Energy and GHG reductions considering embodied impacts of existing dwelling stock retrofit in Greater Melbourne

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We developed an **integrated and systematic approach** to assess the environmental and economic implications of:

•**Dwelling stock retrofit** options

•Across the **metropolitan area** (specifically Metro Melbourne)

•Considering **life cycle energy and GHG emissions** (both embodied and operating)

Existing Residential Buildings

- National energy consumption: **20% from buildings**, of which **60%** is attributed to **residential (**BREE, 2012)
- Australia's population increases at **1.5% p.a (**ABS 2013a)
- Annual replacement rate of existing buildings by new ones, is **less than 3%** (Roberts, 2008)
- By 2050, most current building stock will still remain and contribute **80-90% of energy and carbon** emissions while new buildings will only contribute around 10-20% additional energy consumption (IEA, 2012)
- >**95%** of the total residential buildings were built **before 2005**, before the introduction of minimum energy efficiency regulation in Australia

Metro/Greater Melbourne in Australia

Metro Melbourne & Its 31 LGAs

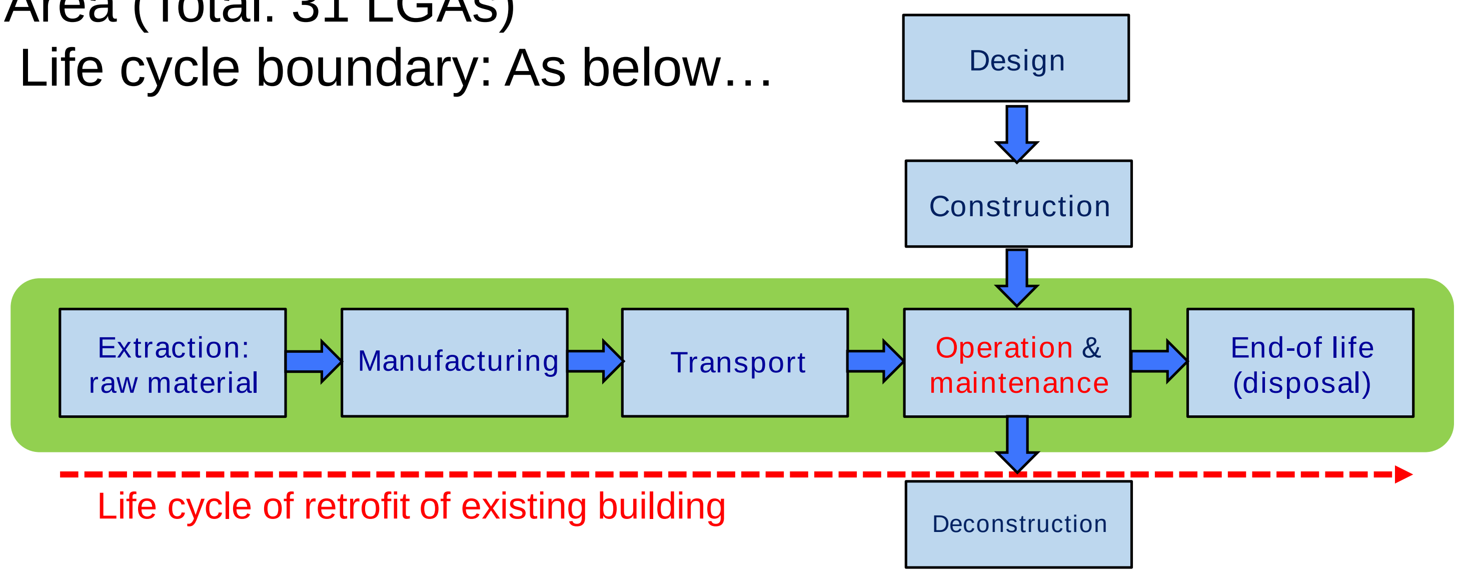
Energy and Carbon Modelling

Urban-scale modelling and analysis

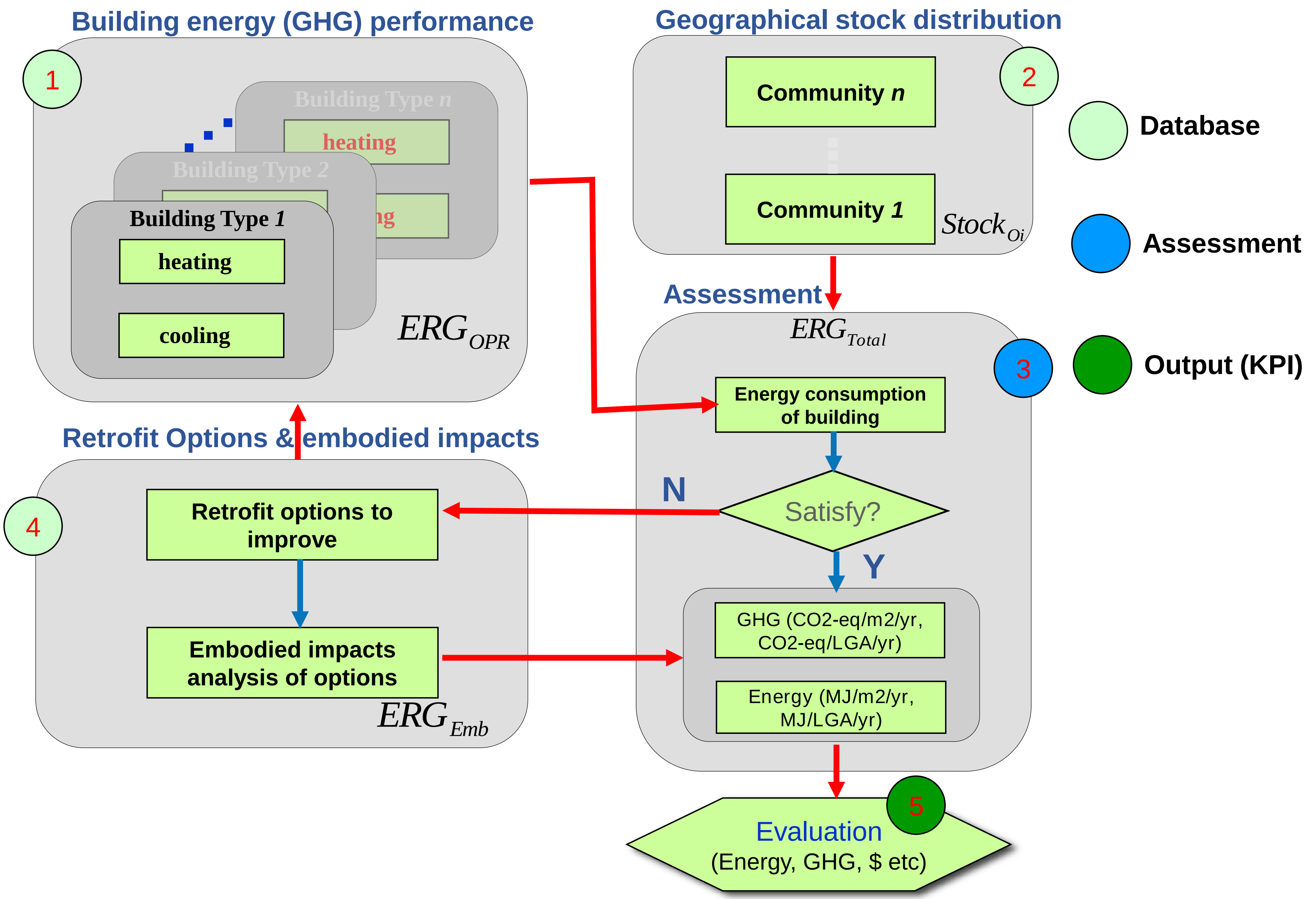
- Bottom-up approach
- Building stock

Boundary:

