CONSULTANCY REPORT

EC1658

THERMAL IMPACTS OF LOW EMISSIVITY FILM

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New Zealand

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REPORT SUMMARY

Objective

Consider the thermal impacts in winter, from low-emissivity film being adhered to the inside surface of single glazed window panes in selected New Zealand houses.

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Executive Summary

Glazing films with low emissivity (Low-E) properties, adhered directly to existing glass panes, are claimed to reduce the heat loss through single-glazed windows in New Zealand housing.

This work uses measurements and modelling from three case studies of New Zealand housing to investigate thermal effects of Low-E window film adhered directly to the interior glass surface.

The work shows that:

1. The application of Low-E glazing film to single glazing in selected New Zealand housing, reduced the heat loss through the glazing by an average of around 20% during winter heating periods.
2. Low-E glazing film reduced the interior surface temperature of single glazing by around half a degree Celsius, and increased condensation on single glazing by about 50%, in the chosen scenarios.
3. Double glazing, and secondary glazing (with a suspended film that creates an air-gap between the film and the glass) can reduce heat loss through glazing by 60%, and can reduce condensation.
4. In houses where condensation on single glazing rarely occurs, Low-E glazing film adhered to single glazing, can reduce heat loss through the windows by up to 25%.

TERMS AND CONDITIONS

This report is issued in accordance with the Terms and Conditions provided by EECA for this work.

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1. BACKGROUND

Background

Housing with single glazed windows can be difficult to heat in winter due to the poor thermal performance (measured by the R-value) of single glazed window panes. Improvements to the R-value of the glazing can be made by several methods. These include the use of:

- insulating glazing units (IGUs – typically double glazing)
- secondary glazing (using a film or pane that is spaced off the original glass)
- low-emissivity (Low-E) film adhered to the inside face of single glazing

The replacement of single glazing with IGUs has become common to improve the R-value of glazing from about R 0.13 m²K/W to about R 0.30 m²K/W[i]. This is an improvement of about 140% over the R-value of single glazing. Secondary glazing can provide a similar improvement in R-value.

Transparent plastic films can be adhered directly to the inside surfaces of single glazing in the windows of housing. These films have a thickness of less than one millimetre, and are claimed[ii] to increase the R-value of glazing, by altering the emissivity of the surface.

Adhering a film with low-emissivity properties to the inside face of single glazing, can improve the R-value of the glazing from 0.13 m²K/W to 0.17 m²K/W[v]. This is an increase of about 33% over the R-value of single glazing, when there is no condensation on the pane.

However, it is suspected that under certain conditions, Low-E films can reduce the temperature of the inside surface of single glazing, since they reflect heat. In winter, this increases the likelihood of condensation appearing on the film. Since condensation is small water droplets (with an emissivity of around 0.9)[iii], the effective emissivity of the glazing (film) surface will increase, and remove some of the desired thermal improvement.

This is of particular concern on winter mornings and evenings, when there is no sun shining on the glass, outdoor temperatures are typically low, indoor spaces are heated, and high R-values are desired.

This work was commissioned to investigate this issue, with the brief as below.

Brief

Determine the frequency, duration and extent of condensation occurring on single glazed window panes treated with Low-E film, for three case studies from NZ housing in winter mornings and evenings.

Discuss the thermal benefits (and dis-benefits) from the application of Low-E window film to single glazed window panes in New Zealand homes.

2. RESEARCH METHODOLOGY

The research methodology included:

- glazing film selection) from those available in the New Zealand market)
- scenario selection (from 170 houses)
- thermal modelling (with the Window 7® software)
- measurement of temperature and humidity (using houses located throughout New Zealand)
- determination of frequency of condensation occurrence (by modelling)
- occurrence of complete condensation coverage of glazing (by modelling)
- determination of number of mornings or evenings when condensation covers glazing (by calculation from the modelling and measurement)
- investigating implications for emissivity, and R-value of single glazing options (by calculation)

2.1   Glazing film selection

Two glazing films applied to clear glass, referred to as 'E1' and 'E4' were selected from four identified in the New Zealand market. The films both claimed low emissivity (Low-E) performance. A typical clear glass pane was chosen as a comparison to the film products[iv]. See Table 1.

