The Impact of Surface-mounted Lighting on Home Thermal Efficiency.

The following paper provides an evaluation of the thermal efficiency benefits associated with surface-mounted LEDs compared to recessed LEDs in residential applications.

The study focuses on the following three areas: energy loss from air leakage as a result of recessed downlight ceiling cutouts, energy loss through insulation gaps required for recessed downlights, and the energy required to run the LED. It includes calculations of the induced energy usage required for recessed LED lights compared to surface-mounted LED lights, accounting for the additional air conditioning energy load associated with air leakage and insulation losses

All calculations are modelled off the use of a standard 16.5W recessed LED downlight and the recently released Brightgreen D900 SH Curve surface-mounted LED downlight.

General assumptions:

- the standard floor area for a Australian house is 214m². (Wilson, 2014)
- the ceiling height is 2.8m
- the building is single story
- the recessed luminaire has the following specifications: 900 lumens, 16.5W, 100mm cutout, 50mm clearance from insulation.
- the D900 SH luminaire has the following specifications: 900 Lumens, 16.5W, no cutout and no change to insulation.
- the desired average lux levels for the given area is 100 lux, therefore 40 luminaries are used for the floor layout (AS1680 average reccomendations)

Downlight Energy Consumption

As stated above, calculations are made according to an average-sized residential home in Australia that requires 40 luminaires, each consuming 16.5W. This totals 660W of power.

The weighted average of luminaires operating each day (based on indoor use only) is 1.55hrs. (Residential Lighting Overview, 2014)

E(kWh) = 660(W) x 565.75(W per year) \ 1000 =
373.4 kWh per year.
Downlight energy consumption

Air leakage

Air leakage energy losses are caused by one of two factors: either conditioned air from heating or cooling leaves the house through cracks and openings, or outside air enters the house through the same cracks and openings. This causes an increased energy load for temperature control systems.

Air leakage can be attributed to a number of factors including, but not limited to:

- unsealed or poorly sealed doors and windows
- the poor design or omission of airlocks
- unsealed vents, skylights and exhaust fans
- gaps around wall penetrations (e.g. pipes, conduits, power outlets, switches, air conditioners and heaters)
- gaps between envelope element junctions (e.g. floor–wall or wall–ceiling)
- poorly fitted or shrunken floorboards.
- gaps in or around ceiling insulation and around ceiling penetrations (e.g. downlights, pipes and cables)

Air leakage (cont.)

For the purpose of this study, air leakage is defined as conditioned air that leaves or enters the house through the cutouts required for recessed lighting.

It has been proven that recessed lighting cutouts contribute to a substantial amount of air leakage. A Melbourne study, reported that homes with an average of 12 recessed downlights saw a reduction of the air infiltration rate by 4.2% when making them airtight.
(Ren & Chen, 2015)

By extrapolating these findings, it can be concluded that using 40 surface-mounted downlights (that totally eliminate airflow) in an average-sized Australian home, air infiltration can be reduced by 13.4%.*

In 2011, the total energy consumption of Australian households was 223 PJ/year, and the estimated number of households was 8.4 Million. This equates to 7374.34 KWh/year. (ABS, 2011)

Heating and cooling accounts for an average of 40% of Australian home energy usage, or 2949.6 kWh/year. (Mosher, McGee & Clarke, 2013) With air-infiltration adding an extra 30-50% of the load to these temperature control systems, resulting in 1474.5 kWh per year. (Younes, 2012)

1474.5(Heating & cooling loss) x 0.134(downlight air infiltration) =
197.58kWh/year
extra energy used due to downlight air infiltration

*The average floor area is not stated in the study "Estimation of air infiltration for Australian housing energy analysis" (Ren & Chen, 2015) and that to conduct the air flow calculations the assumption was made that the pressure drop across the 12 recessed downlights is linearly proportional to that of 40 downlights.