- Physical : Existing residential buildings
- Geographical : Local (city) councils or LGA in Greater Melbourne Area (Total: 31 LGAs)
- Life cycle boundary: As below…



Building Stock LC E/GHG Modelling



Embodied Energy & GHG Emissions

$$E_i\,(Energy\ \ \text{intensity}\ \ of\ \ \ industry\ \ i) = \frac{Energy\ \ consumption\,(MJ)\ \ of\ industry\ \ i}{total\ \ \ production\ \ (\$)\,of\ industry\ \ i} = \frac{\sum_{i=1}^{k} e_i}{X_i}$$

where e_i is the direct energy consumption of industry sector *i*

$$EE_k\,(Embodied\ energy\,of\ industry\,k) = E_i \cdot \left\{I - (I - M_k)\,A\right\}^{-1}$$

$$EGHG_k\,(Embodied\ GHG\,of\ industry\,k) = (E_i \cdot C_j)\cdot\left\{I - (I - M_k)\,A\right\}^{-1}$$

where

$\boldsymbol{EE_k}$ is the embodied energy intensity of industry k (MJ/$);

$\boldsymbol{E_i}$ is the direct energy requirement per dollar’s worth of final demand for industry *k* (MJ/$)

I is the unit matrix; *A* is the transaction matrix between industry sector (I/O table)

$\boldsymbol{EGHG_k}$ is the embodied GHG intensity of industry k (t-CO_2eq/$); C_j is the GHG conversion coefficient of energy *j*.

Embodied E & GHG Intensities of Melbourne LGAs

Local government in GMA*	Energy intensity* (GJ/A$m)	Carbon intensity**(t-CO_2eq/A$m)
Banyule	195.2	21.2
Bayside	200.7	22.1
Boroondara	176.2	17.8
Brimbank	207.7	23.9
Cardinia	212.2	24.5
Casey	205.7	23.2
Darebin	191.9	20.5
Frankston	200.7	22.0
Glen Eira	188.5	20.0
Greater Dandenong	181.6	19.1
Hobsons Bay	202.9	22.6
Hume	207.1	23.7
Kingston	207.4	23.8
Knox	201.0	22.2
Manningham	198.0	21.5
Marybirnong	164.6	16.0
Maroondah	198.0	21.5
Melbourne	149.7	13.6
Melton	203.1	22.6
Monash	197.4	21.8
Moonee Valley	194.1	20.8
Moreland	197.5	21.4
Mornington Peninsular	205.1	23.0
Nillumbik	202.3	22.6
Port Phillip	199.8	21.9
Stonington	171.1	17.1
Whitehorse	180.7	19.1
Whittlesea	207.0	23.8
Wyndham	204.5	22.8
Yarra	184.6	19.7
Yarra Ranges	207.1	23.4

**GMA: Greater Melbourne Area **Consumer price

Recurring EE & GHG Emissions

$$EI_{REC} = \sum_{Mat=1}^{M} \left(\frac{SL_{Bldg}}{SL_{Mat}} - 1 \right) \times \left(Q_{Mat} \times EI_{Mat} \right)$$

EI_{REC} is the recurrent impact (embodied energy in GJ or embodied carbon in *t-CO_2eq*);

SL_{Bldg} is the Service life of building (*year*);

SL_{Mat} is the service life of material/product (*year*);

Q_{Mat} is the quantity of material/product which were used higher energy rating in building (*A$m*);

EI_{Mat} is the embodied intensity of material (embodied energy in GJ/$m and embodied carbon in *t-CO_2eq/$m)*

