PERFORMANCE OF THE PROTECTED MEMBRANE ROOF IN AUSTRALIA

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Built-up roofing in Australia has experienced the same problems as in other parts of the world. The Australian climate ranges from tropical to temperate, consequently exposed membranes experience a wide variety of conditions. Some cities experience summer temperatures in excess of 40C and freeze-thaw cycles in winter.

Since 1981 the protected membrane roof with extruded polystyrene foam insulation has been installed in increasing numbers. Some of these have been monitored for thermal performance.

Data from a roof in Sydney permit comparison of the temperature cycles of a membrane on a protected membrane roof with those of a membrane laid directly on a concrete deck with no insulation. The exposed membrane experienced an annual temperature cycle of 60C and daily cycles as high as 40C. The protected membrane experienced an annual cycle of 12C and daily cycles generally below 4C.

On a roof in Melbourne, the temperature of a membrane placed above 50mm of extruded polystyrene foam insulation is compared with that of a membrane placed below a similar thickness of insulation. Here the exposed membrane reached a maximum of 81C and experienced daily cycles as high as 60 degrees with an annual cycle of 85C. The protected membrane daily cycle only once exceeded 5C. The exposed membrane experienced 22 freeze-thaw cycles during the winter.

AUSTRALIAN ROOFING EXPERIENCE

Built-up roofing has suffered the same traumas in Australia as it has in other parts of the world. A 1950 survey showed that 70 out of 155 roofs inspected were leaking.[1] Excessive temperature cycling and moisture were regarded as principal causes of membrane failure. Ballantyne and Spencer[2] measured surface temperatures of roof membranes on a timber deck in Melbourne over a one-year period. The temperature on a black membrane exceeded 79C with a maximum air temperature of 41C. This is considerably higher than the maximum of 66C observed in Canada.[3] Painting the membrane white was the most effective way of reducing surface temperature, but this only achieved a reduction of about 13C.

Martin attributed failures in built-up roofing to absorption of moisture by the roofing felts and subsequent drying at high temperatures.[4,5] Martin also considered that reduced temperature cycling was the best solution to the problem of membrane failures. He advocated placing paving slabs on spacers above the membrane and found that the maximum temperature attained by a black membrane on a roof in melbourne was reduced from 87.8C to 57.2C by such a system. However, care must be exercised in selecting the size of paving slab and area of spacers. Such a roofing system was used in Singapore,[7] but with massive reinforced concrete slabs placed on concrete blocks. Failure was experienced in this system due to the spacing blocks being pressed into the membrane.

THE PROTECTED MEMBRANE ROOF

In other parts of the world the protected membrane roof, using extruded polystyrene foam insulation placed above the waterproofing membrane, has become an accepted method of insulating roofs,[8,9,10] and performance criteria have been established.[11] This position for the insulation is to be preferred over placing insulation beneath a membrane, since it serves to reduce thermal stresses on a membrane rather than increase them. Martin's proposal of placing paving tiles above the membrane was a form of protected membrane roof.[6] The protected membrane roof is also known as the upside down roof, the inverted roof or the insulated roof membrane assembly (IRMA).

Extruded polystyrene foam, an essential component of the protected membrane roof, has recently become available in Australia[12] leading to the construction of many such roofs. The first two of these were installed on buildings in Sydney in June 1981. Both of these originally had been constructed with a membrane placed directly on a concrete deck. Excessive room temperature on the top floor during summer had convinced the building owners of the need for insulation.

While studies of the thermal performance of protected membrane roofs in cold climates have been made,[13] no such studies have been published for climates such as are found in Australia. Therefore, to gather data on performance of the protected membrane roof in the Australian climate, temperatures have been monitored on roofs in Sydney and Melbourne. For the Sydney roof, the temperature cycles of an exposed membrane placed directly on a concrete roof deck are compared with those of a membrane in a protected membrane roof. For the Melbourne roof, a similar comparison is made for membranes placed above and below the same thickness of extruded polystyrene foam insulation.

