5: MONITORING THE THERMAL BEHAVIOUR OF FABRIC MEMBRANES.

5:1. INTRODUCTION.

In the previous chapter a series of pilot studies were described which investigated the thermal behaviour of a range of spaces enclosed by fabric membranes. The obvious complexity of the observed behaviour suggested that the rest of this research could be much simplified if it were dealt with in two parts:-

- The thermal behaviour of fabric membranes.
- The thermal behaviour of spaces enclosed by fabric membranes.

The next three chapters describe a detailed investigation into the first of these parts, the aim of which was to produce a model capable of generating information regarding *the thermal behaviour of fabric membranes*. The purpose of this information was to allow a more detailed investigation into *the thermal behaviour of spaces enclosed by fabric membranes* to be carried out than had been possible with the pilot studies.

It was apparent from the review of the existing body of knowledge presented in Chapter 3 that relatively little was known about the actual thermal behaviour of fabric membranes. In this chapter therefore, an investigation is described which had two fundamental aims:-

- To assess which of the properties of fabric membranes it was necessary to quantify in order to be able to properly explain their thermal behaviour.
- To provide a comprehensive range of data against which the accuracy of a model used to simulate that behaviour might be tested.

The approach necessary to measure the relevant membrane properties is then described in the Chapter 6, and the development of a model whose purpose was to simulate the thermal behaviour of those membranes is explained in Chapter 7.

5:2. A TEST CELL FOR INVESTIGATING THE THERMAL BEHAVIOUR OF FABRIC MEMBRANES.

5:2.1 The Aim of the Test Cell.

The thermal state of a number of fabric membranes which formed the external envelopes of existing buildings was recorded during the programme of spatial monitoring described in Chapter 8. It may have been considered that this would provide adequate data with which to assess the behaviour of such membranes, however, these '*in situ*' membranes were had material properties which were largely unknown, and there behaviour was affected by complex environmental conditions which were difficult to evaluate.

The construction of a test cell however allowed the behaviour of a range of membranes with known or measurable properties to be monitored under known conditions. It was also be possible to place the test cell along side an existing meteorological station on the roof of the University of Wales, Bute Building in Cardiff. This allowed more detailed climatic information to be gathered than was possible during programme of site monitoring described in Chapter 8.

5:2.2 The Thermal Parameters Monitored Using the Test Cell.

The primary significance of the thermal behaviour of spaces enclosed by fabric membranes is the way in which it affects the comfort of the occupants of such spaces. Thermal comfort is dependent upon a great many parameters, however it may only be affected by a fabric membrane spatial envelope through the amount of heat which allows to enter of leave the enclosed space.

This heat exchange may be facilitated by convection, long wave infra red radiation and solar radiation, and the membrane dependence of these mechanisms is illustrated schematically by the diagrams below.

Figure 5:2.2a The Thermal Behaviour of Spaces Enclosed by Fabric Membranes.

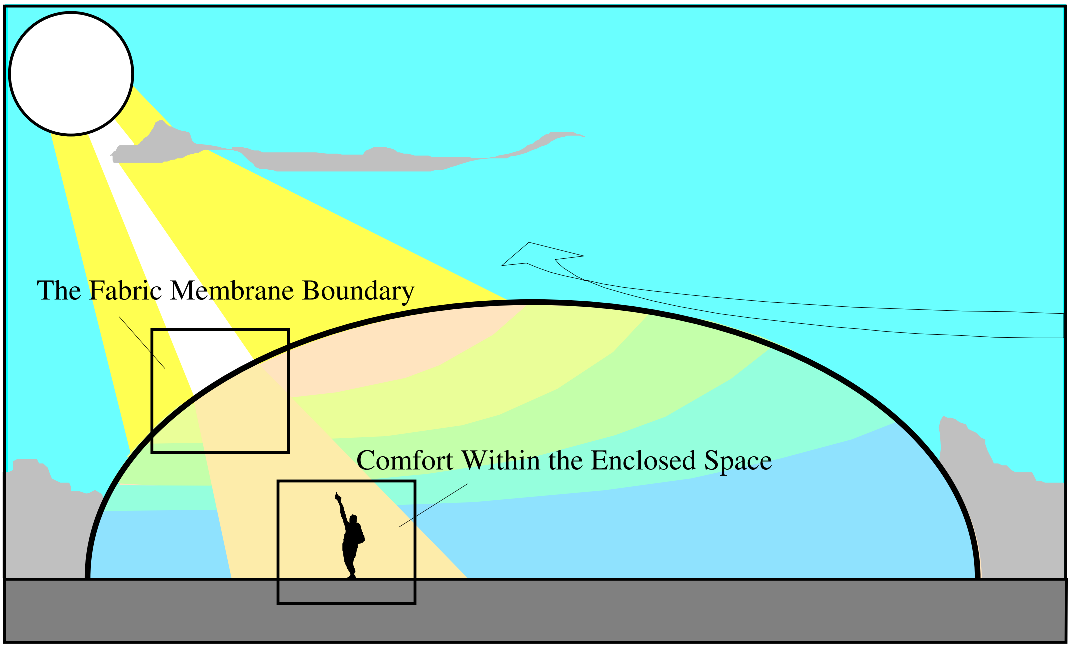


Figure 5:2.2b The Thermal Behaviour of Fabric Membranes.

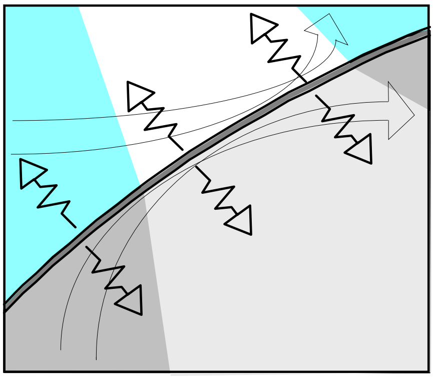


Figure 5:2.2c Thermal Comfort Within the Enclosed Space.

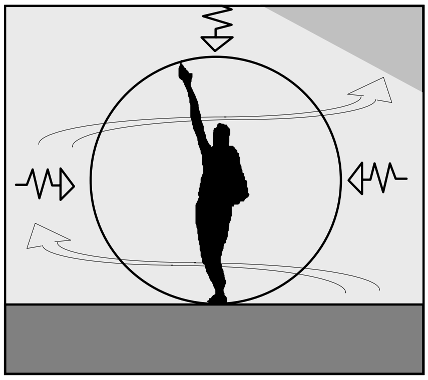


Figure 5:2.2d The Membrane Dependence of Thermal Comfort Within the Enclosed Space.

Comfort Parameters →	**Membrane Dependance** →	Heat Transfer Mechanisms →	**Membrane Properties**
Convection	**Membrane Internal Surface Temperature**	Intra Surface Conduction	**Conductivity**
			Density
			Specific Heat Capacity
		Surface Convection	**Surface Smoothness**
Long Wave Infra Red Radiation		Long Wave Infra Red Radiation Exchange	**Long Wave Infra Red Radiation Absorptance**
		Solar Radiation Absorption	**Solar Absorptance**
Solar Radiation	**Solar Radiation Directed into the Enclosed Space**	Transmitted External Solar Radiation	**Solar Transmittance**
		Reflected Internal Solar Radiation	**Solar Reflectance**

The series of diagrams above show that a fabric membrane boundary can actually only affect the thermal comfort of occupants within a space enclosed by it through two parameters:-

- Its internal surface temperature.
- The solar radiation which it directs into the enclosed space.

