Simulation of roof retrofitting strategies to mitigate attic overheating issues of the terrace house under hot and humid climate.

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Abstract. The purpose of this study is to investigate the potential mitigation strategies to overcome the overheating issue at the attic of the landed residential house located in a hot and humid climate area. An existing terrace house with 178 m^2 was selected for this research. A building simulation model was created and calibrated by using the previous site measurement data collected by Ng et.al. in the year 2018. The calibrated model was subsequently used to evaluate various retrofitting methods and strategies, including roof insulation, and passive radiative cooling methods. The study shows that high albedo cool roof paint is the most effective roof retrofitting strategy compared to other approaches.

1 Introduction

There is an urgency for us to implement energy saving in the building because of the high energy consumption and CO2 emission. Previous research shows approximately 30-40% of total global energy consumption and significant greenhouse gas emission is contributed by the building sector, with HVAC systems being the biggest contributors (Pérez-Lombard et al., 2008). In Malaysia, HVAC system is inevitable for every residential unit because of our hot and humid climate. According to the data collected by the Malaysian Meteorological Department, it shows that in Malaysia there is rarely have a stretch of no-sunshine days except during the northeast monsoon season (General Climate Malaysia, 2017). As a result, the heats penetrate through the building envelope mostly in form of solar radiation, rather than conduction & convection.

1.1 Terrace house in the hot humid climate

Malaysia is a tropical country characterized as warm and humid located within the Tropic of Cancer and Capricorn. The climatic elements are categorized as high temperatures and uniform diurnal patterns throughout the year. The annual mean temperature is 26.4°C with an average daily maximum temperature is 34°C and an average daily minimum of 23°C (Al Tamimi & Syed Fadzil, 2011).

Terraced houses have been popular in Malaysia due to the increasing demand for housing. According to the data from the Department of Statistic Malaysia in the year 2019, 17% of the housing in KL (83,907 units) and 42% of the housing in Selangor (655,269 units) are terraced houses.

As the annual maximum intensities of solar radiation falling on horizontal and vertical surfaces are about 1000 and 850 W/m2 respectively for east and west-facing surfaces (Ossen, 2005) in Malaysia, the large roof surface of the terrace housing is the main factor that contributes to the overheating attic issue. Most of the terrace housing in Malaysia are using dark-coloured clay roof tile which allows most of the heat to conduct down through the roofing materials. The surface temperature of the roof tile will increase drastically and the heat at the roofing materials will then radiates to the interior spaces.

1.2 Roof insulation

The thermal insulation of the membrane materials is characterized by their thermal resistance values (B. Pause, 2015). Hence it can reduce heat loss and heat gain through the building envelope. It helps to keep the indoor temperature stable as well. Mass insulation is generally used and features very low thermal conductivity, of the order of 0.05 W m-1 K-1. Therefore, heat transfer due to conduction is reduced. However, this type of thermal insulation was proven that not effectively reduce heat transfer through radiation.

There is various type of insulation products in the market, such as Rockwool, fibreglass, polyurethane foam, rigid foam, etc. It is normally applied underneath the roof structure or above the ceiling. Mineral wool includes a variety of inorganic insulation materials such as rock wool, glass wool, and slag wool. The average range of thermal conductivity for mineral wool is between 0.03 and 0.04 W/(m.K) and the typical λ-values of glass wool and rock wool are 0.03–0.046 W/(m.K) and 0.033– 0.046 W/(m.K). Low thermal conductivity value, non-flammable, and highly resistant to moisture damage are the common properties of all these materials. (Hung Anh and ZoltánPásztory, 2021).

1.3 Passive Radiative cooling

Previous studies show that building with high roof-to-wall ratios, such as terrace housing, roof surfaces are the main receivers of solar heat gain, leading to 5%–10% of total building energy consumption and more than 40% of energy usage for the higher floors (Gao, 2017). Therefore, radiative roof cooling strategies are proven to be effective in hot climates with high sunlight hours.

Radiative roof cooling is a passive cooling strategy that aims to reduce the effect of heat gain on building roofs during sunny days (Akbari et al., 2006). It works as a reflector of invisible electromagnetic radiation (short-wave and long-wave) and emits heat (infrared radiation), therefore the thermal absorbance from the roof is reduced (Urban and Roth, 2010).

1.4 Research Objectives

The objectives of the research are:

(a) To study the different roof retrofitting strategies to mitigate the attic heat flux issues.

(b) To compare the efficiency of the passive radiant cooling strategies such as high albedo roof paint and radiant barrier to the different insulation strategies including spray foam, rigid foam and phase change materials.

(b) To conclude the best mitigation strategies to reduce the indoor temperature of the attic space by using the building simulation method.

2 Methodology

In this study, the data collected by Tuck et al., (2020) from their previous research will be used as to calibrate the energy model as a benchmark (control group) for this study. The calibrated model will then be modified according to the parameters set and compared with the previous data to evaluate their performance in reducing the indoor temperature of the attic space.

