REPORT ON THE COMPARISON OF ENERGY CONSUMPTION BETWEEN EXISTING AND PROPOSED DESIGN WALK-IN-COLDROOMS

By Dr Clyde Anderson, RPEQ 5482 and
Michael Anderson Certified Energy Efficiency Assessors

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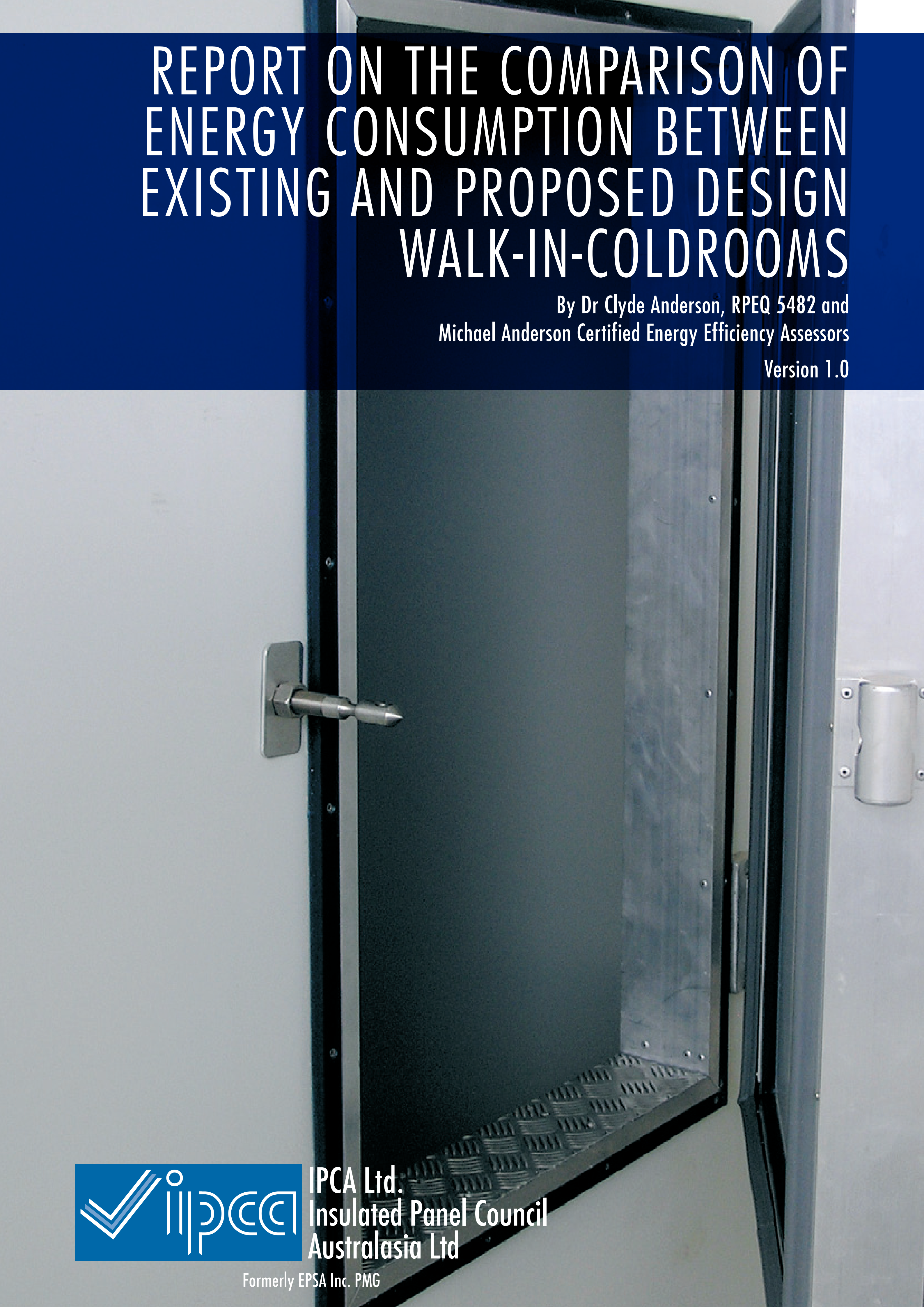

