 | 15.80 |
| 4 | Pitch Flat Roof with concrete slab &75mm Insulation | 143.94 | 3.39 | 1.19 | 17.81 |
| 5 | Pitch Flat Roof with concrete slab &100mm Insulation | 143.72 | 3.61 | 1.26 | 18.95 |
| 6 | Pitch Flat Roof with concrete slab & 200mm Insulation | 143.37 | 3.97 | 1.39 | 20.82 |
| 7 | Pitch Flat Roof with concrete slab &300mm Insulation | 143.23 | 4.10 | 1.44 | 21.53 |
| 8 | Pitch Flat Roof with concrete slab & 400mm Insulation | 143.12 | 4.21 | 1.47 | 22.09 |
| 9 | Pitch Flat Roof with concrete slab & 500mm Insulation | 143.03 | 4.30 | 1.50 | 22.57 |

**Table 8.2.3.5: Simulation Results for Pitch Roof, Air-Conditioning Hours of 10pm to 6am daily**

## 8.3 The Simulation Model

Three (3) types of roof were created for this study on roof insulation. These are:

1. Concrete Flat Roof
2. Pitch Roof with Plasterboard Ceiling
3. Pitch Roof with Cast Concrete Ceiling

### *8.3.1 FLAT ROOF MODEL*

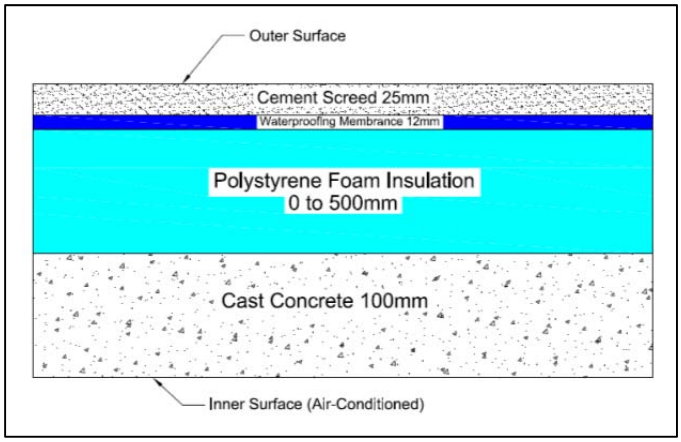



**Figure 8.3.1.1: Cross-Section of a Flat Roof Construction**

| Descriptions | Solar Absorptance | Emissivity | Resistance (m²K/W) |
|---|---|---|---|
| Outer Surface | 0.5 | 0.9 | 0.040 |
| Inside Surface | 0.55 | 0.9 | 0.100 |

| Layers | Material Descriptions (outside to inside) | Thickness (mm) | Conductivity (W/m-K) | Density (kg/m³) | Specific Heat Capacity (J/kg-K) |
|---|---|---|---|---|---|
| 1 | Cement Screed | 25 | 0.9600 | 1800 | 1000 |
| 2 | Waterproofing | 12 | 0.5000 | 1700 | 1000 |

| | | | | | |
|---|---|---|---|---|---|
| | Membrane | | | | |
| 3 | Polystyrene Foam | 0 to 500 | 0.0300 | 25 | 1380 |
| 4 | Cast Concrete | 100 | 1.1300 | 2000 | 1000 |

