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COOL ROOFS
COST BENEFIT ANALYSIS

Volume 12 – Alice Springs, Darwin and Hobart: Analysis and Results of the Climatic and Energy Performance of Cool Roofs. Methodology, Global Results and Conclusions.

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Executive summary

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

1) To investigate the impact of cool roofs on the annual cooling and heating load of different types of buildings in Alice Springs, Darwin and Hobart.
2) To investigate the impact of cool roofs on the cooling/heating load and indoor air temperature of different types of buildings in Alice Springs, Darwin and Hobart.

The study involved the following phase:

Assessment of the energy Cooling/heating load under various boundary conditions during the whole year. The annual cooling and heating load estimations were also performed to assess the annual cooling load savings of cool roofs against their corresponding annual heating penalty. The annual cooling and heating load simulations were performed using the weather data obtained from the Bureau of Meteorology (BoM).

To summarise, it is expected that this study can present a comprehensive overview of the existing climatic conditions, and the overall climatic effect, as well as the modification in building energy and thermal balance after applying the cool roof in the entire city of Alice Springs, Darwin and Hobart.

The following conclusions have been drawn:

Alice Springs:

- The application of cool roofs in individual buildings (scenario 1) can significantly reduce the annual cooling load savings and has a negligible impact on heating loads in all building types in Alice Spring. For instance, the annual cooling load saving in a low-rise office building without insulation is 37.8 kWh/m^2, while the corresponding heating penalty is just 0.9 kWh/m^2.

Darwin:

- The application of cool roofs in individual buildings (scenario 1) significantly reduces the annual cooling load savings and has no impact on heating loads in all building types in Darwin. For instance, the annual cooling load saving in a low-rise office building without insulation is 90.3 kWh/m^2, while the corresponding heating penalty is equal to zero.

Hobart:

- The application of cool roofs in individual buildings (scenario 1) has a higher annual heating load penalty than the annual cooling load saving in all non-commercial buildings in Hobart. For instance, the annual cooling load saving in a low-rise office building without insulation is 3.4 kWh/m^2, while the corresponding heating penalty is 4.3 kWh/m^2.
- The application of cool roofs in individual buildings (scenario 1) has a lower annual heating load penalty than the annual cooling load saving in all commercial buildings in Hobart. For instance, the annual cooling load saving in an existing low-rise shopping mall centre is 11.8 kWh/m^2, while the corresponding heating penalty is just 0.8 kWh/m^2.

1. Alice Springs- Impact of cool roofs on the cooling/heating load and indoor air temperature of buildings

1.1. Introduction

This report investigated the impact of cool roofs on the annual cooling and heating load of different types of buildings in Alice Springs. The annual cooling and heating load simulations were performed using the weather data obtained from the BoM. Specifically, the simulations were performed for seventeen types of buildings and one weather station across Alice Springs. The weather station modelled in Alice Springs is Alice Springs Airport in climate zone 3.

The seventeen typical buildings modelled in this study include the following and their characteristics are listed in **Appendix: Building characteristic**s:

1) A low-rise office building without roof insulation-existing building,
2) A high-rise office building without roof insulation-existing building,
3) A low-rise office building with roof insulation-new building,
4) A high-rise office building with roof insulation-new building,
5) A low-rise shopping mall centre- new building,
6) A mid-rise shopping mall centre- new building,
7) A high-rise shopping mall centre-new building,
8) A low-rise apartment building-new building,
9) A mid-rise apartment building-new building,
10) A high-rise apartment building-new building,
11) A typical stand-alone house-existing building,
12) A typical school building-existing building,
13) A low-rise office building with roof insulation-existing building,
14) A high-rise office building with roof insulation-existing building,
15) A low-rise shopping mall centre-existing building,
16) A high-rise shopping mall centre-existing building,
17) A stand-alone house-new building.

The corresponding building specifications for the buildings in climate zones 3 were considered. The following simulation were performed in this study:

Annual cooling and heating load simulations

The annual cooling and heating load estimations were performed to assess the annual cooling load savings of cool roofs against their corresponding annual heating penalty. The annual cooling and heating load simulations were performed using the measured annual weather data obtained from the BoM. The simulations were performed under two scenarios:

- **Reference scenario:** A reference building with a conventional roof using the BoM annual measured climatic data.
- **Scenario 1 (Reference with cool roof scenario):** The same building as in the reference scenario with a cool roof using the BoM annual measured climatic data.