These parameters in turn could possibly be affected by the *conductivity*, *density*, *specific heat capacity*, *surface smoothness*, *long wave infra red radiation absorptance*, *solar absorptance*, *solar transmittance* and *solar reflectance* of the membrane samples studied. It was these properties and parameters therefor which were investigated using the test cell described in this chapter.

5:2.3 The Design and Construction of the Test Cell and Associated Meteorological Station.

The test cell was intended to provide a flexible and controllable method for monitoring *the internal surface temperature* of a range of membrane samples, and *the quantity of solar radiation directed into a space enclosed by them*. In order to provide the information necessary to explain the observed data however, it was also necessary to monitor the internal and external environmental conditions from which the recorded behaviour resulted.

Rather than designing a purpose built test cell specifically for this purpose, it was decided to adapt the test cell design recommended by the ASTM E 1084-86, '*Standard Test Method for Solar Transmittance (Terrestrial) of Sheet Materials Using Sunlight*'[1]. Slight alterations to this design allowed the thermal state of the membrane samples to be monitored, as well as their angular solar transmittance.

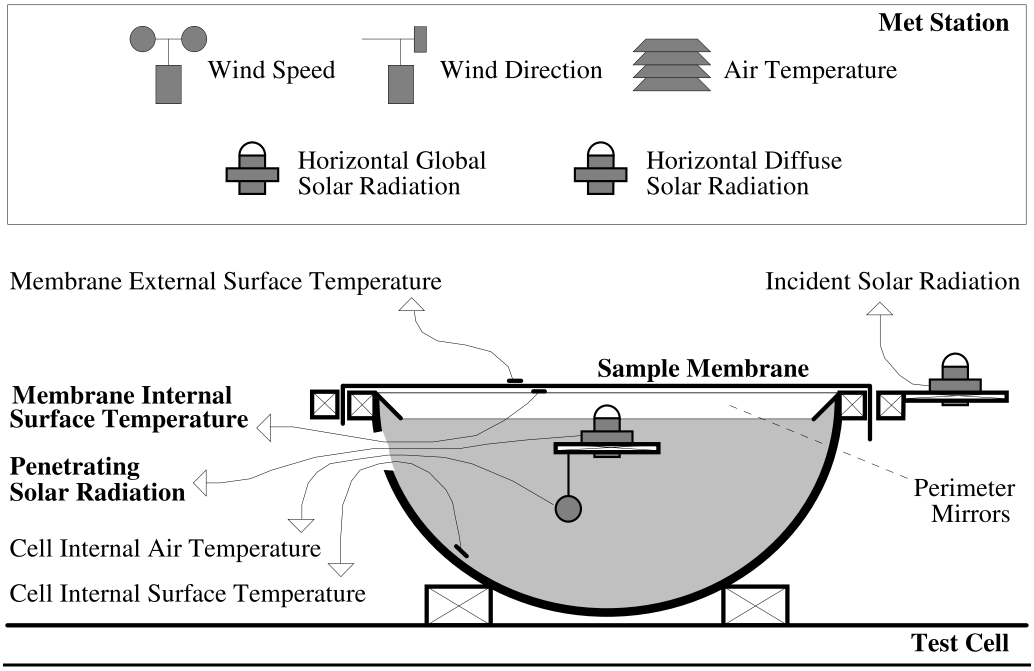
The ASTM design which was adopted was based on a 60cm diameter semi cylindrical box 60cm long. The resulting square face of the box was left open, and its inside surface was blackened so as to have a solar reflectance of less than 1%. A solarimeter was fixed to the inside of the box facing outwards, with the base of its thermopile positioned 50mm from the plane of the opening, and 50mm wide specular mirrors were placed around the perimeter of the box angled at 45^{o} to the face of the opening . The addition of these mirrors was intended to recreate the 180^{o} hemispherical view of the outside that the solarimeter would have had if it were not recessed from the plane of the opening.

A second solarimeter was then attached to the outside of the box facing in the same direction as the first, thus allowing both the solar radiation incident on the outside of the box and the intensity of solar radiation inside the box to be monitored. This meant that when a membrane sample was secured across the square opening of the box, the ratio of external to internal monitored solar radiation should have been indicative of the solar transmittance of the sample.

The test cell was placed on a circular base with angular markings around it, and a plumb line fixed to one of the semicircular sides of the box, allowing the inclination and azimuth of the test samples to be determined. This meant that when the position of the sun was known, the angle of incidence of direct beam solar radiation could be calculated, and so on clear days it should have been possible to calculate the angular solar transmittance of the test samples.

In order to adapt this basic configuration for the purposes of this research, the environmental conditions surrounding the membrane samples, and the two surface temperatures of the membrane samples were also monitored as illustrated below.

Figure 5:2.3 Schematic Illustration of the Components of the Test Cell and the Associated Meteorological Station.



- *List of test cell sensors.*
- A reference solarimeter for measuring the intensity of incident solar radiation, calibrated to output 1mV for every 94.14W/m^2 of solar radiation.
- A solarimeter for measuring the intensity of internal transmitted solar radiation, calibrated to output 1mV for every 104.78W/m^2.
- A shielded Type U, Y.S.I thermistor bead for measuring the internal air temperature, calibrated to give a resistance of 2000Ω at 25^{o}c.
- Three Type K Chromel Alumel thermocouples for measuring the surface temperatures of the membrane and the internal surface temperature of the test cell. These gave a voltage output based on the difference in temperature between the thermocouple and the reference junction at which the voltage was recorded such that:-

Actual Temp = {[Junction Temp / 24.82593] + [Voltage (mv)]} × 24.82593 [2]

- *List of meteorological station sensors.*
- A Shielded Type U, Y.S.I thermistor bead for measuring the external air temperature, calibrated to give a resistance of 2000Ω at 25^{o}c.

- A pulse count Porton Anemometer for measuring wind speed, calibrated so that every 47.3 rotations of the rotor per minute represented the passage of one meter of air per second.
- A Vector Instruments W200G Encoder Windvane for measuring wind direction. This was based on a sixteen sector mean switch output, producing an increasingly accurate average direction over successive readings.
- A solarimeter for measuring the intensity of horizontal global solar radiation, calibrated to output 1mV for every 72.84W/m^2.
- A solarimeter with an adjustable shadowband for measuring the intensity of horizontal diffuse solar radiation, calibrated to output 1mV for 77.03 W/m^2. This was corrected to account for the diffuse component of solar radiation which was obscured by the shadowband itself using the simple Robinson shadow band correction factor (C_f):-

$$C_f = \frac{1}{1 - \left[\left(\frac{2b}{\pi r}\right)\cos(d)\left[\sin(\phi)\sin(d\theta_h) + \cos(\phi)\cos(d)\sin(\theta_h)\right]\right]}$$ [3]

where r is the radius of the shadowband ring, b is the width of the shadowband ring, ϕ the latitude of the test cell, d the solar declination and θ_h the hour angle (defined in Chapter 7).

5:2.4 **The Choice of Membranes to be Examined.**

The ultimate purpose of studying the thermal behaviour of fabric membranes was so that the resultant thermal behaviour of spaces enclosed by such membranes could be investigated in a more informed way than had previously been possible. This meant that for the purposes of this research it was only strictly necessary to investigate the thermal behaviour of those fabric membranes which formed the external envelopes of the spaces investigated. For this purpose four buildings where chosen, three of which had previously been monitored during the pilot studies:-

- Landrell Fabric Engineering, Factory Space.
- The Royal International Eisteddfod Pavilion, Main Arena.
- The Cheriton Passenger Terminal, Administration and Amenities Building.
- The AELTC Indoor Tennis Centre, Covered Courts.