SYDNEY TEST ROOF

This test section was laid on a small area of roof over a stairwell that protruded as a separate wing from a building complex in the Sydney suburb of Chatswood. One section consisted of a three-ply bituminous membrane laid directly on the concrete roof deck and painted white. Adjacent to it was a protected membrane roof section consisting of an EPDM single-ply membrane, 50mm of an extruded polystyrene foam, a layer of filter fabric, and washed river gravel ballast at a level of 60 kg/m². Copper-constantan thermocouples were placed in these sections as shown in Figure 1a. Temperatures were recorded on a Texas Instruments Tigraph 100 recorder. Temperatures were monitored from Feb. 10, 1983 to July 15, 1984.

Two examples of the daily temperature cycles are shown in Figure 2. December 21, 1983 was the highest temperature recorded on the exposed membrane. Note the overnight low temperature of 18C at about 0600 hours and the high of just over 60C at 1300 hours, a cycle of over 40C. Yet the membrane temperature beneath 50mm of extruded polystyrene foam insulation cycled through only 2C during the day. The maxiumum and minimum air temperatures recorded by the bureau of meteorology were 35.0C and 18.9C respectively, with 12.8 hours of sunshine and no rainfall. The effect of solar radiation raised the exposed membrane 25C above maximum air temperature, even though it was painted white and laid directly on the thermal sink of a concrete roof deck. The rapid drop in temperature seen during the afternoon is caused by a shadow from a turret on the building falling across the membrane, the subsequent increase in temperature at the top of the ballast occurs when the shadow has passed completely across the thermocouples.

Figure 2b gives the temperature cycle for June 28, 1983. On this day the maximum air temperature was 13.6C, the minimum was 5.0C and there were six hours of sunshine and 0.2mm of rain. Note that the exposed membrane cycled between 4C and 22C while that beneath the insulation again cycled less than 2C.

The data for the Sydney roof are plotted for the total period in Figure 3. Here, the dashed line shows the maximum daily temperature of the exposed membrane, while the dotted line is its minimum daily temperature. The solid line plots the daily cycles of the protected membrane. The benefits of placing insulation above the membrane are obvious. There is a large reduction in maximum temperature and daily cycles. Consequently there is a large reduction in heat load on the building. The temperature of the top of the concrete roof slab is reduced, thereby reducing heat gain of the building during summer days.

The data are summarized in Table 1. This table gives the number of days on which the minimum and maximum temperature of each membrane falls within five-degree ranges. The frequency of the daily cycles for each five degree range is also shown. Note that the daily cycle on the protected membrane never exceeded 5C. On 406 of the 523 days for which data were recorded, the membrane cycled one degree or less, and the cycle exceeded 3C on only 30 days. The extreme temperature range experienced by the protected membrane over the period studied was 13 to 30C. The temperature variation of the protected membrane in Sydney was rather more than found in Melbourne because the building over which it was placed was not fully air conditioned. It was also adjacent to the uninsulated section of roof covered by the unprotected membrane.

MELBOURNE TEST ROOF

A protected membrane roof was installed on an office building in the Dow Chemical plant at Altona, a Melbourne suburb, late in 1983. Temperature monitoring of this roof commenced on December 19, 1983. Figure 1b shows a cross-section of the test sections and location of the copper-constantan thermocouples. The thermocouples were connected to a data logger designed by S.M.E. Systems Ltd. The data sampling rate varied with time of day from a frequency of 5 minutes at times when rapid temperatures changes were expected, to 30 minutes at times of stable temperature. Data were transferred to a VAX-780 computer for analysis.

The test installation was designed to compare the performance of a conventional roof with an EPDM single-ply black membrane placed on top of 50mm of extruded polystyrene foam insulation and a protected membrane roof with three-ply bituminous membrane under the same thickness of extruded polystyrene foam insulation.

Figure 4 shows a plot of the maximum and minimum daily temperature underneath the black membrane placed above the insulation. The daily cycles of the membrane underneath the insulation are plotted on the same graph, as are the daily maximum and minimum air temperatures. The number of days on which the membrane temperature fell within each five degree range is shown in Table 2.

Note that the temperature of the black membrane above the insulation rose above 70C several times. Its maximum temperature was 81C on January 14, 1984, when the maximum air temperature was 32C. The minimum membrane temperature was −5C on July 15, 1984 when the lowest overnight temperature for the whole winter, −0.1C, occurred. During the winter, this membrane experienced 22 freeze-thaw cycles.

