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COMPUTER MODELLING OF STRATIFIED FLOWS INSIDE AN EXPERIMENTAL BUILDING

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ABSTRACT

Comparison of computed and physical measurements are made for the air flow patterns, temperature distributions and cooling loads in a cooled pool of air in an insulated depression (a *Cool Pool*) with warmer ambient air flowing across its upper surface. Close agreement was noted between computed and physical measurements of higher speed air flow patterns, temperature distributions and cooling loads.

KEYWORDS

Computational Air Flow Modelling Interior Buildings

INTRODUCTION

The study outlined in this paper was a joint effort between the Departments of Architecture and Mechanical Engineering at the University of Auckland. The study compares full-scale measurements of air flow and heat exchange in a stratified flow with 3-d computer modelled flows using PHOENICS fluid dynamics software.

COOL POOL CONCEPT AND APPLICATIONS

Indoor thermal comfort in warm humid climates is usually provided by air conditioning or air flow from fans. In developing countries where energy costs are high an alternative is the use of *Cool Pools* [1]. This involves partial cooling using pools of cooled air retained in shallow, insulated, walled enclosures approximately 1 metre deep. This approach has the advantages of:

(a) Reducing the volume of air to be cooled.
(b) Reducing the degree of cooling in odrer to avoid condensation, and
(c) Allowing natural ventilation above the cooled air.

Sills of external openings such as doorways and windows are set 1 metre above the pool floor level. Air is cooled to approximately 1 degree C above ambient dew point temperature to avoid condensation on cooled walls and floor. Cooling was provided by chilled water circulated through pipes in the floor.

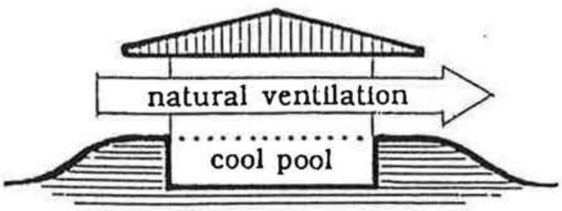


Figure 1a. *Cool Pool* Concept

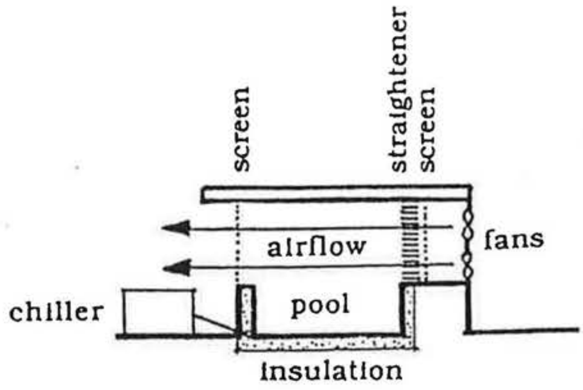


Figure 1b.View of Physical Model.

The full-scale test model 2.5 metres high consisted of a timber framed structure clad with fibreboard above 1 metre height. The pool below the 1 metre height, including the floor, was constructed with 200 mm thick polystyrene foam insulation to minimize heat gain to air in the *cool pool*. Internal dimensions of the of the *cool pool* were 2 metres by 2.4 metres wide and 0.8 metres deep.

Heat transfered to the *cool pool* was measured experimentally from flow rate and temperature changes in coolant required to maintain a constant temperature in the pool. These were 140 Watts without ambient air flow, 109 Watts at 0.5 m/s (23 W/m^2 of floor area), 137 Watts at 1.0 m/s (29 W/m^2) and 148 Watts at 1.5 m/s (31 W/m^2). The coolant pipe was formed into a helical coil and centered on the *cool pool* floor.

BASIC EQUATIONS AND BOUNDARY CONDITIONS

The PHOENICS software package was used to solve equations describing the flow through the cool pool test model. PHOENICS is an acronym for Parabolic, Hyperbolic or Elliptic Numerical Integration Series, a general purpose software package for simulating single and multiple phase heat flow and /or mass transfer in 1, 2 or 3 dimensions and chemical reaction phenomena.

