AN INVESTIGATION INTO THE THERMAL BEHAVIOUR OF SPACES ENCLOSED BY FABRIC MEMBRANES

A thesis
submitted to the
University of Wales
for the degree of
Philosophiae Doctor

by

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March 1996

SUMMARY.

This thesis describes a programme of research the aim of which was to investigate the thermal behaviour of spaces enclosed by fabric membrane envelopes.

Initial analysis of the overall situation suggested that a fabric membrane can affect conditions within a space enclosed by it as a result of its internal surface temperature and the amount of thermal radiation it directs into that space. In order to investigate these two parameters, a test cell was constructed which allowed the thermal behaviour of a range of fabric membranes to be monitored.

The monitored data revealed that the thermal behaviour of fabric membranes is only significantly affected by their angular thermal optical properties. These properties were then measured and a dynamic spread sheet model was developed which was able to simulate the monitored behaviour fairly accurately.

In order to investigate the thermal behaviour of spaces enclosed by such membranes, conditions within four existing fabric roofed buildings were monitored. The monitored data revealed that comfort temperatures could vary significantly from place to place within such spaces. These variations were produced by both the stratification of internal air temperatures and differences in internal radiant temperatures.

An attempt was made to simulate the behaviour of the buildings monitored, using a general applications CFD code in conjunction with information generated by the spread sheet model. Whilst simple behaviour patterns could be simulated accurately using this approach, it was apparent that over simplistic boundary specification options left the CFD code unable to accurately predict strong internal stratification.

It was proposed that improving the reliability of this process would require the development of a more holistic CFD model which should be able to accurately predict the thermal behaviour of fabric membranes itself.

CONTENTS.

LIST OF FIGURES.

5: MONITORING THE THERMAL BEHAVIOUR OF FABRIC MEMBRANES......57

6: MEASURING THE THERMAL PROPERTIES OF FABRIC MEMBRANES......80

ACKNOWLEDGEMENTS.

Roger Ambrose, The All England Lawn Tennis an Croquet Club.
Mike Barnes, City University.
Carolyn Brindle, Royal International Eisteddfod Pavilion,
Anne Frith, Imagination Ltd.
Paul Gibbins, Building Design Partnership,
Chris Harding, Eurotunnel.
Ian King, Ian King Architects.
Professor Phil Jones, UWCC.
Dr Peter Lewis, UWCC.
Peter Moseley, Buro Happold.
James Newman Jr, Birdair Inc.
Eric Newton, John Heathcoat & Co.
Monotobu Nohmura, Taiyo Koygo Corporation.
Professor Derek Poole, UWCC.
Norman Robson-Smith, UWCC.
Lance Rowell, Landrell Fabric Engineering.
Dr Chris Williams, University of Bath.

DECLARATION AND STATEMENT.

Declaration.

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Statement 1.

This thesis is the result of my own investigations, except where otherwise stated.
Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Statement 2.

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed ....(Candidate)

Date ....

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LIST OF SYMBOLS.