1.2. Summary of results

This report investigated the impact of cool roofs on the annual cooling and heating load of different types of buildings in Alice Spring. In this chapter, simulation results and detailed discussions are presented. The annual cooling and heating load under two scenarios including reference scenario and reference with cool roof scenario (scenario 1) is given in **Table 1**.

Table 1 The annual cooling and heating load under two scenarios including reference scenario and reference with cool roof scenario (scenario 1)

Stations	Reference scenario				Reference with cool roof scenario (scenario 1)			
	Annual cooling load (kWh/m^2)		Annual heating load (kWh/m^2)		Annual cooling load (kWh/m^2)		Annual heating load (kWh/m^2)	
	Sensible	Total	Sensible	Total	Sensible	Total	Sensible	Total
A low-rise office building without roof insulation-existing building	101.3	110.1	2.6	4.9	65.8	72.3	3.1	5.7
A high-rise office building without roof	72.3	79.3	1.1	2.6	66.4	73.0	1.3	2.9

insulation-existing building								
A low-rise office building with roof insulation-new building	69.8	77.4	1.3	3.0	66.6	73.8	1.4	3.2
A high-rise office building with roof insulation-new building	67.5	74.4	0.9	2.3	66.9	73.7	0.9	2.3
A low-rise shopping mall centre-new building	272.7	304.0	1.7	4.9	266.0	297.1	1.7	5.0
A mid-rise shopping mall centre-new building	265.8	296.8	1.4	4.3	262.6	293.6	1.4	4.4
A high-rise shopping mall centre-new building	263.1	294.1	1.3	4.2	261.0	292.0	1.3	4.2
A low-rise apartment building-new building,	53.7	65.8	7.2	11.9	50.2	62.2	7.5	12.4
A mid-rise apartment building-new building	52.3	64.6	6.7	11.2	50.3	62.5	6.9	11.5
A high-rise apartment building-new building	51.3	63.6	6.4	10.9	50.1	62.4	6.6	11.1
A typical stand-alone house-existing building,	61.6	71.1	13.0	15.7	41.2	49.6	15.8	18.7

A typical school building-new building	89.0	107.3	2.6	14.0	86.8	104.5	2.7	14.2
A low-rise office building with roof insulation-existing building	82.1	90.4	1.6	3.5	65.4	72.2	1.8	4.0
A high-rise office building with roof insulation-existing building	69.3	76.3	0.9	2.4	66.5	73.2	1.0	2.5
A low-rise shopping mall centre-existing building	283.8	314.8	1.7	5.7	253.0	283.5	1.8	6.0
A high-rise shopping mall centre-existing building	265.3	296.1	1.3	4.4	256.2	286.9	1.3	4.5
A stand-alone house-new building.	50.2	59.6	10.6	13.0	38.8	47.7	11.4	13.9

The annual cooling load saving and heating load penalty by application of cool roofs in individual buildings (scenario 1) is given in **Table 2**.

Table 2 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.

Stations	**Annual cooling load saving**				**Annual heating load penalty**		**Annual total cooling & heating load saving**			
	Sensible		**Total**		**Sensible**	**Total**	**Sensible**		**Total**	
	(kWh/m^2)	**%**	**(kWh/m^2)**	**%**	**(kWh/m^2)**		**(kWh/m^2)**	**%**	**(kWh/m^2)**	**%**
A low-rise office building without	35.5	35.0	37.8	34.4	0.5	0.9	35.0	33.7	37.0	32.2

roof insulation-existing building										
A high-rise office building without roof insulation-existing building	5.9	8.2	6.4	8.0	0.2	0.3	5.7	7.8	6.1	7.4
A low-rise office building with roof insulation-new building	3.2	4.6	3.6	4.7	0.1	0.1	3.2	4.5	3.5	4.3
A high-rise office building with roof insulation-new building	0.6	0.9	0.6	0.9	0.0	0.0	0.6	0.8	0.6	0.8
A low-rise shopping mall centre-new building	6.7	2.5	6.9	2.3	0.0	0.1	6.7	2.4	6.8	2.2
A mid-rise shopping mall centre-new building	3.2	1.2	3.2	1.1	0.0	0.0	3.2	1.2	3.2	1.1
A high-rise shopping mall centre-new building	2.0	0.8	2.0	0.7	0.0	0.0	2.0	0.8	2.0	0.7
A low-rise apartment building-new building,	3.5	6.6	3.6	5.5	0.3	0.4	3.2	5.2	3.2	4.1
A mid-rise apartment building-new building	2.0	3.8	2.0	3.2	0.2	0.3	1.8	3.0	1.8	2.4
A high-rise apartment building-new building	1.2	2.3	1.2	1.9	0.1	0.2	1.1	1.8	1.1	1.4
A typical stand-alone house-existing building,	20.4	33.1	21.5	30.2	2.8	3.0	17.6	23.6	18.5	21.3