The calibrated model will be used for parametric studies of various mitigation strategies. The performance of the mitigation strategies will be evaluated using the data simulated. The lower the indoor air temperature as compared to the control group (previous research data), the more effective the mitigation strategies.

2.1 Investigated house and calibration of the model

Field measurement was conducted on a two-story corner terrace house (Figure 1) located in Taman Melati, Kuala Lumpur, Malaysia (3∘13'10.3"N 101∘43'33.9" E) from 15th February until 11th March 2018. The total built-up area of the house is 177.7 m2.

Referring to Table 2, the construction of the house was completed in 2004 with brick walls on the reinforced concrete frame structure. The floor slabs on both floors are reinforced concrete slabs. The first floor was covered with cement board ceiling and concrete roof tiles on the roof level. No heat insulation was installed in the roof attic and wall. Table 1 shows detailed information on orientation, floor area, ratios of wall and window area over room volume and specification on materials of the investigated house.

The previous research is focused on the efficiency of the High-Density Poly Ethylene (HDPE) roof cover in improving the indoor thermal environment. This study shows that the roof cover can effectively reduce air temperature in the attic by approximately 1.4°C on average for a whole day and by up to 3.5°C in the daytime.

As the previous research focuses mainly only one of the mitigation methods to lower the indoor temperature, this paper is to broaden the research scope by simulating various cooling strategies using the building simulation method.

The comparison of the field measurement data and building simulation is tabulated in Table 3 and Graph 1. The temperature difference is lesser than 2% and both data sets' standard deviation is between 1.21 and 1.22. Hence the calibrated model is proven accurate and ready for building simulation.

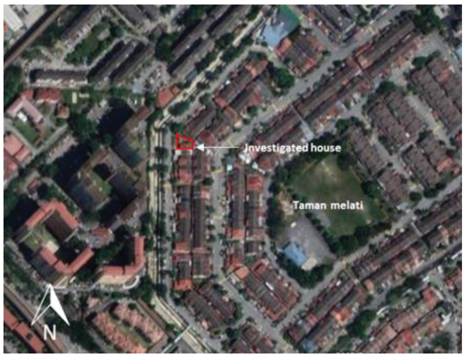


Figure 1: Site plan of the investigated house.

Table 1. Characteristics of the investigated room. (Tuck et al., (2020))

Characteristic	Master bedroom
Level	First
Orientation of the external wall	West
Floor area (m2)	15.2
External wall area (m2)	8.1
Window area (m2)	2.9
Window to wall ratio	0.36
External wall to floor ratio	0.53

Table 2. Construction data of the investigated house for the (Tuck et al., (2020))

Component	Material (Structure)	U Value [W/(m²·K)]
Window	Aluminium frame fixed single clear glass casement window	5.7
Door	25mm thick solid hardwood panel door	4.9
Ceiling (First Floor)	4.5mm thick cement board	66.7
Wall	114mm thick brick wall with 18mm thick cement plasters on both sides	3.1
Floor (Ground Floor)	150mm thick reinforced concrete slab with a 15mm thick broken marble finish	0.9
Floor (First Floor)	150mm thick reinforced concrete slab with a 5mm thick hardwood parquet finish	1.0
Roof	12mm thick concrete roof tile	70.8
Shading device to window	Canopy roof with concrete roof tiles	-

Table 3: Parameter and inputs data for Numerical Simulation.

Parameter	Input to energy model
Location	Taman Melati, Kuala Lumpur
Weather data	Kuala Lumpur 486470 (IWEC)
Construction	As per Table 2
Ventilation mode	Natural ventilation
Occupancy schedule	ASHRAE 90.7 – 2007 Residential Occupancy
Air change rate (ACH)	0.58 ACH (Tuck et al., (2020))

Graph 1. Comparison between field measurement data (FM) and simulation data for model calibration purposes (NS).

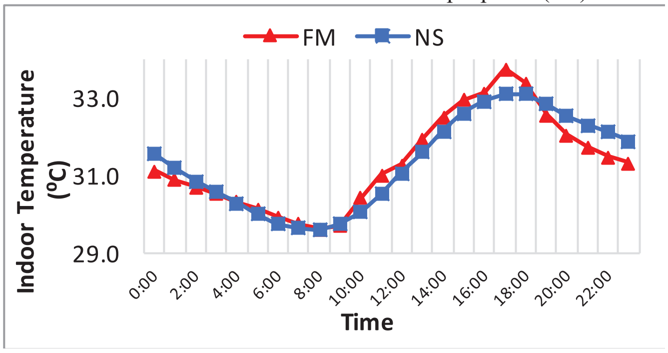


Table 4. Comparison between field measurement data (FM) and the calibrated data (NS), with the outdoor temperature data measure on field (OT) as reference.

