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Surface Temperature Variations

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CLIMATES

Surface temperature variations

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The climate at the "building surface" differs from the general climate nearby. The difference is sometimes substantial. Firstly, solar warming will at times raise the surfaces to very high temperatures. This solar warming, even when only to a limited degree, also lowers the local relative humidity of the air at the surface.

A second effect is night time clear sky cooling, the reverse of solar warming. Clear sky cooling has the effect of raising the local relative humidity of the air at the surface, and, if a surface becomes cool enough, it will collect surface condensation, called "dew".

Timber, too, is hygroscopic and will exchange moisture with its surroundings at any humidity, inwards or outwards according to the balance between its own moisture content and the local humidity. Building surfaces easily become contaminated with wind-driven ocean salt, or with metal oxides, and both of these are hygroscopic, ie, they will actively absorb moisture out of the air if the humidity exceeds certain values.

Surfaces that are exposed to windborne salt and are not rain-washed tend to become much dirtier. Unwashed metal surfaces corrode faster. Once corrosion begins, the appearance of oxides helps to maintain the cycle.

Many materials and coatings are assessed for durability under "natural weathering", by observing small samples fully exposed at 45 degrees to the horizontal, facing the equator. "Natural weathering" conditions may be quite different from those experienced by a piece of the same material used as a building cladding. Although exposed to similar sun, wind and other climatic forces, the test sample is at a different orientation to typical building surfaces, it is exposed to convective cooling or warming on its back surface, and it is always rain-washed. Real claddings are likely to get both colder and warmer, to retain dew for longer, and may or may not be rain-washed.

This paper discusses surface temperatures and moisture conditions calculated from a five-year hour-by-hour climate data file (Sustep/Climdata, Leslie 1977). The method of calculation is described, and the frequency of occurrence of various levels of surface temperature presented for building surfaces of different orientation and location in New Zealand.

This paper develops data from a five year climatic file on the frequency of various degrees of surface heating.

The consequential effects on local surface humidity and moisture at those surfaces are then described, and frequencies presented. These are assessed for their effect on corrosion risk. Brief results from a 35-day summer monitoring project in 1975 in Wellington, not previously published, are offered for comparative purposes. Finally, the frequencies of various levels of window solar heat gain are considered under real weather conditions, with cloud and wind.

Temperatures at the building surface

The basic assessment of surface temperature used here is the "sol-air temperature". This was introduced by Mackey & Wright, 1944, and can be described as the temperature which a well insulated lightweight surface would reach.

The usual sol-air temperatures apply to "normal" conditions of flat, exposed surfaces with simple foregrounds. There will be places on ordinary buildings where considerably more (or less) solar warming will occur, due to shading, shelter, or reflection. Recessed sunlit enclosures will have much less wind and/or more reflected sunshine from other surfaces, and so get much hotter. Exposed corners are likely to stay cooler because of extra local wind.

Sol-air temperatures were calculated from climate data from a file Climdata (Leslie, 1977) containing air temperatures, solar radiation intensities, wind velocity, cloud cover, and humidity.

The sol-air temperature formula in equation (1) from the IHVE Guide Book A, 1970, was used to calculate sol-air temperatures. The same formula appears in many other sources, such as Rao and Ballantyne, 1970.

$$Ts = Ta + [\,Rs(\alpha.I - f.E.I_l)] \qquad (1)$$

Ts = sol-air temperature °C
Ta = air temperature °C
I = (direct + diffuse + ground reflected) solar radiation intensity. W/m^2
α = solar absorption coefficient
Rs = external surface resistance $m^2.°C/W$
E = longwave emittance of surface
I_l = longwave radiation from a black surface W/m^2
f = sky view factor 1.0 for horizontal surfaces, 0.5 for vertical surfaces

These quantities have been treated in this paper in the following ways. The terms "Ta" and "I" are simply the values reported from normal meteorological measurements. The solar absorption coefficient has been taken as 0.8 for "black" surfaces, and 0.4 for "white" surfaces. Although some "whites" can be more reflective than this, they are not believed to retain lower absorption for long. The external resistance Rs has here been adjusted for nominal wind speed, using the relation from ASHRAE Handbook of Fundamentals 1989.

$$Rs = 1/(11 + 1.5{*}V) \quad m^2°C/W \qquad (2)$$

V = wind speed, knots (this unit is used because the file contains wind speed in knots)

The longwave emittance, "E", of the surface is taken throughout as 0.9. This value is appropriate for surfaces of all colours, but not for bright metal finishes. The limited amount of bright metal external finishes that might be met, would in daytime tend to have a lower temperature rise than coloured surfaces. At night they would frequently be effectively black — any trace of dew on bright metal will cause the longwave emittance to immediately rise to a high value (Bassett & Trethowen

1984). Finally, consider the longwave radiation "I_l". The IHVE Guide 1970 suggests using 100 W/m² for roofs in clear conditions. For the present case it was necessary to consider skies that may have cloud, and this has been done by assigning a proportionate cover, as follows:

$$I_l = 100*(8\text{-}C)/8 \qquad (3)$$

C = cloud cover in octals

A ground reflectance of 20 per cent of the direct beam is used here. Ground reflectance values are not particularly well known, and will vary with time as site conditions change, and other buildings or vegetation come and go.