The clear glass was chosen because:

- It has approximately the same thickness as the overall thickness of the film adhered to 3 mm glass
- While 4mm glass is the typical minimum thickness for standard clear float glass in windows, 3 mm glass was widely used in housing before 1990
- Data was available in the International Glazing Database (IGDB) for glass of this thickness

Of the films readily available, E1 and E4 were chosen because:

- they have verified data available in the IGDB[v]
- they represent products currently available in New Zealand
- they are from different manufacturers
- they have similar, low emissivity properties
- EECA agreed to their selection
- The visible transmission (T_{vis}), is closer to the T_{vis} of clear glass than the other two films identified, E2 and E3

Selected parameters of these products (when adhered to a clear glass substrate) were extracted from the IGDB, and are reported in Table 1.

Table 1: Product selection and performance parameters (Source: IGDB v41)

Product name	Thickness (mm) (Glass + film)	T_{vis}	$\mathcal{E}$ (Emissivity)
E1	3.28	0.678	0.092
E2	3.07	0.343	0.048
E3	3.07	0.343	0.048
E4	3.09	0.697	0.090
Clear glazing	3.18	0.902	0.840

2.2   Scenario selection

Three scenarios of temperature/humidity conditions in selected New Zealand housing were chosen, as detailed in Table 2. These scenarios were selected from measurements taken in 170 New Zealand houses for a previous heatpump project 'Heat pumps in New Zealand' report, (Burrough, Saville-Smith, & Pollard, 2015) – publication pending. The indoor conditions are significantly affected by the outdoor conditions, which were obtained from the CLIFLO database (NIWA, 2007).

The rationale for selection of these scenarios, was to choose three cases with a range of outdoor and indoor conditions, where condensation was expected to occur. Scenarios with condensation expected to be occurring were chosen to test if there was a distinct difference in the amount of condensation accumulating on the film and the clear glass. This would then allow comparisons to be drawn between the thermal performance, surface temperatures and condensation accumulation on Low-E film and clear single glazing.

The three scenarios represent three houses where:

- Data for the winter time-period was available
- Condensation was expected on the inside of single glazed windows
- Heat pumps were used as a heating source
- Indoor temperature profiles were relatively consistent across the winter
- The range of conditions expected inside New Zealand housing during cold outdoor conditions was exhibited
- Temperature profiles were markedly different between data sets, where:
  o Heating was available intermittently and indoor temperatures were cold all day (Scenario 1)
  o Heating was available intermittently and indoor temperatures were cool all day (Scenario 2)
  o Heating was available all day (from 9 am), and indoor temperatures were moderate all day (Scenario 3)

Table 2: Case study scenarios

	Scenario 1	Scenario 2	Scenario 3
Main heating source	Heat pump	Heat pump	Heat pump
Indoor temperature profile	Cold all day	Cool all day	Moderate all day
Date of data	June – August 2010	June – August 2009 and 2010	June – August 2010