	FM	NS	Variance		OT
Time	°C	°C	°C	%	°C
00:00	31.1	31.6	-0.45	**-1.5%**	34.4
01:00	30.9	31.2	-0.30	**-1.0%**	34.6
02:00	30.7	30.9	-0.16	**-0.5%**	34.7
03:00	30.5	30.6	-0.04	**-0.1%**	34.8
04:00	30.3	30.3	0.04	**0.1%**	34.8
05:00	30.1	30.0	0.13	**0.4%**	34.9
06:00	29.9	29.8	0.18	**0.6%**	34.9
07:00	29.7	29.6	0.11	**0.4%**	34.9
08:00	29.6	29.6	0.02	**0.1%**	35.0
09:00	29.7	29.7	-0.03	**-0.1%**	35.1
10:00	30.4	30.0	0.35	**1.2%**	35.1
11:00	31.0	30.5	0.49	**1.6%**	34.9
12:00	31.3	31.1	0.20	**0.7%**	34.2
13:00	31.9	31.6	0.32	**1.0%**	34.2
14:00	32.5	32.1	0.37	**1.1%**	34.3
15:00	32.9	32.6	0.34	**1.0%**	34.2
16:00	33.1	32.9	0.21	**0.6%**	34.0
17:00	33.7	33.1	0.64	**1.9%**	34.0
18:00	33.4	33.1	0.26	**0.8%**	34.3
19:00	32.6	32.8	-0.27	**-0.8%**	34.4
20:00	32.0	32.5	-0.47	**-1.5%**	34.7
21:00	31.7	32.3	-0.58	**-1.8%**	34.8
22:00	31.5	32.1	-0.64	**-2.0%**	34.6
23:00	31.3	31.9	-0.57	**-1.8%**	34.4
Mean:	**31.33**	**31.33**			**34.6**
Standard deviation:	**1.22**	**1.21**			

2.2 Insulation materials and Passive Radiative Cooling Strategies

Three different types of insulations are selected for the research, including rigid foam, spray foam and phase change material. Data from various insulation materials were collected and tabulated in Table 4 to compare their performance. According to Al-Homoud et al., (2005), PU Spray foam and Extruded polystyrene have the least thermal conductivity compared to other similar insulation types, hence it is selected as the insulation materials for the simulation works.

Referring to Table 8, various types of Phase Change Materials (PCM) insulation had been studied and compared based on their material properties. Although paraffin wax has the lowest thermal conductivity among other PCMs, it's not recommended to insulate residential housing due to its flammable properties. Hence, BioPCM M25 panels are selected to represent PCMs material in this study.

There are 2 materials chosen as the passive radiant cooling strategies for this study, which are aluminium foil (radiant barrier) and high albedo cool roof paint. The aluminium foil will be placed under the roof tiles and serve as a radiant barrier to reflect the heat from the roof tile, hence preventing heat from entering the indoor space. While the high albedo cool roof paint with high solar reflectance can reflect solar radiation and prevent it to be absorbed by the roof tiles. The detailed material properties are stated in Table 7.

2.3 Building simulation

The energy model was built using Design Builder software according to the field measurement data including the adjacent block and the existing awning position (Figure 2).

The calibrated simulation model was modified from the corner terrace house to an intermediate terrace house layout to get simulated result that represent the most typical terrace house layout in Malaysia. (Figure 2a). In this study, the indoor radiative temperature of the attic and the room below attic, which is the master bedroom after roof retrofitting will be simulated and analyzed.

The heat flux of the space will be calculated based on the formula (Figure 4), in order to study the effectiveness of the roof retrofitting strategies in lowering down the heat flux of the internal space.