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EXECUTIVE SUMMARY

1. Walk-In-Coldrooms (WICs) have not been regulated for minimum energy efficiency performance. There is a proposal from the Equipment Energy Efficiency Committee (E3) of the Australian and New Zealand Ministerial Council on Energy to regulate elemental parts of WIC systems.
2. Rudimentary thermal modelling was included in the proposed 10 year strategic Draft proposal “In From the Cold... ”.
3. Manufacturers of Insulated panel and the Insulated enclosure and doors of Coldrooms through the industry governing body “Expanded Polystyrene Panel Manufacturers Group” Expanded Polystyrene Australia Incorporated - A Special Interest Group of PACIA are planning to make a submission to the Committee regarding the benefits of the proposed insulation increases.
4. This Report addresses only the proposed changes in minimum R-value insulation of wall, ceiling and floor panels and shows that increasing R-value will only slightly reduce the energy consumed in WICs.
5. There are many transient heat loads that are part of the operation of WICs that cannot be included in any energy efficiency regulation.
6. Compared to steady-state (closed box) heat transfer, one important parameter in the calculation of total kWh energy is the loss of cold air due to door opening (infiltration).
7. **Increasing insulation will not achieve the expected overall benefits as the envelope heat transfer is only a small percentage of the total heat load.**
8. Infiltration should be addressed before increasing R-values of WIC envelopes, as this would give a more cost-effective energy reduction.
9. A holistic, total system approach to efficiency certification of WICs is advocated since the incorrect application of efficient components can result in an inefficient design.
10. Performance-based assessment under a National regulatory body like the Australian Building Codes Board, is appropriate for WICs.

Disclaimer:
Whilst the data in this Report are provided with reference to calculations and computer simulations, they are only as good as the information provided and the assumptions used in the simulations. Alternative data and assumptions will produce different simulation results. Different building designs and building fabric will also produce different simulation results.

1. INTRODUCTION

As part of the delivery stream from food source to consumer, refrigerated Walk-In-Coldrooms (WICs) are employed in a wide range of applications. The Draft Strategic Plan ("the Plan") "In From the Cold - Strategies to increase the energy efficiency of non-domestic refrigeration in Australia and New Zealand" includes extensive discussion on the different types of commercial refrigeration.

Of interest is the large number of WICs in the 9m² to 100m² floor size range discussed in In From the Cold - Background Technical Report Volume 2, Section 6. Larger cold stores were discussed elsewhere in the Plan as part of industrial and manufacturing processes. Four nominal sizes of commercial WICs were examined in the Plan with approximate numbers in brackets:

Description	Length, m	Width, m	Height, m	# Volume, m³	Number
Mini	3.0	3.0	2.4	~17	38,871
Small	6.0	4.0	3.0	~62	19.773
Medium	6.0	6.0	4.0	~128	3,640
Large	10.0	10.0	4.0	~365	1,151
TOTAL					**63,435**

Volume depends on insulation thickness (assumed 100mm) and external dimensions were assumed