The reasons for the choice of these particular spaces and detailed descriptions are explained in Chapter 8, however there were problems associated with thermal analysis of three out of the four membranes as described overleaf.

- The Factory Space of Landrell Fabric Engineering was enclosed by an obscure membrane combination which had since gone out of production.
- A sample of the Eurotunnel membrane was not made available by the manufacturers.
- Only a small sample of the Wimbledon membrane could be obtained which was not large enough to cover the test cell opening.

This left only the Eisteddfod Arena membrane for which it was possible to obtain a large sample of any quality.

These problems meant that it was necessary to examine the behaviour of a range of widely used fabric membranes in order to gain a representative impression of their characteristic thermal behaviour. It was then be possible to draw some general findings from the recorded data which could be used to suggest the likely behaviour of those materials which were unavailable for testing.

The fabric membranes monitored with the test cell therefore included the Eisteddfod Arena membrane, and a number of the standard range of membrane types previously discussed in Chapter 2. The investigation concentrated on PVC coated polyester membranes because of the difficulties caused by the bleaching of PTFE on exposure to solar radiation which will be discussed further throughout the course of the thesis. The basic range however included:-

- Type 1 PVC coated polyester, gauge 0.6mm.
- Type 2 PVC coated polyester, gauge 0.7mm.
- Type 3 PVC coated polyester, gauge 0.85mm.
- Type 4 PVC coated polyester, gauge 1.1mm.
- Eisteddfod Arena PVC coated polyester, (Clyde Canvas), gauge 0.7mm.
- PTFE coated glass (new), Verseidag Indutex Type B, gauge 0.75mm.

Other than the Eisteddfod Arena membrane, all of these samples were obtained from Landrell Fabric Engineering.

5:3. MEMBRANE BEHAVIOUR RECORDED USING THE TEST CELL.

5:3.1 **Data Collected Using the Test Cell.**

The test cell was positioned on the roof of the UWCC Bute Building locating it at an altitude of 30m, longitude 3.183^{o}W and latitude 51.483^{o}N. This placed it alongside the existing meteorological station, on a fairly exposed site where it had a relatively clear view of the horizon. Monitoring could begin as soon as the test cell was positioned, without necessarily waiting for it to achieve a cyclic steady state as the behaviour of the test cell itself was of no particular concern, only the thermal state of the membrane relative to it.

The intention was to compile as comprehensive and varied a range of data as possible, and for this purpose the test cell was monitored every minute for a total of more than 90 hours. In order to ensure that analysis concentrated on only the most accurately collected, and representative data however, six of the monitored periods were chosen which it was considered most comprehensively illustrated the observed characteristic behaviour. All analysis and validation work presented hereafter in this thesis refers to the 3183 time steps represented by those six monitored periods, as listed below.

Figure 5:3.1a List of The Test Cell Data used for Analysis and Validation Purposes.

Fig 5:3.1	**Date**	**Start Time**	**Stop Time**	**Membrane Type**	**Inclination Angle**	**Azimuth Angle**
b	16/9/94	10:19	13:58	Type 1	59.2	47.6 E of S
c	20/9/94	10:30	15:37	PTFE	60.5	46.3 E of S
d	10/10/94	10:05	16:40	Type 2	66.9	40.8 E of S
e	16/12/94	9:46	15:59	Type 3	0^{o}	n/a
f	10/4/95	9:44	17:12	Eisteddfod	0^{o}	n/a
g	n/a	2/5/95	5/5/95	Type 4	0^{o}	n/a

Some of the behaviour and conditions recorded during these periods are presented chronologically overleaf. Because of the construction of the test cell, it could only be used under dry conditions, and this explains why the duration of the monitored time periods illustrated varies. The last time the test cell was used however, it no longer mattered if it became damaged, and so behaviour was monitored for three complete days, one of which is illustrated by Figure 5:3.2e.

A great number of environmental parameters were monitored, and to present all of them would have produced confusing graphs. In order to retain as much clarity as possible therefore, only the internal and external air temperature, the internal surface temperature of the membrane sample, and the intensity of incident solar radiation are illustrated. The final graph however also includes the external surface temperature of the membrane. The reasons this are explained in the next parts of this section, along with a general analysis of the data presented.

Figure 5:3.1b Test Cell Data: Type 1 PVC Coated Polyester.

16/9/94. Inclination **59^{o}** from Horizontal, Azimuth **47.5^{o}** East of South.

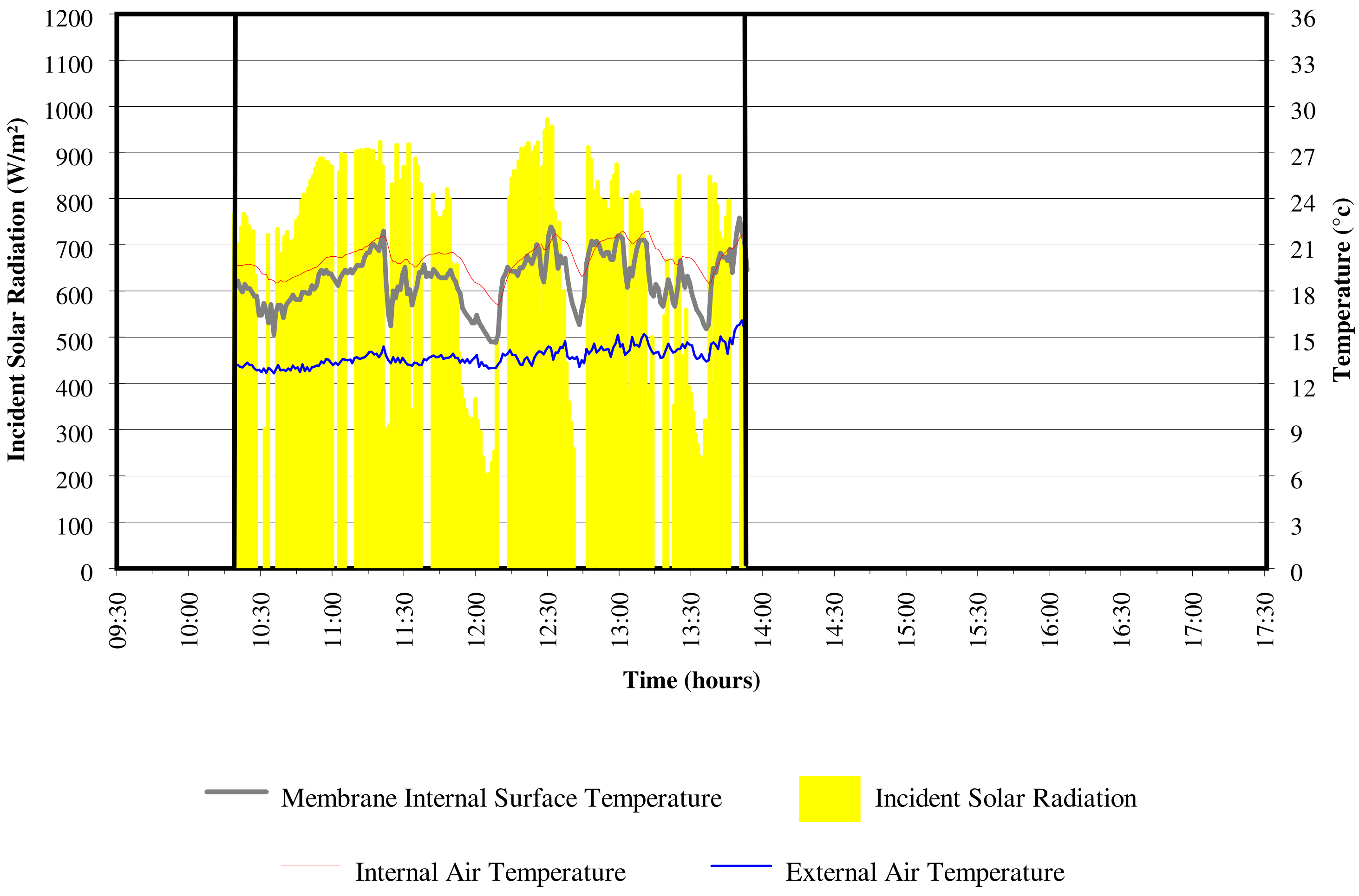


Figure 5:3.1c Test Cell Data: PTFE coated glass (new).