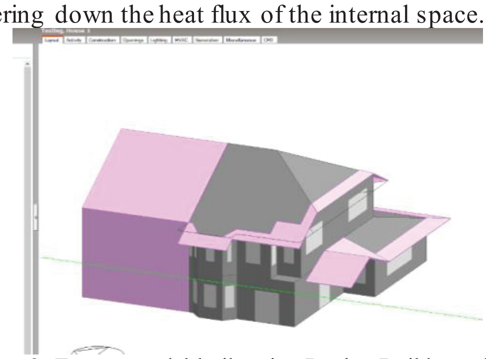


Figure 2: Energy model built using Design Builder software

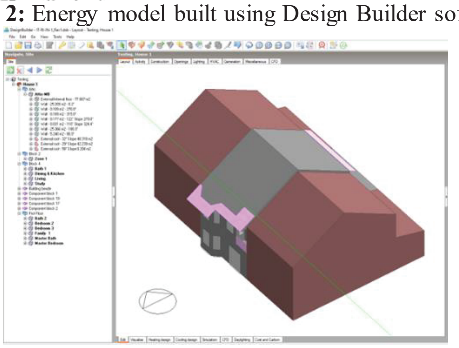
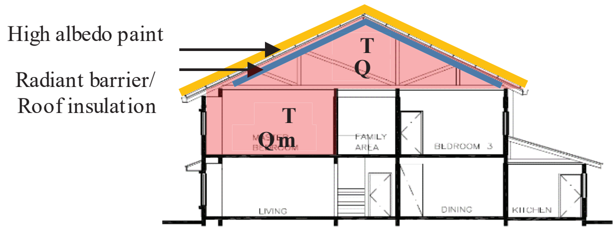
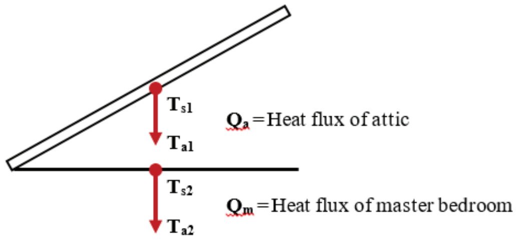


Figure 2a: Simulation model based on the intermediate house setting



Tm: Master bedroom indoor temperature
Ta: Attic space indoor temperature
Qm: Master bedroom heat flux
Qa: Attic space heat flux

Figure 3: Section showing the investigated space and the construction of the roof retrofitting strategies



$$Q_h = h_c (T_s - T_a)$$

Q_h = Convective heat flux of the internal space
h_c = Convective heat transfer coefficient
T_s = Surface temperature
T_a = Air temperature

Figure 4: Heatflux calculation diagram

Table 5: Thermal Properties of selected insulation matreials

Case	Roof Retrofitting strategies
A1	50mm thick Tigerfoam Polyurethane spray foam
A2	50mm thick INSULFOAM Expanded polystrene
A3	BioPCM Panel Q25
A4	50mm thick ComfortBoard 80-Rockwool
A5	50mm thick Formaldehyde-Free™ Fiberglass foam
A6	50mm thick ISOCELL Cellulose
A7	50mm thick DUPONT Extruded polystrene panel
B1	FIX-FAS Single sided woven film
B2	COOLROOF Heat Reflective paint
B3	FIX-FAS Single sided woven film + COOLROOF Heat Reflective paint
C1	FIX-FAS Single sided woven film + COOLROOF Heat Reflective paint + 50mm thick Tigerfoam Polyurethane spray foam
C2	FIX-FAS Single sided woven film + COOLROOF Heat Reflective paint + 50mm thick INSULFOAM Expanded polystrene
C3	FIX-FAS Single sided woven film + COOLROOF Heat Reflective paint + BioPCM Panel Q25
C4	FIX-FAS Single sided woven film + COOLROOF Heat Reflective paint + 50mm thick ComfortBoard 80-Rockwool
C5	FIX-FAS Single sided woven film + COOLROOF Heat Reflective paint + 50mm thick Formaldehyde-Free™ Fiberglass foam
C6	FIX-FAS Single sided woven film + COOLROOF Heat Reflective paint + 50mm thick ISOCELL Cellulose
C7	FIX-FAS Single sided woven film + COOLROOF Heat Reflective paint + 50mm thick DUPONT Extruded polystrene panel

Table 6: Thermal Properties of selected insulation matreials

Insulation Material	Thermal conductivity (U-value) (W/m.K)	Thermal resistance (R-value)	Density (kg/m3)
50 mm thick ComfortBoard 80-Rockwool	0.036	25.43	126
50mm thick ISOCELL Cellulose	0.043	25.13	30
50mm thick Formaldehyde-Free™ Fiberglass foam	0.036	29.15	34
50mm thick DUPONT Extruded polystrene panel	0.033	32.29	46
50mm thick INSULFOAM Expanded polystrene	0.039	25.16	30
50mm thick Tigerfoam Polyurethane spray foam	0.024	43.48	38

Table 7: Thermal properties of the selected radiant cooling method.

Material	Solar Reflectance	SRI (Solar reflectance Index)	Infrared emittance	Thermal emissivity	Solar absorptance(%)
Aluminiuim foil	0.61	56	0.25	0.55	0.2
Cool roof paint (White colour)	0.85	107	0.91	0.55	18.7 (white colour)

Table 8: Thermal properties of Phase Change Material (PCM) insulations..

PCM Insulation	Thermal conductivity (W/m-K)	Density (Kg/m3)	Specific heat (kJ kg−1 K−1)	Melting point (°C)	Latent heat (kJ kg−1)	Sources
PCM: Paraffin wax	0.13	Liquid: 783 Solid: 830	Liquid: 2.53 Solid: 2.44	44	174.12	Hasan et al., 2018
PCM: Butyl Stearate	0.152	861	-	18.64	120.59	Hasan et al., 2021
PCM: thickness of 2.5 cm which accommodates inorganic salt hydrate	Solid 1.09 Liquid 0.54	1640	1.44 [0–26.5 °C], 125 [26.5–28 °C], 1.44 [28–60 °C]	26-28	188	Athanasius et al., 2008
BioPCM M25	0.15-0.25	850-950	2.5	25	210-250	Phase Change Energy Solutions, n.d.