Figure 1, Figure 2, and Figure 3, show the carpet plots[vi] of these houses. While data was compiled from different winters (2009 and 2010) the differences in the weather between the logging periods was not of concern, since these were case studies selected to illustrate a range of internal conditions. Data for winter mornings (am) and evenings (pm) were extracted and analysed from the case studies.
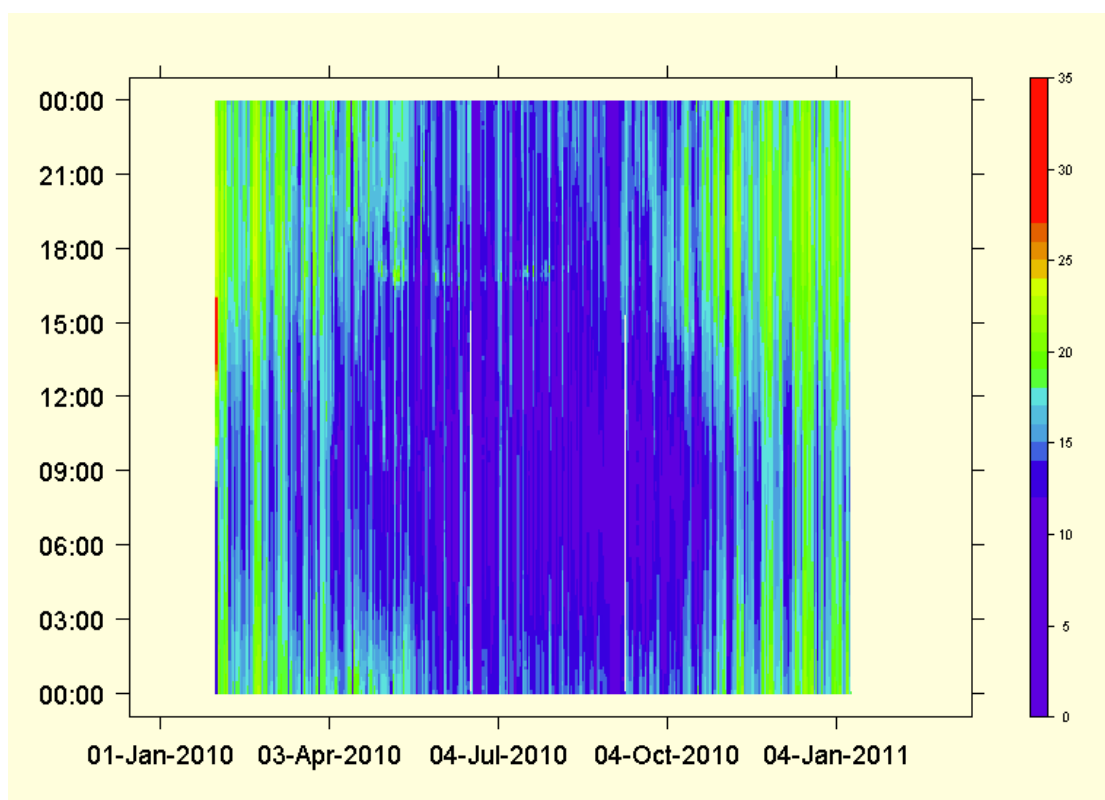

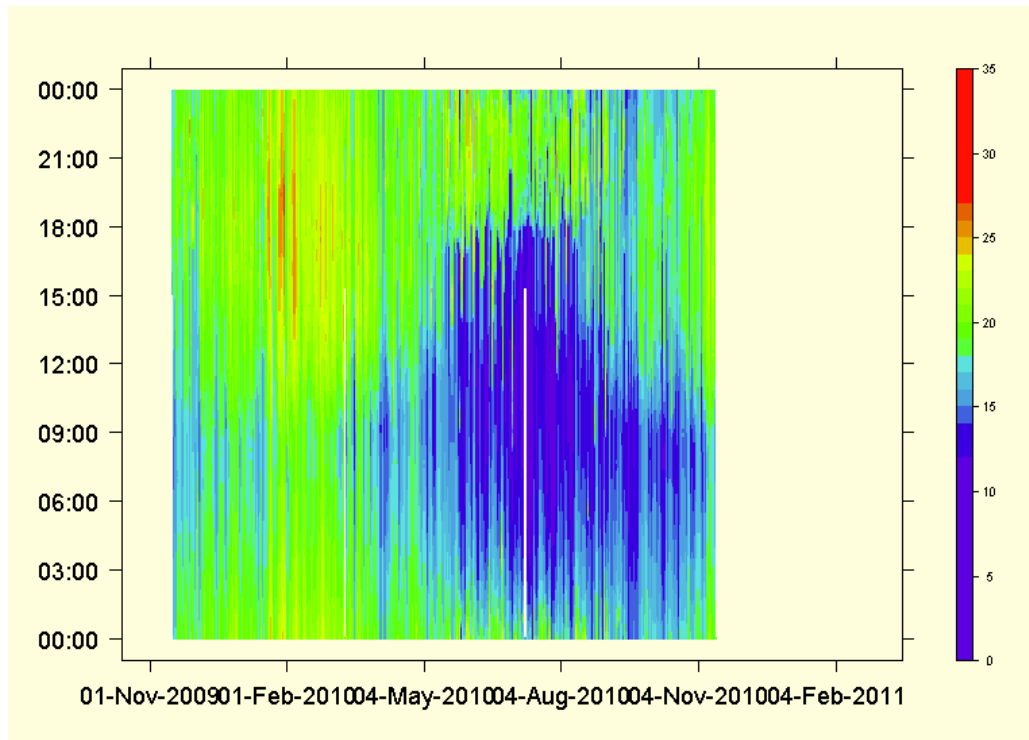**Figure 1: Scenario 1. Temperature inside heated space of Scenario 1 home**