20/0/94. Inclination **60.5°** from Horizontal, Azimuth **46.3°** East of South.

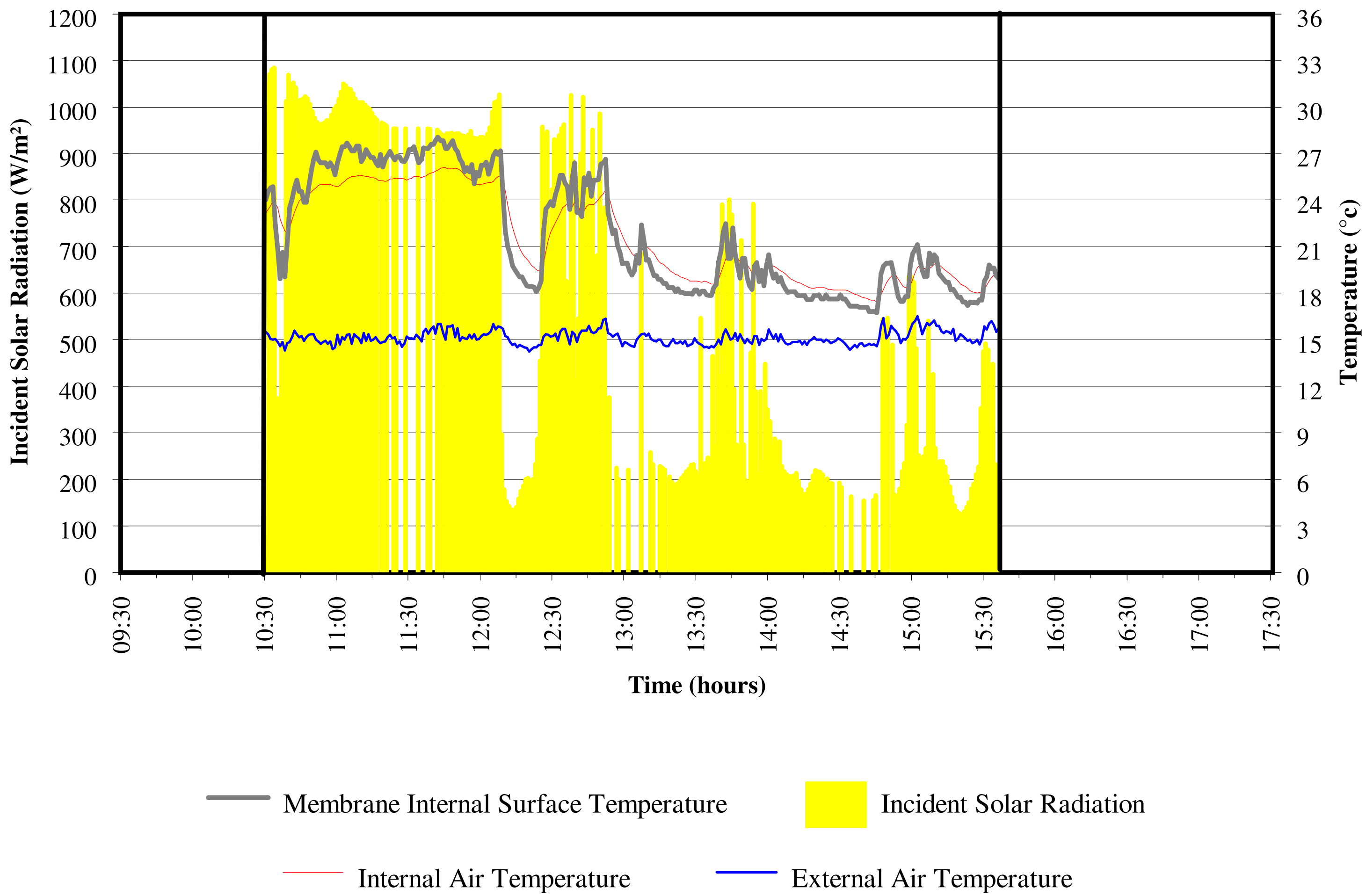


Figure 5:3.1d Test Cell Data: Type 2 PVC Coated Polyester.

10/10/94. Inclination **67°** from Horizontal, Azimuth **41°** East of South.