3 Result and Discussion

The simulation result is shown in Table 9 and Graph 2 to 4.

3.1 Indoor temperature of Master Bedroom

The average day time temperature ranges from 32.2°C to 35.6°C, with the highest in A3 and the lowest in B2. The average night time temperature ranges from 30.4°C to 33.5°C, with the highest in A2 and the lowest in B2. The max temperature ranges from 34.6°C to 40.3°C, with the highest in A1 and the lowest in B3. The min temperature ranges from 28.2°C to 31.5°C, with the highest in A2 and the lowest in B2.
The standard deviation ranges from 1.5 to 4.5, with the lowest in C1-C2 and the highest in Baseline. The median ranges from 31.5°C to 33.8°C, with the lowest in B2 and the highest in A2. The mean ranges from 31.3°C to 33.7°C, with the lowest in B2 and the highest in A3.

3.2 Indoor temperature of Attic

The average day time temperature ranges from 31.7°C to 33.4°C, with a mean of 31.8°C. The average night time temperature ranges from 31.7°C to 33.6°C, with a mean of 31.9°C. The maximum temperature ranges from 32.3°C to 34.4°C, with a mean of 33.3°C. The minimum temperature ranges from 29.4°C to 32.5°C, with a mean of 31.3°C. The standard deviation ranges from 0.9°C to 1.4°C, with a mean of 1.0°C. The median temperature ranges from 31.9°C to 33.5°C, with a mean of 33.0°C. The mean temperature ranges from 31.8°C to 33.5°C, with a mean of 32.9°C.

3.3 Heat flux of Master bedroom

The average daytime heat flux values range from 3.1 W/m2 to 5.6 W/m2 with a mean of 3.7 W/m2 and median of 3.9 W/m2. The average nighttime heat flux values range from -3.3 W/m2 to 2.5 W/m2 with a mean of -1.2 W/m2 and median of -1.8 W/m2. The maximum heat flux values range from 1.3 W/m2 to 12.0 W/m2 with a mean of 1.3 W/m2 and median of -1.8 W/m2. The minimum heat flux values range from -6.0 W/m2 to 2.4 W/m2 with a mean of -2.5 W/m2 and median of -3.1 W/m2.

3.4 Heat flux of Attic

The heat flux values are separated into two categories, "Day time heat flux" and "Night time heat flux." The average day time heat flux values range from -1.2 W/m^2 (A1) to 7.2 W/m^2 (A3), while the average night time heat flux values range from -14.9 W/m^2 (NV) to -6.1 W/m^2 (A7 and B2 to B3).

The maximum heat flux values range from 2.1 W/m^2 (A1) to 16.8 W/m^2 (A3), and the minimum heat flux values range from -17 W/m^2 (A1) to -2.2 W/m^2 (C1). The standard deviation of the heat flux values ranges from 0.5 (A2) to 8.9 (A3), with a mean of 5.1. The median heat flux values range from -13.6 W/m^2 (NV) to -1.9 W/m^2 (C1), and the mean heat flux values range from -5.1 W/m^2 (NV) to -3.3 W/m^2 (A6 and A7).

Table 9: Average temperature of different roof retrofitting strategies. (A1 to A7, B1 to B3, C1 to C7)

	BASELINE	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3
Average Day time temperature (°C)	33.0	31.7	31.7	31.9	31.8	31.8	31.8	31.8	31.8	30.9	31.0
Average Night time temperature (°C)	32.7	31.8	31.9	31.7	31.9	31.9	31.9	31.9	31.7	30.9	31.0
Max temperature (°C)	34.5	33.1	33.0	33.7	33.3	33.3	33.3	33.3	33.7	32.3	32.4
Min temperature(°C)	31.2	30.3	30.5	29.9	30.3	30.4	30.4	30.4	29.8	29.4	29.5
Standard Deviation	1.1	1.0	0.9	1.4	1.0	1.0	1.0	1.0	1.4	1.0	1.0
Median	32.9	31.8	31.8	31.9	31.9	31.9	31.9	31.9	31.8	31.0	31.0
Mean	32.9	31.8	31.8	31.8	31.9	31.9	31.9	31.9	31.8	30.9	31.0

	C1	C2	C3	C4	C5	C6	C7
Average Day time temperature (°C)	33.4	33.3	32.6	33.3	33.3	33.3	33.3
Average Night time temperature (°C)	33.6	33.5	32.7	33.5	33.5	33.5	33.5
Max temperature (°C)	34.4	34.4	33.7	34.3	34.3	34.3	34.3
Min temperature(°C)	32.5	32.4	31.5	32.4	32.4	32.3	32.3
Standard Deviation	0.7	0.7	0.8	0.7	0.7	0.7	0.7
Median	33.5	33.4	32.7	33.4	33.4	33.4	33.4
Mean	33.5	33.4	32.6	33.4	33.4	33.4	33.4