The conditions applying at night time can be quite adequately described using equations (1) — (3), with "I" equal to zero. For convenience, these night-time temperatures are also referred to here as sol-air temperatures.

Some statistical distribution of sol-air temperatures computed in this way are illustrated in figures 1-4 for four New Zealand centres. Fuller details for Wellington are given in Table 1, to show how these values vary over the seasons. Other centres showed similar patterns. The temperature rise for other colours can be found by interpolation using the solar absorption coefficient for that colour. All three tables include the effects of clear sky cooling, and this is why there are negative temperatures in the (a) and (b) tables, even though no subzero air temperatures have been recorded. Peak temperatures over 80°C were calculated, with the highest values being associated apparently with least wind. Minimum temperatures about 8°C lower than air temperature were calculated for roofs, 4°C for walls.

Table 1: Sol-air Temperatures, Wellington

Temperature Interval, °C

	-10	-5	0	10	20	30	40	50	60	70	80	
Hor			210	2409	3923	1239	675	237	62	16	2	
N			57	2125	4277	1520	589	139	48	17	2	1
NE			57	2128	4377	1373	547	159	79	49	3	1
E			57	2157	4617	1341	399	115	44	28	13	2
SE			58	2271	4885	1309	199	37	13	1		
S			61	2368	5108	1140	90	6				
SW			61	2338	4891	1285	181	16	1			
W			61	2280	4594	1349	395	80	11	2	1	
NW			60	2244	4346	1374	597	118	23	8	2	

(a). Sol-air Temperature Occurrence, hours/year, black surface

Temperature Interval, °C

	-10	-5	0	10	20	30	40	50	60	70	80
Hor			210	2505	4486	1294	260	16	1		
N			57	2225	4967	1369	145	8			
NE			57	2222	4987	1305	189	14			
E			57	2269	5160	1149	115	23	1		
SE			58	2385	5378	918	34				
S			61	2467	5505	729	10				
SW			61	2240	5359	887	26				
W			61	2382	5160	1079	86	5			
NW			60	2331	4950	1305	121	6			

(b). Sol-air Temperature Occurrence, hours/year, white surface

Temperature Interval, °C

	-8	-6	-4	-2	0	10	20	30	40	50	60	70
Hor	153	236	342	936	2389	3154	1093	371	80	17	3	
N			152	675	2889	3646	1074	219	71	32	15	1
NE			152	684	3052	3516	899	267	98	61	43	2
E			152	684	3083	3843	662	212	63	40	26	9
SE			152	687	3133	4315	403	59	28	5		
S			154	728	3285	4404	195	8				
SW			154	712	3085	4448	356	17	1			
W			154	711	3012	4055	706	114	17	4	1	
NW			154	710	2994	3623	1046	194	33	12	8	

(c). Sol-air Temperature Difference Occurrence, hours/year

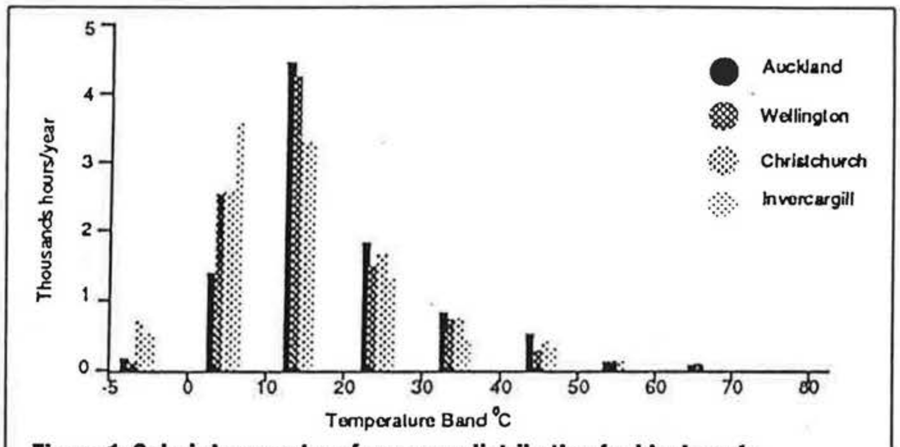

Figure 1: Sol-air temperature frequency distribution for black roofs.