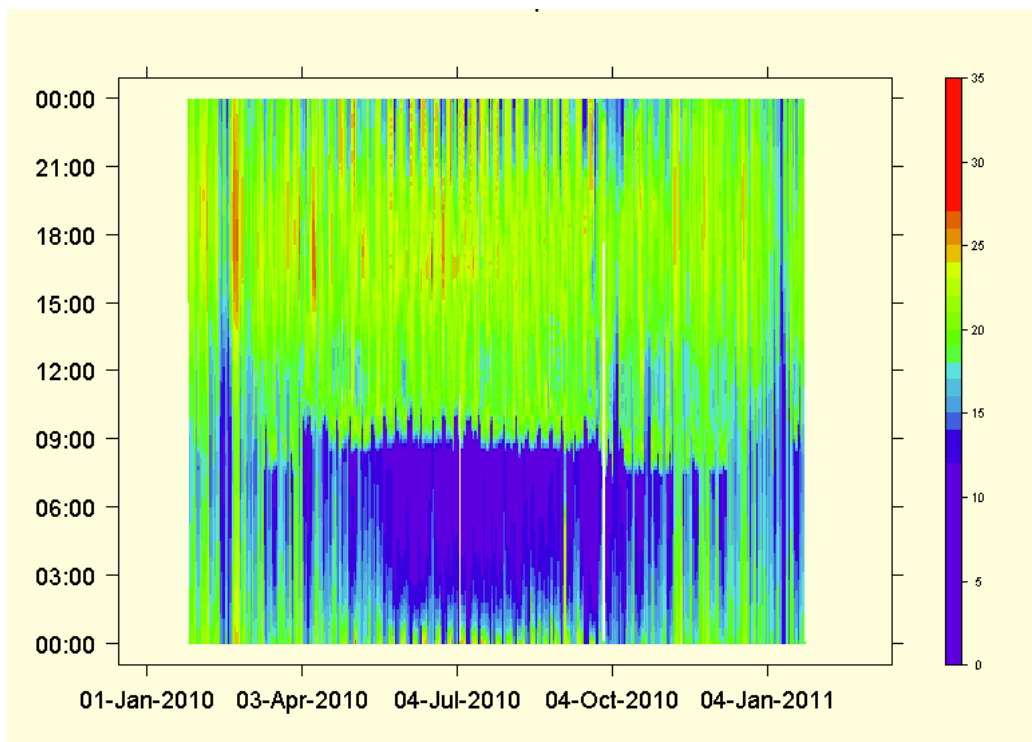**Figure 2: Scenario 2. Temperature inside heated space of Scenario 2 home**

Figure 3: Scenario 3. Temperature inside heated space of Scenario 3 home

2.3 Data

The data for the three scenarios was obtained in the 2009 and 2010 winters. The period between 0700 and 0900 was chosen as the morning heating period. Similarly, the period between 1700 and 2300 was used to represent the evening heating period.