Comparison of the data for Melbourne and Sydney shows that placing a membrane on top of insulation subjects it to greater extremes of temperature, and larger daily temperature cycles than when it is placed directly on a concrete roof deck with no insulation.

SUMMARY AND CONCLUSIONS

The data generated indicate clearly the effectiveness of extruded polystyrene foam insulation in reducing the temperature cycles of a membrane in the protected membrane roof. Comparisons made with a membrane, uninsulated laid directly on a concrete roof deck, and with a membrane laid on top of insulation, as in the conventional roof, show the effectiveness of the protected membrane roof in reducing temperature cycling of a membrane.

ACKNOWLEDGEMENT

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Temperature Range °C	Number of days on which temperatures fell within each range					
	Exposed Membrane			Protected Membrane		
	Min.	Max.	Daily Cycle	Min.	Max.	Daily Cycle
0— 5	11	0	31	0	0	523
5—10	121	1	61	0	0	
10—15	177	6	68	10	10	
15—20	193	38	95	150	112	
20—25	20	76	106	261	262	
25—30	1	94	75	87	140	
30—35		86	70			
35—40		76	16			
40—45		46	1			
45—50		57				
50—55		36				
55—60		6				
60—65		1				

Table 1 Sydney test roof frequency distribution of temperatures of exposed and protected membranes

Temperature Range °C	Number of days on which temperatures fell within each range					
	Exposed Membrane			Protected Membrane		
	Min.	Max.	Daily Cycle	Min.	Max.	Daily Cycle
−5— 0	22	0	0	0	0	
0— 5	141	0	12	0	0	278
5—10	95	1	10	0	0	1
10—15	18	11	14	10	1	
15—20	2	10	31	250	196	
20—25	1	17	46	19	80	
25—30		44	33		2	
30—35		43	27			
35—40		28	30			
40—45		19	22			
45—50		23	21			
50—55		17	21			
55—60		19	11			
60—65		24	1			
65—70		17				
70—75		4				
75—80		1				
80—85		1				

Table 2 Melbourne test roof frequency distribution of temperature of exposed and protected membranes