Figure 1 shows the distribution of actual sol-air temperatures for black roofs in each of the centres. Figure 1 indicates that the frequency of distribution does not vary hugely between the centres, although the central trend data (0-20 degrees C) clearly reflects the warmer mean temperature of the more northern centres.

Figure 2 shows the temperature difference data for flat black surfaces in Wellington, using a logarithmic scale for the vertical axis. Very high sol-air temperature rises are indicated as rather rare. They may be loosely described as occurring at a frequency about 0.1 per cent over 60°C, 1 per cent over 40°C, 10 per cent over 20°C above air temperature.

Figure 3 shows a similar graph for different orientations of surface, Auckland. Here too, although there are clear orientation effects, orientation seems less important than one might expect.

Figure 4 shows the importance of

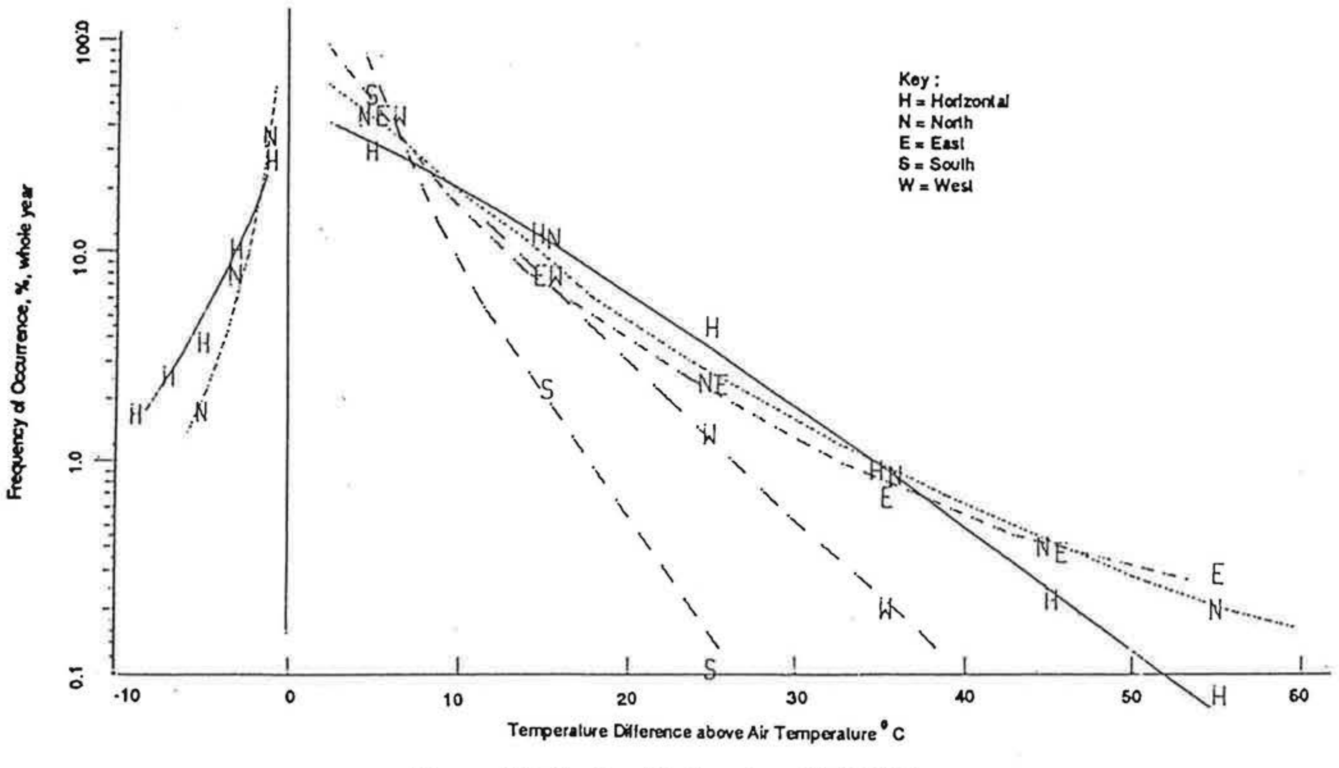

Figure 2: Wellington, black surface 1970-1972.

colour. Fairly similar frequencies are seen for both black and white colours up to temperatures about 30°C, which happens to be about the maximum air temperature. Black surfaces reach high temperatures much more frequently than do white, with peak temperatures some 40°C higher than white surfaces.