Insulation Energy Loss

Insulation acts as resistance to heat flow and is essential for keeping houses warm in winter and cool in summer. A well-insulated and well-designed house provides year-round comfort, cutting cooling and heating bills by up to half. This, in turn, reduces greenhouse gas emissions. (Mosher, McGee & Clarke, 2013)

Unless otherwise stated, recessed downlights cannot be covered by insulation, as this can result in fire hazards. The Australian standard, AS/NZS-3000:2007 (Acima, 2007) provides safe clearances for insulation as a preventative measure. For the purpose of the following calculations, it has been assumed that a 200mm square cutout (100mm for luminaire, 50mm clearance each side) is required for each recessed downlight installation.

Cutouts reduce the effectiveness of the installed insulation (reducing ceiling R value) and results in unwanted thermal energy transfer through the ceiling. To calculate the energy losses that occur as a result of insulation being compromised because of the gap requirements of recessed downlights, insulation R-values were evaluated.

R-Value is a measure of the thermal resistance properties different insulation materials. The higher the R-value, the more resistant the insulation product is to the transfer of heat. The R-value of insulation is affected differently from heating and cooling. An averaged R-value of both "up" and "down" (heat infiltration and heat loss) has been used in the following calculations.

According to Building Codes Australia, most residential areas require a minimum R-value of 4.1 for the ceiling of new builds. (Mosher, McGee & Clarke, 2013) This can vary depending on climate and location, so for the purpose of this study an R-value of 5 was used.

To calculate the change in R-value due to downlight cutouts in ceilings, an online calculator by "Australian Cellulose Insulation Manufacturers Association" was used. (Australian Cellulose Insulation Manufacturers Association, n.d)

Variables

UP/HEATING

Open area	0.04 (22cm: 10cm 6cm: AS-3999:1992 4.2.e review) ▼	0.04	m²
Reduced area	0.04 (Downlight Mitt/FF130 - not covered²) ▼ clause 4.5.2.3.b¹	0.04	m²
Insulation	0.23 (Mitt/FF130 - not covered²) ▼	0.23	K·m²/W
Plaster board	0.056 (10mm or 0.375") ▼	0.056	K·m²/W
Ceiling air films	0.11 (up/heating) ▼	0.11	K·m²/W
Area per downlight	10 ▼	10	m²
	Undo changes	Calc	0.50 ▼

DOWN/ COOLING

Open area	0.04 (22cm: 10cm 6cm: AS-3999:1992 4.2.e review) ▼	0.04	m²
Reduced area	0.04 (Downlight Mitt/FF130 - not covered²) ▼ clause 4.5.2.3.b¹	0.04	m²
Insulation	0.23 (Mitt/FF130 - not covered²) ▼	0.23	K·m²/W
Plaster board	0.056 (10mm or 0.375") ▼	0.056	K·m²/W
Ceiling air films	0.16 (down/cooling) ▼	0.16	K·m²/W
Area per downlight	10 ▼	10	m²
	Undo changes	Calc	0.50 ▼

Insulation Energy Loss (cont.)