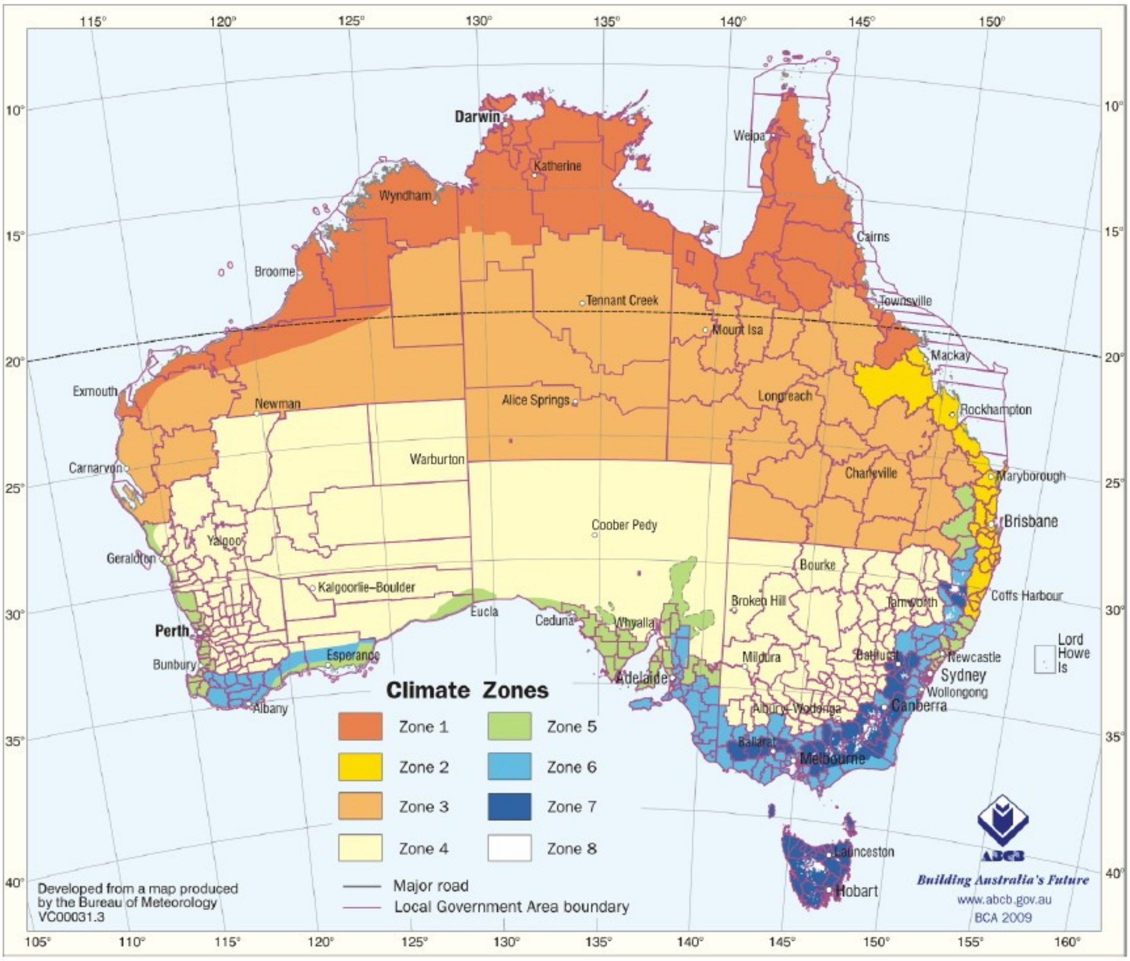
Table 1 Walk-In-Coldroom Sizes

There was a need to establish base-line thermal performance data for these WICs. The current Report establishes the thermal performance in terms of cooling Capacity kW, and total annual Energy MWh. The performance of the four sizes was studied; both inside conditioned (retail) buildings and as detached structures in eight representative Locations across Australia.

The Building Code of Australia defines eight Climate Zones across Australia (Figure 1). Thermal modelling was performed for Locations in Table 2, which cover climates for most of Australia.

BCA Climate Zone	Location
1	Darwin
2	Brisbane
3	Longreach
4	Wagga Wagga
5	Perth
5	Sydney
6	Melbourne (Moorabbin)
7	Canberra

Table 2 Thermal Modelling Locations



Notes:

1. This map can be viewed in enlargeable form on the Energy Efficiency page of the ABCB web site at www.abcb.gov.au.
2. A Zone 4 area in South Australia, other than a council area, at an altitude greater than 300 m above the Australian Height Datum is to be considered as Zone 5.