These choices are explained in (Burrough, Saville-Smith, & Pollard, 2015).

2.4 Temperatures

The outside air temperature during the morning and evening heating periods for the relevant locations was obtained from the CLIFLO climate database, described in the 'The National Climate Database' (NIWA, 2007). This was used to calculate an average external air temperature for the morning and evening in each location.

The indoor air temperatures at 5 minute intervals were extracted from the measured data sets for the morning and evenings for the three scenarios. The average internal air temperature measured during each heating period for the winter months, was used to calculate an average internal glass surface temperature with the Window 7® software for each location.

2.5 Condensation

The method promoted by Vaisala was used in Excel to calculate dew-point from temperature and humidity, using a curve fitting algorithm (Vaisala, 2013).

This was undertaken for each record in the dataset for the three scenarios during the winter period of June to August inclusive. The window panes were assumed to have only two states – completely covered with condensation, or completely clear of condensation.

The average indoor glazing surface temperature was then compared with the dew-point temperature to determine when complete condensation coverage was likely in each scenario. The proportion of time when complete coverage of the glazing with condensation was likely during the morning and evening heating periods was then calculated. The number of days when condensation completely covered the inside of the glazing in the morning and the evening was modelled, as a proportion of the total number of winter days (92).

2.6 Emissivity impact

The effective emissivity (ε_{eff}) of the inside face of the glazing was calculated using a time weighting method, assuming that condensation completely covers the film (glazing), and increases the emissivity to 0.9[vii].

The effective R-value (R_{eff}) of the glazing was then calculated, based upon the effective time-weighted emissivity.

3. RESULTS

The result of the modelling and analysis of data gathered from the case study homes, are shown in Table 3 and Table 4.

3.1 Glazing surface temperatures

The average surface temperatures of the inside of the glazing with and without film was assessed, when no sun was shining of the windows. The results in Table 3 show that the average interior film surface was 0.5 degrees lower than the temperature of the clear glass. The average internal glass surface temperature in each scenario varied from 6.2 to 12.2 °C, while the average temperature of the film surface varied from 5.6 to 11.3°C. This is a sufficient temperature difference to reveal differences in condensation and thermal performance.

3.2 Frequency, duration and extent of condensation

The results in Table 3 are separated into results for the morning and evening in each column (am / pm). The average dew-point of the indoor air in the morning and evening, the average indoor and outdoor air temperatures, and the resultant temperatures on the glazing interior surfaces are in degrees Celsius.

Table 3: Condensation duration and frequency on interior glazing surfaces

Parameter	Scenario 1		Scenario 2		Scenario 3	
	am	pm	am	pm	am	pm
Average dewpoint (°C)	4.5	6.9	7.3	10.4	2.7	7.3
Average indoor air temperature (°C)	11.0	13.7	12.9	18.6	10.9	21.1
Average outdoor air temperature (°C)	3.7	6.0	8.2	8.7	5.9	7.5
Film - Average surface temperature (°C)	5.6	8.0	9.4	11.3	7.2	11.1
Clear glass – Average surface temperature (°C)	6.2	8.6	9.8	12.1	7.6	12.2
Film - proportion of days with full condensation coverage (%)	13	93	37	73	17	7
Clear glass – proportion of days with full condensation coverage (%)	8	64	25	49	11	0
Film - average duration of condensation (%)	9	26	25	26	2	0
Clear glazing – average duration of condensation (%)	6	16	18	15	1	0

The number of days (frequency) during which condensation can be expected to fully cover the glazing at some time within the evening and morning heating periods varies. The range for clear glazing is from 0 to 64% of the time (average of 26%), and for film, from 7 to 93% (average of 40%) of the time. This indicates that condensation occurs on approximately 50% more days on film, than on clear glass, during the heating periods assessed.

