Executive summary

This study is performed to assess the energy and environmental benefits as well as the cost-benefit of reflecting or cool roofs in the city of Brisbane, Australia. Specifically, the purposes of this report are:

1) To evaluate the existing reference climatic conditions in the city of Brisbane, understand the characteristics of the urban overheating, and develop detailed climatic data through advanced mesoscale climatic modelling.
2) To evaluate the magnitude and spatial variation of the mitigation /cooling potential generated by the cool roofs when implemented at the city scale, as well as how its application affects the urban ambient temperature and the other main climatic parameters.
3) To investigate the impact of cool roofs on the cooling/heating load and indoor air temperature of different types of buildings in Brisbane.
4) To understand the process of how specific building characteristics affect the performance of cool roofs and the advantages of applying cool roofs in various stations.
5) To investigate the impact of cool roofs on energy efficiency ratio (EER) of air-conditioning (AC) systems and

of a low-rise office building without roof insulation-existing building by 36% and 35% in Redland and Amberley stations, respectively.

14) In existing buildings without insulation/with low level of insulation and under free-floating condition in a typical summer period, application of cool roofs in individual buildings (scenario 1) can significantly decrease the

hours with ambient temperature below 19 ºC from 18-29 hours to 26-31 hours in a typical existing low-rise office building with roof insulation.

21) The application of cool roofs in both individual buildings and at the whole urban area is predicted to improve the

q0.000008874 0.000061035 595.5 842.52 reW* nBT/F1 6.48 Tf1 0 0 1 2035.14769.94Tm0 g0 G[29]TJETQq0.000008

Objectives

This study is performed to assess the energy and environmental benefits as well as the cost-benefit of reflecting or cool roofs in the city of Brisbane, Australia. Specifically, the purposes of this report are:

1) To evaluate the existing reference climatic conditions in the city of Brisbane, understand the characteristics of the urban overheating, and develop detailed climatic data through advanced mesoscale climatic modelling.
2) To evaluate the magnitude and spatial variation of the mitigation /cooling potential generated by the cool roofs when implemented at the city scale, as well as how its application affects the urban ambient temperature and the other main climatic parameters.
3) To investigate the impact of cool roofs on the cooling/heating load and indoor air temperature of different types of buildings in Brisbane.
4) To understand the process of how specific building characteristics affect the performance of cool roofs and the advantages of applying cool roofs in various stations.
5) To investigate the impact of cool roofs on EER of AC systems and the corresponding cooling load savings.
6) To evaluate the feasibility of energy-saving measures, like the application of cool roofs and the refurbishment of existing ones.

Figure 8 Reduction of PBL height at (a) 06:00 LT (b) 14:00 LT, and (c) 18:00 LT.

1.6 Regional impact on sea breeze circulations

t

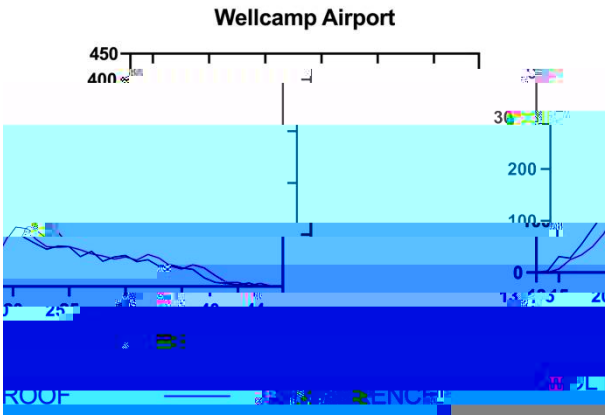
The intensification of sea breeze circulation is dependent on the large-scale synoptic background, which plays an important role in modulating the prevailing wind at the near-surface. In the vertical dimension, the report revealed the height of the PBL in Brisbane is linked closely with the advection of the sea breeze. The circulation can be modified when the cool roof is implemented at the city scale **(Figure 9)**. The cool roof could alter the PBL height and potentially trigger localized circulation over the urban domain of Brisbane. Results also indicate that the onset of the sea breeze ZDV GHOD\HG WR DIWHUQRRQ /7 GXH WR WKH ³UHJLRQDO KLJK´ HII flow above the PBL. The denser cool air over the urban domain flows towards the suburban area to replenish the buoyant warm air. The cool roof materials can suppress the process of vertical lifting of urban thermals, tdsland3( )- TJETQq0

The report also shows the implementation of the cool roof over the city scale can affect the pressure gradient between the city and surrounding surface due to a significant drop in ambient temperature up to 2.5°C and wind speed decrease up to 2.5 ms-1. Thus, changes in roof reflectivity, sensible heating, and wind result in feedback within the local climate of the city during peak hour (14:00 LT). The higher urban albedo values decrease the advective flow between the city and its surroundings, improving the cooling potential of reflective materials. It creates a µ U H J L R Q D O K L J K ¶ Z K L F both horizontal and vertical wind speed over the

Figure 12 Location of the 31 weather stations in Brisbane.