Recurring EE & GHG Emissions

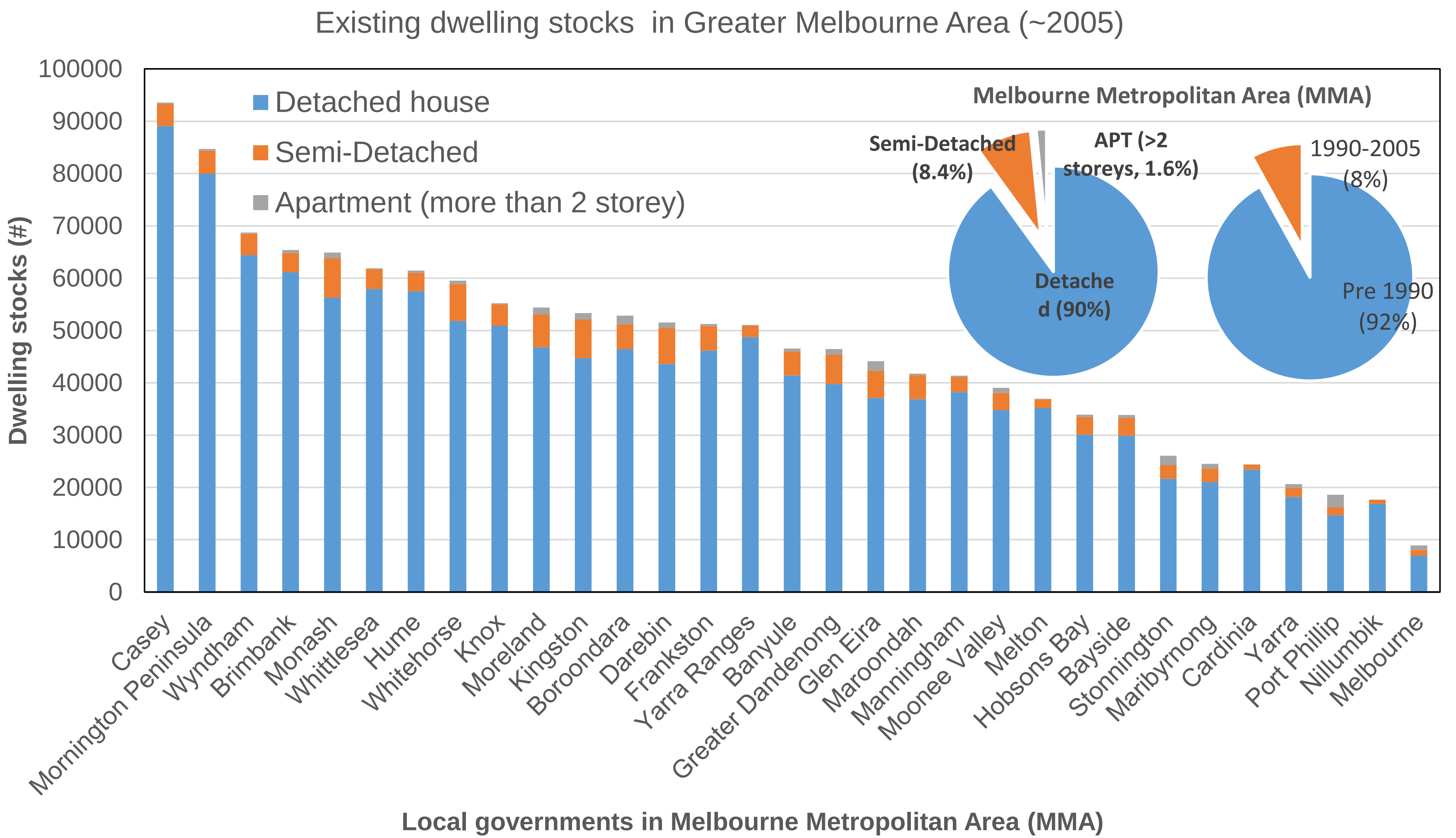
Service life of key retrofit materials

Material	Cost ($/m^2)+	Service life (year)	Note
Sealing	15.0	7*	5-10 (NIS (2016)
External blinds	100	12*	10-15 (GS (2016)
Ceiling insulation (R2.5)	10.7	Lifetime	Assumption
Ceiling insulation (R4.0)	14.0	Lifetime	Assumption
Ceiling insulation (R5.0)	17.4	Lifetime	Assumption
Ceiling insulation (R6.0)	19.0	Lifetime	Assumption
Wall insulation (R0.45)	13.8	Lifetime	Assumption
Wall insulation (R1.0)	30.7	Lifetime	Assumption
Wall insulation (R1.5)	33.8	Lifetime	Assumption
Wall insulation (R3.0)	50.6	Lifetime	Assumption
Wall insulation (R4.0)	62.9	Lifetime	Assumption
Plasterboard (13mm thick)	30.1	17.5*	15-20 (DoH, 2013)
Timber/uPVC double glazed	648.0	17.5	15-20 (Rauf and Crawford, 2015)
Timber/uPVC double glazed (argon gap)	680.4	17.5	15-20 (Rauf and Crawford, 2015)
+Rawlinsons (2013) ***average value**			

Metro Melbourne Residential Dwelling Stock

Local government	Population*	Number of dwelling**	Total domestic floor area**
Banyule	118,300	50,667	13,007,377
Bayside	91,800	38,750	8,805,025
Boroondara	159,180	66,406	14,521,826
Brimbank	182,700	69,225	18,246,859
Cardinia	74,170	24,106	7,329,733
Casey	252,380	93,818	27,468,198
Darebin	136,470	59,812	11,154,409
Frankston	126,450	54,261	14,585,242
Glen Eira	131,000	58,091	10,250,121
Greater Dandenong	135,600	52,143	11,158,782
Hobsons Bay	83,860	37,162	7,617,142
Hume	167,500	61,687	14,583,414
Kingston	142,400	61,835	12,521,472
Knox	149,300	57,198	17,844,843
Manningham	111,300	44,395	13,528,882
Maribyrnong	71,600	30,214	4,477,475
Maroondah	103,800	44,620	12,526,437
Melbourne	93,600	28,179	946,715
Melton	109,250	37,146	8,082,623
Monash	169,280	68,956	18,271,878
Moonee Valley	107,400	46,022	9,343,157
Moreland	147,240	63,579	11,540,864
Mornington Peninsula	144,600	89,027	29,132,608
Nillumbik	60,340	18,666	6,741,340
Port Phillip	91,370	47,200	2,467,033
Stonington	93,140	44,985	5,515,551
Whitehorse	151,300	65,577	15,338,460
Whittlesea	154,880	62,112	15,110,427
Wyndham	161,575	68,455	17,120,782
Yarra	74,090	30,544	2,743,029
Yarra Ranges	144,540	52,287	17,860,031
* ABS (2011c) ** Dunford (2014)			

Metro Melbourne Residential Dwelling Stock



Prototype Existing Dwellings

Prototype buildings condition

	type	Floor area	Energy rating	Conditioned area and schedule
Pre 90	Detached	114	1.5	• Living and kitchen (07:00~09:00 & 16:00~24:00) • Bedroom (16:00 ~09:00)
	Semi-detached	57		
Post 90	Detached	182	3.1	
	Semi-detached	132		

(DEWHA, 2008, Ret et al., 2012)

Thermostat setting for space heating and cooling in Melbourne

zone	Heating		Cooling
Living/kitchen	20° C		24° C
Bedrooms	15° C, 0:00-7:00	18° C, 7:00-9:00 and 16:00-24:00	24° C

Prototype Existing Dwellings

Prototype building energy and GHG emissions

$$ERG_{OPR} = \sum_{i=1}^{4}\left[\left(\frac{ERG_{i,h}}{COP_{i,h}} + \frac{ERG_{i,c}}{COP_{i,c}}\right) \times HH_i\right]$$

$$GHG_{OPR} = \sum_{i=1}^{4}\left[\left(\frac{ERG_{i,h}}{COP_{i,h}} \times cf_k + \frac{ERG_{i,c}}{COP_{i,c}} \times cf_j\right) \times HH_i\right]$$

where

i is the index of the dwelling prototype (total 4, i.e., detached and semi-detached built pre-1990 and 1991-2005, respectively)

$ERG_{i,h}$ (MJ/m2/*y*) and $ERG_{i,c}$,(MJ/m2/*y*) are the space heating and cooling energy requirement for building type i calculated by AccuRate

HH_i is the floor area of dwelling type i in m^2, which sum up over the 31 local governments in GMA

GHG_{OPR} is the total GHG emissions due to heating and cooling energy requirements in GMA in $t\text{-}CO_2eq$;

COP_h and COP_c are the coefficient performance of the heating and cooling systems, which are chosen from AccuRate database for this study

cf_k is the GHG emission factor of energy type k ($t\text{-}CO_2eq/GJ$ of energy, 51.*33kg* CO_2eq/GJ for natural gas for heating and 1.18*kg* CO_2eq/kWh for electricity in Victoria, (DoE, 2014)).