**Table 8.3.1.1: Flat Roof Construction Properties**

### *8.3.2 PITCH ROOF WITH PLASTERBOARD CEILING MODEL*

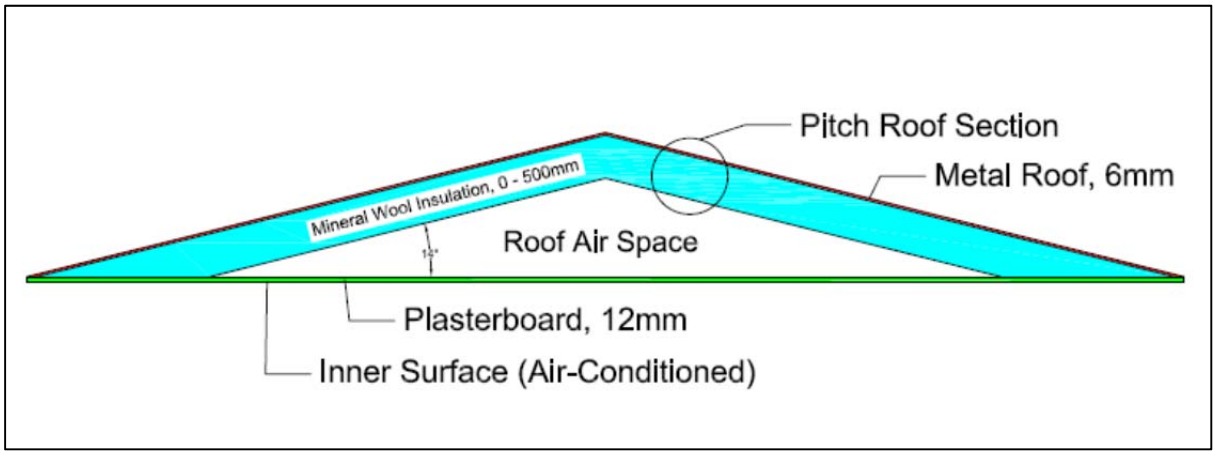



**Figure 8.3.2.1: Cross-Section of a Pitch Roof Construction with Plasterboard as Ceiling**

| Descriptions | Solar Absorptance | Emissivity | Resistance (m²K/W) |
|---|---|---|---|
| Outer Surface | 0.5 | 0.9 | 0.040 |
| Inside Surface | 0.55 | 0.9 | 0.100 |

| Layers | Material Descriptions (outside to inside) | Thickness (mm) | Conductivity (W/m-K) | Density (kg/m³) | Specific Heat Capacity (J/kg-K) |
|---|---|---|---|---|---|
| 1 | Metal Steel Sheet | 6 | 50.000 | 7800 | 480 |
| 2 | Mineral Wool | 0 to 500 | 0.035 | 30 | 1000 |

**Table 8.3.2.1: Construction Properties of Pitch Roof Section**

| Descriptions | Solar Absorptance | Emissivity | Resistance (m²K/W) |
|---|---|---|---|
| Outer Surface | 0.55 | 0.9 | 0.100 |
| Inside Surface | 0.55 | 0.9 | 0.100 |

| Layers | Material Descriptions (outside to inside) | Thickness (mm) | Conductivity (W/m-K) | Density (kg/m³) | Specific Heat Capacity (J/kg-K) |
|---|---|---|---|---|---|
| 1 | Plasterboard | 12 | 0.1600 | 22 | 1000 |

**Table 8.3.2.2: Construction Properties of Ceiling Section**

Roof air space was modeled with an infiltration rate of 1 air-change per hour.

### *8.3.3 PITCH ROOF WITH CONCRETE CEILING MODEL*

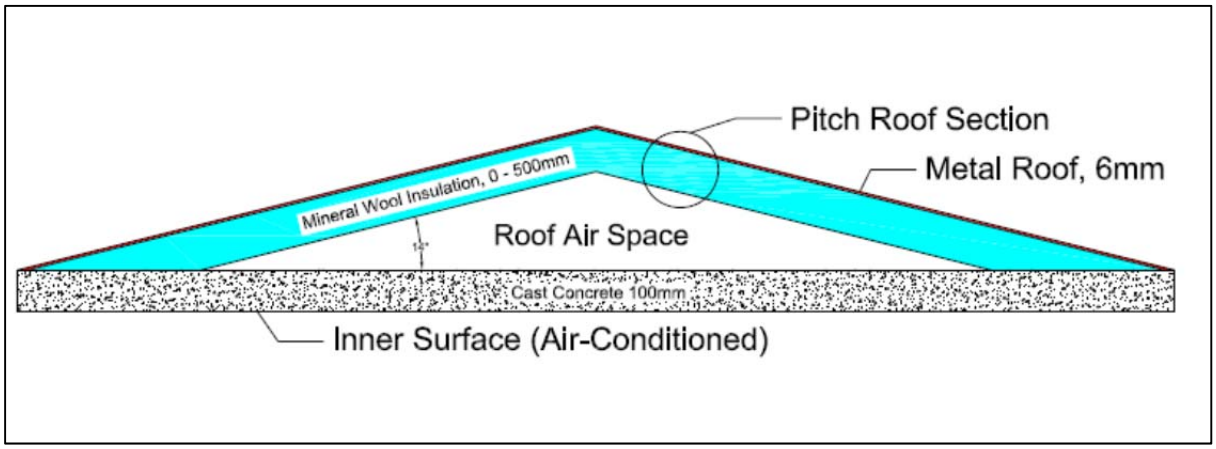



**Figure 8.3.3.1: Cross-Section of a Pitch Roof Construction with Concrete as Ceiling**

| Descriptions | Solar Absorptance | Emissivity | Resistance ($m^2K/W$) |
|---|---|---|---|
| Outer Surface | 0.5 | 0.9 | 0.040 |
| Inside Surface | 0.55 | 0.9 | 0.100 |

| Layers | Material Descriptions (outside to inside) | Thickness (mm) | Conductivity (W/m-K) | Density ($kg/m^3$) | Specific Heat Capacity (J/kg-K) |
|---|---|---|---|---|---|
| 1 | Metal Steel Sheet | 6 | 50.000 | 7800 | 480 |
| 2 | Mineral Wool | 0 to 500 | 0.035 | 30 | 1000 |