2.2 Histogram of WRF simulated ambient temperature in Brisbane

The entire 2-month hourly ambient temperature of 31 stations in Brisbane simulated by WRF has been divided into a series of data with consecutive and non-overlapping interval



(c)

Figure 13 Histogram of WRF simulated ambient temperature in 31 stations in Brisbane.

In average, compared to the reference scenario, most of the peaks in the curve of the cool roof scenario is shifted to the left by around 1-3 °C, indicating the cooling benefits of cool roof, as shown in **Table 5**. Around 45%-74% of the ambient temperatures in all stations concentrate in the range of 18-25 °C.

Table 5 The temperature range with the most data at each weather station, including both the reference and cool roof scenarios.

Ambient air temperature starts from	18	19	20	21	22	23	24	25	Percentage of data concentrated in 18-25 °C (%)
Amberley COOL ROOF					147				55
Amberley REFERENCE						162			48
Archerfield COOL ROOF						223			58
Archerfield REFERENCE							232		47

2.3 Cooling Degree Hours (CDH) calculation

For all scenarios, Cooling Degree Hours (CDH) Base 26 °C, which measures how much (in degrees), and for how long (in hours), outside air temperature is higher than 26 °C, has been calculated for the entire simulation period. It is a rough indication of the cooling load of a building, and it was calculated by firstly subtracting 26 from the hourly dry-bulb air temperature and then adding all the positive differences in the two months. The calculated CDH for control cases, cool roof applied cases, their differences, as well as the percentage of CDH reduction due to the implementation of the cool roof in the 31 weather stations are shown in **Table 6** and **Figure 14**. Compared with the control case, the largest percentage reduction (62%) is observed in BANANA BANK NORTH BEACON, and the smallest (16%) is found in

DOUBLE ISLAND POINT LIGHTHOUSE	1584.1	958.4	625.7	39
UNIVERSITY OF QUEENSLAND GATTON	4167.1	3446.5	720.7	17

The frequency distribution of the CDH values for the 31 weather stations in both the control cases and the cool roof cases is shown in **Figure 15**. In control cases, the CDH centred around 1800 and 2000 has the largest proportion: each accounting for 19.4 % of the total, while all the remaining intervals have proportions of less than 10%. In cool roof cases, the CDH centred around 1000 and 1400 has the two largest proportions of 25.8% and 22.6%, respectively. The data of

Figure 16 The sum of Cooling degree hours in Jan and Feb of the control cases in the 31 stations in Brisbane.