A typical school building-new building	2.2	2.5	2.8	2.6	0.1	0.2	2.2	2.4	2.6	2.1
A low-rise office building with roof insulation-existing building	16.6	20.3	18.2	20.1	0.3	0.5	16.4	19.6	17.7	18.8
A high-rise office building with roof insulation-existing building	2.9	4.1	3.1	4.1	0.0	0.1	2.8	4.0	3.0	3.9
A low-rise shopping mall centre-existing building	30.8	10.8	31.3	9.9	0.1	0.3	30.7	10.7	31.0	9.7
A high-rise shopping mall centre-existing building	9.0	3.4	9.2	3.1	0.0	0.1	9.0	3.4	9.1	3.0
A stand-alone house-new building.	11.4	22.8	12.0	20.1	0.8	0.8	10.7	17.6	11.1	15.3

1.3. Conclusion

The conclusions drawn from this study are:

- The application of cool roofs in individual buildings (scenario 1) can significantly reduce the annual cooling load savings and has a negligible impact on heating loads in all building types in Alice Spring. For instance, the annual cooling load saving in a low-rise office building without insulation is 37.8 kWh/m^2, while the corresponding heating penalty is just 0.9 kWh/m^2.

2. Darwin- Impact of cool roofs on the cooling/heating load and indoor air temperature of buildings

2.1. Introduction

This report investigated the impact of cool roofs on the annual cooling and heating load of different types of buildings in Darwin. The annual cooling and heating load simulations were performed using the weather data obtained from the BoM. Specifically, the simulations were performed for seventeen types of buildings and one weather station across Darwin. The weather station modelled in Darwin is Darwin Airport in climate zone 1.

The seventeen typical buildings modelled in this study include the following and their characteristics are listed in **Appendix: Building characteristic**s:

1) A low-rise office building without roof insulation-existing building,
2) A high-rise office building without roof insulation-existing building,
3) A low-rise office building with roof insulation-new building,
4) A high-rise office building with roof insulation-new building,
5) A low-rise shopping mall centre- new building,
6) A mid-rise shopping mall centre- new building,
7) A high-rise shopping mall centre-new building,
8) A low-rise apartment building-new building,
9) A mid-rise apartment building-new building,
10) A high-rise apartment building-new building,
11) A typical stand-alone house-existing building,
12) A typical school building-existing building,
13) A low-rise office building with roof insulation-existing building,
14) A high-rise office building with roof insulation-existing building,
15) A low-rise shopping mall centre-existing building,
16) A high-rise shopping mall centre-existing building,
17) A stand-alone house-new building.

The corresponding building specifications for the buildings in climate zones 3 were considered. The following simulation were performed in this study:

Annual cooling and heating load simulations

The annual cooling and heating load estimations were performed to assess the annual cooling load savings of cool roofs against their corresponding annual heating penalty. The annual cooling and heating load simulations were performed using the measured annual weather data obtained from the BoM. The simulations were performed under two scenarios:

- **Reference scenario:** A reference building with a conventional roof using the BoM annual measured climatic data.

- **Scenario 1 (Reference with cool roof scenario):** The same building as in the reference scenario with a cool roof using the BoM annual measured climatic data.

2.2. Summary of results

This report investigated the impact of cool roofs on the annual cooling and heating load of different types of buildings in Darwin. In this chapter, simulation results and detailed discussions are presented. The annual cooling and heating load under two scenarios including reference scenario and reference with cool roof scenario (scenario 1) is given in **Table 3**.

Table 3 The annual cooling and heating load under two scenarios including reference scenario and reference with cool roof scenario (scenario 1)

Stations	Reference scenario				Reference with cool roof scenario (scenario 1)			
	Annual cooling load (kWh/m^2)		Annual heating load (kWh/m^2)		Annual cooling load (kWh/m^2)		Annual heating load (kWh/m^2)	
	Sensible	Total	Sensible	Total	Sensible	Total	Sensible	Total
A low-rise office building without roof insulation-existing building	170.2	264.9	0.0	0.0	107.7	174.6	0.0	0.0
A high-rise office building without roof insulation-existing building	119.3	189.0	0.0	0.0	108.7	172.4	0.0	0.0
A low-rise office building with roof insulation-new building	111.6	183.3	0.0	0.0	106.3	171.2	0.0	0.0