The following equations describe the *cool pool* test rig mass and heat flow:

The Continuity Equation;

$$\Delta.\mathbf{v} = 0 \tag{1}$$

The Momentum Equation;

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\Delta)\mathbf{v} = -\frac{\Delta \mathrm{p}}{p} + \mathbf{g} + \Delta.(\upsilon\Delta\mathbf{v}) \tag{2}$$

and the Energy Equation;

$$\frac{\partial T}{\partial t} + (\mathbf{v}.\Delta)T = \Delta.(\ \alpha T) \qquad (3)$$

These equations are for an incompressible fluid where the three unknowns are pressure (p), velocity (**v**) and temperature of walls and floor (*T*). The constants in these equations are assumed to be kinematic viscosity υ the thermal conductivity coefficient α, and the air density p.

Boundary Conditions appropriate to the flow under study are; V=0 at walls, V_i some specified value at the inlet, $T_{entry} - T_{walls\ \&\ floor}$ = some specified difference between the temperature of the incoming air and that of the floor and walls of the pool. Temperature of the walls is assumed to be the initial temperature of the pool, and Q is the unknown heat transferred to the cooling pipes in the floor, [Figure 2]

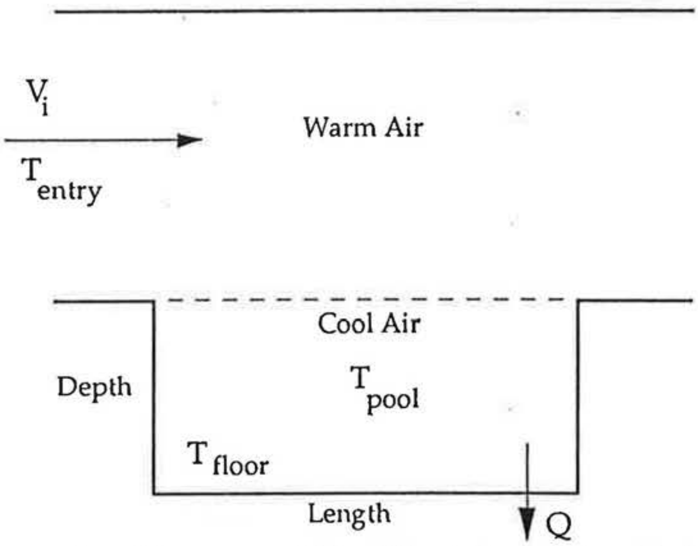


Figure 2. Diagram of *Cool Pool* Computer Model.

Turbulence was accounted for by time averaging the local kinetic energy and the energy dissipation rate and using these quantities to compute modified local values of the viscosity and thermal diffusivity. This is the k-e turbulence model. Default values for constants in the model were used in the absence of specific data. Turbulence levels at the inlet to the room were assumed to be similar to those in the fully developed flow.

An important assumption is the treatment of air as a single phase fluid where the effect of the water vapour is ignored. This was considered to be valid as the cool pool temperature would be kept slightly higher than dew point.and is not expected to condense water vapour from the air.