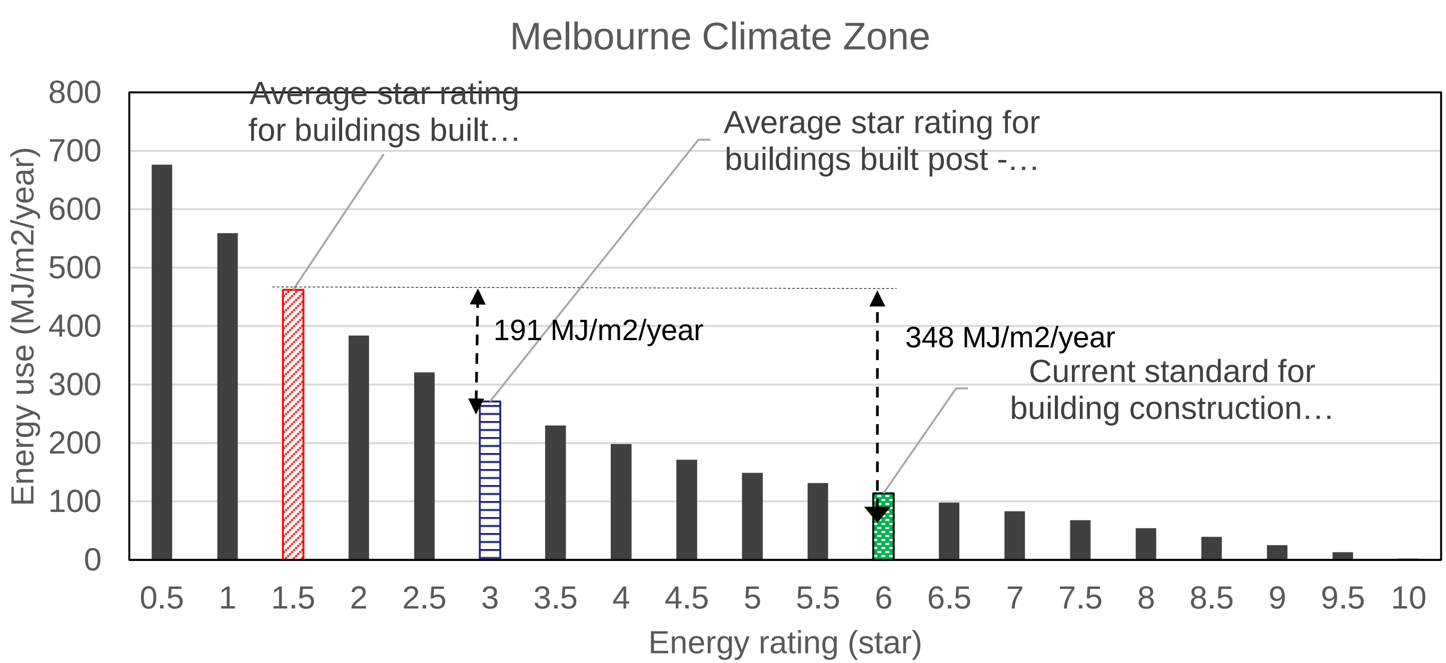
Prototype Existing Dwellings & Retrofit

type		Stocks built Pre 1990								Stocks between 91~2005							
		Detached				Semi-detached				Detached				Semi-detached			
Average energy star for BAU		1.5				1.5				3.1				3.1			
Floor Area (m2)		114				57				182				132			
External wall (m2)		139				55				135				126			
Scenario		3	4	5	6	3	4	5	6	3	4	5	6	3	4	5	6
Draught sealing (window, door, fan etc.)		√	√	√	√	√	√	√	√	-	√	√	√	-	√	√	√
Drapes/pelmets/external blind		√	√	√	√	√	√	√	√	-	√	√	√	-	√	√	√
Ceiling insulation		√	√	√	√	√	√	√	√	-	√	√	√	-	√	√	√
Wall insulation	R	5.0	6.0	6.0	6.0	0.5	4.0	4.0	6.0	-	6.0	4.0	6.0	-	2.5	6.0	6.0
		√	√	√	√	-	-	√	√	-	√	√	√	-	-	√	√
	R	0.5	3.0	3.0	4.0	-	-	0.5	1.5	-	1.0	3.0	3.0	-	-	1.5	3.0
Double glazed		-	-	√+	√*	-	-	-	-	-	-	√+	√*	-	-	-	√*

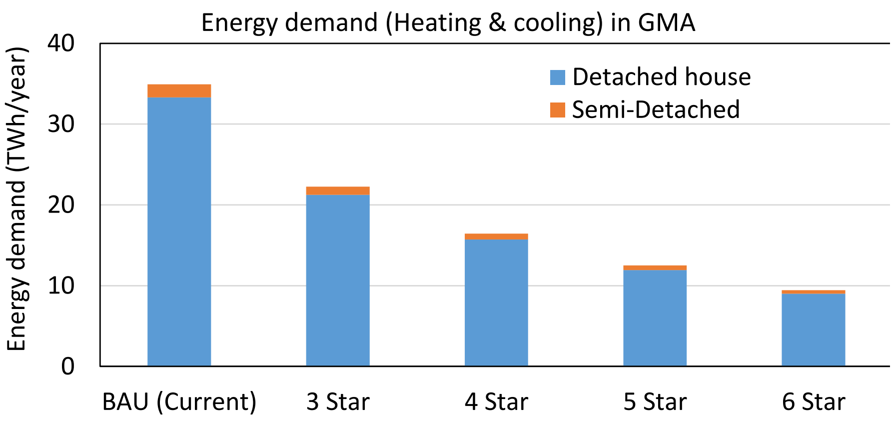
+ timber/uPVC double grazed (clear 6mm air gap)
*** timber/uPVC double grazed (clear 11mm argon gap)**

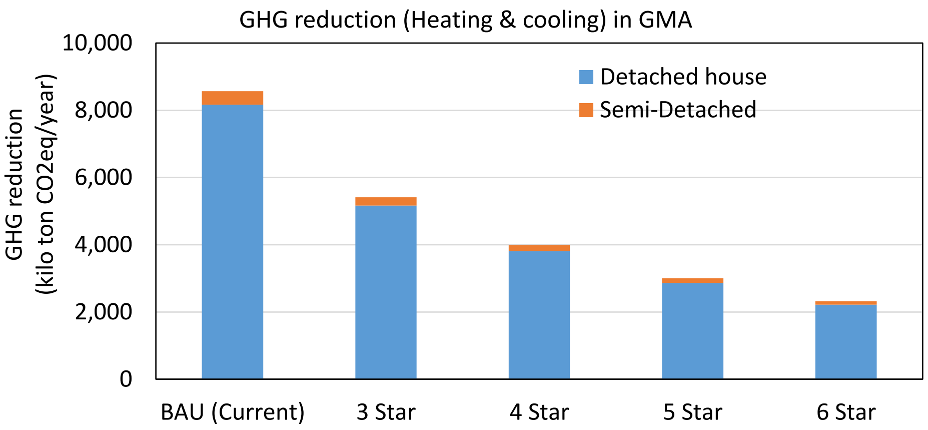
Prototype Existing Dwellings & Retrofit

Type	Energy Star Improve	Cost ($) to improvement			
		3	4	5	6
Pre 90	Detached (1.5)	15,237	20,544	39,151	41,794
	Semi-Detached (1.5)	3,851	4,683	7,172	8,615
Post 90	Detached (3.1)	-	24,188	65,859	62,809
	Semi-Detached (3.1)	-	5,591	16,669	18,789