Table 10: Average heatflux of different roof retrofitting strategies. (A1 to A7, B1 to B3, C1 to C7)

	BASELINE	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3
Average Day time heatflux (W/m2))	3.9	3.5	3.3	5.6	3.4	3.1	3.3	3.1	5.6	0.9	0.9
Average Night time heatflux (W/m2))	3.5	1.9	2.5	-3.0	-0.6	-0.3	-0.5	-0.3	-3.0	-3.3	-3.3
Max heatflux (W/m2))	4.5	5.8	4.3	12.0	6.5	5.9	6.2	5.7	12.0	3.8	3.8
Min heatflux (W/m2))	2.4	-0.5	0.6	-5.2	-2.8	-2.4	-2.6	-2.3	-5.2	-4.9	-4.9
Standard Deviation	0.7	2.0	1.1	6.3	3.2	2.9	3.1	2.8	6.4	3.1	3.1
Median	3.9	2.8	3.1	-1.8	0.9	1.1	1.0	1.3	-1.8	-2.2	-2.1
Mean	3.7	2.7	2.9	1.3	1.4	1.4	1.4	1.4	1.3	-1.2	-1.2

	C1	C2	C3	C4	C5	C6	C7
Average Day time heatflux (W/m2))	**-0.4**	**1.5**	**-0.6**	**-0.5**	**0.1**	**-0.5**	**0.4**
Average Night time heatflux (W/m2))	**-1.5**	**0.4**	**-4.3**	**-2.0**	**-1.5**	**-2.0**	**-1.0**
Max heatflux (W/m2))	**1.3**	**2.7**	**2.5**	**1.4**	**2.0**	**1.4**	**2.1**
Min heatflux (W/m2))	**-3.5**	**-1.3**	**-6.0**	**-3.9**	**-3.3**	**-3.9**	**-2.9**
Standard Deviation	**1.6**	**1.3**	**2.9**	**1.7**	**1.7**	**1.7**	**1.6**
Median	**-0.9**	**1.3**	**-3.1**	**-1.2**	**-0.6**	**-1.2**	**-0.2**
Mean	**-1.0**	**1.0**	**-2.5**	**-1.2**	**-0.7**	**-1.3**	**-0.3**