<u>Figure 1 Building Code of Australia - Climate Zones</u>

2. THERMAL MODELLING

The Plan Background Technical Report Volume 2 has steady-state Heal Load Calculations of Coldrooms using Heatcraft software. The total energy consumption of WICs includes the items listed in Table 3.

All energy consumption of WICs is variable. To use a thermal model as a steady-state calculation of total energy consumption ignores the effect of the variable elements. It can be shown that the transient nature of WICs is an integral part of the equipment sizing and relates strongly to product longevity.

Refrigerating Compressor
Circulating Fan(s)
Defrosting
Lighting
Electrical Controls
Product (Sensible and Latent heat)
Air (Sensible and Latent heat)
Infiltration (door opening and air leaks)
Personnel & equipment heat loads
WIC Envelope (walls, doors, ceiling, floor)

Table 3 Energy Consumption (Heat) Elements of WICs

This Report uses a comprehensive 3-dimensional thermal model of WICs in different Climates. DesignBuilder™ meets the requirements of the Australian Building Codes Board, Protocol for Building Energy Analysis Software 2006.1, since it uses EnergyPlus™ as the thermal calculation engine. EnergyPlus is developed and maintained by the US Department of Energy to be the state-of-art in building thermal modelling software. DesignBuilder has nearly weekly beta versions available for use with major releases roughly every 6 months. For more information visit www.designbuilder.co.uk.

Assumptions used in the thermal modelling include [Proposed values in brackets]:

Building Elevation:	One Storey, Ground floor adjacent to ground
Airflow Circulation:	Minimum air changes per hour, no natural ventilation
Infiltration:	Varies 0.05, 0.5 and 5.0 air changes per hour (not including personnel fresh air)
External walls:	Mini R2.1, Others R2.8 sandwich panels, very-light colour [R4.5 sandwich panel] Retail - tilt concrete lined with plasterboard
Internal walls, Doors	Mini R2.1, Others R2.8 sandwich panels, very-light colour [R4.5 sandwich panel]
Floor:	200mm Concrete base, Mini 100mm slab to R2.1, Others 100mm slab to R2.8 [100mm slab to R4.9], Ground temperature fixed at 15°C
Ceiling:	Mini R2.1, Others R2.8 sandwich panels, very-light colour [R4.5 sandwich panel] Retail - plasterboard no added insulation
Windows:	none
Roof:	Mini R2.1, Others R2.8 sandwich panels, very-light colour [R4.5 sandwich panel] Retail - metal, R2.0 insulation, very-light colour
Domestic Hot Water:	n/a
Air Conditioning:	Compact Packaged Direct Expansion, average chiller COP = 1.5, Set Point 5°C, Retail = 20° to 24°C, standard fan operation, temperature control per zone, electrical resistance heating (Retail)
Lighting:	As per BCA Part J6 Deemed-To-Satisfy, Mini 20W/m², Others 14W/m², excluding Retail

Whilst very-small WICs often have no insulated floor, it was assumed that these standard WICs were constructed on-site and were assumed to have insulation below the surface slab. A set-down in the main building slab allows no-step entry. The Mini WIC has less insulation because of the smaller size.

The Retail building modelled around the WIC was not particularly important as the maintenance of wall surface temperature conditions to the WIC was the aim. Consequently, the location was relatively immaterial for these internal WIC results. A WIC that shares an external wall with a Retail building will have more heat transfer than the surrounded WIC, but less heat transfer than a detached WIC.

Varying Infiltration air-changes per hour (ACH) was an important part of the thermal modelling. It was not in the current scope of work to translate the ACH in terms of door sizes, door opening frequency, door opening total time, door closers, use of plastic curtain strip seals and other devices including air-locks and ante-rooms, with other causes of air leakage. However, it is desirable for industry to understand the relationships between these infiltration issues.