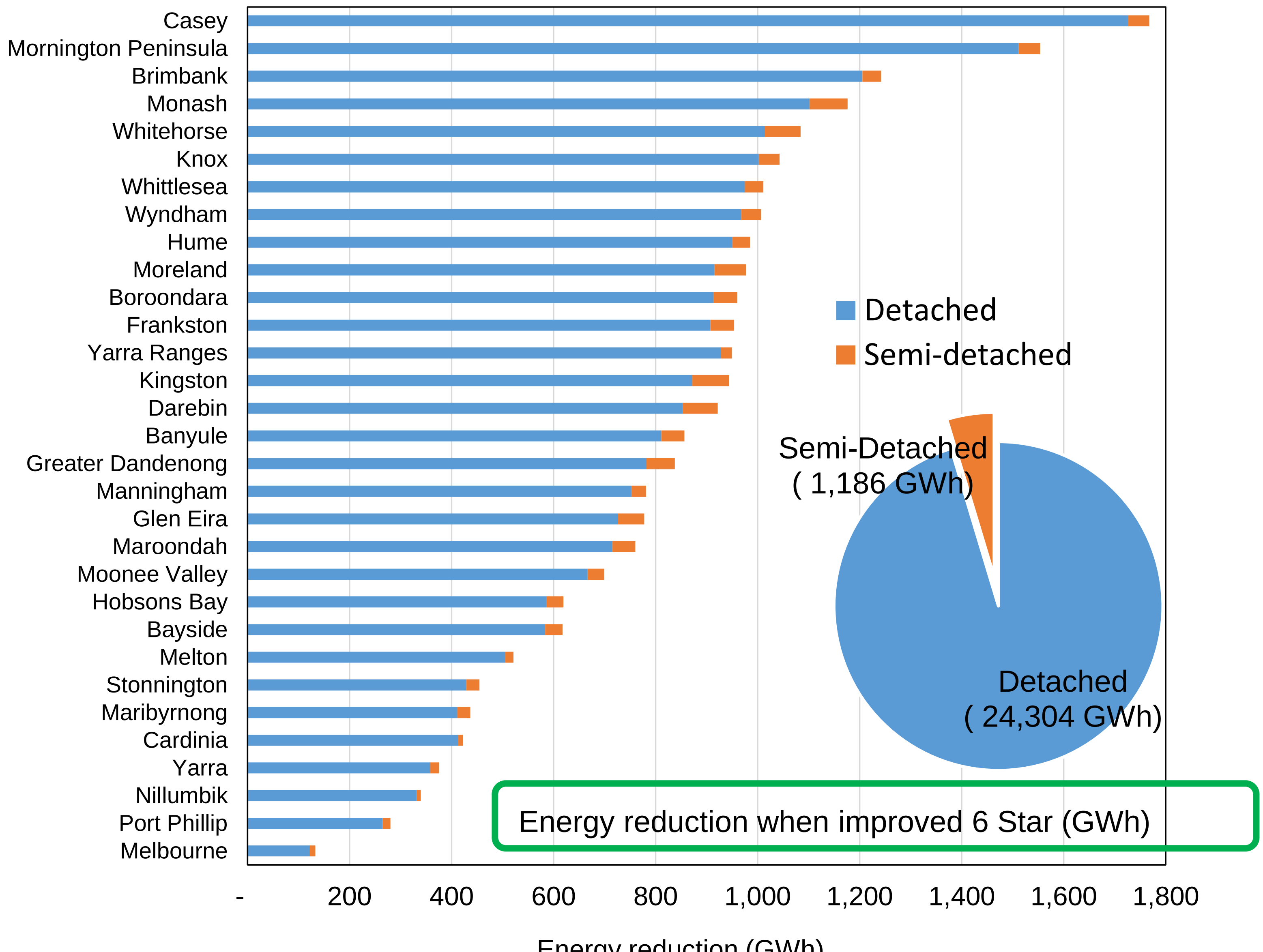
Results: Operational Energy & GHG





		Unit	BAU (Current)	Improvement			
				3-Star	4-Star	5-Star	6-Star
Operational Energy (a)	Detached	TWh/y	33.32	21.24	15.71	11.94	9.02
	Semi-Detached		1.61	1.01	0.74	0.57	0.43
Operational GHG (b)	Detached	10^6 ton CO_2eq/y	8.17	5.17	3.81	2.87	2.22
	Semi-Detached		0.40	0.25	0.18	0.14	0.10

Results: Operational Energy & GHG



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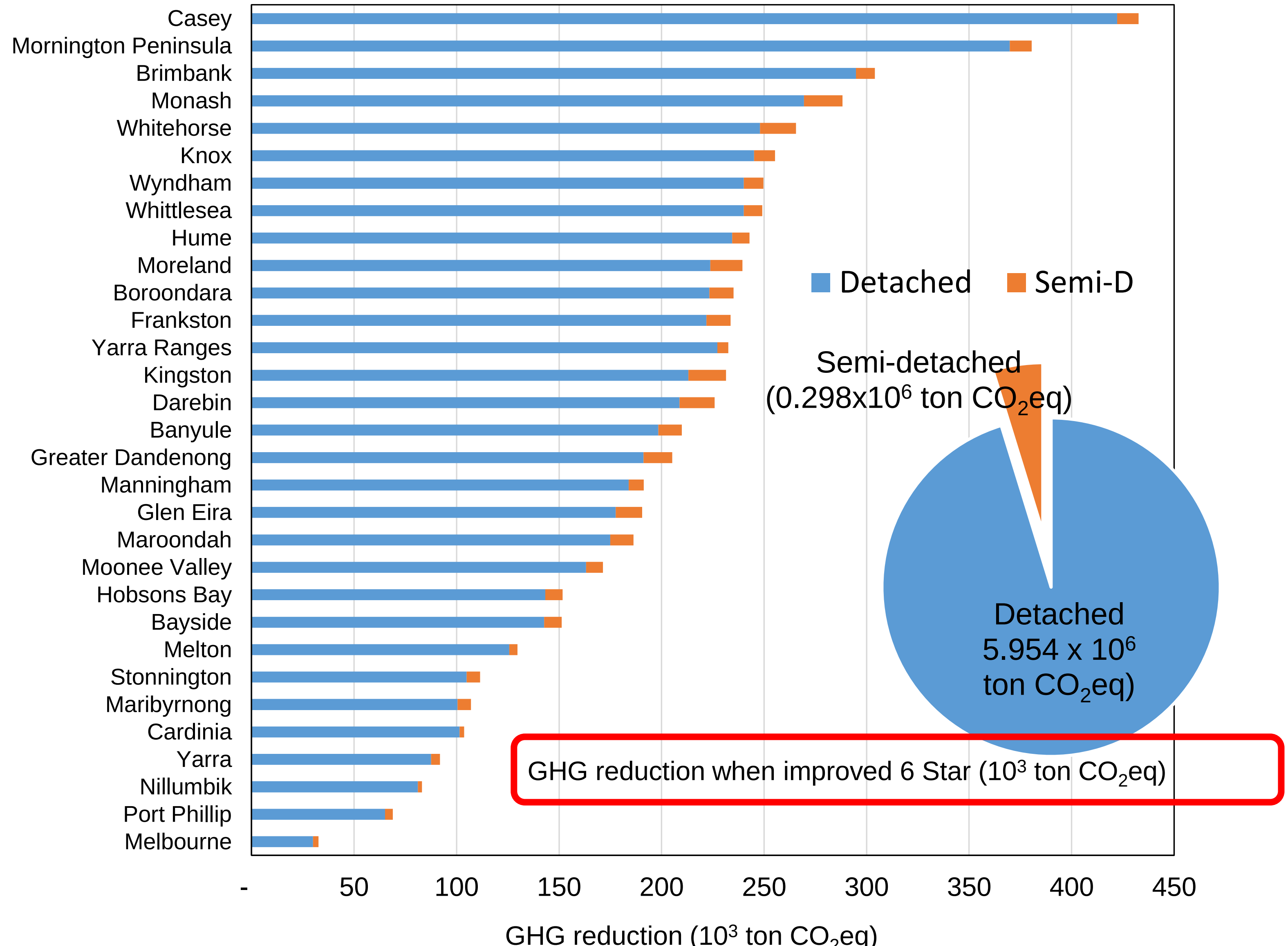
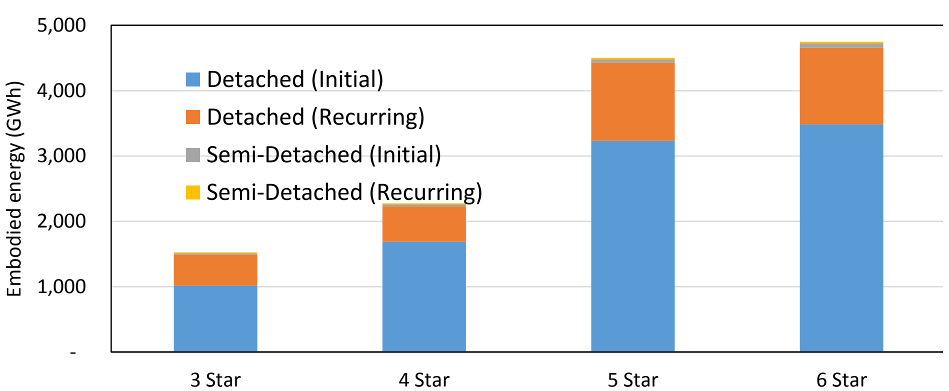
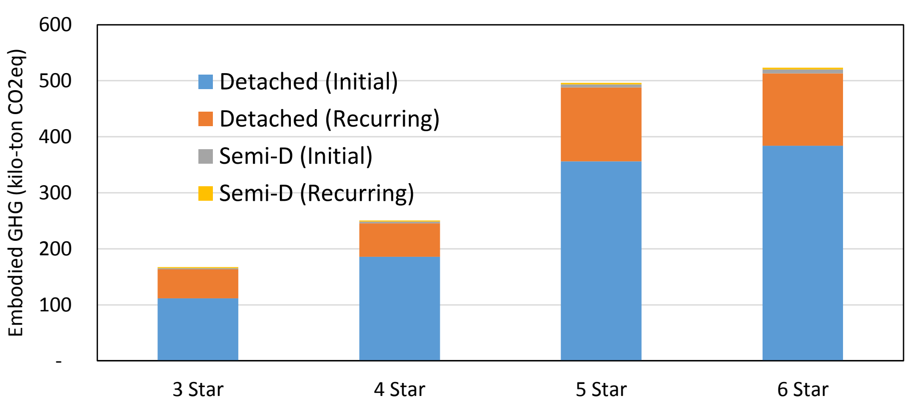