When we consider winter heating energy requirements, the factor of interest is the mean value of surface sol-air temperature. Table 2 shows this relation for Wellington, and this will give some idea of this effect for other centres also. It can be seen that a small but quite significant warming influence is present, amounting to an effective warming of the apparent climate by about 3°C over a whole year, made up as nearly 5°C in summer and about 1°C in winter. An effective winter warming of 1°C in winter has a bigger influence than it may seem, being 10-15 per cent of winter heating energy for Wellington.

Sol-air temperatures have been measured for Melbourne by Rao and Ballantyne, 1970, and were used in support of their development of the sol-air temperature formulae. Those measurements were designed to show whether the formula reliably predicted the sol-air temperatures, and did not attempt to reflect the frequency of various degrees of warming. In New Zealand a brief study at BRANZ in 1975, previously unpublished, tried to assess the difference between calculations based on Wellington townbelt observatory

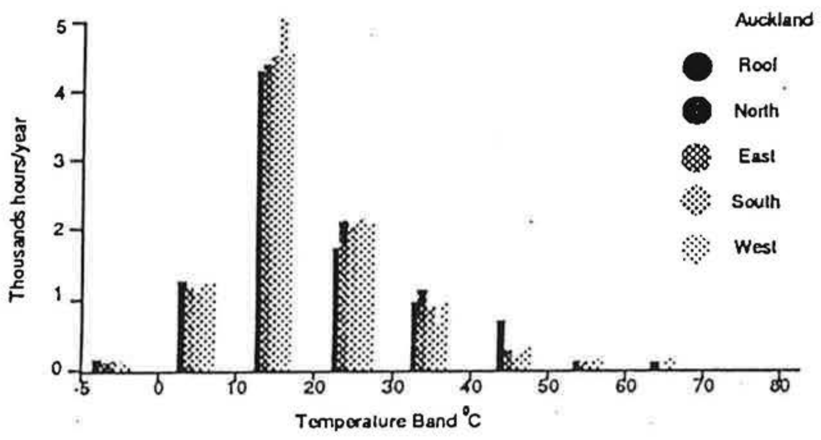

Figure 3: Sol-air temperature distribution for different orientations, black.

	Whole Year	Summer	Winter
		°C	°C
Horiz	3.2	6.0	0.6
N	3.7	3.9	2.9
NE	3.7	4.7	2.2
E	3.0	4.5	1.1
SE	1.8	3.2	0.3
S	1.2	2.0	0.2
SW	1.6	2.9	0.3
W	2.5	4.0	1.0
NW	3.2	4.1	2.1

Table 2: Mean Sol-air Temperature Elevation for "Black Surfaces; by Season, Wellington 1970