A high-rise office building with roof insulation-new building	110.0	175.1	0.0	0.0	108.9	172.6	0.0	0.0
A low-rise shopping mall centre-new building	343.2	596.0	0.0	0.0	329.7	580.1	0.0	0.0
A mid-rise shopping mall centre-new building	334.7	584.1	0.0	0.0	328.1	576.9	0.0	0.0
A high-rise shopping mall centre-new building	332.1	581.0	0.0	0.0	327.4	575.9	0.0	0.0
A low-rise apartment building-new building,	88.1	217.8	0.0	0.0	74.6	206.2	0.0	0.0
A mid-rise apartment building-new building	83.1	214.9	0.0	0.0	74.8	207.8	0.0	0.0
A high-rise apartment building-new building	79.9	212.6	0.0	0.0	74.8	208.3	0.0	0.0
A typical stand-alone house-existing building,	108.3	197.1	0.0	0.0	62.7	152.8	0.0	0.0
A typical school building-new building	65.4	274.9	0.0	0.0	62.4	267.1	0.0	0.0
A low-rise office building with roof insulation-existing building	136.3	222.8	0.0	0.0	105.4	171.3	0.0	0.0
A high-rise office building with roof insulation-existing building	114.2	182.1	0.0	0.0	108.5	172.3	0.0	0.0
A low-rise shopping mall centre-existing building	389.3	648.2	0.0	0.0	324.3	575.1	0.0	0.0
A high-rise shopping mall centre-existing building	346.4	596.4	0.0	0.0	325.3	573.0	0.0	0.0
A stand-alone house-new building.	91.7	186.1	0.0	0.0	53.5	151.9	0.0	0.0

The annual cooling load saving and heating load penalty by application of cool roofs in individual buildings (scenario 1) is given in **Table 4**.

Table 4 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

Stations	Annual cooling load saving				Annual heating load penalty		Annual total cooling & heating load saving			
	Sensible		Total		Sensible	Total	Sensible		Total	
	(kWh/m²)	%	(kWh/m²)	%	(kWh/m²)		(kWh/m²)	%	(kWh/m²)	%
A low-rise office building without roof insulation-existing building	62.5	36.7	90.3	34.1	0.0	0.0	62.5	36.7	90.3	34.1
A high-rise office building without roof insulation-existing building	10.6	8.9	16.6	8.8	0.0	0.0	10.6	8.9	16.6	8.8
A low-rise office building with roof insulation-new building	5.3	4.8	12.0	6.6	0.0	0.0	5.3	4.8	12.0	6.6
A high-rise office building with roof insulation-new building	1.1	1.0	2.5	1.4	0.0	0.0	1.1	1.0	2.5	1.4
A low-rise shopping mall centre-new building	13.5	3.9	16.0	2.7	0.0	0.0	13.5	3.9	16.0	2.7
A mid-rise shopping mall centre-new building	6.6	2.0	7.2	1.2	0.0	0.0	6.6	2.0	7.2	1.2
A high-rise shopping mall centre-new building	4.7	1.4	5.2	0.9	0.0	0.0	4.7	1.4	5.2	0.9
A low-rise apartment building-new building,	13.5	15.3	11.6	5.3	0.0	0.0	13.5	15.3	11.6	5.3
A mid-rise apartment building-new building	8.3	9.9	7.1	3.3	0.0	0.0	8.3	9.9	7.1	3.3

A high-rise apartment building-new building	5.1	6.4	4.3	2.0	0.0	0.0	5.1	6.4	4.3	2.0
A typical stand-alone house-existing building,	45.6	42.1	44.3	22.5	0.0	0.0	45.6	42.1	44.3	22.5
A typical school building-new building	3.0	4.7	7.8	2.9	0.0	0.0	3.0	4.7	7.8	2.9
A low-rise office building with roof insulation-existing building	30.9	22.7	51.5	23.1	0.0	0.0	30.9	22.7	51.5	23.1
A high-rise office building with roof insulation-existing building	5.7	5.0	9.7	5.4	0.0	0.0	5.7	5.0	9.7	5.4
A low-rise shopping mall centre-existing building	65.0	16.7	73.1	11.3	0.0	0.0	65.0	16.7	73.1	11.3
A high-rise shopping mall centre-existing building	21.1	6.1	23.4	3.9	0.0	0.0	21.1	6.1	23.4	3.9
A stand-alone house-new building.	38.2	41.6	34.3	18.4	0.0	0.0	38.2	41.6	34.3	18.4

2.3. Conclusion

The conclusions drawn from this study are:

- The application of cool roofs can in individual buildings (scenario 1) significantly reduces the annual cooling load savings and has no impact on heating loads in all building types in Darwin. For instance, the annual cooling load saving in a low-rise office building without insulation is 90.3 kWh/m^2, while the corresponding heating penalty is equal to zero.