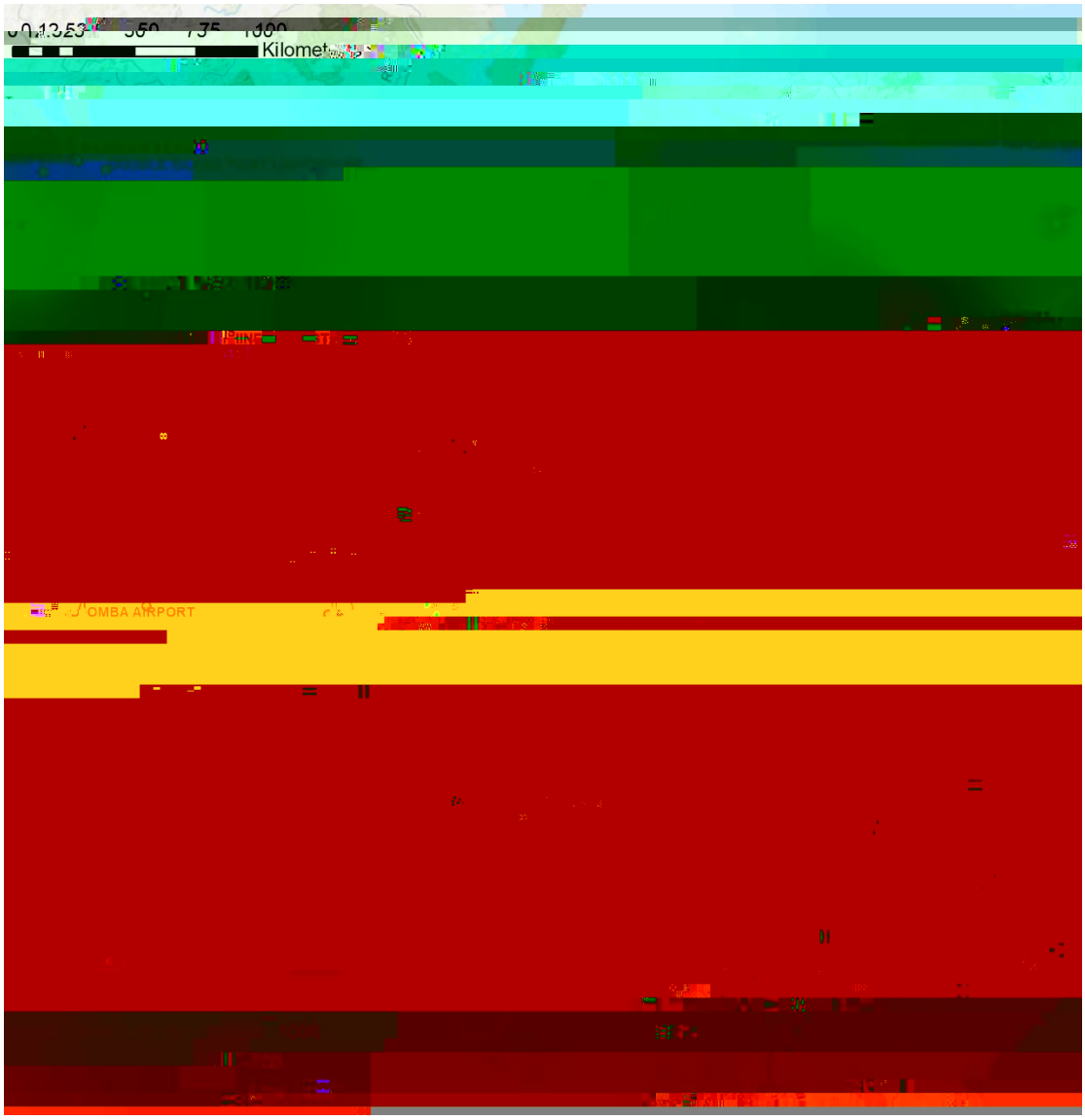


Figure 17 The sum of Cooling degree hours in Jan and Feb of the cool roof cases in the 31 stations in Brisbane.

Figure 19 The percentage of CDH reduction due to the implementation of the cool roof in the 31 stations in Brisbane.

2.4 Conclusions

- In average, compared to the reference scenario, temperature with the peak distribution in the cool roof scenario is mostly around 1-3 °C lower than that in the reference scenario, indicating the cooling benefits of cool roof. Around 45%-74% of the ambient temperatures in all stations concentrate in the range of 18-25 °C.
- In control cases, CDH ranges from 956.6 to 4167.1, and about 40% of the data is concentrated in 1800 - 2000. CDH gradually increases from the east of the city to the west.
- In cool roof cases, CDH ranges from 377.7 to 3446.5, and about 50% of the data is concentrated in 1000 - 1400. Its spatial distribution is also similar to that of the control case.
- The percentage of CDH reduction due to the implementation of the cool roofm70 G[The)-4(pe)4(rcenta)7(ge)-4(of C)-

17) A stand-alone house-new building.

The seven weather stations modelled in Brisbane include (See **Figure 20**):

1) Brisbane Airport -Climate zone 2,

2) Amberley-

1) Cooling load simulations for two summer months:

The cooling load simulations were performed for two summer months of January and February. Two sets g0 simulations wer

A low-rise office building without roof insulation-existing building	43.6-46.3	11.3-15.6	25.6-33.7	18.7-21.3	42.9-46.2
A high-rise office building without roof insulation-existing building	34.2-35.2	2.0-3.0	5.7-8.8	8.6-10.4	24.9-29.6
A low-rise office building with roof insulation-new building	32.1				

Table 9 Annual cooling load saving, heating load penalty, and total cooling and heating saving for reference with cool roof scenario (scenario 1) vs reference scenario for all building types using annual measured weather data for COP=1 for heating and cooling

Building Type	**Annual cooling load saving**		**Annual heating load penalty**	**Annual total cooling & heating load saving**	
	kWh/m^2	**%**	**kWh/m^2**	**kWh/m^2**	**%**
A low-rise office building without roof insulation-existing building	34.7-52.7	34.6-40.0	0.5-0.9	34.2-52.2	33.8-39.4

A mid-rise
shopping mall
centre-new
building

A stand

centre-new building						

1)

b. Scenario 1 cooling reduction	Slope	Y-intercept	Equation
B01 (Existing_Low-rise_no insulation)	0.001828	7.823	Y = 0.001828*X + 7.823
B02 (Existing_High-rise_no insulation)	0.0003923	1.205	Y = 0.0003923*X + 1.205
B03 (New_Low-rise_insulated)	0.0001448	0.8074	Y = 0.0001448*X + 0.8074
B04 (New_High-rise_insulated)	0.00005349	0.09037	Y = 0.00005349*X + 0.09037
B13 (Existing_Low-rise_insulated)	0.0007941	3.903	Y = 0.0007941*X + 3.903
B14 (Existing_High-rise_insulated)	0.0002184	0.4941	Y = 0.0002184*X + 0.4941

c. Scenario 2 cooling reduction	Slope	Y-intercept	Equation
B01 (Existing_Low-rise_no insulation)	0.001727	9.543	Y = 0.001727*X + 9.543
B02 (Existing_High-rise_no insulation)	0.0003720	2.595	Y = 0.0003720*X + 2.595
B03 (New_Low-rise_insulated)	0.0001187	2.225	Y = 0.0001187*X + 2.225
B04 (New_High55.44 TmTQ98 0.4804 5 n			

Figure 22 For shopping mall center a) The correlation between CDH and the sensible cooling of the reference scenario; b) The correlation between CDH and the cooling load reduction of scenario 1 compared to the reference scenario; c) The correlation between CDH and the cooling load reduction of scenario 2 compared to the reference scenario.