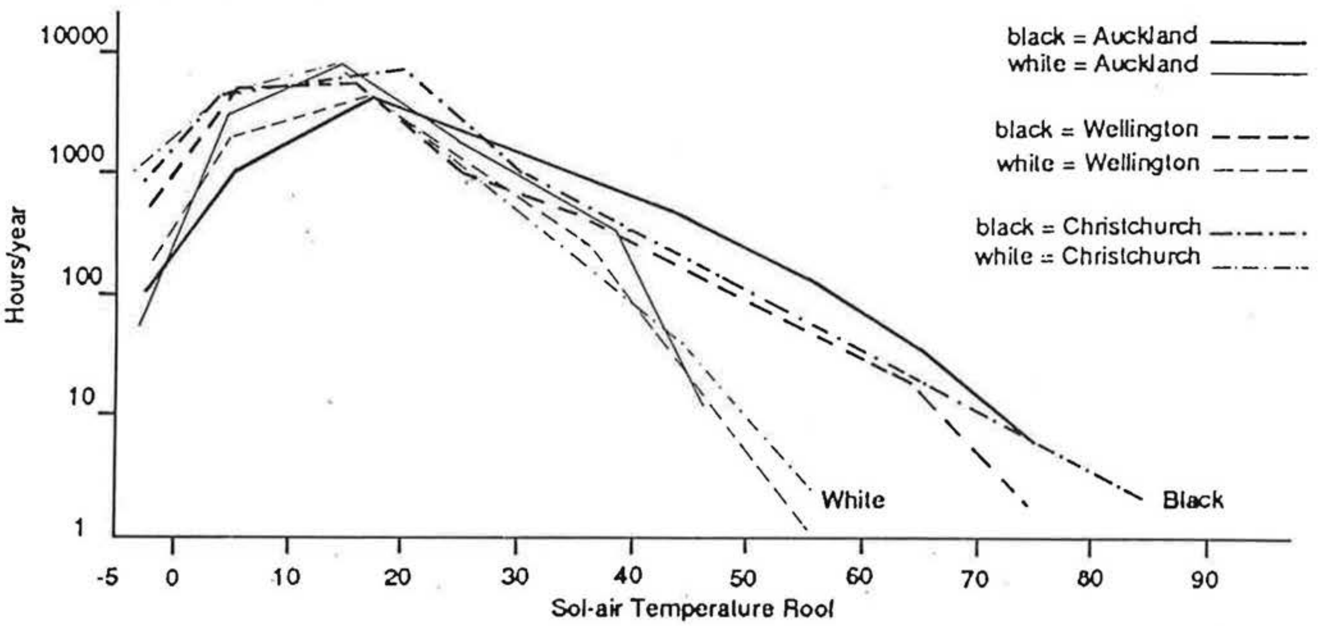

Figure 4: Sol-air temperature distribution for black and white roofs.

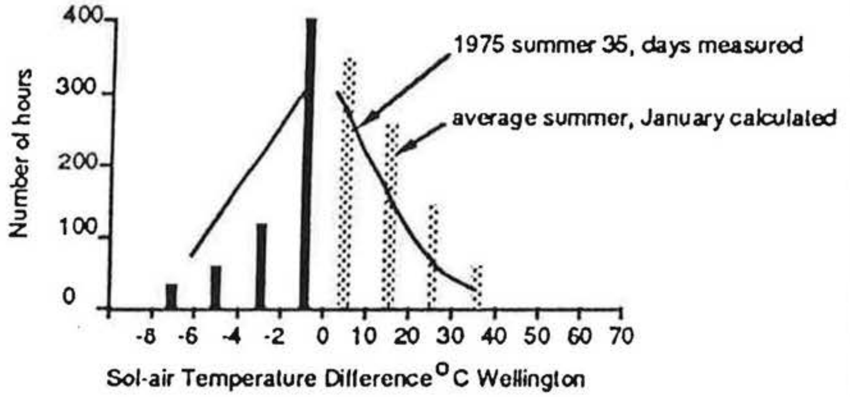

Figure 5: Comparison of measured downtown Sol-air temperature difference with mean calculated from observatory data, flat black roof.

records, from those observed at a downtown site.

The sol-air temperatures were measured as the actual surface and air temperatures on a blackened polystyrene foam octagonal prism of about 400mm dimension. Measurements were virtually continuous over a period of 35 days in the peak December/January summer period. The frequency of observed surface temperatures, compared with those for the average January year from Climdata, are shown in Figure 5. Close fit is not expected for such a short observation period, even without site difference, but there is a broad similarity between calculation and observation, for night-time depression of temperature as well as day-time elevation.

Auckland

Month	Hor	N	NE	E	SE	S	SW	W	NW
J	5.65	2.17	3.13	3.69	2.94	1.78	2.54	3.23	2.92
F	4.58	2.25	2.99	3.12	2.23	1.26	1.87	2.64	2.69
M	3.74	3.00	3.30	2.82	1.70	1.08	1.42	2.25	2.80
A	2.54	3.02	2.84	2.01	1.02	0.76	0.87	1.57	2.38
M	1.82	2.92	2.50	1.47	0.66	0.58	0.61	1.15	2.08
J	1.41	2.71	2.28	1.21	0.48	0.44	0.45	0.87	1.81
J	1.73	3.12	2.61	1.43	0.58	0.52	0.54	1.08	2.15
A	2.28	3.12	2.80	1.81	0.85	0.69	0.76	1.40	2.31
S	3.03	2.87	2.77	2.15	1.25	0.90	1.12	1.89	2.54
O	4.01	2.55	2.95	2.79	1.95	1.27	1.76	2.51	2.74
N	4.82	2.26	2.99	3.24	2.52	1.62	2.24	2.87	2.74
D	5.46	2.12	2.98	3.54	2.93	1.92	2.65	3.25	2.85