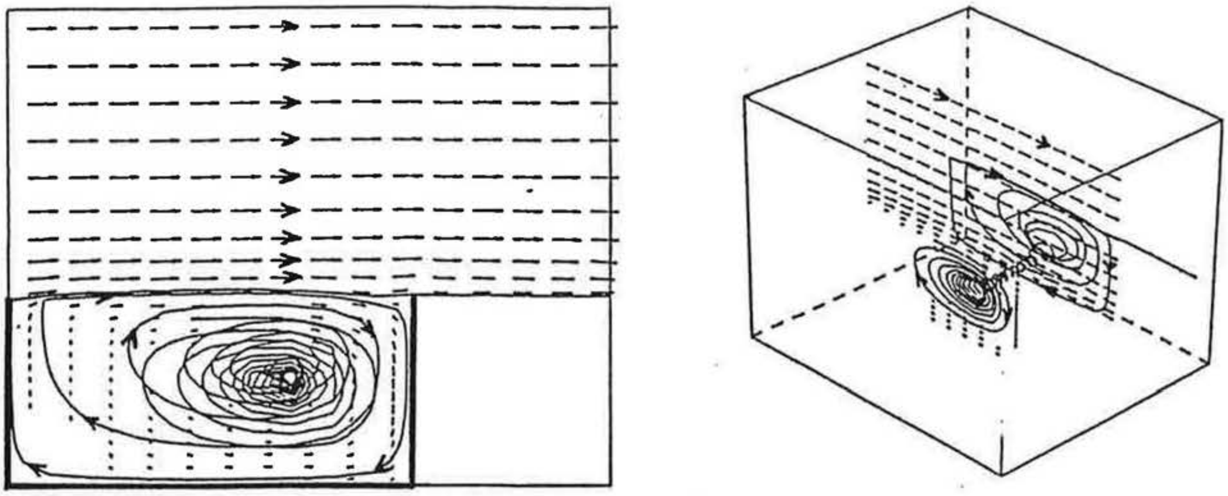
The character of the recirculating air flow pattern is determined by the shape factors of the cavity, particularly the depth/length ratio, length being the dimension in the direction of ambient flow [2].

The domain solved by PHOENICS was divided into small cells and an equation for each cell was derived using the finite volume approach. The equations representing the conservation of mass and momentum were solved using the SIMPLEST algorithm [3]. Those representing other conserved quantities, such as temperature were solved using an implicit integral over each time step. The overall solution process was iterative. A fully three dimensional and unsteady model is expensive and for this study only steady state solutions were obtained.

RESULTS AND DISCUSSION

Restrictions on the length of this paper prevent full tabulation of results so summaries of results are given.

As can be seen from Figure 3 the air flow at the centre location of the *Cool Pool* predicted by PHOENICS spirals inwards and undergoes a sideways movement towards the walls of the *Cool Pool*. The flow then spirals outwards and exits the *Cool Pool*. This observation is in agreement with the studies made by Lewis [4].

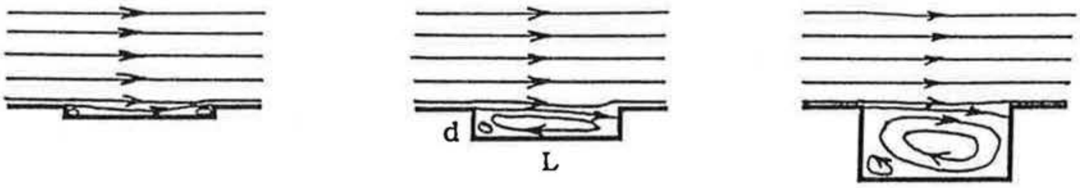


Slice at x = 1.2 m with stream lines

Perspective view of flow vectors at x = 1.2 m and streamline in pool.

Figure 3. Computed 3-D Flow Patterns in Cool Pool.

This observation of well established circulating flow in the pool was in general agreement with experimental observations made by Mills [5].



$0 \leq d/L \leq 0.1$
Boundary Layer flow and corner eddies

$0.1 \leq d/L \leq 0.25$
Flat stable eddy and possible small eddy

$0.25 \leq d/L \leq 0.80$
Unsteady main vortex and eddy

Figure 4. Flow Regimes in Cavities fot Depth/Length Ratios (After Mills [5])

Experimental flow visualisation using infrared photography and fog machines at full scale suggested that circulation patterns within the *Cool Pool* did exist, but observed flow was not sufficiently defined to enable a detailed comparison to be made between the results obtained from the full scale physical model and PHOENICS.