Table 13 Slope, Y intercept and equation of linear regression lines in a) reference scenario; b) scenario 1 cooling reduction; 3) scenario 2 cooling reduction.

a. Reference scenario	**Slope**	**Y-intercept**	**Equation**
B05 (New_ Low-rise)	0.002691	55.82	Y = 0.002691*X + 55.82
B06 (New_Mid-rise)	0.002507	55.41	Y = 0.002507*X + 55.41
B07 (New_High-rise)	0.002416	55.23	Y = 0.002416*X + 55.23

B06 (New_Mid-rise)	-0.0000

a. Reference scenario	Slope	Y-intercept	Equation
B08 (New_Low-rise_apartment)	0.001146	11.57	Y = 0.001146*X + 11.57
B09 (New_Mid-rise_apartment)	0.001138	11.29	Y = 0.001138*X + 11.29
B10 (New_High-rise_apartment)	0.001095	11.19	Y = 0.001095*X + 11.19
B11 (Existing_Standalone house)	0.001478	9.947	Y = 0.001478*X + 9.947
B17 (New-Standalone house)	0.001277	10.51	Y = 0.001277*X + 10.51

b. Scenario 1 cooling reduction	Slope	Y-

‡ **Scenario 2** (Cool roof with modified urban temperature scenario): The same building as in the reference scenario with a cool roof using the climatic data simulated by WRF considering an extensive use of cool roofs in the city.

The seventeen typical buildings modelled in this study include:

1. A low-rise office building without roof insulation-existing building,

2. A high-rise office building without roof insulation-existing building,

3. -487 Building office building with roof insulation-new building,ng,

4.

Table 17 Two-months sensible cooling load in reference scenario and average median average ratio of hourly sensible cooling load in cool roof with modified urban temperature scenario (Scenario 2) to reference scenario for seventeen building types in Redland and Amberley stations.

Buildings	**Station**	**Two-months sensible cooling loads-Reference scenario (kWh/m^2)**	**Average median ratio of hourly sensible cooling load in cool roof with modified urban temperature scenario (Scenario 2) to reference scenario**
B01- low-rise office building without roof insulation-existing building			

B12- typical school building-existing building	Redland	19	1.00
	Amberley	20.7	1.00
B13- low-rise office building with roof insulation-existing building	Redland	24.3	0.76
	Amberley	27.3	0.72
B14- high-rise office building with roof insulation-existing building	Redland	20.4	0.93
	Amberley	22.2	0.9
B15- low-rise shopping mall centre-existing building	Redland	65.2	0.87

Figure 29

Figure 32 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a low-rise apartment-new building in Redland station.

Figure 33 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a mid-rise apartment-new building in Redland station

Figure 34 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a high-rise apartment-

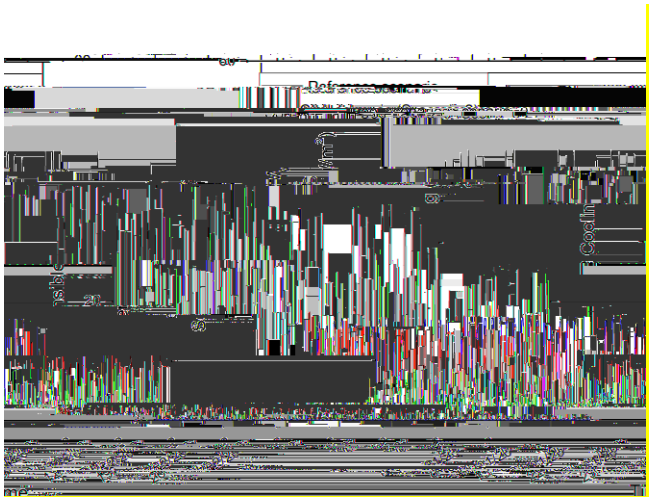


Figure 35 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a typical stand-alone house-existing building in Redland station

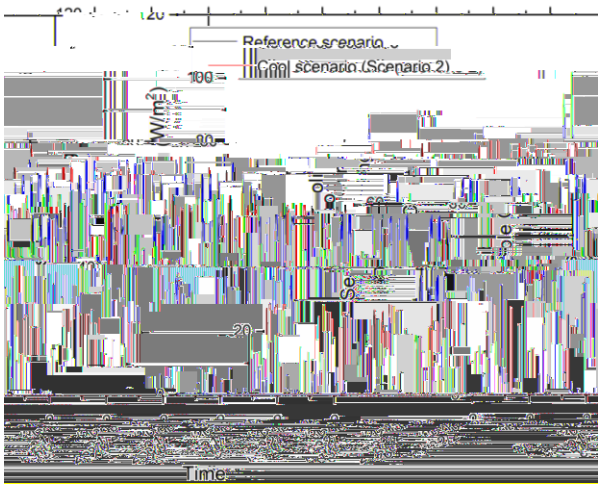


Figure 36 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a typical school building-existing building in Redland station