UP/HEATING

Reduction in Ceiling System R-value due to Uninsulated Downlights

Without	Ceiling area in m² for each downlight: -																				Treatment
	1		2		3		4		5		6		7		8		9		10		
R 2.00	R1.6	-0.4	R1.8	-0.2	R1.8	-0.2	**R1.9**	**-0.1**	R1.9	-0.1	R1.9	-0.1	R1.9	-0.1	R1.9	-0.1	R1.9	-0.1	R2.0	-0.0	Open
	R1.9	-0.1	R1.9	-0.1	R2.0	-0.0	**R2.0**	**-0.0**	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	Covered
R 2.50	R1.9	-0.6	R2.2	-0.3	R2.3	-0.2	**R2.3**	**-0.2**	R2.3	-0.2	R2.4	-0.1	R2.4	-0.1	R2.4	-0.1	R2.4	-0.1	R2.4	-0.1	Open
	R2.3	-0.2	R2.4	-0.1	R2.4	-0.1	**R2.4**	**-0.1**	R2.5	-0.0	R2.5	-0.0	R2.5	-0.0	R2.5	-0.0	R2.5	-0.0	R2.5	-0.0	Covered
R 3.00	R2.2	-0.8	R2.5	-0.5	R2.7	-0.3	**R2.7**	**-0.3**	R2.8	-0.2	R2.8	-0.2	R2.8	-0.2	R2.9	-0.1	R2.9	-0.1	R2.9	-0.1	Open
	R2.7	-0.3	R2.8	-0.2	R2.9	-0.1	**R2.9**	**-0.1**	R2.9	-0.1	R2.9	-0.1	R2.9	-0.1	R3.0	-0.0	R3.0	-0.0	R3.0	-0.0	Covered
R 3.50	R2.4	-1.1	R2.8	-0.7	R3.0	-0.5	**R3.1**	**-0.4**	R3.2	-0.3	R3.2	-0.3	R3.3	-0.2	R3.3	-0.2	R3.3	-0.2	R3.3	-0.2	Open
	R3.0	-0.5	R3.3	-0.2	R3.3	-0.2	**R3.4**	**-0.1**	R3.4	-0.1	R3.4	-0.1	R3.4	-0.1	R3.4	-0.1	R3.4	-0.1	R3.4	-0.1	Covered
R 4.00	R2.6	-1.4	R3.1	-0.9	R3.4	-0.6	**R3.5**	**-0.5**	R3.6	-0.4	R3.7	-0.3	R3.7	-0.3	R3.7	-0.3	R3.8	-0.2	R3.8	-0.2	Open
	R3.4	-0.6	R3.7	-0.3	R3.8	-0.2	**R3.8**	**-0.2**	R3.9	-0.1	R3.9	-0.1	R3.9	-0.1	R3.9	-0.1	R3.9	-0.1	R3.9	-0.1	Covered
R 4.50	R2.8	-1.7	R3.4	-1.1	R3.7	-0.8	**R3.9**	**-0.6**	R4.0	-0.5	R4.1	-0.4	R4.1	-0.4	R4.2	-0.3	R4.2	-0.3	R4.2	-0.3	Open
	R3.7	-0.8	R4.1	-0.4	R4.2	-0.3	**R4.3**	**-0.2**	R4.3	-0.2	R4.3	-0.2	R4.4	-0.1	R4.4	-0.1	R4.4	-0.1	R4.4	-0.1	Covered
R 5.00	R3.0	-2.0	R3.7	-1.3	R4.1	-0.9	**R4.3**	**-0.7**	R4.4	-0.6	R4.5	-0.5	R4.6	-0.4	R4.6	-0.4	R4.6	-0.4	R4.7	-0.3	Open
	R4.0	-1.0	R4.5	-0.5	R4.6	-0.4	**R4.7**	**-0.3**	R4.8	-0.2	R4.8	-0.2	R4.8	-0.2	R4.9	-0.1	R4.9	-0.1	R4.9	-0.1	Covered
R 5.50	R3.1	-2.4	R4.0	-1.5	R4.4	-1.1	**R4.6**	**-0.9**	R4.8	-0.7	R4.9	-0.6	R5.0	-0.5	R5.0	-0.5	R5.1	-0.4	R5.1	-0.4	Open
	R4.4	-1.1	R4.9	-0.6	R5.1	-0.4	**R5.2**	**-0.3**	R5.2	-0.3	R5.3	-0.2	R5.3	-0.2	R5.3	-0.2	R5.3	-0.2	R5.4	-0.1	Covered
R 6.00	R3.3	-2.7	R4.2	-1.8	R4.7	-1.3	**R5.0**	**-1.0**	R5.1	-0.9	R5.3	-0.7	R5.4	-0.6	R5.4	-0.6	R5.5	-0.5	R5.5	-0.5	Open
	R4.6	-1.4	R5.2	-0.8	R5.5	-0.5	**R5.6**	**-0.4**	R5.7	-0.3	R5.7	-0.3	R5.8	-0.2	R5.8	-0.2	R5.8	-0.2	R5.8	-0.2	Covered
Gap%:	4.00		2.00		1.33		1.00		0.80		0.67		0.57		0.50		0.44		0.40		Open
	4.00		2.00		1.33		1.00		0.80		0.67		0.57		0.50		0.44		0.40		Covered