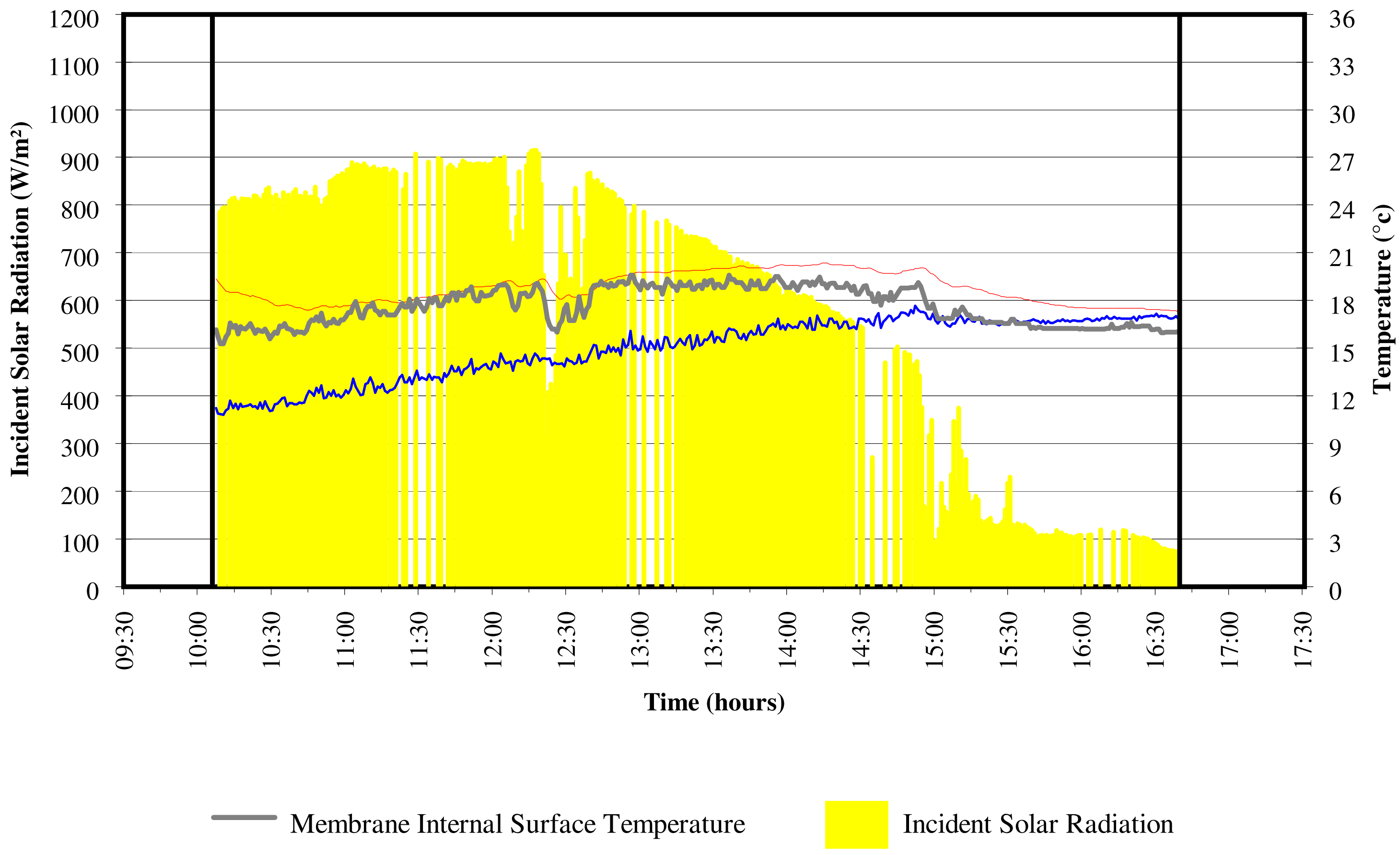


Figure 5:3.1e Test Cell Data: Type 3 PVC Coated Polyester.

16/12/94.Inclination **0^o** from Horizontal, Azimuth **n/a.**

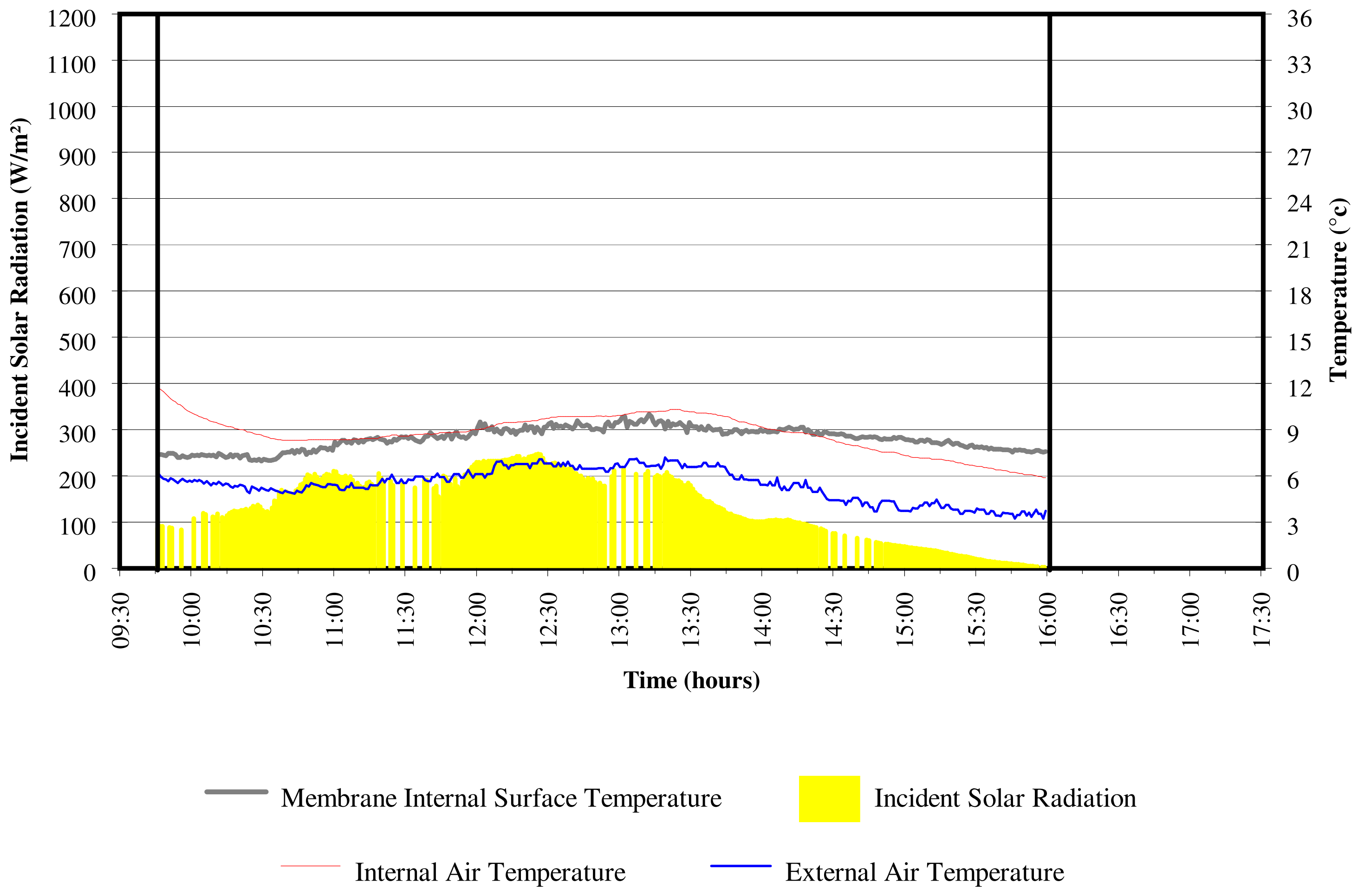


Figure 5:3.1f Test Cell Data: Eisteddfod Arena Membrane (PVC Coated Polyester).