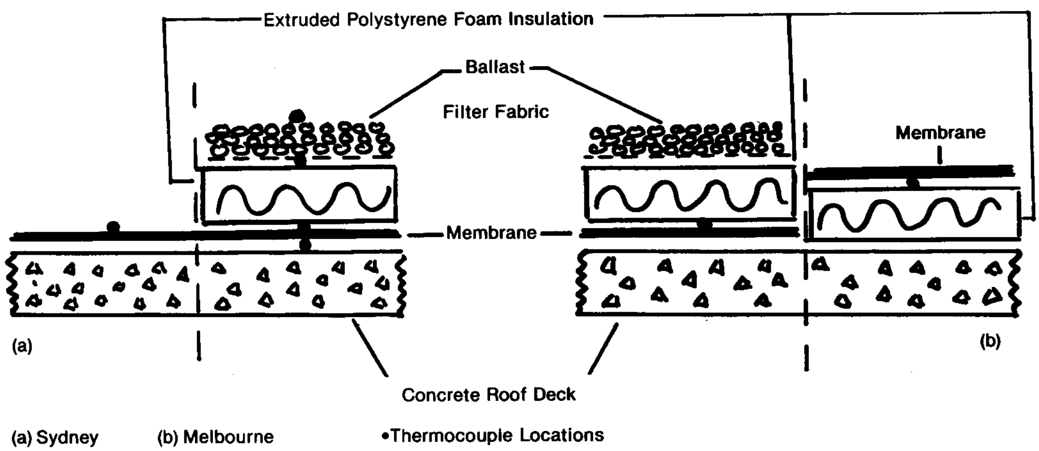
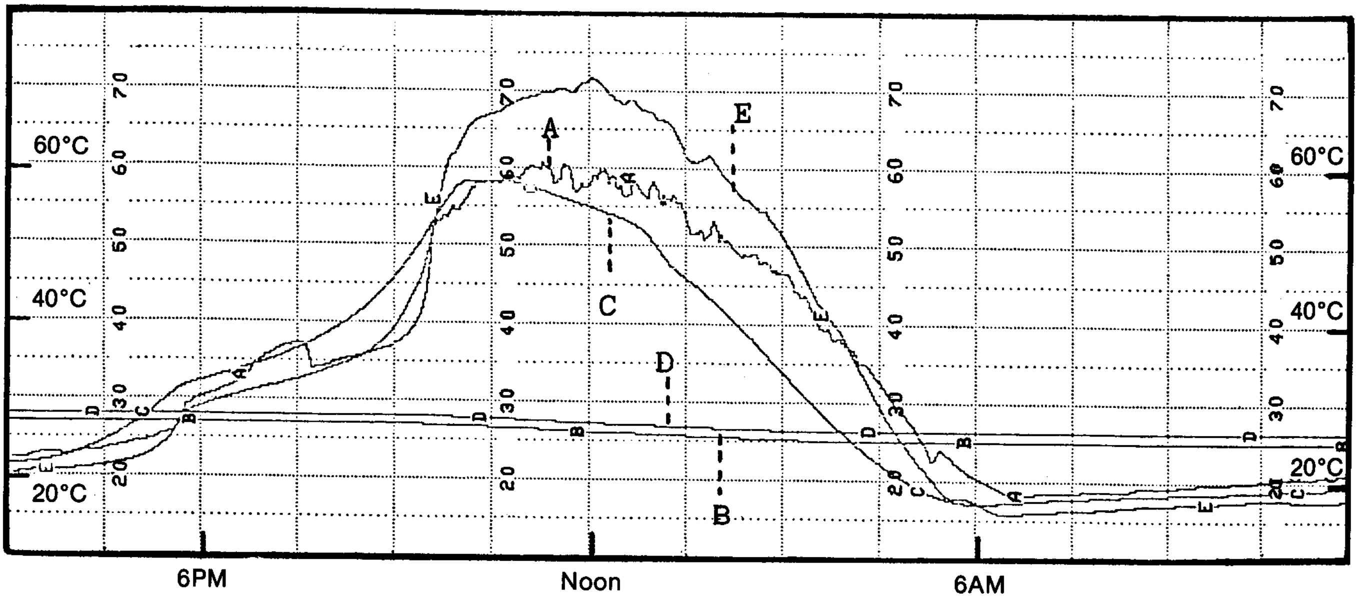
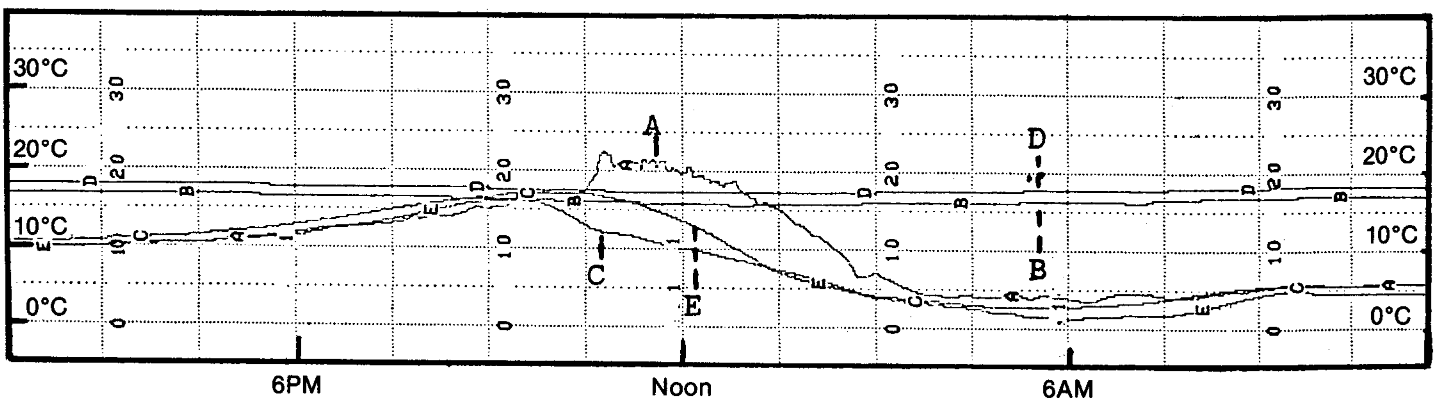