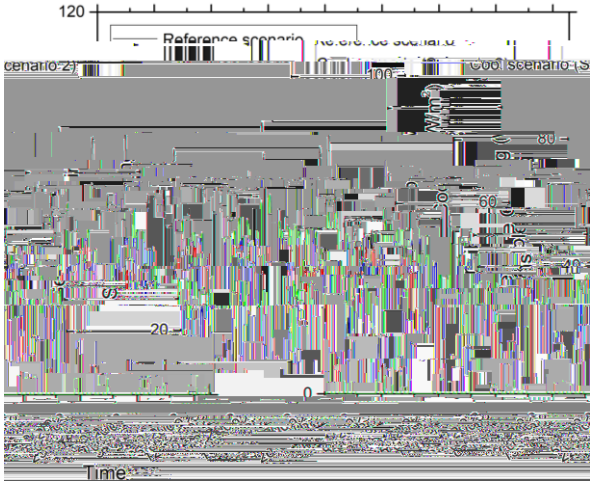


Figure 37 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a typical low-rise office-existing building in Redland station

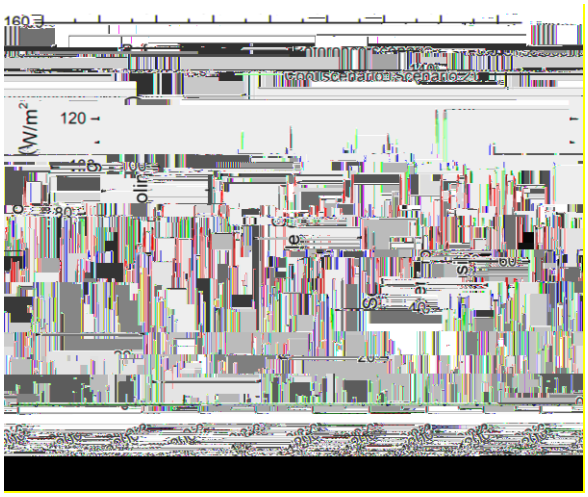


Figure 53 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a typical school building-existing building in Amberley station

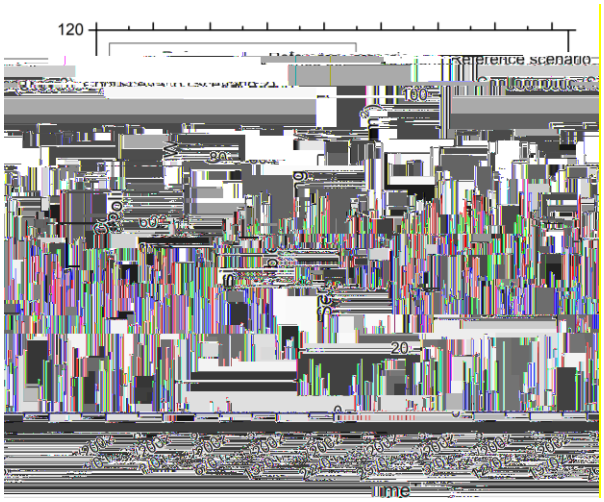


Figure 54 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a typical low-rise office-existing building in Amberley station

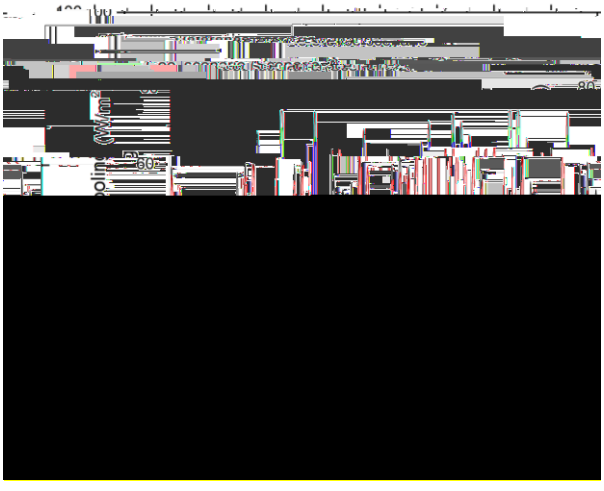


Figure 55 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a typical high-rise office-existing building in Amberley station