Detailed, three dimensional Computational Fluid Mechanics modelling can reveal the relative and absolute infiltration from different control measures. For example, **observations can reveal that opening a door for about 10 seconds can result in over 5m³ of cold air lost**. Consequently the operation of WICs, particularly the duration and frequency of door opening, significantly affects the infiltration.

Higher ACH is likely in smaller WICs due to the relative ratio of volume to door area. However, where pallets are handled by fork-lift trucks in the larger WICs, doors may not be closed on each entry and exit. For the four WIC sizes investigated the different infiltration rates are equivalent to the values listed in Table 4.

Description	0.05 ACH	0.5 ACH	5.0 ACH
Mini	0.014 m³/min	0.14 m³/min	1.4 m³/min
Small	0.051 m³/min	0.51 m³/min	5.1 m³/min
Medium	0.107 m³/min	1.07 m³/min	10.7 m³/min
Large	0.304 m³/min	3.04 m³/min	30.4 m³/min

Table 4 Air Leakage per Minute for WIC Sizes and Infiltration Rates

The thermal modelling investigated three main variations:
- Effect of size, both inside a Retail building and in Brisbane, Infiltration 0.5 ACH
- Effect of Location for the Small Size, Infiltration 0.5 ACH
- Effect of Infiltration, Small Size in Brisbane

Whilst the volume of data available from the thermal simulations was extensive (e.g. temperature for every hour of the year) only the Design Cooling Capacity kW and Total Annual Energy MWh are reported. Both these figures grossly underestimate the actual cooling capacity required and the actual annual energy. For a realistic WIC the transient influences mentioned above (Table 3) dominate the kW and MWh calculations.

The Design Cooling Capacity is nothing more than the kW heat leakage for the hottest day in the nominated Climate with all other transient heat loads switched off (e.g. empty). It is the minimum cooling capacity to overcome the envelope heat leakage from outside.

The Total Annual Energy is nothing more than a building operated for a year in this empty operation mode with no transient heat loads (Table 3). The actual MWh of a working WIC can be many times this MWh due to these transient heat loads. However, in order to quantify one of these heat loads, the effect of infiltration is calculated. If a heat load schedule is provided, it can be included in the thermal simulations. Personnel heat loads are assumed to present in the WIC with a density of 0.3 persons/m³ according to a BCA Specification JV Retail Occupation Schedule. Fewer people less often than the Schedule will be more energy efficient. However, some sort of operation was assumed for the comparisons.

The efficiency of the chiller is not being tested in this Report and a mid-range Chiller COP of

1.5 was selected based on the proposed MEPS for medium temperature applications. Likewise the efficiency of the lighting was based on the BCA Part J6 allowance for storage areas with adjustment for Room Index. More efficient lighting which is switched-on less than the BCA Specification JV (Retail) schedule will reduce the direct electricity consumption in the lights as well as the heat load to the chiller from the light energy converted to heat. There were no additional electrical equipment nor hot water heat loads in the WICs.

DesignBuilder had a minimum temperature of the supply air of 0.5°C, which effectively means the software was not suitable for modelling freezer applications (designed for buildings). It can successfully model coldrooms at nominal 5°C. The results for freezers are expected to be along the same trends as the results for coldrooms, except the magnitude of the comparative differences will be higher, due to the higher temperature differences. It is possible to model a WIC in a heated room to simulate the temperature difference from a freezer to ambient, but this was considered too approximate to be useful in the current discussion. Freezers have a significant latent heat load due to humidity.

3. RESULTS

Table 5 gives the modelled Capacity kW and Annual Energy MWh for variable WIC sizes. The Location was Brisbane. The internal WIC results were a sum of the total heat transfer due to the ceiling, floor, walls (+door), infiltration, lighting and occupancy.