3. Hobart- Impact of cool roofs on the cooling/heating load and indoor air temperature of buildings

3.1. Introduction

This report investigated the impact of cool roofs on the annual cooling and heating load of different types of buildings in Hobart. The annual cooling and heating load simulations were performed using the weather data obtained from the BoM. Specifically, the simulations were performed for seventeen types of buildings and one weather station across Hobart. The weather station modelled in Hobart is Hobart Airport in climate zone 3.

The seventeen typical buildings modelled in this study include the following and their characteristics are listed in **Appendix: Building characteristic**s:

1) A low-rise office building without roof insulation-existing building,
2) A high-rise office building without roof insulation-existing building,
3) A low-rise office building with roof insulation-new building,
4) A high-rise office building with roof insulation-new building,
5) A low-rise shopping mall centre- new building,
6) A mid-rise shopping mall centre- new building,
7) A high-rise shopping mall centre-new building,
8) A low-rise apartment building-new building,
9) A mid-rise apartment building-new building,
10) A high-rise apartment building-new building,
11) A typical stand-alone house-existing building,
12) A typical school building-existing building,
13) A low-rise office building with roof insulation-existing building,
14) A high-rise office building with roof insulation-existing building,
15) A low-rise shopping mall centre-existing building,
16) A high-rise shopping mall centre-existing building,
17) A stand-alone house-new building.

The corresponding building specifications for the buildings in climate zones 3 were considered. The following simulation were performed in this study:

Annual cooling and heating load simulations

The annual cooling and heating load estimations were performed to assess the annual cooling load savings of cool roofs against their corresponding annual heating penalty. The annual cooling and heating load simulations were performed using the measured annual weather data obtained from the BoM. The simulations were performed under two scenarios:

- **Reference scenario:** A reference building with a conventional roof using the BoM annual measured climatic data.
- **Scenario 1 (Reference with cool roof scenario):** The same building as in the reference scenario with a cool roof using the BoM annual measured climatic data.

3.2. Summary of results

This report investigated the impact of cool roofs on the annual cooling and heating load of different types of buildings in Hobart. In this chapter, simulation results and discussions are presented. The annual cooling and heating load under two scenarios including reference scenario and reference with cool roof scenario (scenario 1) is given in **Table 5.**

Table 5 The annual cooling and heating load under two scenarios including reference scenario and reference with cool roof scenario (scenario 1)

Stations	Reference scenario				Reference with cool roof scenario (scenario 1)			
	Annual cooling load (kWh/m^2)		Annual heating load (kWh/m^2)		Annual cooling load (kWh/m^2)		Annual heating load (kWh/m^2)	
	Sensible	Total	Sensible	Total	Sensible	Total	Sensible	Total
A low-rise office building without roof insulation-existing building	6.1	6.3	6.5	13.0	2.8	2.9	9.2	17.3
A high-rise office building without roof insulation-existing building	3.4	3.5	4.0	9.0	2.9	3.0	4.5	9.8
A low-rise office building with roof insulation-new building	3.5	3.6	3.7	8.2	3.2	3.3	3.8	8.6
A high-rise office building with roof	3.1	3.2	3.0	7.4	3.1	3.2	3.0	7.5

insulation-new building								
A low-rise shopping mall centre-new building	63.6	66.8	3.6	10.8	60.7	63.9	3.7	11.1
A mid-rise shopping mall centre-new building	58.0	61.2	3.2	10.5	56.7	59.9	3.2	10.6
A high-rise shopping mall centre-new building	56.0	59.1	3.1	10.5	55.2	58.3	3.1	10.6
A low-rise apartment building-new building,	0.8	0.9	35.0	51.5	0.7	0.7	36.0	52.7
A mid-rise apartment building-new building	0.7	0.8	34.1	50.6	0.6	0.7	34.7	51.3
A high-rise apartment building-new building	0.6	0.7	33.9	50.4	0.6	0.6	34.2	50.9
A typical stand-alone house-existing building,	2.6	2.8	40.0	47.5	0.7	0.7	48.1	56.3
A typical school building-new building	5.5	5.5	6.5	41.3	5.2	5.2	6.6	41.9
A low-rise office building with roof insulation-existing building	4.3	4.5	4.8	10.4	2.9	3.0	5.5	11.8
A high-rise office building with roof insulation-existing building	3.2	3.3	3.3	8.0	3.0	3.1	3.4	8.3
A low-rise shopping mall centre-existing building	61.0	64.0	4.1	13.4	49.4	52.2	4.4	14.2
A high-rise shopping mall centre-existing building	54.5	57.5	3.2	11.4	51.3	54.3	3.3	11.6
A stand-alone house-new building.	1.3	1.4	29.5	35.9	0.6	0.6	31.4	38.1