Figure 1 Cross section of test roof installations



a) December 21, 1983



b) June 28, 1983

Extruded membrane on concrete deck

A) Temperature above membrane protected membrane beneath 50mm extruded polystyrene foam insulation

B) Under membrane

C) Above insulation

D) Above membrane

E) Above ballast

Figure 2 Temperature profiles on Sydney test roof

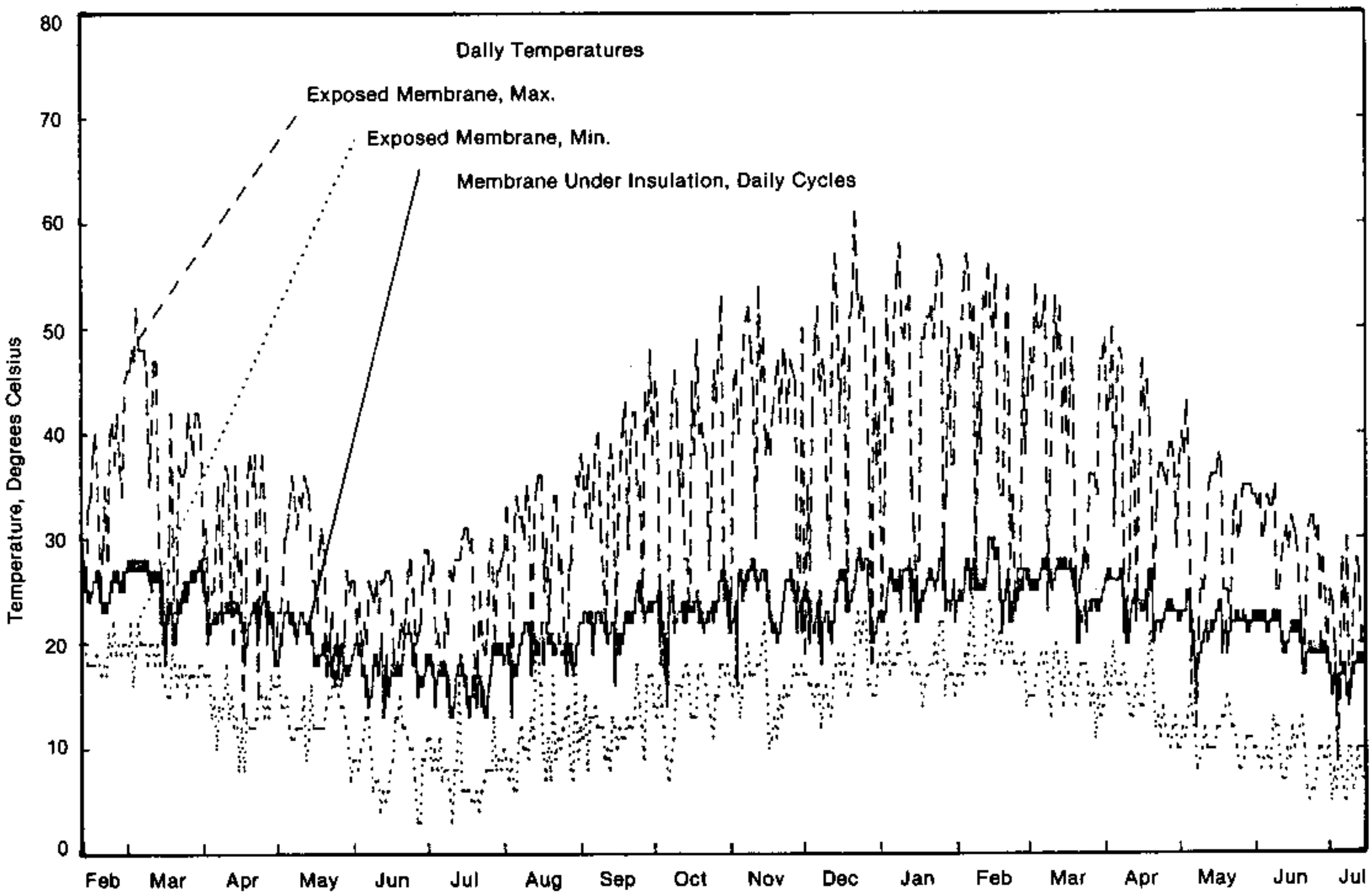