Wellington

Month	Hor	N	NE	E	SE	S	SW	W	NW
J	5.39	2.37	3.15	3.47	2.65	1.62	2.28	3.05	2.95
F	4.33	2.47	3.01	2.96	2.04	1.19	1.64	2.43	2.69
M	3.38	3.01	3.07	2.48	1.44	0.94	1.21	2.06	2.74
A	2.19	2.97	2.68	1.78	0.83	0.62	0.71	1.40	2.27
M	1.40	2.67	2.18	1.20	0.50	0.45	0.46	0.97	1.89
J	1.08	2.50	1.96	0.95	0.37	0.34	0.35	0.76	1.73
J	1.21	2.55	2.10	1.12	0.43	0.39	0.40	0.84	1.75
A	1.79	2.77	2.36	1.45	0.68	0.58	0.62	1.20	2.08
S	2.71	2.86	2.73	2.03	1.11	0.78	0.95	1.69	2.43
O	3.90	2.74	3.10	2.82	1.86	1.16	1.56	2.37	2.77
N	4.68	2.38	3.03	3.19	2.39	1.48	1.99	2.71	2.76
D	5.44	2.30	3.11	3.61	2.90	1.82	2.41	3.09	2.89

Christchurch

Month	Hor	N	NE	E	SE	S	SW	W	NW
J	4.55	2.39	2.93	3.11	2.42	1.62	2.08	2.70	2.72
F	3.76	2.41	2.72	2.56	1.79	1.18	1.57	2.25	2.51
M	2.86	2.70	2.71	2.16	1.31	0.94	1.13	1.76	2.35
A	1.88	2.55	2.29	1.50	0.78	0.63	0.68	1.16	1.92
M	1.22	2.31	1.94	1.06	0.48	0.44	0.45	0.80	1.61
J	0.85	1.88	1.51	0.74	0.33	0.33	0.33	0.58	1.29
J	1.01	2.07	1.72	0.90	0.40	0.38	0.38	0.67	1.41
A	1.54	2.36	2.04	1.26	0.65	0.56	0.59	1.01	1.75
S	2.47	2.72	2.59	1.92	1.12	0.85	0.98	1.59	2.26
O	3.64	2.80	3.07	2.73	1.83	1.22	1.52	2.20	2.64
N	4.35	2.49	3.02	3.10	2.34	1.54	1.99	2.64	2.73
D	5.00	2.42	3.03	3.35	2.69	1.81	2.33	2.98	2.87

Invercargill

Month	Hor	N	NE	E	SE	S	SW	W	NW
J	4.68	2.55	2.98	3.10	2.39	1.60	2.19	2.96	3.00
F	3.85	2.61	2.81	2.58	1.78	1.17	1.67	2.49	2.82
M	2.85	2.88	2.72	2.08	1.25	0.89	1.11	1.86	2.58
A	1.56	2.33	2.02	1.29	0.65	0.53	0.59	1.09	1.81
M	0.95	1.97	1.61	0.85	0.38	0.35	0.36	0.67	1.38
J	0.71	1.91	1.55	0.71	0.27	0.26	0.26	0.51	1.25
J	0.89	2.21	1.70	0.78	0.33	0.32	0.32	0.68	1.56
A	1.53	2.82	2.41	1.38	0.58	0.49	0.52	1.03	1.98
S	2.35	2.82	2.61	1.85	1.02	0.76	0.90	1.55	2.31
O	3.40	2.78	2.86	2.43	1.61	1.12	1.47	2.20	2.69
N	4.28	2.61	3.02	3.00	2.23	1.47	1.95	2.68	2.85
D	5.07	2.59	3.18	3.44	2.71	1.82	2.42	3.15	3.07

Table 4, Mean daily window solar gain (KWh/m^{2}d) 1970-1974

Moisture conditions at the building surface

This section considers the accumulation of moisture at building surfaces. Dew (or rain) obviously might affect any cladding material, but local humidity at the surface is also important. Timber will become damper or drier according to the humidity, affecting swelling or warping. The emphasis here will be on moisture-induced corrosion, and this is dependent on humidity.

On any building surface there is likely to be a cocktail of contaminants including salts, oxides and hydroxides. Most of these contaminants are hygroscopic (ie, they actively absorb moisture from the air) above a certain limit of humidity. Common salt has a hygroscopic limit of about 75 per cent RH and iron oxide about 85 per cent RH (Barton, 1973) Furthermore, if a surface is cooled below adjacent air temperature by an amount exceeding the local dew point depression, then humidity at the surface will reach 100 per cent and condensation or 'dew' will occur. Three corrosion risk indicator conditions can therefore be chosen corresponding to these three situations. For this paper they have been called the "100 per cent", "85 per cent", and "73 per cent" humidity conditions.

The frequency of occurrence of these conditions has been calculated for Wellington, 1971. It was assumed that the surface was lightweight and insulated, ie, the surface temperature would be similar to the sol-air temperature. It was also assumed that the air was sufficiently mixed to equalise the vapour pressure across the boundary layer. The local dewpoint temperature at the surface was calculated from Climdata and used with the sol-air temperature to determine a local relative humidity at the surface.