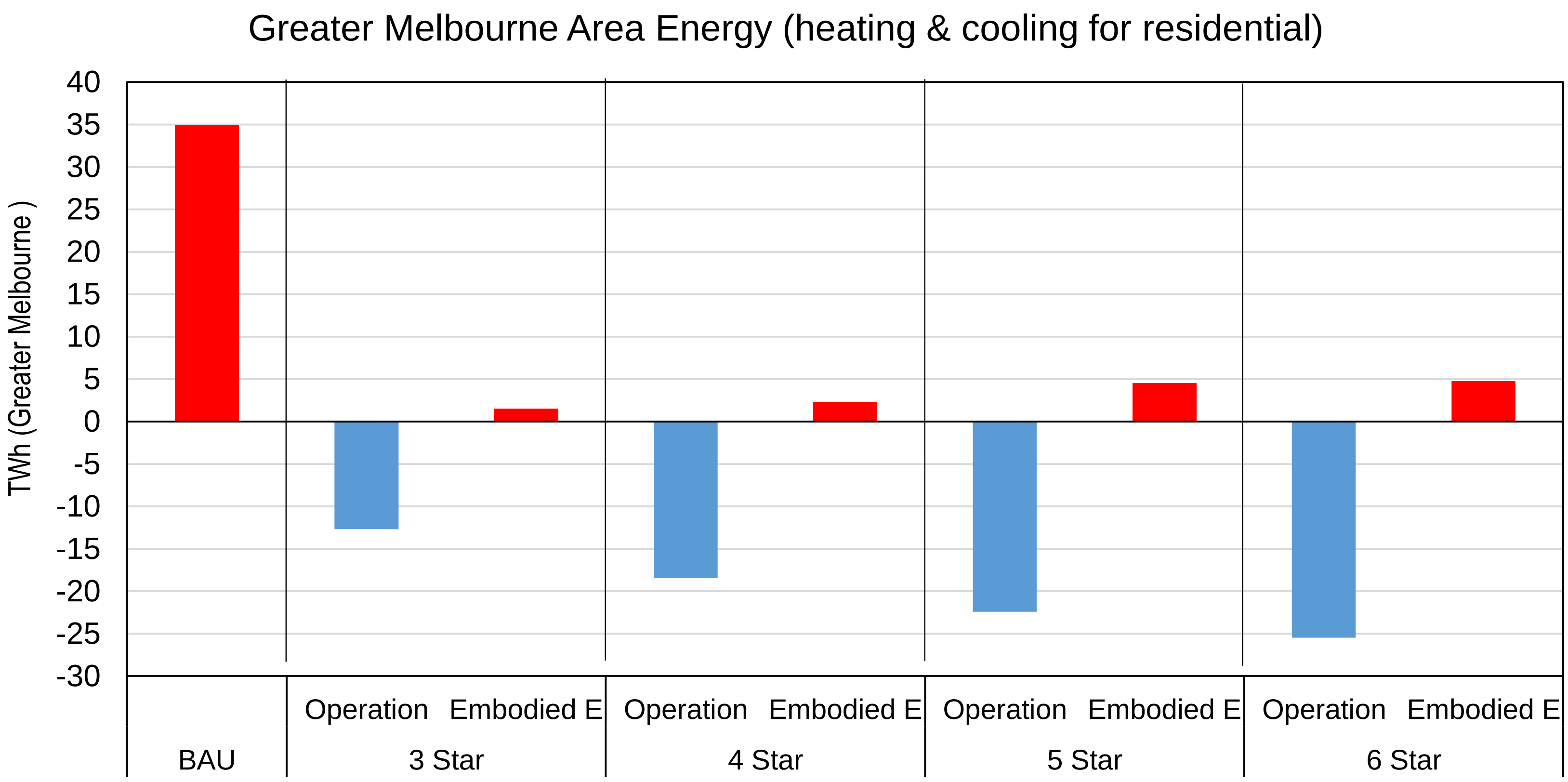
Results: Embodied Energy & GHG

			3-star	4-star	5-star	6-star
(a) Embodied energy (GWh)	Detached	Initial	1,017	1,686	3,231	3,483
		Recurring	471	541	1,196	1,174
	Semi-Detached	Initial	19	29	51	65
		Recurring	17	18	25	25
	Sum		1,523	2,274	4,503	4,748
(b) Embodied GHG (kilo ton CO_2eq)	Detached	Initial	112	186	356	384
		Recurring	52	60	132	129
	Semi-Detached	Initial	2.1	3.1	5.6	7.1
		Recurring	1.8	2.0	2.8	2.8
	Sum		167	250	496	523