The proportion of time during the heating periods when condensation is expected to fully cover the glazing (duration), is shown as a percentage. It varies from zero to 18% for clear glass, (with an average of 9%), and from zero to 26% of the heating period for film (average of 15%). This indicates that the duration of condensation is approximately 50% longer on film, than on clear glass, during the heating periods assessed.

The range of average internal dew-points (2.7 to 10.4 °C) and air temperatures (10.9 to 21.1 °C) from these scenarios cover a reasonable range of winter conditions expected in New Zealand housing. The minute by minute temperatures and humidities measured within the three scenarios varied over a wider range.

3.3 Effective emissivity and R-value

When there is no condensation on the inside of glazing (glass or film), the initial emissivity (ε) and the initial R-value of the glazing (R), are shown in Table 4.

In the presence of condensation, the effective emissivity (ε_{eff}) is considerably impacted, causing the R-value to drop. On the clear glazing the emissivity is only slightly affected by condensation, and the R-value remains at about 0.13 m²K/W. See Table 4.

The effective emissivity has been calculated based upon the proportion of time when condensation covers the glass (ε of 0.9), compared to the proportion of time when it is clear (ε of 0.09)[vii]. The effective R-value of the glazing with adhered film in the winter heating periods is reduced by condensation, from 0.17 to 0.16 m²K/W, on average.

Table 4: Effective emissivity and R-value for the three glazing products.

Product name	Thickness (Glass + film) (mm)	ε	ε_{eff}	R (m²K/W)	R_{eff} (m²K/W)
E1	3.277	0.092	0.21	0.17	0.16
E4	3.088	0.090	0.21	0.17	0.16
Clear glass	3.175	0.840	0.85	0.13	0.13

4. DISCUSSION

Modelling and analysis of measurements from case study data was undertaken. Results confirm that application of Low-E films to the inside of single glazed window panes in the three case study houses has an impact on the R-value of the glazing.

The case studies used measurements of conditions in actual homes, being chosen to illustrate the likely range of conditions found in New Zealand homes in winter.

4.1 Glazing internal surface temperature

Single glazing with a Low-E film adhered to the inside was found by modelling, to be colder than standard clear glazing in the three houses and two heating periods investigated in winter. This modelling assumed that sunlight was not shining on the glazing during the periods investigated. The average difference in temperature is 0.5°C, and is sufficient to alter the occurrence of condensation, and performance of the glazing.

4.2 Condensation

To reduce the likelihood of condensation on the inside of single glazing, typical recommendations are that surface temperatures are maintained above the dew-point, moisture is removed at source, and adequate ventilation is provided. Interior glazing surface temperatures that are below the dew-point of the internal air, allow the occurrence of condensation on the inside of single glazing.

Through modelling, condensation was found to occur approximately 50% more often on film, and to stay for 50% longer than occurred on the clear single glazing. This indicates that condensation is likely to be more of a problem in winter mornings and evenings, when Low-E film is adhered to the inside of clear single glazing.

This work examined only the morning and evening heating periods. However, it is likely that condensation would also occur overnight, and during some day lit hours, whether or not heating is provided.

4.3 Thermal performance.

For the time when there was no condensation on the inside of single glazing, the application of film improved the R-value of the single glazing. The R-value of clear glazing increases from about 0.13 m²K/W to about 0.17 m²K/W by applying Low-E film, an improvement of around 33% in R-value.

However, this performance is not always achieved. When the film surface is covered with condensation (15% of the time), the R-value of the product reduces to approximately the same value as clear glass (0.13 m²K/W). This reduction in performance will occur whenever there is condensation present on film adhered to single glazing. As soon as the interior film surface has dried (condensation removed) the full thermal performance of 0.17 m²K/W is restored.

Modelling showed that the R-value of the Low-E film drops on average, to around 0.16 m²K/W during the heating periods in the scenarios investigated, due to condensation.