The results of these calculations are presented in Table 3. This shows the frequency of occurrence of the three chosen corrosion risk indicator conditions, for lightweight claddings fully exposed to sun, sky, wind, and cloud, but ignoring rain.

Table 3 shows that a remarkably high occurrence of dew-forming conditions are to be expected in Wellington, about 20 per cent of all hours for roofs, and 10 per cent-15 per cent of all hours for walls. If rain effects were added, then the number of wet hours per year would be even larger.

The effects of orientation are not large. The total dew-exposed hours for a south wall is only slightly larger than for north. A far stronger factor is likely to be the effects of contaminants on the surfaces of metals. Salt, for instance, which is known to be a strong corrosive agent on metals, is predicted here to be in an actively wetting mode for over half the hours in a year. Corresponding calculations for other centres have not

(%)	> 85% hour/y	(%)	> 75% hour/y	(%)
(0.3)	325	(3.7)	417	(4.8)
(2.9)	1494	(17.1)	2009	(22.9)
(6.3)	1414	(16.1)	1807	(20.6)
(6.3)	673	(7.7)	796	(9.1)
(1.9)	165	(1.9)	772	(8.8)
(.05)	4	(.05)	4	(.05)
zontal Roof (all colours)				
(1.1)	381	(4.3)	457	(5.2)
(4.3)	1706	(19.5)	2269	(25.9)
(4.2)	1331	(15.2)	1791	(20.4)
(1.2)	237	(2.7)	354	(4.0)
(.02)	2	(.02)	4	(.05)
North Wall (all colours)				
(1.2)	406	(4.6)	506	(5.8)
(4.7)	1814	(20.7)	2516	(28.7)
(4.5)	1429	(16.3)	1968	(22.5)
(1.3)	257	(2.9)	381	(4.3)
(.02)	2	(.02)	3	(.03)
) South Wall (all colours)				

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" — Oxides will be self-wetting
" — Sea Salt will be self-wetting

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the ASHRAE Handbook of Fundamentals, 1989, Ch.27. The window overall heat gain was calculated from Climdata for each hour, for each orientation of window, and then summed over each month and averaged. The average window gains from this process are listed in Table 4.

Table 4 shows the average daily window solar gain for each month, for the actual weather conditions (sun, wind, cloud, etc) for that month. These values have been compared in Table 5 with the total clear-day gains, and in the main the average gain is about 60-70 per cent of the clear-day gain. However this varies in one important way, with the average gain exceeding the clear-day total when diffuse radiation dominates, eg northerly windows in mid-summer, southerly windows all year.

A rather interesting offshoot of this is given in Figure 6, which shows how the calculated daily window gains values vary with the amount of cloud. There is a very clear trend that the heat gains did not reduce, or even increase,

Wellington

Month	Hor	N	NE	E	SE	S	SW	W	NW
J	0.73	0.98	0.85	0.84	0.94	1.19	0.81	0.74	0.80
F	0.75	0.81	0.83	0.90	1.08	1.37	0.88	0.74	0.74
M	0.71	0.67	0.74	0.85	1.13	1.28	0.95	0.70	0.66
A	0.72	0.62	0.72	0.89	1.25	1.20	1.05	0.69	0.61
M	0.71	0.58	0.66	0.87	1.23	1.16	1.14	0.69	0.57
J	0.72	0.60	0.67	0.86	1.15	1.08	1.07	0.68	0.58
J	0.63	0.56	0.65	0.84	1.11	1.04	1.02	0.63	0.54
A	0.59	0.56	0.62	0.72	1.04	1.10	0.94	0.59	0.54
S	0.61	0.65	0.68	0.73	0.93	1.13	0.83	0.62	0.61
O	0.63	0.80	0.77	0.78	0.92	1.22	0.77	0.65	0.68
N	0.66	1.00	0.84	0.81	0.90	1.18	0.76	0.69	0.77
D	0.70	1.10	0.89	0.86	0.95	1.15	0.78	0.73	0.83

Table 5, Ratios (mean day)/(clear day) solar heat gain for windows

as cloud cover increased from zero. Not until the cloud cover became very heavy, usually over 50 per cent, did the window heat gain value start to diminish much, except for northerly facing windows in winter.

The largest average north window gains do not occur in summer, but in spring and autumn. "Roof" windows, or skylights, collect less than half the average gain of a north window in winter, but two to three times as much in summer. And yet skylights are often considered as an energy conserving measure for supplementing building heating.