Symbol	Description	Units
A	Area	m^2
A_s	Solar altitude	^{o}
A_z	Solar azimuth	^{o}
A_w	Azimuth of surface normal	^{o}
b	Shadowband ring width	mm
C_{core}	Core conductivity	$W/m^{2o}c$
C_{core1}	External membrane core conductivity	$W/m^{2o}c$
C_{core2}	Internal membrane core conductivity	$W/m^{2o}c$
C_f	Robinson's shadowband correction factor	ratio
D	Cloudy sky horizontal diffuse solar radiation	W/m^2
d	Solar declination	^{o}
E_{ot}	Equation of time	ratio
F	Solar heat gain coefficient	ratio
F_ε	Emissivity factor	ratio
G	Theoretical clear sky horizontal global solar radiation	W/m^2
g	Gauge	m
g_1	External membrane gauge	m
g_2	Internal membrane gauge	m
H	Horizontal global solar radiation	W/m^2
H_a	Incident clear sky long wave infra red radiation	W/m^2
H_{ac}	Horizontal clear sky long wave infra red radiation	W/m^2
h	Elevation	km
h_{ci}	Inside surface convection heat transfer coefficient	$W/m^{2o}c$
$h_{ci(i)}$	Inclined surface convection heat transfer coefficient	$W/m^{2o}c$
h_{co}	Outside surface convection heat transfer coefficient	$W/m^{2o}c$
h_i	Inside surface thermal resistance	$W/m^{2o}c$
h_o	Outside surface thermal resistance	$W/m^{2o}c$
h_{ri}	Inside surface radiant heat transfer coefficient	$W/m^{2o}c$
h_{ro}	Outside surface radiant heat transfer coefficient	$W/m^{2o}c$
I	Incident solar radiation	W/m^2
I_d	Incident direct beam solar radiation	W/m^2
I_{dhl}	Theoretical clear sky direct horizontal solar radiation	W/m^2
I_{dn}	Direct normal solar radiation	W/m^2
I_{dnl}	Theoretical clear sky direct normal solar radiation	W/m^2
I_{et}	Normal extraterrestrial solar radiation	W/m^2
I_f	Incident diffuse solar radiation	W/m^2

Comment [J1]: Page: 23

I_{fhl}	Theoretical clear sky diffuse horizontal solar radiation	W/m^2
I_{sc}	Solar constant	W/m^2
I_{sc1}	Corrected solar constant	W/m^2
I_{sf}	Incident sky diffuse solar radiation	W/m^2
$I_{\delta(ext)}$	Remaining external incident solar radiation at depth δ	W/m^2
$I_{\delta(int)}$	Remaining internal incident solar radiation at depth δ	W/m^2
i	Angle of incidence	o
K_{ext}	External incident radiation extinction coefficient	W/g
K_{int}	Internal incident radiation extinction coefficient	W/g
K_{λ}	Extinction coefficient at wavelength λ	W/g
K_t	Clearness index	ratio
L	Characteristic length	m
m	Air mass	ratio
N	Cloudiness index	ratio
P_{λ}	power distribution of a full radiator at 283^{o}K	W/λ
Q_{sol}	Solar heat gain	W/m^2
Q_{mem}	Boundary heat transfer	W/m^2
q	Net power exchange	W
q_{condi}	Net internal surface conductive heat transfer	W/m^2
q_{condo}	Net external surface conductive heat transfer	W/m^2
q_{cvi}	Net internal surface convection exchange	W/m^2
q_{cvo}	Net external surface convection exchange	W/m^2
q_i	Net internal surface heat transfer	W/m^2
q_{lwi}	Net internal surface long wave infra red radiation exchange	W/m^2
q_{lwo}	Net external surface long wave infra red radiation exchange	W/m^2
q_o	Net external surface heat transfer	W/m^2
$q\rho_i$	Reflected direct beam solar radiation	W/m^2
$q\rho_f$	Reflected diffuse solar radiation	W/m^2
$q_{\rho(ext)}$	Reflected external incident solar radiation	W/m^2
$q_{\rho(int)}$	Reflected internal incident solar radiation	W/m^2
q_{τ}	Solar radiation directed into an enclosure	W/m^2
$q\tau_i$	Transmitted direct beam solar radiation	W/m^2
$q\tau_f$	Transmitted diffuse solar radiation	W/m^2
$q_{\tau(ext)}$	Transmitted external incident solar radiation	W/m^2
$q_{\tau(int)}$	Transmitted internal incident solar radiation	W/m^2
q_{α}	Absorbed solar radiation.	W/m^2
$q\alpha_i$	Absorbed direct beam solar radiation	W/m^2
$q\alpha_f$	Absorbed diffuse solar radiation	W/m^2
$q_{\alpha(int)}$	Absorbed internal incident solar radiation	W/m^2
$q_{\alpha(ext)}$	Absorbed external incident solar radiation	W/m^2