The annual cooling load saving and heating load penalty by application of cool roofs in individual buildings (scenario 1) is given in **Table 6**. The simulations results show that cool roofs may have a negative impact on total heating and cooling loads in all building types excluding commercial buildings. Also, the application of cool roofs can slightly decrease the annual cooling and heating loads of commercial buildings.

Table 6 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

Stations	Annual cooling load saving				Annual heating load penalty		Annual total cooling & heating load saving			
	Sensible		Total		Sensible	Total	Sensible		Total	
	(kWh/m^2)	%	(kWh/m^2)	%	(kWh/m^2)		(kWh/m^2)	%	(kWh/m^2)	%
A low-rise office building without roof insulation-existing building	3.3	54.3	3.4	53.7	2.7	4.3	0.6	4.9	-0.9	-4.9
A high-rise office building without roof insulation-existing building	0.5	14.4	0.5	14.1	0.5	0.8	0.0	-0.2	-0.3	-2.5
A low-rise office building with roof insulation-new building	0.3	8.0	0.3	7.9	0.2	0.4	0.1	1.4	-0.1	-0.8
A high-rise office building with roof insulation-new building	0.0	1.5	0.0	1.4	0.0	0.1	0.0	0.2	0.0	-0.3
A low-rise shopping mall centre-new building	2.9	4.5	2.9	4.3	0.1	0.3	2.8	4.1	2.6	3.4
A mid-rise shopping mall centre-new building	1.3	2.2	1.3	2.1	0.0	0.1	1.3	2.1	1.2	1.7
A high-rise shopping mall	0.8	1.5	0.8	1.4	0.0	0.1	0.8	1.3	0.7	1.0

centre-new building										
A low-rise apartment building-new building,	0.2	19.8	0.2	20.2	1.0	1.3	-0.9	-2.4	-1.1	-2.1
A mid-rise apartment building-new building	0.1	12.6	0.1	12.9	0.6	0.7	-0.5	-1.4	-0.6	-1.2
A high-rise apartment building-new building	0.0	7.8	0.1	7.9	0.3	0.4	-0.3	-0.9	-0.4	-0.7
A typical stand-alone house-existing building,	2.0	74.4	2.1	74.7	8.1	8.8	-6.1	-14.4	-6.7	-13.3
A typical school building-new building	0.3	6.0	0.3	6.0	0.1	0.7	0.2	1.8	-0.3	-0.7
A low-rise office building with roof insulation-existing building	1.4	32.6	1.4	32.2	0.7	1.4	0.7	8.2	0.0	0.0
A high-rise office building with roof insulation-existing building	0.2	6.9	0.2	6.8	0.1	0.3	0.1	1.4	0.0	-0.4
A low-rise shopping mall centre-existing building	11.6	19.0	11.8	18.4	0.2	0.8	11.3	17.4	11.0	14.2
A high-rise shopping mall centre-existing building	3.1	5.8	3.2	5.6	0.1	0.2	3.1	5.3	3.0	4.3
A stand-alone house-new building.	0.7	53.0	0.7	53.9	1.9	2.2	-1.2	-4.0	-1.4	-3.9

3.3. Conclusion

The conclusions drawn from this study are:

- The application of cool roofs in individual buildings (scenario 1) has a higher annual heating load penalty than the annual cooling load saving in all non-commercial buildings in Hobart. For instance, the annual cooling load saving in a low-rise office building without insulation is 3.4 kWh/m^2, while the corresponding heating penalty is 4.3 kWh/m^2.
- The application of cool roofs in individual buildings (scenario 1) has a lower annual heating load penalty than the annual cooling load saving in all commercial buildings in Hobart. For instance, the annual cooling load saving in an existing low-rise shopping mall centre is 11.8 kWh/m^2, while the corresponding heating penalty is just 0.8 kWh/m^2.

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