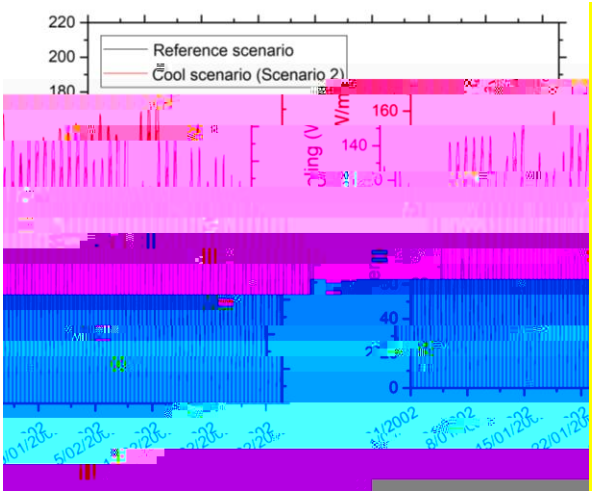


Figure 56 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a typical low-rise shopping mall centre-existing building in Amberley station

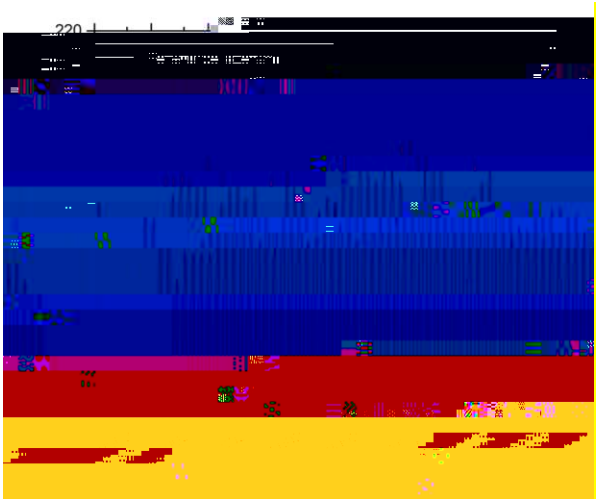


Figure 57 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a typical high-rise shopping mall centre-existing building in Amberley station

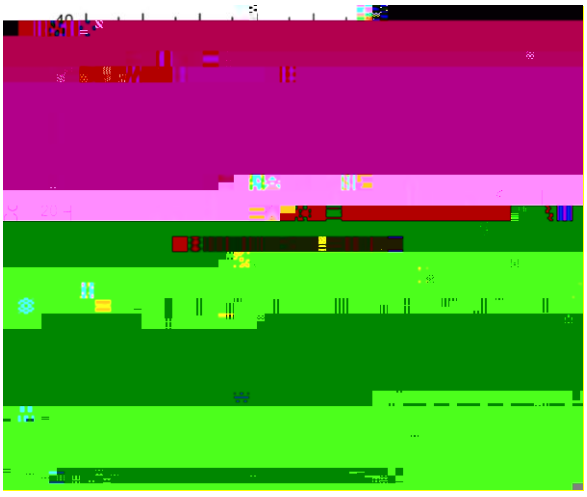


Figure 58 Sensible cooling load in cool roof with modified urban temperature scenario (scenario 2) and reference scenario for a stand-alone house-new building in Amberley station

Residential-Split system-Eq 4

B14	20.4	1.0	5	2.0	10	1.3	6	1.4	7	1.4	7	2.2	11	3.0	14	1.5	7
B15	65.2	6.9	11	9.5	15	4.2	6	4.5	7	4.5	7	7.1	11	9.4	14	4.6	7
B16	61	2.1	3	4.7	8	4.2	7	4.5	7	4.6	7	7.1	12	9.5	16	4.7	8
B17	12.9	3.0	23	4.4	3												

B17- stand-
alone
house-

6. Feasibility of cool roofs: Evaluation of refurbishment of 17 buildings for Amberley and Redland weather conditions

6.1 Methodological approach

A series of investment appraisal methods can be applied to evaluate the feasibility of energy-saving measures, like the application of cool roofs and the refurbishment of existing ones. The most widely used methods are the following:

1)

Demerits:

(a) Projecting the future rates of interest at which the cash inflows will be reinvested is difficult.

4) Life Cycle Cost Analysis

Life cycle cost analysis (LCC or LCCA) is an approach used to assess the total cost of owning a facility or running a project. LCCA considers all the costs associated with obtaining, owning, and disposing of an investment. It is especially useful where a project comes with multiple alternatives, and all of them meet performance necessities, but they differ with regards to the initial as well as the operating cost. In this case, the alternatives are compared to find one that can maximize savings.

In that sense, it is ideally suited to energy-saving measures, and project-related costs are classified into initial costs,

Table 28

In order to comparatively illustrate the results for the 17 buildings, in the following **Figure 61** and **Figure 62** are depicted their Internal Rate of Return and their Life Cycle Cost values