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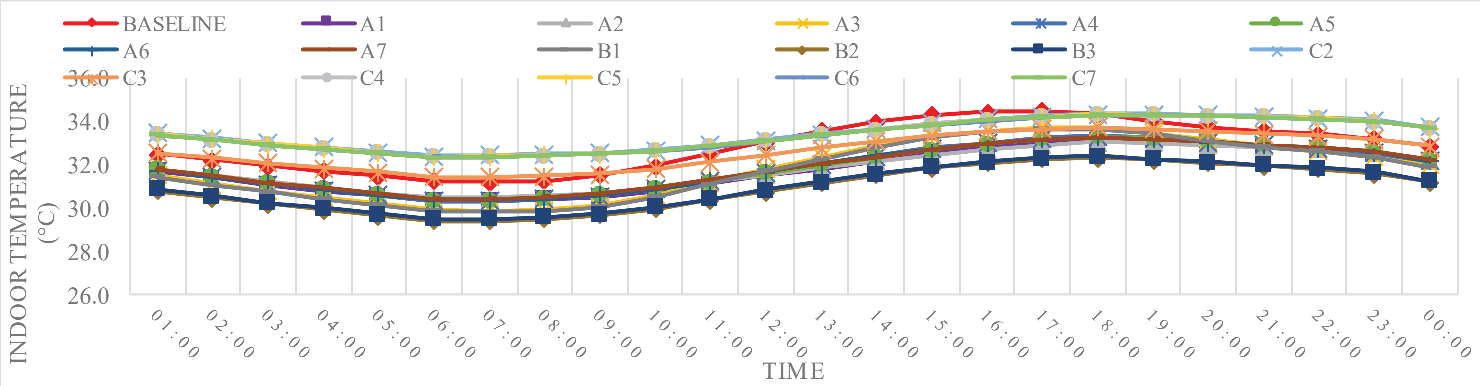
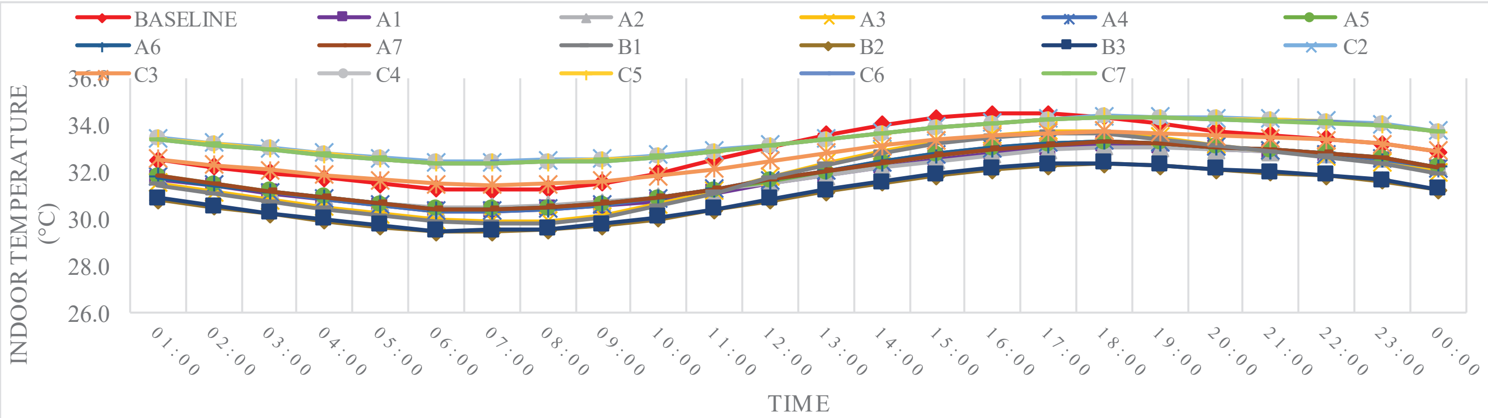
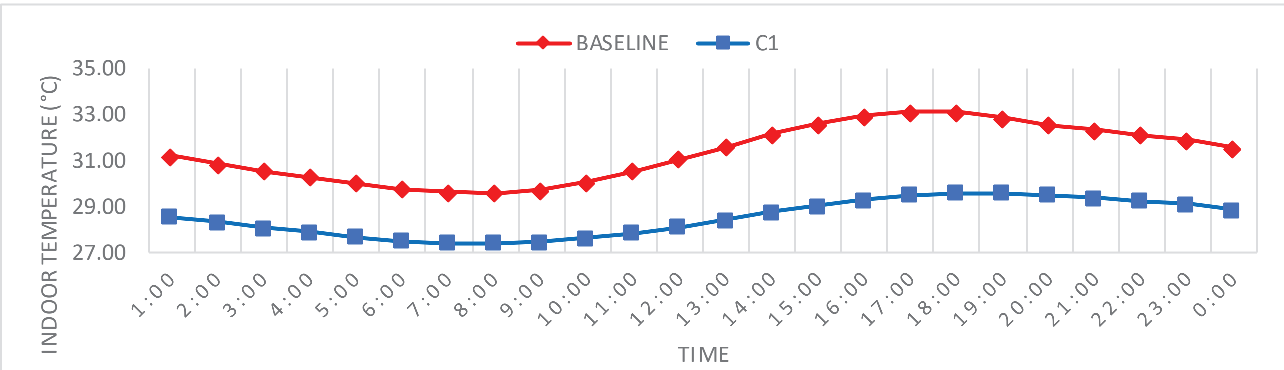


Graph 2: Graph showing the indoor temperature after retrofitting (Master bedroom).



Graph 3: Graph showing the indoor temperature after retrofitting (Attic).



Graph 4: Graph showing the effectiveness of the recommended roof retrofitting strategies (Spray Polyurethane foam roof insulation with radiant barrier and high albedo white coloured roof paint)

4 Conclusion

A numerical simulation was conducted to find out the suitable roof retrofitting method to reduce the indoor temperature of the terrace house attic space. The data was extracted from the energy model with various combinations of retrofitting strategies. The significant conclusion is as below:

(a) Both roof insulation and passive radiant cooling strategies can reduce the operative temperature as well as reduce the heat flux effects of the attic space.

(b) High albedo cool roof paint (B2) is the most effective roof retrofitting strategy compared to other approaches. Hence, it shows that by reflecting the sunlight from the building envelope, especially the rooftop surface, the indoor temperature drops significantly.

(c) By combining high albedo cool roof paint, radiant barrier and spray PU foam roof insulation into the roof, the indoor temperature of the attic space can be even lower. It can reduce the indoor temperature by 2 to 3°C.

(d) The heat flux data in the attic space indicated that the insulation types have different levels of effectiveness in preventing heat transfer, with the Case C1 showing the lowest heat flux values.

References

[1] Tuck, N. W., Zaki, S. A., Hagishima, A., Rijal, H. B., & Yakub, F. (2020). Affordable retrofitting methods to achieve thermal comfort for a terrace house in Malaysia with a hot–humid climate. *Energy and Buildings*, *223*.

[2] Utaberta, N., Elina, N. F., Mohd Rasdi, M. T., & Othuman Mydin, M. A. (2015). A Critical Analysis of 20th Century Modern Terrace Housing in Malaysia. Applied Mechanics and Materials, 747(March), 36–39.

[3] Alchapar, N. L., & Correa, E. N. (2016). The use of reflective materials as a strategy for urban cooling in an arid "OASIS" city. Sustainable Cities and Society, 27, 1–14.