Capacity, kW / Energy, MWh	Base Case	Proposed Insulation	Difference
Mini	0.7 / 3.4	0.5 / 2.4	-24% / -29%
Small	2.7 / 12.9	2.6 / 12.1	-4% / -6%
Medium	3.9 / 18.3	3.8 / 17.4	-3% / -5%
Large	6.8 / 28.2	6.1 / 23.8	-11% / -16%
AVERAGE			**-11% / -14%**

Table 5 Comparison - Inside a Retail Store

The internal WIC results are influenced by the surrounding building that is not conditioned from midnight to morning. The size of this building was selected at 20m square and 6m high. Consequently, when the Retail space is not conditioned the temperature varies according to the external temperature and thermal mass of the building. Therefore the internal WIC results are not easily comparable to the detached WIC results. The results for the Large WIC are likely to be influenced by the finite volume of the surrounding Retail building.

It was not clear if the WIC results were completely isolated from the Retail results. For example, the Retail heating was reported in the WIC results in the data output file.

The higher relative improvement for the Mini design was related to the lower R-value for this Base Design (R2.1 compared to R2.8 for the other WICs). In general, the increase in insulation reduced the kW capacity for the envelope by an average of 11% and the annual MWh energy for the envelope by an average of 14%.

Table 6 gives the results for the detached WICs. The higher insulation for the Proposed WICs has the benefit of an average 20% less kW capacity for the envelope and 14% less MWh energy for the envelope.

Capacity, kW / Energy, MWh	Base Case	Proposed Insulation	Difference
Mini	0.8 / 3.1	0.5 / 2.4	-33% / -22%
Small	1.8 / 7.0	1.6 / 6.2	-14% / -10%
Medium	2.5 / 10.1	2.1 / 8.9	-18% / -13%
Large	7.6 / 30.8	6.4 / 27.5	-15% / -11%
AVERAGE			**-20% / -14%**

Table 6 Comparison - Detached WIC

Table 6 results are for Brisbane which has a different climate than other parts of Australia. Simulations were repeated for the Small WIC with 0.5 ACH infiltration for all Locations (Table 2), with the results in Table 7. Even though the kW capacity and MWh energy reduces in colder climates, the improvement due to increasing insulation is consistently approximately 15% less kW capacity for the envelope and 10% less MWh energy for the envelope. Sydney results were close to the average for the eight locations.

Capacity, kW / Energy, MWh	Base Case	Proposed Insulation	Difference
Darwin	1.9 / 9.2	1.7 / 8.2	-14% / -11%
Brisbane	1.8 / 7.0	1.6 / 6.2	-14% / -10%
Longreach	1.9 / 7.5	1.6 / 6.6	-15% / -12%
Wagga Wagga	1.7 / 5.5	1.5 / 4.9	-15% / -10%
Perth	1.8 / 6.3	1.5 / 5.6	-15% / -11%
Sydney	1.7 / 6.5	1.5 / 5.8	-15% / -11%
Melbourne	1.8 / 5.3	1.5 / 4.8	-15% / -10%
Canberra	1.7 / 5.0	1.4 / 4.5	-16% / -10%
AVERAGE	**1.8 / 6.5**	**1.6 / 5.8**	**-15% / -10%**

Table 7 Comparison for Different Locations

The above Tables appear to endorse the increase in insulation as being more energy efficient. However, the unwanted heat transfer through the WIC envelope is only part of the total heat transfer that occurs in practice (Table 3).

Whilst many of the operational heat loads in Table 3 cannot be modelled, the effect of air infiltration can be investigated using DesignBuilder. Results for Brisbane, Small WIC are given in Table 8.