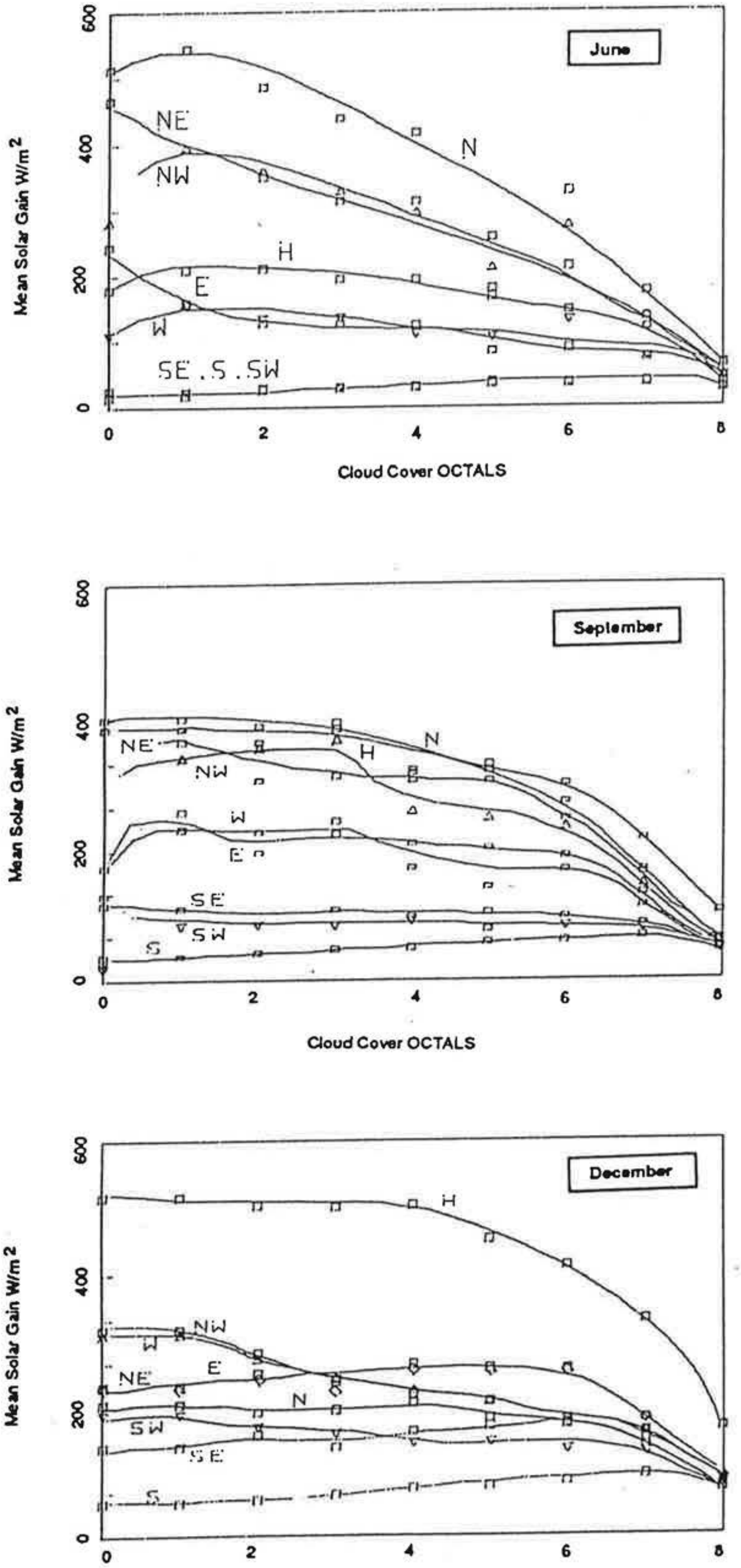

Figure 6: Variation of Solar Gain with Cloud Cover, Wellington. 1970-1974 Single Glass Windows.

Conclusions

The main conclusions which this paper draws (for NZ) are:

- Clear night sky cooling by up to about 8°C below air temperature is typical for roofs, 4°C for walls, all colours.
- Although very high sol-air temperatures occur, the maximum values (> 60-70°C) have limited occurrence. Sol-air temperature rise can be loosely described as over 60°C for 0.1 per cent of time, over 40°C for 1 per cent, and over 20°C for 10 per cent.
- The nett effect of radiation is to raise the apparent mean temperature by about 3°C, over a whole year, made up as 5°C in summer and 1°C in winter.
- Cloud cover has to exceed about 50 per cent before the solar gains from windows drop significantly.
- Dew-forming conditions on building exteriors occur for 10-20 per cent of the time, and moisture-induced corrosive conditions for nearly half to two thirds of the time.

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