Results: LC Impacts of Dwelling Retrofits



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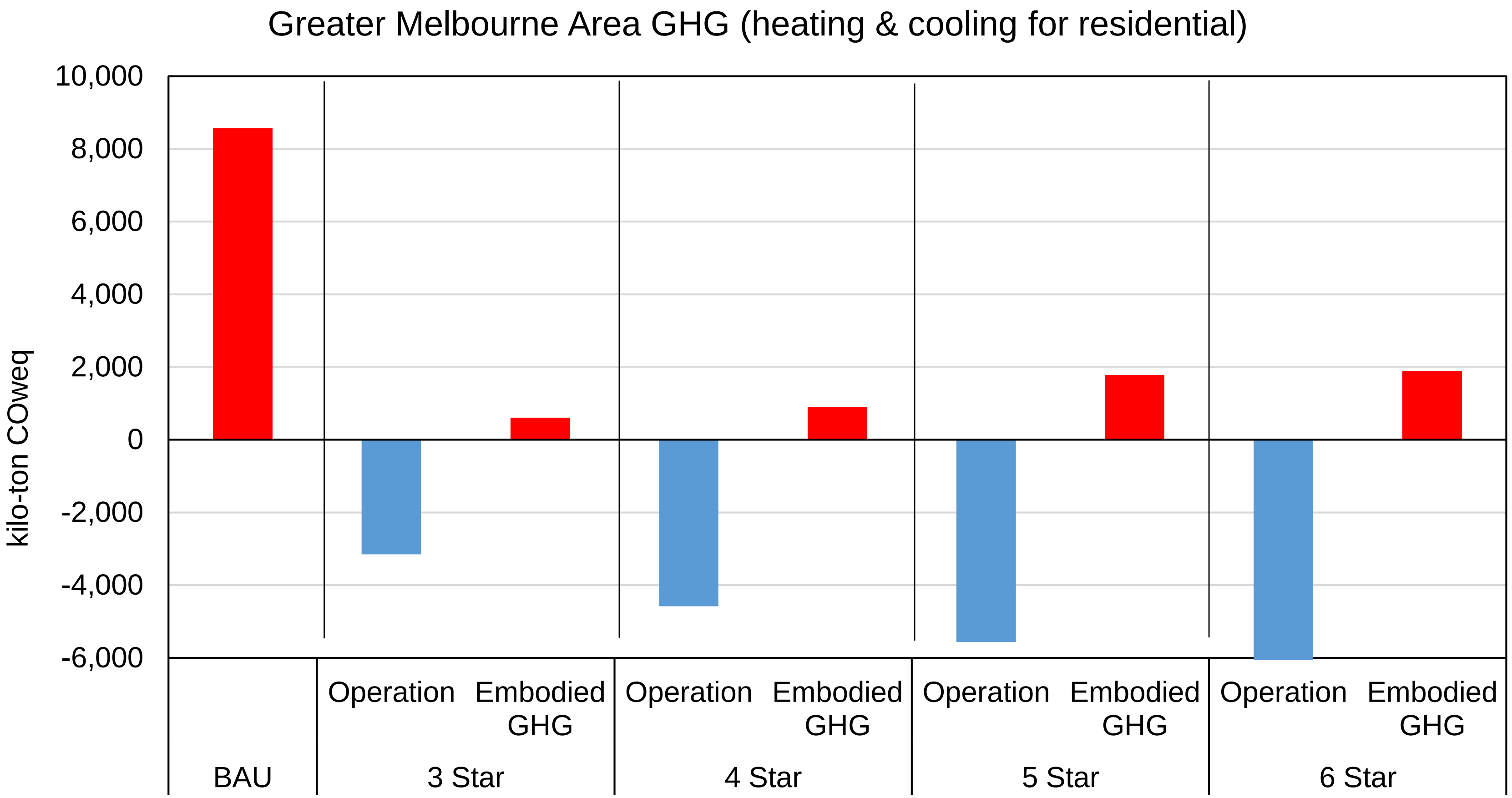


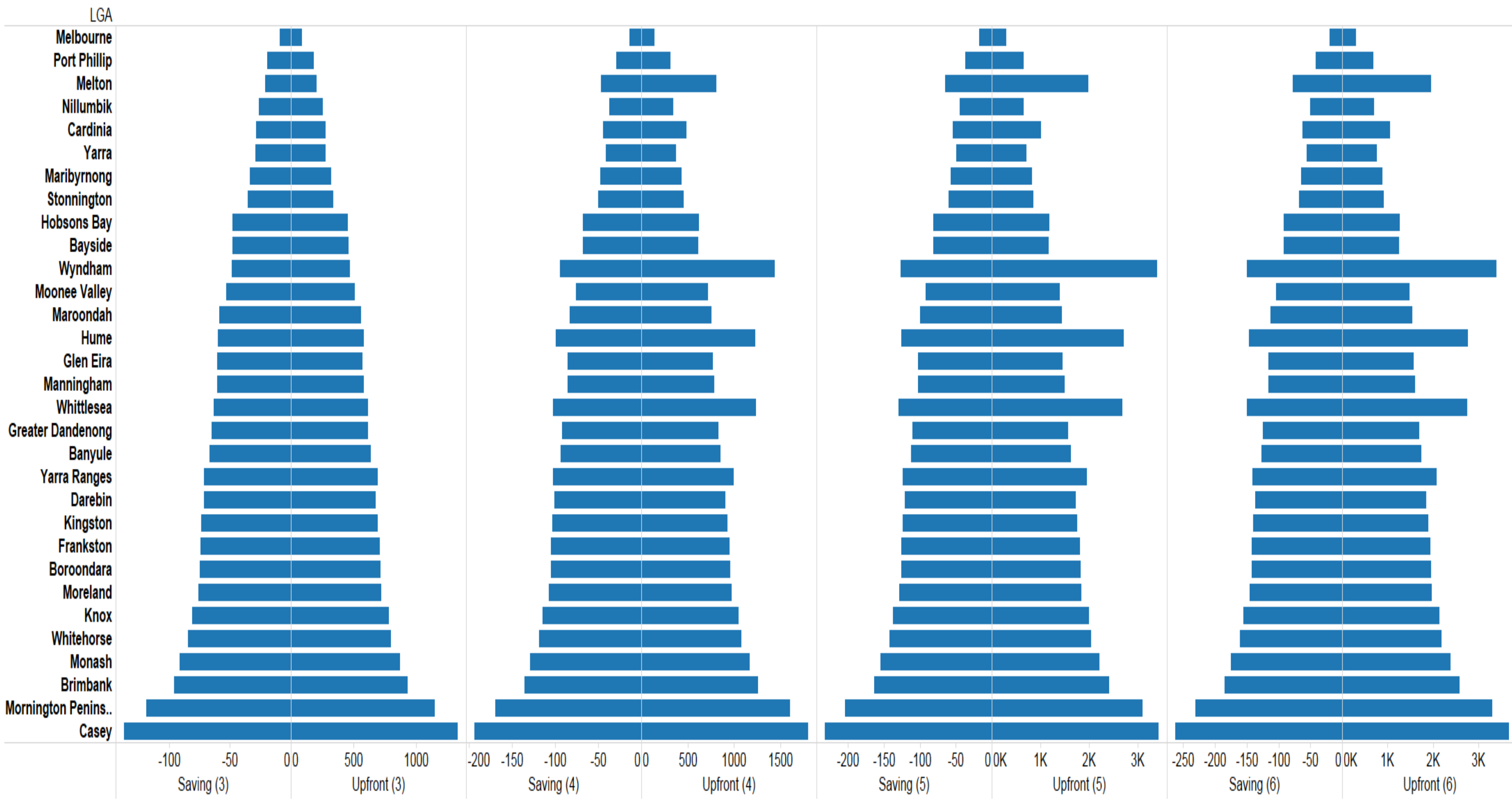
LC Impacts of Dwelling Retrofits (each LGA)