R	Thermal resistance	$m^2 {}^oc/W$
R_c	Core thermal resistance	$m^2 {}^oc/W$
R_s	Air gap thermal resistance	$m^2 {}^oc/W$
R_{si}	Inside surface thermal resistance	$m^2 {}^oc/W$
R_{so}	Outside surface thermal resistance	$m^2 {}^oc/W$
r	Shadowband ring radius	mm
SC	Shading Coefficient	ratio
SHGF	Solar Heat Gain Factor	W/m^2
S_t	Solar time	ratio
T	Surface temperature	${}^oc$
T_c	Turbidity coefficient	ratio
T_e	External hemisphere black body surface temperature	${}^oc$
T_{grd}	Ground temperature	${}^oc$
T_i	Internal surface temperature	${}^oc$
T_L	Atmospheric turbidity	unitless
$T_L(A_s)$	Solar altitude corrected turbidity	unitless
T_{max}	Maximum observed surface temperature	${}^oc$
T_{min}	Minimum observed surface temperature	${}^oc$
T_o	External surface temperature	${}^oc$
T_{obs}	Obstruction temperature	${}^oc$
T_{sky}	Equivalent black body sky temperature	${}^oc$
t_i	Inside air temperature	${}^oc$
t_{is}	Enclosure surface temperature	${}^oc$
t_o	Outside air temperature	${}^oc$
t_q	Equivalent enclosure surface temperature	${}^oc$
t_r	Radiant temperature	${}^oc$
t_{res}	Resultant temperature	${}^oc$
U	Thermal conductivity (U value)	$W/m^2 {}^oc$
V	Local surface velocity	m/s
V_f	Free stream wind speed	m/s
V_{grd}	Ground view factor	ratio
V_i	Internal air velocity	m/s
V_{obs}	Obstruction view factor	ratio
V_p	Parallel flow velocity	m/s
V_{sky}	Sky view factor	ratio
$v(0)$	Voltage at near normal angle of incidence	v
$v(i)$	Voltage at angle of incidence i	v
W	Precipitable water content	mm
Y	Day number	(1 - 365)

Symbol	**Description**	**Units**
α	Absorptance	ratio
$\alpha(0)$	Near normal solar absorptance	ratio
$\alpha_{(ext)}$	Solar Radiation absorbed by internal half of membrane	W/m^2
$\alpha_{(int)}$	Solar Radiation absorbed by external half of membrane	W/m^2
$\alpha(i)$	Hemispherical solar absorptance at angle of incidence i	ratio
$\alpha(f)$	Diffuse solar absorptance	ratio
α_{lw}	Long wave infra red absorptance	ratio
β	Inclination of surface from horizontal	^{o}
δ	depth	mm
ε_{ac}	Horizontal clear sky apparent emittance	ratio
ε_{am}	Horizontal cloudy sky apparent emittance	ratio
ε_{eq}	Equivalent emissivity	ratio
ε_h	Hemispherical emissivity	ratio
ε_i	Membrane internal surface emissivity	ratio
ε_{int}	Enclosed space emissivity	ratio
ε_n	Near normal emissivity	ratio
ε_o	Membrane external surface emissivity	ratio
ϕ	Latitude	^{o}
$\varnothing$	Time lag	seconds
λ	Wavelength	nm (μm)
θ_y	Day angle	^{o}
θ_h	Hour angle	^{o}
ρ	Reflectance	ratio
$\rho(0)$	Near normal solar reflectance	ratio
$\rho(f)$	Diffuse solar reflectance	ratio
$\rho(i)$	Hemispherical solar reflectance at angle of incidence i	ratio
ρ_{lw}	Long wave infra red reflectance	ratio
ρ_λ	Reflectance at wavelength λ	ratio
σ	Steffan- Boltzmann constant $5.6697 * 10^{-8}$	W/m^2K^4
τ	Transmittance	ratio
τ_{av}	Average solar transmittance of membrane.	ratio
$\tau(0)$	Near normal solar transmittance	ratio
$\tau(f)$	Diffuse solar transmittance	ratio
$\tau(i)$	Hemispherical solar transmittance at angle of incidence iratio	
τlw	Long wave infra red transmittance	ratio
$\tau\lambda$	Transmittance at wavelength λ	ratio