**Table 8.3.3.1: Construction Properties of Pitch Roof Section**

| Descriptions | Solar Absorptance | Emissivity | Resistance ($m^2K/W$) |
|---|---|---|---|
| Outer Surface | 0.7 | 0.9 | 0.100 |
| Inside Surface | 0.55 | 0.9 | 0.100 |

| Layers | Material Descriptions (outside to inside) | Thickness (mm) | Conductivity (W/m-K) | Density ($kg/m^3$) | Specific Heat Capacity (J/kg-K) |
|---|---|---|---|---|---|
| 1 | Cast Concrete | 100 | 1.400 | 2100 | 840 |

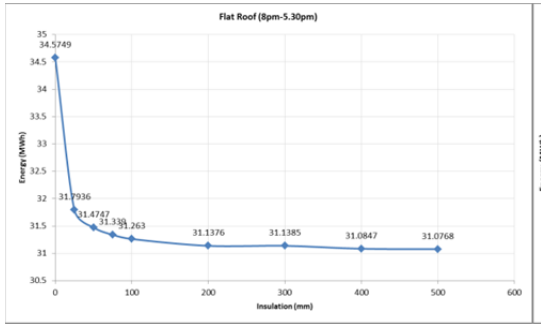
**Table 8.3.3.1: Construction Properties of Ceiling Section**

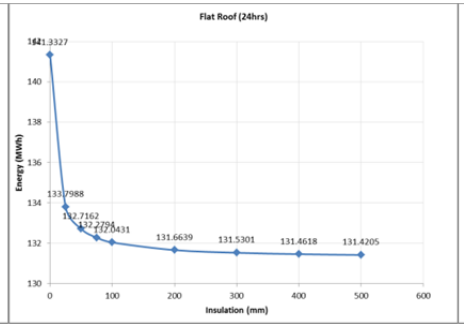
Roof air space was modeled with an infiltration rate of 1 air-change per hour.

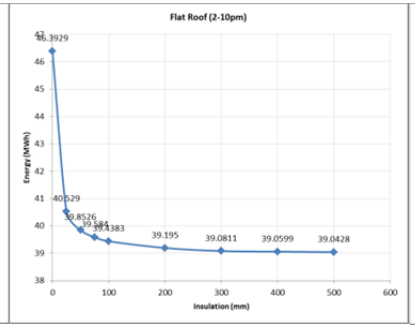
### *8.3.4 AIR-CONDITIONING SYSTEM*

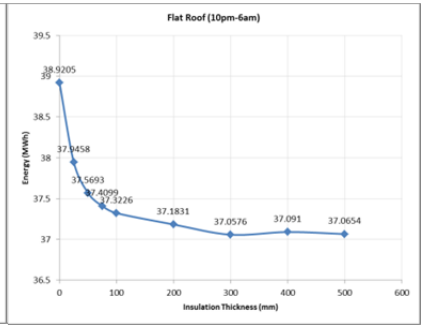
A simplified air conditioning system was modeled assuming a fixed System Coefficient of Performance (SCOP) of 3.0. This efficiency is equivalent to typical new split-unit air-conditioning system used in residential homes today.