DOWN/ COOLING

Reduction in Ceiling System R-value due to Uninsulated Downlights

Without	Ceiling area in m² for each downlight: -																				Treatment
	1		2		3		4		5		6		7		8		9		10		
R 2.00	R1.7	-0.3	R1.8	-0.2	R1.9	-0.1	**R1.9**	**-0.1**	R1.9	-0.1	R1.9	-0.1	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	Open
	R1.9	-0.1	R2.0	-0.0	R2.0	-0.0	**R2.0**	**-0.0**	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	R2.0	-0.0	Covered
R 2.50	R2.0	-0.5	R2.2	-0.3	R2.3	-0.2	**R2.4**	**-0.1**	R2.4	-0.1	R2.4	-0.1	R2.4	-0.1	R2.4	-0.1	R2.4	-0.1	R2.4	-0.1	Open
	R2.3	-0.2	R2.4	-0.1	R2.4	-0.1	**R2.5**	**-0.0**	R2.5	-0.0	R2.5	-0.0	R2.5	-0.0	R2.5	-0.0	R2.5	-0.0	R2.5	-0.0	Covered
R 3.00	R2.3	-0.7	R2.6	-0.4	R2.7	-0.3	**R2.8**	**-0.2**	R2.8	-0.2	R2.9	-0.1	R2.9	-0.1	R2.9	-0.1	R2.9	-0.1	R2.9	-0.1	Open
	R2.8	-0.2	R2.9	-0.1	R2.9	-0.1	**R2.9**	**-0.1**	R2.9	-0.1	R3.0	-0.0	R3.0	-0.0	R3.0	-0.0	R3.0	-0.0	R3.0	-0.0	Covered
R 3.50	R2.6	-0.9	R3.0	-0.5	R3.2	-0.3	**R3.2**	**-0.3**	R3.3	-0.2	R3.3	-0.2	R3.3	-0.2	R3.4	-0.1	R3.4	-0.1	R3.4	-0.1	Open
	R3.1	-0.4	R3.3	-0.2	R3.4	-0.1	**R3.4**	**-0.1**	R3.4	-0.1	R3.4	-0.1	R3.4	-0.1	R3.5	-0.0	R3.5	-0.0	R3.5	-0.0	Covered
R 4.00	R2.9	-1.1	R3.4	-0.6	R3.5	-0.5	**R3.6**	**-0.4**	R3.7	-0.3	R3.8	-0.2	R3.8	-0.2	R3.8	-0.2	R3.8	-0.2	R3.9	-0.1	Open
	R3.5	-0.5	R3.8	-0.2	R3.8	-0.2	**R3.9**	**-0.1**	R3.9	-0.1	R3.9	-0.1	R3.9	-0.1	R3.9	-0.1	R3.9	-0.1	R3.9	-0.1	Covered
R 4.50	R3.1	-1.4	R3.7	-0.8	R3.9	-0.6	**R4.1**	**-0.4**	R4.1	-0.4	R4.2	-0.3	R4.2	-0.3	R4.3	-0.2	R4.3	-0.2	R4.3	-0.2	Open
	R3.9	-0.6	R4.2	-0.3	R4.3	-0.2	**R4.3**	**-0.2**	R4.4	-0.1	R4.4	-0.1	R4.4	-0.1	R4.4	-0.1	R4.4	-0.1	R4.4	-0.1	Covered
R 5.00	R3.4	-1.6	R4.0	-1.0	R4.3	-0.7	**R4.5**	**-0.5**	R4.6	-0.4	R4.6	-0.4	R4.7	-0.3	R4.7	-0.3	R4.7	-0.3	R4.8	-0.2	Open
	R4.3	-0.7	R4.6	-0.4	R4.7	-0.3	**R4.8**	**-0.2**	R4.8	-0.2	R4.9	-0.1	R4.9	-0.1	R4.9	-0.1	R4.9	-0.1	R4.9	-0.1	Covered
R 5.50	R3.6	-1.9	R4.3	-1.2	R4.7	-0.8	**R4.8**	**-0.7**	R5.0	-0.5	R5.0	-0.5	R5.1	-0.4	R5.1	-0.4	R5.2	-0.3	R5.2	-0.3	Open
	R4.6	-0.9	R5.0	-0.5	R5.2	-0.3	**R5.2**	**-0.3**	R5.3	-0.2	R5.3	-0.2	R5.3	-0.2	R5.4	-0.1	R5.4	-0.1	R5.4	-0.1	Covered
R 6.00	R3.8	-2.2	R4.6	-1.4	R5.0	-1.0	**R5.2**	**-0.8**	R5.4	-0.6	R5.5	-0.5	R5.5	-0.5	R5.6	-0.4	R5.6	-0.4	R5.7	-0.3	Open
	R4.9	-1.1	R5.4	-0.6	R5.6	-0.4	**R5.7**	**-0.3**	R5.7	-0.3	R5.8	-0.2	R5.8	-0.2	R5.8	-0.2	R5.9	-0.1	R5.9	-0.1	Covered
Gap%:	4.00		2.00		1.33		1.00		0.80		0.67		0.57		0.50		0.44		0.40		Open
	4.00		2.00		1.33		1.00		0.80		0.67		0.57		0.50		0.44		0.40		Covered