Temperature differentials ranged from approximately 1.5^{0} C to 2^{0} C between the air within the *Cool Pool* and ambient air.

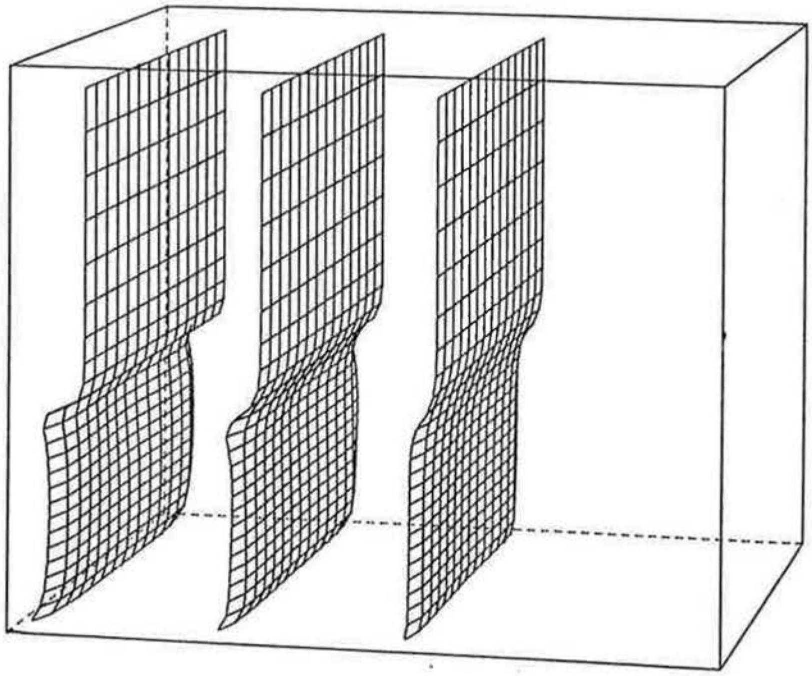


Figure 5. Computed Temperature Profiles in Cool Pool with ambient air flow of 1.5 m/s above pool.

The results obtained through experimental testing compared favourably with the temperature profiles predicted by PHOENICS, Figure 5, with the main difference between the computed and physical models being the size of the lower temperature zones.

Cooling loads were estimated numerically by calculating the transfer of enthalpy from the floor and walls of the pool and by calculating the rate of change of the enthalpy of the air flowing over the pool. The total floor/wall enthalpy transfer was taken as equal to the overall value of change of the air stream enthalpy: this balance was used as a convergence check for the numerical solution process.

Numerical estimates of this rate of enthalpy transfer from the floor and walls of the cool pool (and hence from the layer of air above the pool) are listed in Table 1 which also lists the experimentally measured cooling loads. The better agreement between the all surface estimates and the experimental loads indicates that the cooling coils, by providing the only source of cooling, were sensing the total load.

Wind Speed Warm Air (m/s)	Computed Cooling Loads (W)		Measured Cooling Loads (W)
	Floor Only	Walls & Floor	
0.5	30	56	109.3
1.0	51	95	136.8
1.5	69	130	147.7

Table 1. Computed 3 D and Measured Cooling Loads for Cool Pool

CONCLUSIONS

The sensitivity of the 3D PHOENICS modelling of the *Cool Pool* cooling loads to ambient wind speed changes was found the be greater than those from experimental test measurements. The 3-d PHOENICS model predicted with reasonable accuracy the temperature distribution within the *Cool Pool*. The computed 3-d flow patterns were in general agreement with observed flow within the experimental test room.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge funding provided by the University of Auckland for this project. Acknowledgement is also given to the generous support by way of materials and loans of fans, pumps etc. from the following organisations:
Ziehl-ebm New Zealand Division, Auckland, Mark Petch Pumps Ltd., Auckland, and New Zealand Fibreglass Co., Auckland.

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