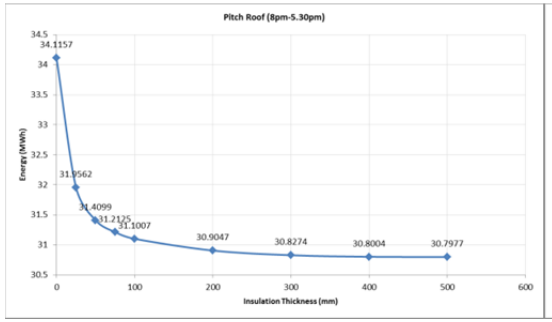
## 8.4 Detailed Simulation Results

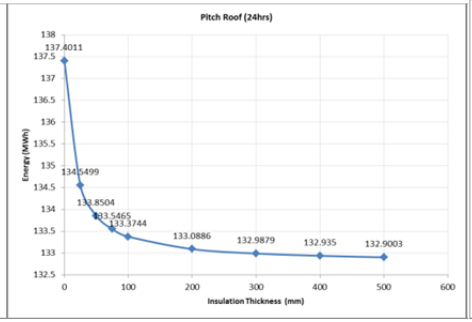


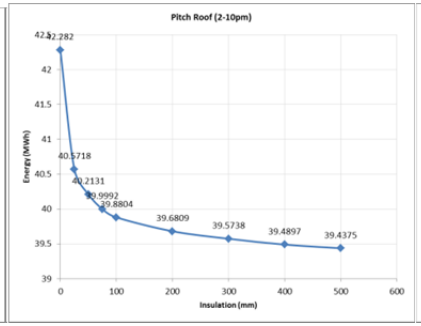



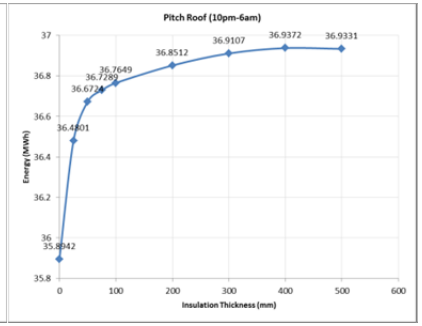



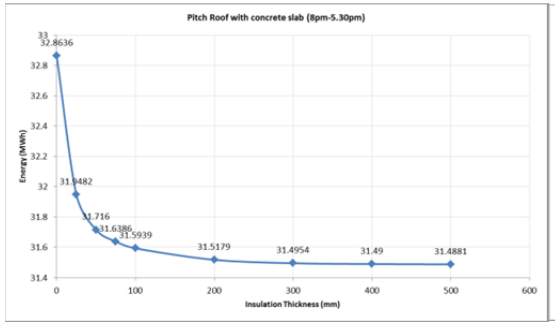



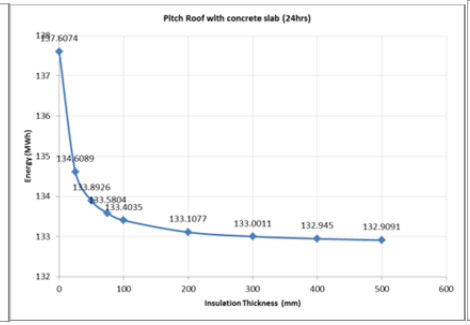



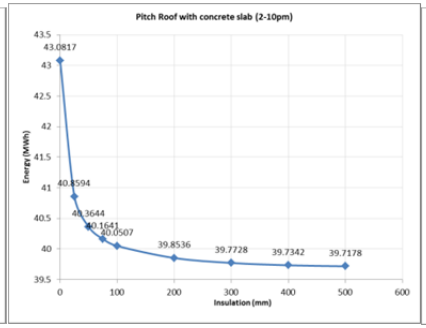



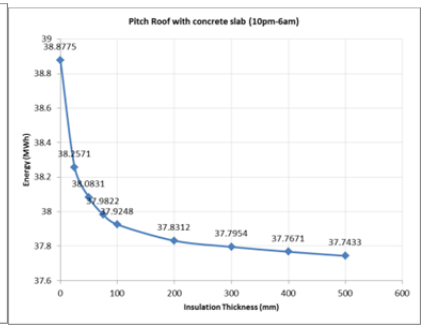




Flat Roof are insulated using Polystyrene Foam with k-value of 0.030 W/m-K

Pitch Roof are insulated using Mineral Wool with k-value of 0.035 W/m-K

Almost in all cases, providing insulation beyond 100mm thickness does not provide much further advantage in terms of energy efficiency. Provision of the initial 25mm insulation provided the highest incremental energy saving. As the insulation material becomes incrementally thicker, the incremental energy saved becomes smaller and smaller until it is almost insignificant, especially after an insulation thickness of 200mm onwards.

These results showed that Malaysian climate is not an extreme climatic zone and does not require very heavy roof insulation to provide it with adequate protection.

It is also very interesting to note that the provision of insulation for a pitch roof where the air-conditioning is switched on during night time showed energy consumption increases with more insulation provided. This clearly reflects the effect of the insulation preventing heat loss from the space below into the night sky above. The night sky in Malaysia has an average temperature of 15°C (refer to Chapter 2) and is a heat sink for objects on the ground such as building roofs. Objects on the ground that has temperature above 15°C will radiate heat to the night sky, cooling the object down.

However, when concrete roof were used instead, the thermal mass effect of the concrete roof changes this behavior. The heavy thermal mass of concrete absorbs heat during daytime and when the air-conditioning system is switched on during night time the heat from the concrete is released into the room causing higher energy use by the air-conditioning system. Therefore, when heavy thermal mass roof is used, insulation of it will reduces cooling energy of the building even when air-conditioning system is only switched on at night.

It is also interesting to note that although the computed U-value of the pitch roof with plasterboard ceiling and pitch roof with concrete ceiling is very similar, but the energy consumption behavior when air-conditioning is switched on at night is totally different with and without insulation.

Unless is it specifically known that the air-conditioning system will ONLY be switched on during night time, it is recommended to provide insulation to a pitch roof because the savings provided when the air-conditioning system is turned on during daytime far exceed the extra cost to cool the building during night time.

_____End of Chapter 8_____