10/4/95. Inclination **0^{o}**, ***Azimuth*** *n/a.*

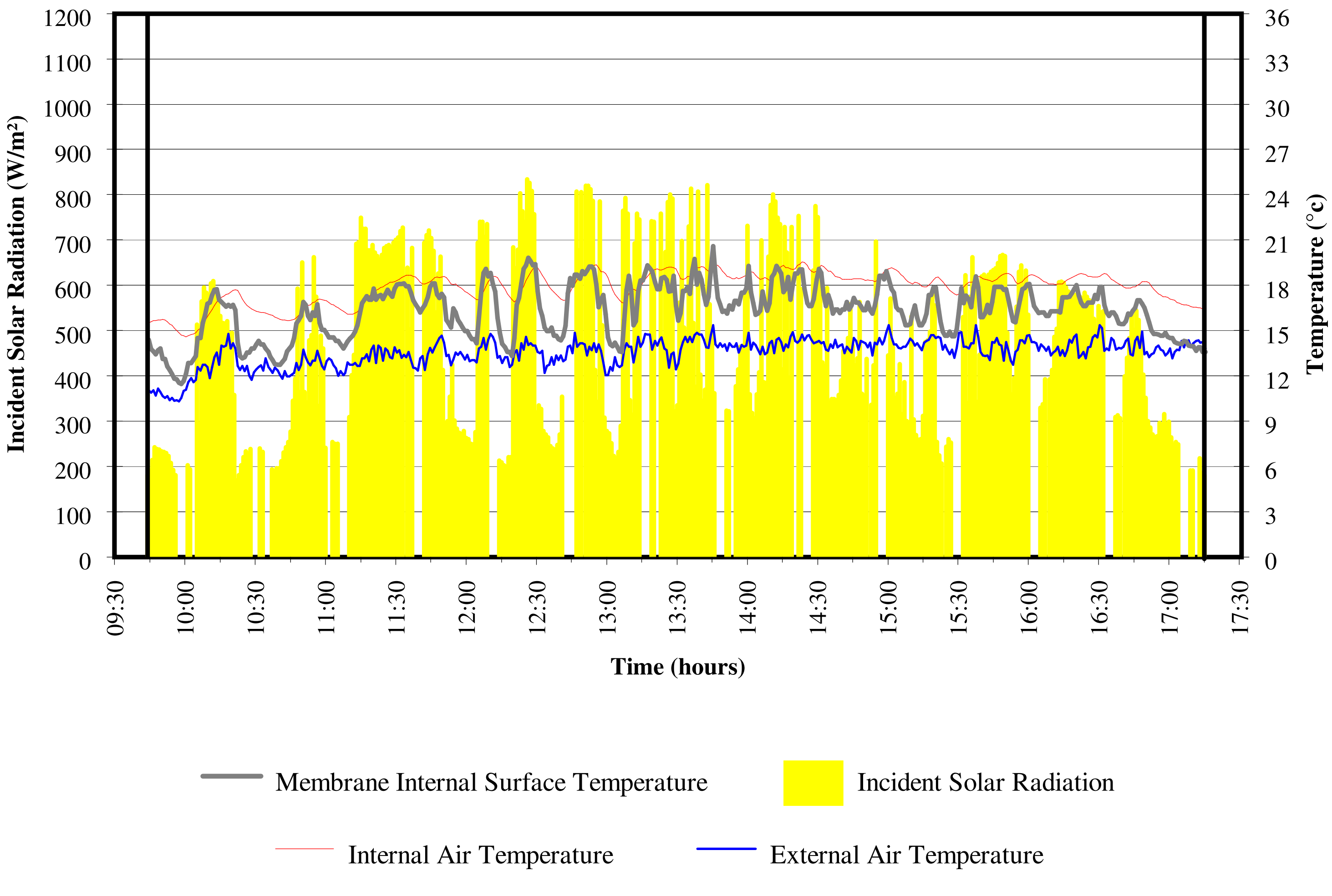
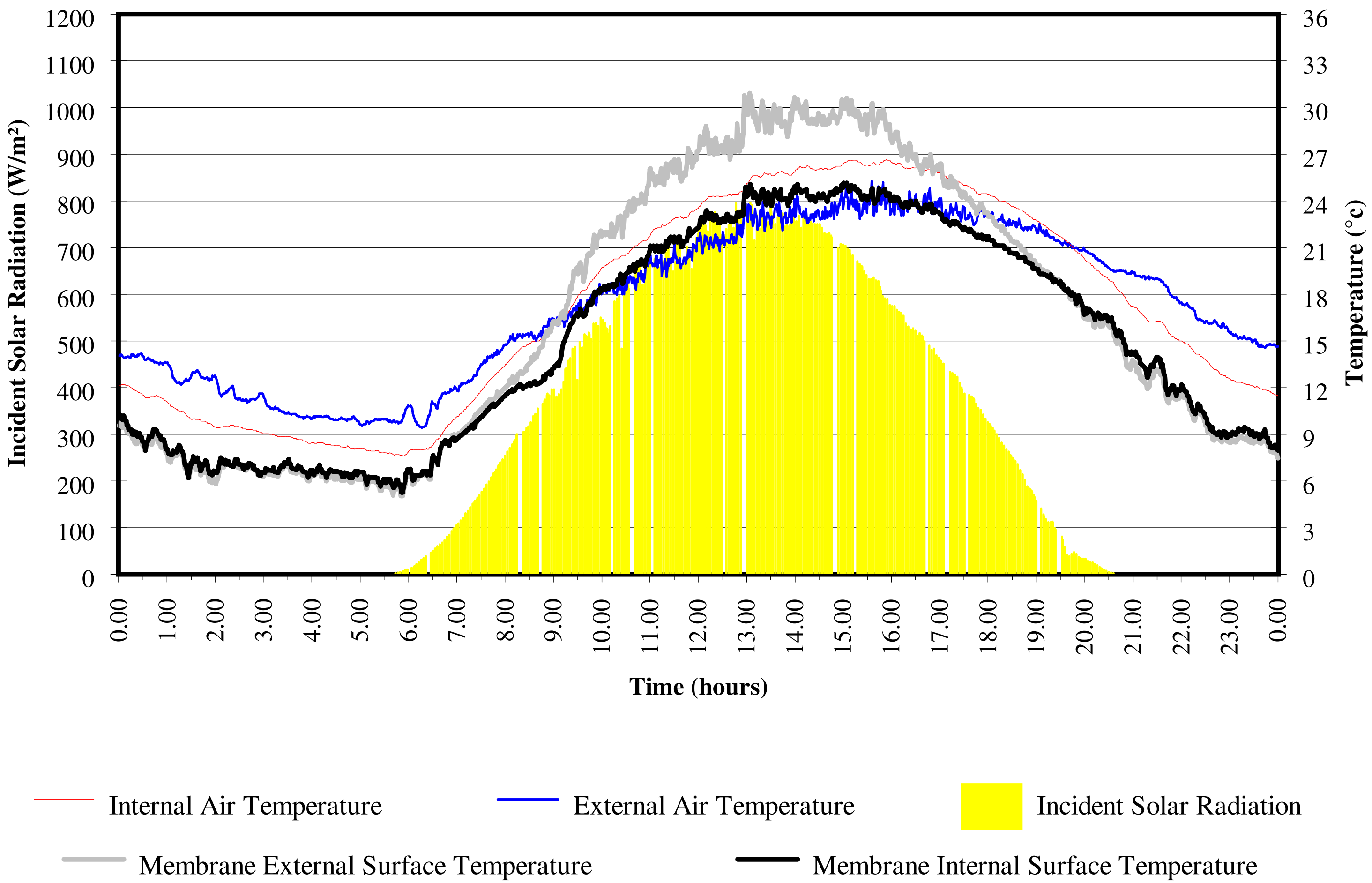


Figure 5:3.1g Test Cell Data: Type 4 PVC Coated Polyester.

3/5/95. Inclination **0º** from Horizontal, Azimuth **42º** East of South.



In the rest of this section, the data presented in the above graphs is analysed in order to determine which of the properties of fabric membranes it is necessary to quantify in order to properly explain their thermal behaviour. This is done according to the basic heat transfer categorisation previously identified in Section 5:2.2:-

- Intra surface conduction.
- Surface convection.
- Surface long wave infra red radiation exchange.
- Solar radiation absorption.
- Transmitted external solar radiation and reflected internal solar radiation.

5:3.2 **Intra Surface Conduction.**

In order to properly assess the rate at which variations in conditions at one surface of the membrane were able to transmit to the other, both internal and external membrane surface temperatures were recorded. *Figure 5:3.1g* above illustrates both the surface temperatures of the thickest membrane investigated.