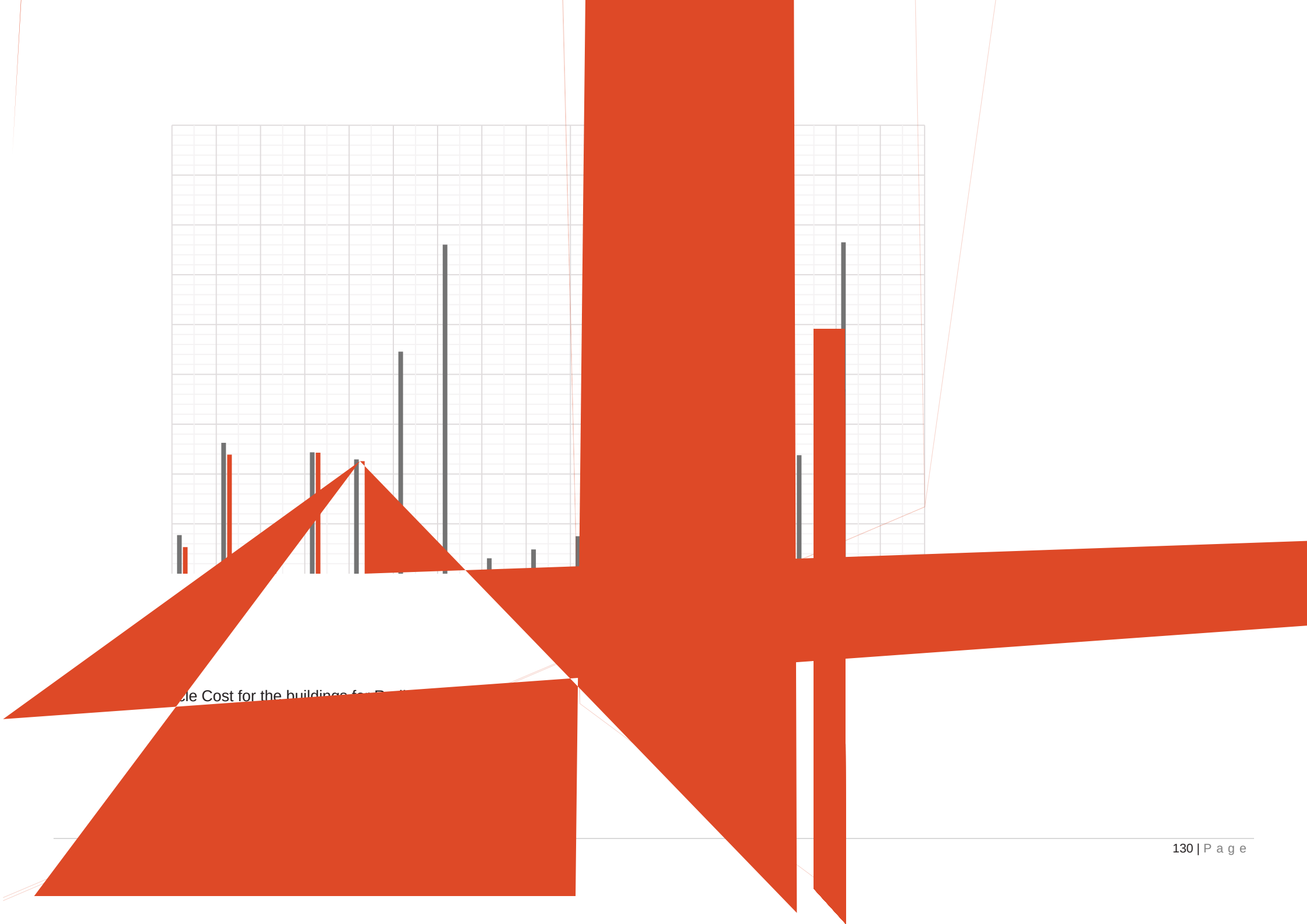
Figure 60 Net Present Value for the buildings for Amberley weather conditions

6.5.2 Part 2. Results for Redland weather conditions

Table 30 Net Present Value for Redland weather data

NPV	Low Electricity Price		High Electricity Price	
Building	**Metal Roof**	**Coating**	**Metal Roof**	**Coating**

In order to comparatively illustrate the results for the 17 buildings, in the following **Figure 65** and **Figure 66** are depicted their Internal Rate of Return and their Life Cycle Cost values.