[4] Al-Homoud, D. M. (2005). Performance characteristics and practical applications of common building thermal insulation materials. Building and Environment, 40(3), 353–366.

[5] Arumugam, R. S., Garg, V., Ram, V. V., & Bhatia, A. (2015). Optimizing roof insulation for roofs with high albedo coating and radiant barriers in India. Journal of Building Engineering, 2, 52–58.

[6] Baniassadi, A., Sailor, D. J., Crank, P. J., & Ban-Weiss, G. A. (2018). Direct and indirect effects of high-albedo roofs on energy consumption and thermal comfort of residential buildings. Energy and Buildings, 178, 71–83.

[7] Soubdhan, T., Feuillard, T., & Bade, F. (2005). Experimental evaluation of insulation material in roofing system under tropical climate. Solar Energy, 79(3), 311–320.

[8] Cabeza, L. F., Castell, A., Medrano, M., Martorell, I., Pérez, G., & Fernández, I. (2010). Experimental study on the performance of insulation materials in Mediterranean construction. Energy and Buildings, 42(5), 630–636.

[9] Chen, J., & Lu, L. (2021). Comprehensive evaluation of thermal and energy performance of radiative roof cooling in buildings. Journal of Building Engineering, 33, 101631.

[10] Fosas, D., Coley, D. A., Natarajan, S., Herrera, M., Fosas de Pando, M., & Ramallo-Gonzalez, A. (2018). Mitigation versus adaptation: Does insulating dwellings increase overheating risk? Building and Environment, 143(May), 740–759.

[11] García-Solórzano, L. A., Esparza-López, C. J., & Al-Obaidi, K. M. (2020). Environmental design solutions for existing concrete flat roofs in low-cost housing to improve passive cooling in western Mexico. Journal of Cleaner Production, 277.

[12] Hung Anh, L. D., & Pásztory, Z. (2021). An overview of factors influencing thermal conductivity of building insulation materials. Journal of Building Engineering, 44, 102604.

[13] Jayasinghe, M. T. R., Attalage, R. A., & Jayawardena, A. I. (2003). Roof orientation, roofing materials and roof surface colour: their influence on indoor thermal comfort in warm humid climates. Energy for Sustainable Development, 7(1), 16–27.

[14] Kharseh, M., & Al-Khawaja, M. (2016). Retrofitting measures for reducing buildings cooling requirements in cooling-dominated environment: Residential house. Applied Thermal Engineering, 98, 352–356.

[15] Kumar, D., Alam, M., Zou, P. X. W., Sanjayan, J. G., & Memon, R. A. (2020). Comparative analysis of building insulation material properties and performance. Renewable and Sustainable Energy Reviews, 131(July), 110038.

[16] Lei, Jiawei & Yang, Jinglei & Yang, En-Hua. (2016). Energy performance of building envelopes integrated with phase change materials for cooling load reduction in tropical Singapore. Applied Energy. 162. 207-217. 10.1016/j.apenergy.2015.10.031.

[17] Li, D., Zheng, Y., Liu, C., & Wu, G. (2015). Numerical analysis on thermal performance of roof contained PCM of a single residential building. Energy Conversion and Management, 100, 147–156.

[18] Miranville, F., Boyer, H., Lauret, P., & Lucas, F. (2008). A combined approach for determining the thermal performance of radiant barriers under field conditions. Solar Energy, 82(5), 399–410. https://doi.org/10.1016/j.solener.2007.10.012

[19] Pisello, A. L., & Cotana, F. (2014). The thermal effect of an innovative cool roof on residential buildings in Italy: Results from two years of continuous monitoring. Energy and Buildings, 69, 154–164.

[20] Pomfret, L., & Hashemi, A. (2017). Thermal Comfort in Zero Energy Buildings. In Energy Procedia (Vol. 134, pp. 825–834). Elsevier Ltd. https://doi.org/10.1016/j.egypro.2017.09.536

[21] Rosado, P. J., Faulkner, D., Sullivan, D. P., & Levinson, R. (2014). Measured temperature reductions and energy savings from a cool tile roof on a central California home. Energy and Buildings, 80, 57–71.

[22] Seifhashem, M., Capra, B. R., Milller, W., & Bell, J. (2018). The potential for cool roofs to improve the energy efficiency of single storey warehouse-type retail buildings in Australia: A simulation case study. Energy and Buildings, 158, 1393–1403.

[23] Synnefa, A., Santamouris, M., & Livada, I. (2006). A study of the thermal performance of reflective coatings for the urban environment. Solar Energy, 80(8), 968–981.

[24] Xue, X., Yang, J., Zhang, W., Jiang, L., Qu, J., Xu, L., … Zhang, Z. (2015). The study of an energy efficient cool white roof coating based on styrene acrylate copolymer and cement for waterproofing purpose - Part II: Mechanical and water impermeability properties. Construction and Building Materials, 96, 666–672.