The significant differences between the recorded values had not been expected, and for this reason, it was considered necessary to re-assess the conduction process as a whole:-

Conduction is a transient process describing how '*...a fluctuation of heat at one boundary of a solid material finds its way to another, being diminished in magnitude due to material storage and shifted in time.*'[4]. The transient conductivity of a material is dependent upon its *density*, *specific heat capacity* and *conductivity:-*

- *Density* refers to the mass of a material per unit volume. The density of membrane samples is generally provided in manufacturers information, and typically ranges from 1100 to 1600 kg/m^3, however, because of the thickness typical of fabric membranes, this usually results in a weight per unit area of around 0.8 to 1.5kg/m^2.
- *Specific heat capacity* refers to the heat required to raise a unit mass of a substance by a unit temperature interval under specified conditions. Moseley proposed that the specific heat capacity of a 1mm PVC coated polyester membrane was 200J/kg^{o}c[5].
- C*onductivity* describes the rate of heat flow normally through a substance per unit area. Typically, the steady state U-values quoted by membrane manufacturers are calculated based on the sum of the membrane core resistance, and standard values representative of the thermal resistance of its internal and external surfaces. The core resistance values used for this purpose generally range from 150 to 300W/m^{2o}c depending on the thickness of the membrane.

These properties are related by the concept of *thermal diffusivity:-*

diffusivity = conductivity / (density × specific heat capacity) [6]

When heat conducts very rapidly from one surface of a material to another, it is said to have a high *thermal diffusivity*. This suggests that the material has little thermal mass, and it is often reasonable in such cases to assume that its conductivity can be accurately investigated using steady state techniques[7].

From a material's thermal diffusivity, it is possible to calculate its *time lag*. This represents the likely time delay between the impact of a temperature fluctuation on the outside surface of the material and the resultant fluctuation of its internal surface temperature. This will vary depending on the type of fluctuation being studied, however the time lag of a material to a 24 hour periodic heat fluctuation may be calculated using the standard equation below, and this may be considered indicative the significance of the thermal mass of a material.

$$\varnothing = 1.38\ g \sqrt{(1 / \text{diffusivity})}$$ [8]

where ∅ is the time lag in seconds and g is the thickness of the material in mm.

The limited range of conductivities, densities and specific heat capacities of fabric membranes produce relatively low values of thermal diffusivity, however their small cross section resulted in very small time lags which of less than a minute. This compares to 25 minutes for a 25mm wooden board, and up to around 5 hours for a single leaf brick wall [9].

This very short delay implied that for most practical purposes, it was reasonable to assume the thermal mass of fabric membranes was insignificant, and so their conductivity could be adequately represented using steady state analysis techniques. This suggested that it was not necessary to quantify the specific heat capacity or density of fabric membrane in order to accurately predict their thermal behaviour.

In general the monitored data seemed to agree with these assumptions. It was seen that the temperature of the internal surface of the membrane samples could change by as much as 5^{o}c in a minute (*Figure 5:3.2b*) and there was no significant delay between the thermal response of the internal and external surfaces of the membranes. The theoretical analysis described above however also suggested that there should not have been any significant difference between internal and external surface temperatures of the membranes investigated.

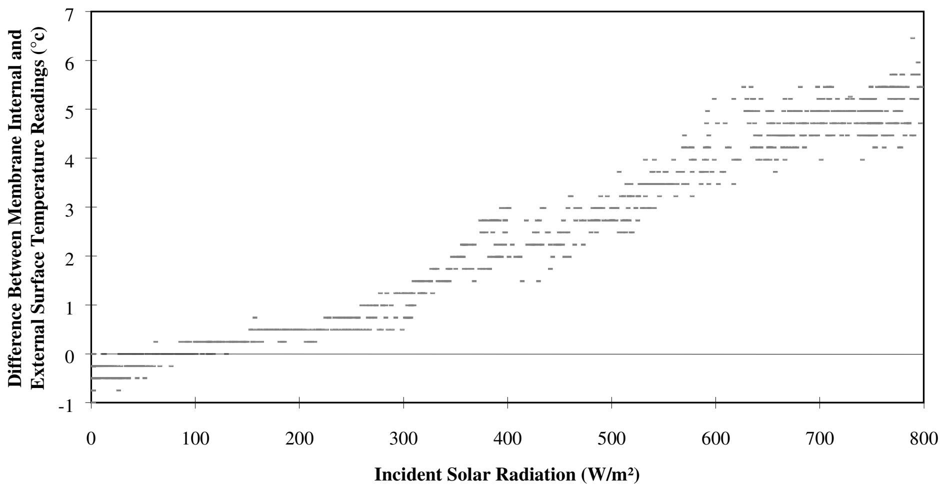
In fact *Figure 5:3.2g* clearly shows that significant differences between the internal and external membrane surface temperatures were recorded. During bright sunshine the thermocouple attached to the external surface of the thick type 4 PVC coated polyester membrane recorded temperatures as much as 6.5^{o}c hotter than those recorded at the internal surface, and on clear nights the external surface thermocouple recorded temperatures as much as 1.1^{o}c cooler than the thermocouple on the inside surface.

It did not seem possible that differences of this magnitude could be generated by the mass of the membranes themselves, and so it seemed more likely that they resulted from a measurement inaccuracy.

Measuring surface temperatures at all proved difficult. There were physical problems associated with attaching sensors to the surfaces of fabric membranes because of their slightly rough and non stick nature, but more importantly the thermal properties of the sensor itself appeared to affect the conditions they recorded. In affect, the thermocouples were monitoring their own temperature, not the temperature of the membrane surface. Whilst steps could be taken to try and ensure that the temperature of the thermocouples was fairly close to those of the membrane surfaces, it was unlikely to be exactly the same.

Typically, the high solar absorptance and low emissivity of the chromel alumel thermocouples, meant that they were likely to heat up more under the influence of solar radiation than other materials. This meant that under bright solar radiation, the more exposed external surface temperature sensor was likely to record temperatures higher than the internal surface sensor, whilst at night it was likely to cool down faster and more significantly. The graph below clearly illustrates these effects, and data recorded from other membrane types agreed with this basic trend.

Figure 5:3.2 Diagram to Show the Relationship Between the Difference in Temperatures Recorded at the Internal and External Surfaces of a Type 4 PVC Coated Polyester Membrane, and the Intensity of Solar Radiation Incident on its External Surface (03/05/95).



It seemed likely that the internal surface temperature reading was more representative of the temperature of the membrane than the external sensor as it was generally less exposed to severe external conditions. As this was also the surface which actually affected the behaviour of the enclosed space, it seemed reasonable that the research presented in the rest of this thesis should concentrate on these *internal surface temperature* readings.

In light of these difficulties however the boundary model described in Chapter 7 was developed so as to predict the thermal behaviour of fabric membranes based on two independent surface temperatures linked by a core conductance. This allowed the theoretical extent of the thermal gradient across the membrane to be more accurately assessed.

5:3.3 Surface Convection.

Convection describes the exchange of heat between a surface and air close to it as a result of a temperature difference between them. The only material property which may significantly affect the rate at which heat is exchanged by convection is the *roughness* of the surface[10]. Within the built environment, the relatively large area of most building surfaces, and their generally smooth finish means that it is usually acceptable to consider that they have a roughness of zero[11].

With a total cross section typically less than a millimetre, and with smooth surface coatings, it was not considered that fabric membranes would be an exception to this general rule.

5:3.4 Surface Long Wave Infra Red Radiation Exchange.

The amount of long wave infra red radiation which a surface of known temperature will emit to its surroundings is determined by its *emissivity*.

It was clearly seen from *Figure 5:3.1g* that the internal surface temperature of fabric membranes could drop to as much as 3^{o}c below both the internal and external air temperatures during the night as a result of long wave infra red radiation exchange with the clear sky. During the day, it proved more difficult to separate the effects of long wave radiation from those of solar radiation, however solar absorption probably resulted in the membrane samples becoming relatively hotter than their surroundings, and so long wave infra red radiation losses were likely to increase still further.