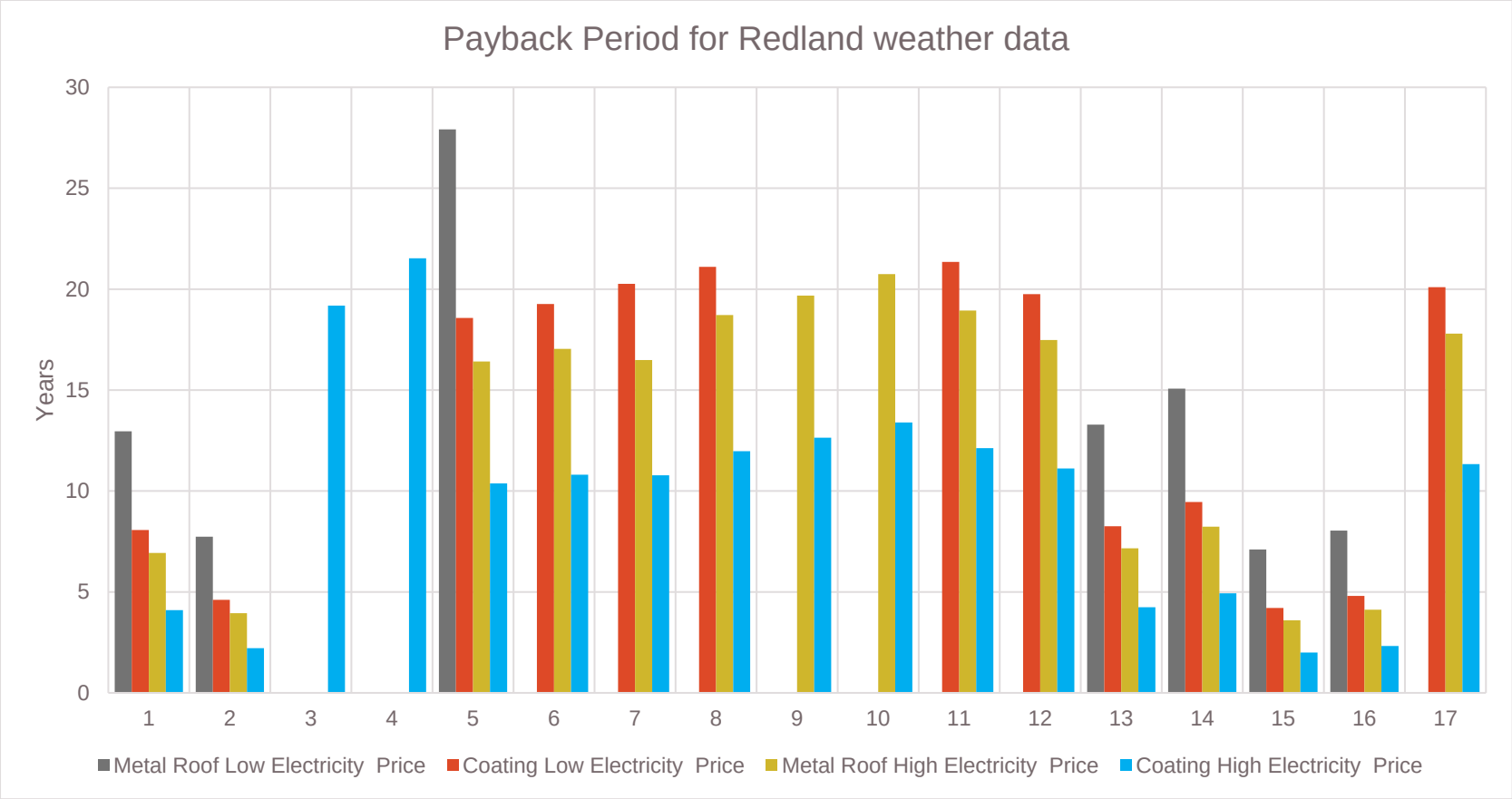


Figure 67 Payback Period for the buildings for Redland weather conditions

6.6 Discussion of the results

A series of interesting conclusions can be drawn from the results presented:

For all 17 buildings, the solution of the coating for the cool roof presents the least Life Cycle Cost and is, in that sense, W K H P R V W µ W K U L I W \ ¶ F K R L F H it features a significantly lower initial investment cost compared to cool metal roof, yet achieves comparatively similar savings.

This applies both for the low and the high electricity price scenario, albeit as expected for the high electricity price sce

Average of January	-131.1	-615.4	-212.6	-226.1

10. Appendix: Building characteristics_ Cool roofs project simulations inputs _ Climate zone 2

The following **Table 40** to **Table 43** have presented the general building parameters, internal gains, and ventilation; operation schedules; ventilation, HVAC, and setpoints parameters and building envelope parameters employed in the simulations in **Chapter 3**.

Table 42 Ventilation, HVAC, and setpoints parameters

	Office			Shopping mall		School	Standalone House		Apartment
Building ID	**B01, B02**	**B03, B04**	**B13, B14**	**B05, B06, B07**	**B15, B16**	**B12**	**B11**	**B17**	**B08, B09, B10**
Building Type	Existing uninsulated	New	Existing w/ roof ins.	New	Existing	Existing	Existing	New	New
Ventilation op. hours (l/s. p)	7.5 (same for all buildings)								
Infiltration (op. hours) (ac/h)	1 (same for all buildings)								
Infiltration (non-op. hours) (ac/h)	1.5								
HVAC system type				Heat pump air-cooled reverse cycle PAC		Non-ducted reverse cycle split units	Split-system central AC		Split-system central AC
HVAC fan efficiency	1								
Heating setpoint (°C)	20 (same for all buildings)								
Heating setback (°C)	NA (system off out of working ours for commercial buildings, following NCC)								
Cooling setpoint (°C)	25 (same for all buildings)								
Cooling setback (°C)	NA (system off out of working ours for commercial buildings, following NCC)								

Continues

In the study by Delta Q (the one provided by Kavya for the archetypes),

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