Figure 3 Sydney test roof, 1983-84

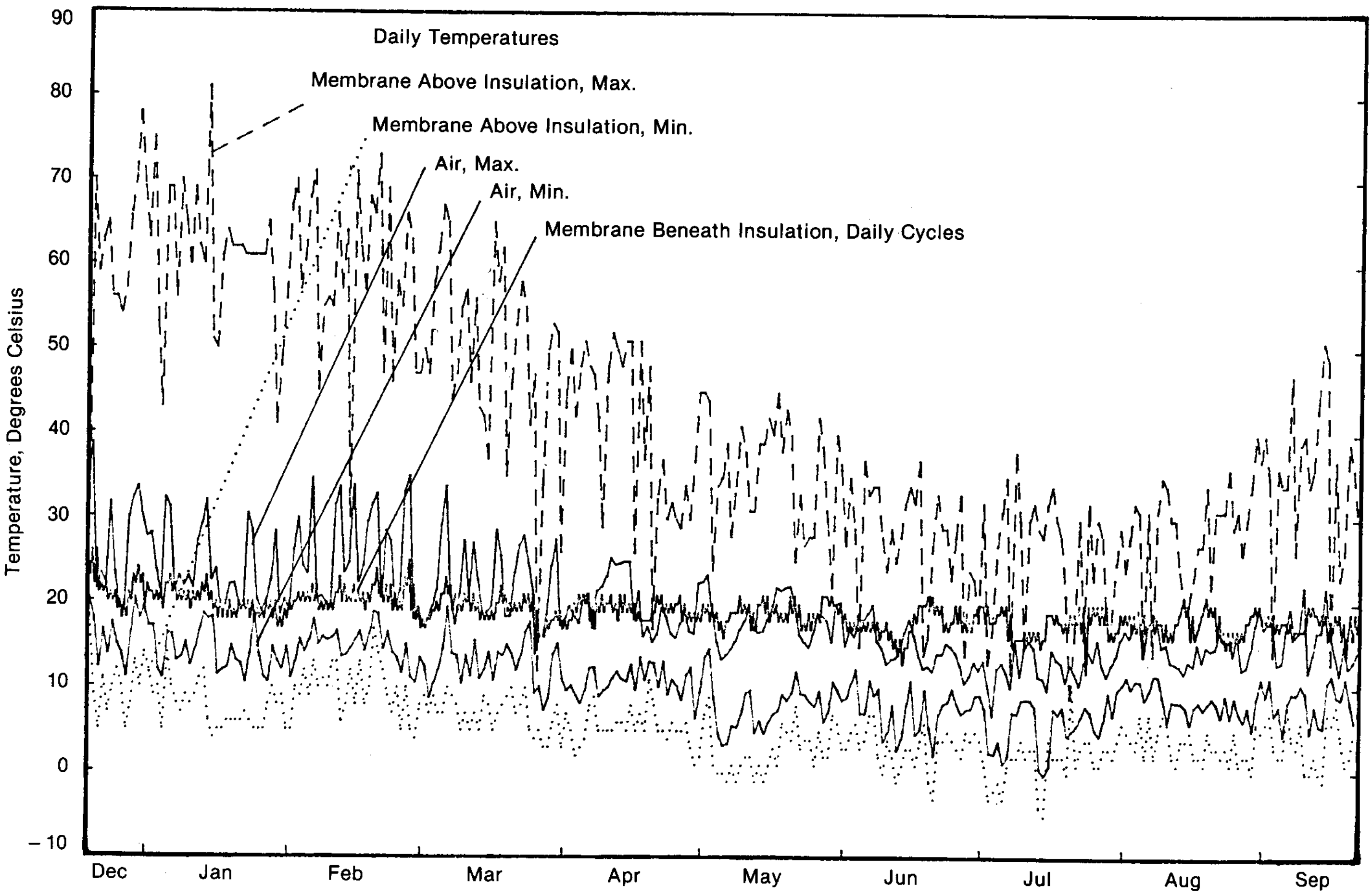


Figure 4 Melbourne office roof, 1983-84

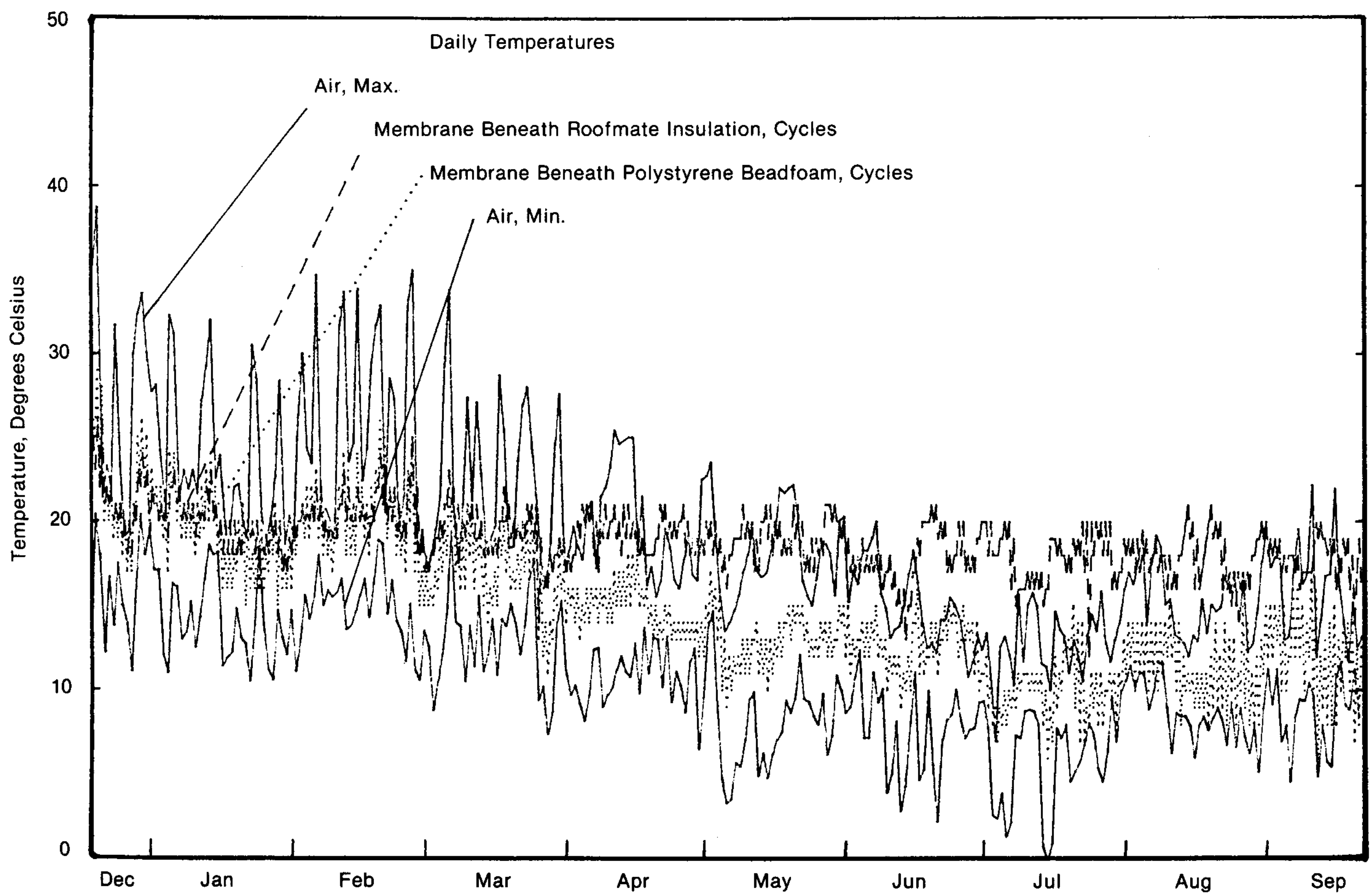


Figure 5 *Melbourne office building, 1983-84*