This meant that in order to accurately predict the internal surface temperature of the membranes studied, it was necessary to accurately determine their surface emissivities.

5:3.5 Solar Radiation Absorption.

The affect of solar radiation on the internal surface temperature of the membrane samples investigated was clearly noticeable during all of the monitored periods studied. It can be seen from *Figure 5:3.2c* that varying intensities of solar radiation incident upon the membrane caused its internal surface temperature to fluctuate quickly and significantly despite the relatively constant external air temperature. The internal surface temperature of the membranes became over 12^{o}c hotter than the external air temperature during periods of bright sunshine, and temperatures of over 35^{o}c were not uncommon.

Quantifying this relationship in the way that Moseley did however[12], proved impossible because of the tendency for solar radiation to also cause the external air temperature and the temperature of the test cell itself to increase. This meant that it was extremely important to accurately quantify the actual solar absorptance of the membranes studied in order that their internal surface temperatures could be predicted.

5:3.6 Transmitted External Solar Radiation and Reflected Internal Solar Radiation.

Figure 5:2.2d identified two mechanisms by which the fabric membrane samples may direct solar radiation into the test cell:-

- Transmitted external solar radiation.
- Reflected internal solar radiation.

Because the inside of the test cell had a solar reflectance of less than 1% however it should have been possible to isolate the first of these mechanisms for detailed investigation.

The programme of thermal monitoring could be carried out under any conditions, and indeed as wide a variety of conditions as possible was desirable in order to provide comprehensive data. The ASTM however recommended that the transmittance method itself only be used up to incident angles of 60^{o}, and only on days '...*with no cloud cover within* 45^{o} *of the sun and a minimum solar irradiance of* $700W/m^{2}$ *and constant to within 1% during the individual tests...no more than 3h before or after solar noon'.*[13]

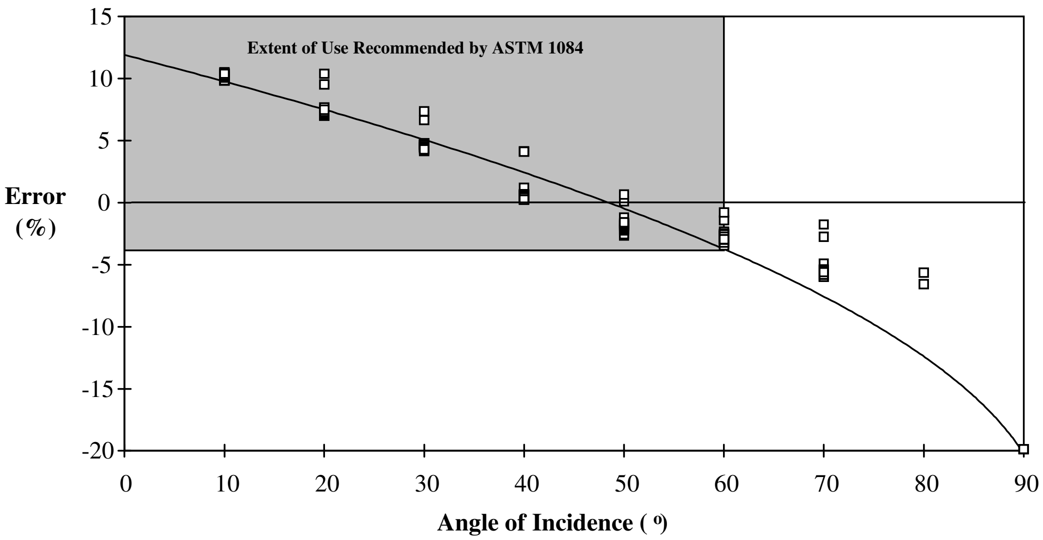
An attempt was made to calibrate the two solarimeters attached to the test cell under such conditions in order to account for any potential bias within its construction. This was done by varying the angle of the test cell relative to the sun, but with no test sample covering the open aperture. Both the solarimeter inside the test cell and the solarimeter attached to the outside should have recorded the same intensities of solar radiation, however this proved not to be the case because of two serious inaccuracies inherent in the method:-

- Firstly, the angled mirrors at the perimeter of the test cell aperture caused specular solar radiation to be focused directly onto the internal solarimeter. This increased the intensity of direct beam solar radiation incident on the internal solarimeter compared to that recorded by the external solarimeter. These errors were as much as 12.5% at near normal angles of incidence.

- Secondly, because the internal solarimeter was slightly recessed within the test cell, it tended to underestimate the intensity of incident diffuse solar radiation by as much as 4%, even within the 60^{o} maximum angle of incidence recommended by the ASTM method.

The significance of these errors can be clearly seen on the diagram below. The shaded box in the top left hand corner represents the extent of use recommended by the ASTM, the small squares illustrate the actual errors recorded by the test cell, and the curved line indicates the extrapolated trend of this data.

Figure 5:3.6 Diagram to Show the Relationship Between the Angle Incidence of Solar Radiation Striking the Test Cell, and the Inaccuracy of the Solar Intensity Recorded by the Internal Solarimeter.



If the perimeter mirrors had been removed, the 50mm recess of the thermopile base form the plane of the sample would have reduced the effective view that the solarimeter had of the sample from 180^{o} to approximately 157^{o}[14]. Whilst this would have little affect on the recorded transmittance of perfectly specularly transmitting materials such as glass, it could cause a significant error when applied to diffusely transmitting membranes.

It was decided therefore that the procedure described by ASTM E 1084 - 86 was inappropriate for accurately measuring the angular solar transmittance of sheet materials. For this reason the test cell was disregarded as a means of recording the intensity of solar radiation directed into a space by fabric membranes.

In the next chapter, an alternative approach is described which was used to measure the actual angular solar optical properties of the membrane samples. This allowed the intensity of solar radiation within the spaces they enclosed to be calculated.

5:4. CONCLUSION.

In this chapter, an investigation was described which had two fundamental purposes:-

- To determine which of the thermal properties of thin fabric membranes could significantly affect their thermal behaviour.
- To provide a comprehensive data set with which the accuracy of a model developed in order to simulate that behaviour might be tested.

It was proposed that the behaviour of fabric membranes can only affect the thermal conditions within the spaces which they enclose through the quantity of solar radiation which they directed into it, and by their internal surface temperature.

A test cell was constructed which was intended to allow the internal surface temperature, and the solar transmittance of a range of membrane samples to be monitored under a variety of known environmental conditions. The solar transmittance measurements obtained using this method however proved unreliable and so the test cell could only be used in order to investigate the internal surface temperatures of the membrane samples.

The internal surface temperature of the samples investigated was seen to change significantly and rapidly as a result of variations in external conditions. This appeared to result from their low thermal mass which meant that they had little thermal storage capacity or thermal resistance and resulted in exceptionally '*dynamic*' behaviour patterns which were difficult to quantify empirically.

Because of this low thermal mass, it appeared that in order to be able to accurately predict their internal surface temperature, it is only necessary to determine their *solar absorptance* and their *long wave infra red radiation absorptance* (emissivity). To predict the quantity of solar radiation directed into a space by these fabric membranes however it was also necessary to determine their *solar reflectance* and *solar transmittance*.

The measurement of these properties is described in the next chapter, and in Chapter 7 the development of a model which could be used to simulate the thermal behaviour of fabric membranes is explained. The accuracy of this model is then tested against the monitored data presented in this chapter.

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