5. CONCLUSION

This modelling and analysis of measured case study data, has shown that in three scenarios of New Zealand housing, the use of low emissivity films adhered to the inside of single glazing:

- reduces the interior surface temperature of the glazing under winter heating conditions by around 0.5°C
- increases the occurrence of condensation on the interior of the glazing (approximately 50% more condensation)
- increases the length of time that condensation remains on the interior glazing surface by about 50%
- on average increases the R-value of single glazing by about 25% during the winter heating periods, i.e. reducing heat loss through the glass by about a fifth
- in houses where condensation on single glazing rarely occurs, applying low-e glazing film to single glazing can increase the R-value by 33% (reduces heat loss through glazing by about a quarter)

6. REFERENCES

Burrough, L., Saville-Smith, K., & Pollard, A. (2015). *Heat pumps in New Zealand.* Wellington: BRANZ Ltd.

Lawrence Berkeley National Laboratories (LBNL). (2013, June 25). *LBNL IGDB.* Retrieved from Window Optics: http://windowoptics.lbl.gov/data/igdb

NIWA. (2007, June 1). *The National Climate Database*. Retrieved from General CliFlo Info: http://cliflo.niwa.co.nz/

Vaisala, O. (2013). *Humidity conversion formulas.* Helsinki, Finland: Vailsala Oyj, PO Box 26, FI-00421.

End Notes

[i] These R values are calculated for the centre of glazing only, with Window 7® software, using the boundary conditions recommended by WANZ for use in New Zealand. The conditions are referenced in European standard EN 673. They refer to 3 and 4 mm clear glazing with reference number 9802 in the International Glazing Data Base (IGDB), with a 12 mm air gap. They do not necessarily match the values used in NZS 4218.

[ii] Claims by the manufacturers and suppliers of low emissivity glazing films are regularly made in the media, about the thermal performance of their products.

[iii] An emissivity of 1 means that all the heat energy at the glass/air surface can be radiated away to free air. An emissivity of 0 means that no heat is radiated away. This property depends upon the surface being clean (no dirt or condensation), and exposed to air. Typical clear window glass has an emissivity of 0.84 when clean. Films are marketed in New Zealand with an emissivity of 0.09.

[iv] The typical clear glazing used as a comparison in this work is the 'Clear_32' pane from Guardian (IGDB v19, #3000).

[v] The IGDB is the International Glazing Database maintained by Lawrence Berkeley National Laboratories (LBNL) in San Fransisco. It is the major, verified North American source of reliable thermal performance data on glazing panes. Version 41 (IGDB v41) is currently used in the Window 7® software, and is freely available from Lawrence Berkeley Laboratories (LBNL IGDB, 2013).

[vi] A carpet plot is a plot of three variables; the horizontal axis gives the day of the year (increasing from left to right), while the vertical axis gives the time of day, from midnight at the bottom of the graph, extending to 11:59 pm at the top of the graph. At the intersection of these two variables, the variable of interest is plotted as a blob of colour according to the scale on the right. Missing data is white. For the temperatures shown, the comfortable range between 18°C and 24°C are in shades of green. Temperatures over 24°C are in colours ranging from orange to deep red represented warmer temperatures. Temperatures below 18°C start off as light blue becoming increasingly darker as the temperature drops.

[vii] The emissivity of free water is in the range of 0.993 to 0.998 (averaging 0.996) (http://www.engineeringtoolbox.com/radiation-heat-emissivity-d_432.html). However, we assume conservatively that a low emissivity pane of glass "completely" covered with condensation, will only be about 90% covered with droplets of water, and 10% free of water. Using an emissivity of 0.09 for the moisture-free areas, and area weighting this, gives us 0.9 x 0.996 + 0.1 * 0.09, giving an average emissivity of 0.905, which we conservatively round down to 0.9. We assume that the emissivity of a un-treated glass surface covered with condensation can still be taken as 0.84, since the variation is within the uncertainty of the measurement.