Insulation Energy Loss (cont.)

Calculations where modelled off the:

- The "without" value is R 5.00 and the
- The treatment is open.
- There is one downlight per every $5m^2$

—$214m^2$ (average Australian house) / 40 (downlights) = $5.3m^2$

Impact of recessed downlight gaps on insulation R-values

This results in an R-value of 4.4 (reduction of 0.6) and R4.6 (reduction of 0.4) for up/heating and down/cooling respectively. These values are averaged to R-value 4.5 (reduction of 0.5)

The difference in conditioned energy lost between a R3 insulated ceilings and a R5 insulated ceilings is as follows:

- R3 Ceiling insulation - Conditioning energy 186 MJ/m^2 per annum
- R5 Ceiling insulation - Conditioning energy 173 MJ/m^2 per annum (ICANZ, 2011)

This results in a difference in **13 MJ/m^2 per annum for a change in 2 R-value.**

Therefore, the total energy loss from gaps in insulation for a standard Australian household with 40 recessed downlights is **3.61 kWh/ m^2 per annum**

For a standard-sized Australian home, the total amount of energy lost due to gaps in insulation =
776.15KWh per annum

For the purpose of this study we are assuming that the conditioning energy lost acts in a linear fashion and that the simulations run by ICANZ, matches a similar design to our $214m^2$ house (it is mentioned that their simulated house is "...single storey brick veneer/concrete slab on ground dwelling in the melbourne climate zone". (ICANZ, 2011) It was then assumed that if a difference in 2 Rvalue results in power consumption of **776.15KWh per annum**, then a **0.5 Rvalue** difference should result in **194 kWh per annum**

brightgreen

Conclusion

The following can be concluded from the information above:

- The installation of 40 standard recessed downlights induces an energy consumption of:
- 197.5kWh (air flow)+194 kWh (insulation gaps)+373.4 kWh (lighting Energy)
  = **765 kWh per year**
- A D900 SH (surface mounted light) requires only **373.4** kWh per year of energy.

COMPARISON	RECESSED DOWNLIGHT	D900 SH
Total induced energy	765 kWh/year	373.4 kWh/year
Carbon Emissions *	695.4Kg CO2/ year	339.4 Kg CO2/ year
Cost (0.3/KWh)**	$229.5 per year	$112.02 per year

*1kWh of electrical energy emits 0.909 kg of CO2 in Australia
**based on 1kWh costing 30c

The total energy consumption of 16.5W standard recessed downlights installed throughout an average-sized Australian home is approximately twice the energy required for Brightgreen 16.5W D900 SH Curve surface-mounted lights.

Homeowners stand to substantially reduce the result of temperature control energy loss through the elimination of gaps in insulation and reduction of ceiling cutouts required for recessed downlights. By creating a more airtight and insulated ceiling space, the Brightgreen D900 SH LED downlight increases residential thermal efficiency and insulation R-values.

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