Capacity, kW / Energy, MWh	Base Case	Proposed Insulation	Difference
0.05 ACH	1.3 / 5.2	1.0 / 4.4	-19% / -13%
0.5 ACH	1.8 / 7.0	1.6 / 6.2	-14% / -10%
5.0 ACH	6.7 / 22.2	6.5 / 21.3	-4% / -4%
AVERAGE			**-12% / -9%**

Table 8 Comparison with Different Infiltration

As discussed above, the range of infiltration modelled covers typical WIC operations, from those that are opened briefly a few times a day to those that have the door open for several minutes each day. Some WICs may have the door open more than several minutes due to high traffic and the high number on deliveries being catered-for. WICs that are undersized for the application or that are used more like large refrigerators are in this class. Doors that are frequently used may not be completely closed each time.

While the arithmetic average of the effect of infiltration seems to confirm the previous trends the absolute number of the differences reveals that infiltration can account for the majority of the kW capacity (e.g. up to 5.2 times more) and MWh energy (e.g. up to 4.3 times more). So much so, that for average to high infiltration WICs, the “savings” made by more insulation are completely overshadowed by higher air leakage.

4. CONCLUSIONS

Walk-In Coldrooms (WICs) can be more energy efficient. There are two main parts to the implementation of improved energy efficiency:

- the design of the equipment and
- the operation of the equipment

Whilst increasing the R-value of the WIC envelope according to the Plan Proposal reduces the unwanted heat transfer, the benefit is an average reduction of only about 10% to 15% of the envelope heat transfer for a 60% increase in wall R-value from R2.8 to R4.5 with a 75% increase in floor insulation from R2.8 to R4.9.

Estimated capital costs increases to meet the Proposal from the base design have been provided by a manufacturer in Table 9. These costs assume all other costs are the same (electrical, motors, chiller, installation etc.). Estimated annual energy savings have been listed in Table 5, 6, 7 and 8. Assuming (high) energy costs of $0.20/kWh, these energy savings can result in dollar savings (all other heat loads being equal). Table 6 (Brisbane, 0.5 ACH) results were considered slightly above the average for all Locations investigated (Sydney was closer to the average). Shorter payback periods would be present for Darwin and Longreach, but there would be longer payback periods for other locations investigated.

WIC	Capital Cost Increase	MWh = $ p.a. Savings	Payback Period
Mini	$2,046	0.66 = $132	15.5 years
Small	$4,378	0.72 = $144	30.4 years
Medium	$5,417	1.28 = $256	21.2 years
Large	$13,627	3.28 = $656	20.8 years
AVERAGE			**22.0 years**

Table 9 Estimated Payback Period

Given the average lifespan of a WIC, the savings in Energy costs do not justify the additional capital costs.

Minimising infiltration is far more important than increasing panel insulation levels, being a factor of 5.2 and 4.3 higher in kW and MWh respectively than increasing insulation to the proposed levels.

A holistic approach to WIC energy efficiency is the key to reducing energy consumption in this sector. Whilst minimum energy performance standards can be imposed on equipment, the cost of testing and compliance must be kept reasonable. Some degree of “system certification” may be desirable to allow for design and operational innovation. Thermal modelling, akin to the Building Code of Australia Verification Method JV3, using standard conditions and schedules may be more appropriate for WICs, than separating individual pieces of equipment for energy efficient attention. Incorrectly combining efficient components and controls will result in an inefficient WIC.

Suitable thermal modelling software for freezers needs to be sought under an appropriate “Protocol and Specification” from a National regulating body, like the Australian Building Codes Board.

Serious attention needs to be given to the minimisation of infiltration through open doors. A few minutes of an open door can negate all the benefits of higher efficiency in motors, compressors, lights and insulation, etc. There could be cost-effective benefits in automatic door closers, door buzzers and alarms, ante-rooms and air locks to minimise air leakage. More investigation is suggested in these areas.

IPCA Ltd.
Insulated Panel Council
Australasia Ltd

Formerly EPSA Inc. PMG

phone: +61 7 3803 9388
mobile: 0419 644 924
email: ceo@insulatedpanelcouncil.org
web: www.insulatedpanelcouncil.org

C/- PO Box 1562
Browns Plains BC
Queensland 4118

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