A STUDY ON THERMAL ENVIRONMENTAL PERFORMANCE IN ATRIA IN THE TROPICS WITH SPECIAL REFERENCE TO MALAYSIA

ABD HALID ABDULLAH

HERIOT-WATT UNIVERSITY
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by

Abd Halid Abdullah

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ABSTRACT

This research investigated the thermal environmental performance of atria in the tropics, with special reference to Malaysia. The main design problems that affect the thermal and energy performance in existing Malaysian atria are overlighting and overheating due to the direct application of western top-lit atrium roof form. As such, this research proposed the side-lit atrium form which aimed at controlling direct sunlight as a way to improve thermal and energy performance of atria in the tropics. Based on the proposed conceptual atrium form, this research examined quantitatively some of the low energy design features and ventilation strategies that can possibly contribute to a better indoor thermal environmental performance of atria in the tropics. The ultimate aim of this research is to propose design principles and guidelines for new low-energy atria in the tropics.

The combined research methods are as follows: developing a conceptual low energy atrium form based on the vernacular design features to be used for computer modelling studies; carrying out field measurement and monitoring on an existing atrium building which provides validation data for dynamic thermal simulation program TAS; modelling exercise on the same monitored building using dynamic thermal modelling to develop confidence in correctly modelling thermal stratification within the multi-level atrium; employing dynamic thermal modelling to model representative atrium forms (i.e. both side-lit and top-lit model) and examine quantitatively the effects of some of the key design parameters (i.e. wall-to-roof void area, roof overhangs, and internal solar blinds) on the thermal comfort and energy performance in atria due to both full natural ventilation and pressurised ventilation; and utilising computational fluid dynamics (CFD) to complement the dynamic thermal simulation results, and to investigate quantitatively the thermal and ventilation performance within the atrium well in response to the changes of design parameters (i.e. varying the inlet to outlet opening area ratio and outlet’s arrangement).

The research findings supported the research proposition and demonstrated the effectiveness of the side-lit form as a way to improve the thermal and energy performance with regard to users’ thermal comfort in atria in the tropics. The main findings from both dynamic thermal simulation and computational fluid dynamics (CFD) are as follows: full natural ventilation strategy is not viable for Malaysian atria; both sufficiently high wall-
to-roof void area and extending high-level internal solar blinds can greatly improve the 
atrium’s thermal performance particularly on occupied levels; sufficiently wide roof 
overhangs above the clerestory areas of the side-lit atrium form generally improves the 
thermal and energy performance within the central atrium throughout the year; reasonably 
comfortable thermal environment on occupied levels of a low-rise atrium can be achieved 
by only supplying cooler air at low-level with sufficient ventilation rate; sufficiently 
higher inlet to outlet opening area ratio can improve the thermal performance on the 
occupied levels; and with equal inlet and outlet opening area, changing the outlet’s 
arrangement (i.e. location and arrangement) would not significantly affect the atrium’s 
thermal performance.
For my parents, beloved wife and children.
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**GLOSSARY OF SYMBOLS**