Star / Local Government	3 Star		4 Star		5 Star		6 Star	
	Saving*	Upfront cost**	Saving	Upfront cost	Saving	Upfront cost	Saving	Upfront cost
	$m/year	$/whole life	$m/year	$/whole life	$m/year	$/whole life	$m/year	$/whole life
Banyule	66.5	638.5	93.9	858.6	112.5	1,628.2	127.2	1,742.5
Bayside	47.9	459.7	67.7	618.2	81.1	1,172.2	91.7	1,254.5
Boroondara	74.5	717.1	105.3	964.5	126.1	1,829.8	142.6	1,957.8
Brimbank	95.9	933.5	135.9	1,266.1	163.0	2,414.0	184.4	2,577.6
Cardinia	28.7	280.8	44.1	489.3	54.6	1,022.1	62.7	1,057.9
Casey	136.8	1,335.6	193.6	1,804.2	232.1	3,435.4	262.5	3,669.6
Darebin	71.5	679.5	101.1	912.7	121.0	1,727.5	136.8	1,850.6
Frankston	74.0	712.5	104.6	958.3	125.3	1,818.2	141.6	1,945.3
Glen Eira	60.3	575.7	85.2	773.6	102.1	1,465.4	115.4	1,569.2
Greater Dandenong	65.0	620.0	91.8	833.1	110.0	1,578.0	124.4	1,689.9
Hobsons Bay	47.7	457.8	67.7	625.5	81.3	1,194.3	91.9	1,275.2
Hume	60.1	583.9	99.2	1,235.0	126.2	2,717.8	146.3	2,767.5
Kingston	73.3	694.9	103.5	933.4	124.0	1,766.1	140.2	1,892.2
Knox	80.9	782.9	114.3	1,053.5	137.0	2,000.6	154.8	2,139.5
Manningham	60.6	586.9	85.6	790.2	102.6	1,501.1	116.0	1,605.1
Maribyrnong	33.9	324.5	47.9	436.2	57.3	826.8	64.8	885.0
Maroondah	59.0	564.8	83.4	759.3	99.8	1,439.1	112.9	1,540.6
Melbourne	9.3	87.9	14.0	145.3	17.2	297.7	19.7	310.8
Melton	21.1	206.3	46.7	811.7	64.7	1,983.4	77.4	1,955.4
Monash	91.3	872.1	129.0	1,172.1	154.5	2,220.7	174.7	2,377.7
Moonee Valley	52.9	510.5	75.9	721.7	91.6	1,398.6	103.8	1,485.6
Moreland	75.8	724.4	107.1	973.6	128.3	1,844.5	145.1	1,974.9
Mornington Peninsula	118.5	1,153.9	169.2	1,609.1	203.7	3,104.7	230.7	3,301.4
Nillumbik	26.3	256.7	37.2	346.5	44.6	659.7	50.4	704.7
Port Phillip	19.1	183.8	29.3	317.5	36.3	660.8	41.6	685.6
Stonnington	35.3	338.3	49.9	454.8	59.7	862.2	67.5	922.9
Whitehorse	84.1	803.2	118.8	1,079.4	142.4	2,044.8	160.9	2,189.5
Whittlesea	63.5	616.6	102.8	1,239.9	129.8	2,694.8	150.1	2,755.1
Wyndham	48.7	473.2	94.5	1,443.6	126.4	3,409.8	149.5	3,397.6
Yarra	29.1	280.7	41.1	377.7	49.3	716.7	55.7	766.7
Yarra Ranges	71.2	695.8	102.8	1,002.5	124.2	1,960.5	141.0	2,074.8

*Annual saving ($m) due to increase energy efficiency of heating and cooling of existing dwelling stocks

**Upfront life cycle cost ($m) to increase energy efficiency of existing dwelling stocks

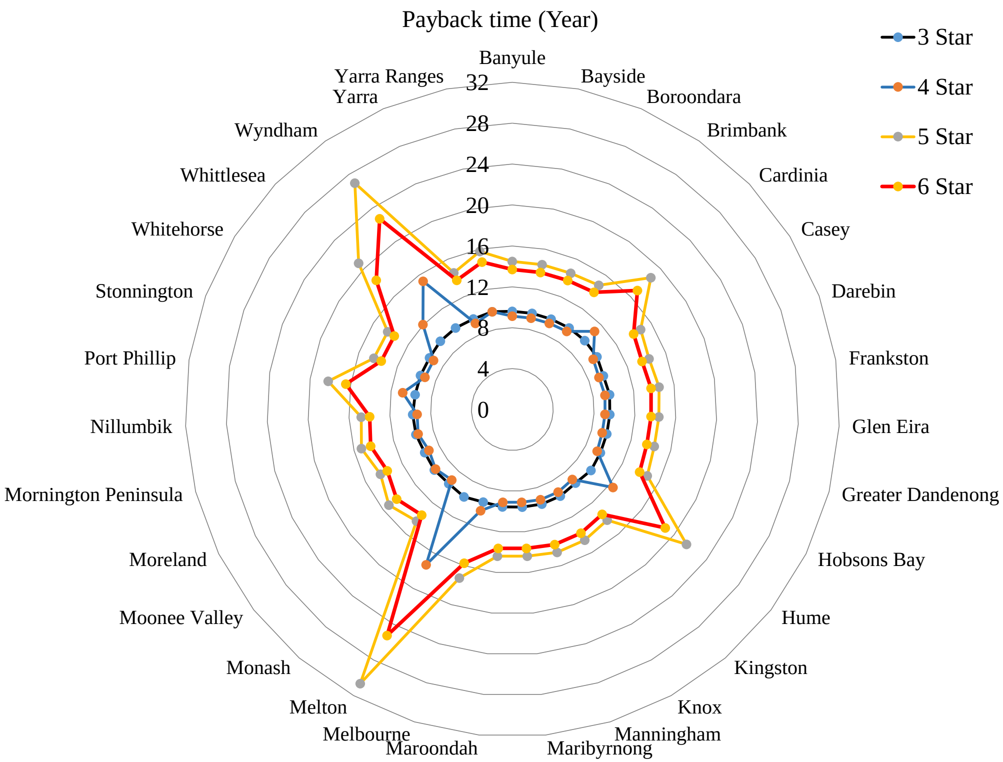
LC Impacts of Dwelling Retrofits (each LGA)



Payback Times of Dwelling Retrofit (each LGA)

- Payback time for 4-star is similar to 3-star upgrade program, except for some local governments (the Cities of Hume, Melton, Whittlesea and Wyndham). These local governments show 12 to 17.4 years (14.3 on average) of payback time, because the large proportion of their existing dwelling stocks were built between 1990 and 2005, with a 3.1-star energy rating on average.

- Payback times for 6 stars are relatively less than that to the 5-star level. This is because the upfront costs to reach the 6-star level is not much different than for the 5-star, but the heating and cooling energy savings are greater for the 6-star than the 5-star level.



Key Findings & Conclusions (1/3)

- When all the dwelling stocks are upgraded to the **3-star** level:
  - **Total heating and cooling energy** can be reduced to 22.3TWh per year, which is 36% less energy consumption compared to the BAU case (34.9TWh)
  - However, the **embodied energy** needed for this 3-star upgrade is equivalent to 7% (1.52TWh) of the annual heating and cooling energy consumption
  - The **GHG** reduction shows 3.16 million tons of CO_{2eq}, which is 33% less than the BAU case
  - But the **total embodied GHG** is 0.60 million tons of CO_{2eq} over the life cycle, which is around 11% of the annual heating and cooling GHG emissions of existing dwellings

Key Findings & Conclusions (2/3)

- When all the dwelling stocks are upgraded to the **6-star** level:
  - **Total heating and cooling energy** can be reduced to 9.4TWh per year, which is a 76% reduction compared to the BAU case
  - But the **embodied energy** needed for this upgrade is equivalent to 50.3% (4.75TWh) of the annual heating and cooling energy consumption
  - The existing dwellings (built pre-2000) represent up to 6.25 million tons of **GHG** reduction by upgrading to 6-star level.
  - But this is 73% less GHG emission compared to the BAU case

Key Findings & Conclusions (3/3)

- **Payback time** for all of the **energy consumption and the corresponding GHG emissions** can be compensated within a year.

- However, the **financial payback time** shows much longer time, at least 9 years for the 3-star dwelling stock upgrade; or more, for higher-rated upgrades

Summary

We developed an **integrated and systematic approach** to assess the environmental and economic implications of:

•**Dwelling stock retrofit** options

•Across the **metropolitan area** (specifically Metro Melbourne)

•Considering **life cycle energy and GHG emissions** (both embodied and operating)