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<td>$A_2$</td>
<td>Opening area of outlet (m$^2$)</td>
</tr>
<tr>
<td>$A_{ci}$</td>
<td>Area of the vena contracta for inlet (m$^2$)</td>
</tr>
<tr>
<td>$A_{c2}$</td>
<td>Area of the vena contracta for outlet (m$^2$)</td>
</tr>
<tr>
<td>$A_{du}$</td>
<td>DuBois area: body surface area of the human body (m$^2$)</td>
</tr>
<tr>
<td>$A_i$</td>
<td>The mean of the internal and external surface areas (m$^2$)</td>
</tr>
<tr>
<td>$C_{ci}$</td>
<td>Contraction coefficient for inlet</td>
</tr>
<tr>
<td>$C_{c2}$</td>
<td>Contraction coefficient for outlet</td>
</tr>
<tr>
<td>$C_d$</td>
<td>Discharge coefficient</td>
</tr>
<tr>
<td>$C_v$</td>
<td>Air velocity coefficient for inlet</td>
</tr>
<tr>
<td>$C_{v2}$</td>
<td>Air velocity coefficient for outlet</td>
</tr>
<tr>
<td>$c_p$</td>
<td>Specific heat capacity at constant pressure of the fluid (=1010 J/kg.K)</td>
</tr>
<tr>
<td>$v_{theo,i}$</td>
<td>Theoretically obtained air velocity for inlet (m/s)</td>
</tr>
<tr>
<td>$v_{theo,2}$</td>
<td>Theoretically obtained air velocity for outlet (m/s)</td>
</tr>
<tr>
<td>$\Delta E_{p2}$</td>
<td>Friction loss due to airflow through the outlet (J/kg)</td>
</tr>
<tr>
<td>$\eta_d$</td>
<td>Ratio of man’s surface area while clothed to while nude</td>
</tr>
<tr>
<td>$g$</td>
<td>Gravitational acceleration (=9.82 m/s$^2$)</td>
</tr>
<tr>
<td>$G_i$</td>
<td>Internal radiant exchange between room surfaces (W/K)</td>
</tr>
<tr>
<td>$h_c$</td>
<td>Convective heat transfer coefficient (W/m$^2$K)</td>
</tr>
<tr>
<td>$h^{int}_c$</td>
<td>Internal convective heat transfer coefficient (W/m$^2$K)</td>
</tr>
<tr>
<td>$h^{ext}_c$</td>
<td>External convective heat transfer coefficient (W/m$^2$K)</td>
</tr>
<tr>
<td>$h^{rad,ext}_c$</td>
<td>External radiative heat transfer coefficient (W/m$^2$K)</td>
</tr>
<tr>
<td>$h^{rad,int}_c$</td>
<td>Internal radiative heat transfer coefficient (W/m$^2$K)</td>
</tr>
<tr>
<td>$H$</td>
<td>Vertical distance between the centre of inlet and the centre of outlet (m)</td>
</tr>
<tr>
<td>$H_1$</td>
<td>Vertical distance between the inlet and the neutral pressure plane (m)</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>$H_2$</td>
<td>Vertical distance between the outlet and the neutral pressure plane (m)</td>
</tr>
<tr>
<td>$I_d$</td>
<td>Thermal resistance of clothing ($m^2 \cdot K/W$)</td>
</tr>
<tr>
<td>$k$</td>
<td>Kinetic energy of turbulence ($m^2/s^2$)</td>
</tr>
<tr>
<td>$L$</td>
<td>Characteristic length of the heat transfer surface (m)</td>
</tr>
<tr>
<td>$M$</td>
<td>Metabolic rate ($W/m^2$)</td>
</tr>
<tr>
<td>$\dot{m}$</td>
<td>Mass flow rate (kg/s)</td>
</tr>
<tr>
<td>$n$</td>
<td>Opening area ratio ($= A_1/A_2$)</td>
</tr>
<tr>
<td>$p$</td>
<td>Radiant proportion</td>
</tr>
<tr>
<td>$p$</td>
<td>Static pressure ($N/m^2$)</td>
</tr>
<tr>
<td>$p_{i1}$</td>
<td>Indoor pressure at inlet (Pa)</td>
</tr>
<tr>
<td>$p_{i2}$</td>
<td>Indoor pressure at outlet (Pa)</td>
</tr>
<tr>
<td>$\Delta p_1$</td>
<td>Pressure difference across the inlet (Pa)</td>
</tr>
<tr>
<td>$p_{o1}$</td>
<td>Outdoor pressure at inlet (Pa)</td>
</tr>
<tr>
<td>$p_{o2}$</td>
<td>Outdoor pressure at outlet (Pa)</td>
</tr>
<tr>
<td>$\Delta p_2$</td>
<td>Pressure difference across the outlet (Pa)</td>
</tr>
<tr>
<td>$P_s$</td>
<td>Water vapour pressure in ambient air (millibar)</td>
</tr>
<tr>
<td>$P_w$</td>
<td>The screen water vapour pressure (millibar)</td>
</tr>
<tr>
<td>PMV</td>
<td>Predicted Mean Vote</td>
</tr>
<tr>
<td>PPD</td>
<td>Predicted Percentage Dissatisfied (%)</td>
</tr>
<tr>
<td>$q_{\text{cond,int}}$</td>
<td>Internal surface conduction heat flux ($W/m^2$)</td>
</tr>
<tr>
<td>$q_{\text{cond,ext}}$</td>
<td>External surface conduction heat flux ($W/m^2$)</td>
</tr>
<tr>
<td>$q_{\text{conv,int}}$</td>
<td>Internal convective heat flux ($W/m^2$)</td>
</tr>
<tr>
<td>$q_{\text{conv,ext}}$</td>
<td>External convective heat flux ($W/m^2$)</td>
</tr>
<tr>
<td>$q_{\text{dir,beam}}$</td>
<td>Direct normal (beam) solar radian intensity ($W/m^2$)</td>
</tr>
<tr>
<td>$q_{\text{dir,hor}}$</td>
<td>Direct solar radiation on the horizontal plane ($W/m^2$)</td>
</tr>
<tr>
<td>$q_{\text{ew}}$</td>
<td>Total long-wave incident on the surface from its environment ($W/m^2$)</td>
</tr>
<tr>
<td>$q^*_{\text{ew}}$</td>
<td>Long-wave radiant flux by the external surface ($W/m^2$)</td>
</tr>
<tr>
<td>$q_{\text{glob}}$</td>
<td>The global radiation incident on the horizontal plane ($W/m^2$)</td>
</tr>
<tr>
<td>$q_{\text{gsky}}$</td>
<td>Long-wave incident on the surface from the sky ($W/m^2$)</td>
</tr>
</tbody>
</table>