CONCLUSIONS

The effectiveness and advantages to be gained with architectural design parameters can be inferred relative to maximum performance, as least favourable. Orientation can be advantageously utilised to influence residential building energy performance offering a possible improvement of 5%. Optimum orientation is indicated at N ±15°. The effect of plan proportion on building energy performance is generally limited. but can be more evident when considered with regard to the allocation of facade glazing. with an optimum plan proportion of P=1-1.5.

Apart from the optimum orientation range recommended. two-side glazing is more advantageous than all-side glazing for orientation range N to NE and SE to S. All-side glazing is better in the range NE to SE. Double glazing and heat reflecting glass can be advantageous providing cooling load improvement of up to 15%, which is comparable to that with application of insulation. Obstruction by neighbouring buildings also offers greater potentials for reduction of building cooling load by a maximum of about 10%.

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PASSIVE COOLING PERFORMANCE EVALUATION USING CFD

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ABSTRACT

A two-dimensional CFD based model named "EVITA" was developed to simulate the transient thermal performance of rectangular building sections. It is based on the finite volume approach, collocated arrangement of variables and a bounded high order treatment of the convective terms. Equations and assumptions required to evaluate usual solar passive cooling techniques have been included. Numerical results are compared with experimental values showing good agreement.

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KEYWORDS

Simulation; thermal performance; passive cooling.

INTRODUCTION

Several Venezuelan cities have a hot and humid climate. Specifically, Maracaibo, a city located at the Northwest part of Venezuela (10.65° latitude) is one where these climatic conditions are extremes. It consumes the highest amount of residential electrical energy in South America, due to mechanical air conditioning systems (AC) usage. By the other hand, 64% of its population can not use AC systems. Therefore, the thermal performance evaluation of buildings is very important when thermal comfort and energy efficient designing are the fundamental premises. An alternative approach for this evaluation is the computational fluid dynamics (CFD). It has proved to be very efficient for the prediction of flow and temperature fields in environment applications. It allows studying the dynamic thermal performance of a system to supply detailed information for faster and cheaper assessment of passive solar building applications. Previous computational (Almao and Rincón, 1993) and non-full scale experimental studies have demonstrated that it is possible to reduce the indoor temperature of a building incorporating solar passive cooling systems (SPCS) for these local climatic conditions, however none full-scale experimental data was available to verify it. In this paper, a two-dimensional computational model named EVITA (Spanish acronym for Evaluación de Viviendas Térmicamente Adaptadas) is presented. It has been developed to simulate. evaluate and compare the thermal performance of a building section. The CFD technique (Rincón and Elder, 1997) along with all those required equations and assumptions to evaluate and characterise the more usual SPCS to be implemented in a location with tropical climate (hot and humid) have been incorporated. Numerical results are compared with experimental data registered in full-scale cells specially built for the evaluation and characterisation of SPCS

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(González, 1997), with very good dynamic performance agreement. This fact makes it different from other lower-level evaluations (Verma *et al.*, 1986, Bansal and Bhandari, 1996).

COMPUTATIONAL MODEL

EVITA is a two-dimensional code based on the volume approach, with a collocated variable arrangement and a bounded high order treatment for the convection. A PISO-like scheme is used to solve the transient form of the coupled equations of Continuity, Momentum and Energy. These equations can be expressed in a general form as:

$$\frac{\partial \phi}{\partial t}+(\bar{u}.\nabla)\phi=\Gamma_{\phi}\nabla^{2}\phi+S_{\phi} \tag{1}$$

Where, ϕ is any of the dependent variable, Γ_{ϕ} it is the effective diffusion coefficient, S_{ϕ} is the source term, ρ is the fluid density and t is time. These equations are reduced to a discretised algebraic equation set. The convective terms are discretised using a bounded high order scheme (Rincón, 1994) and the Boussinesq approximation is used to simulate the indoor buoyancy air motion. The calculation domain is a rectangular section and any material composition for walls, roof and floor are considered under transient boundary conditions. A completely implicit procedure of time marching is utilised. Since the computational model was conceived basically for comparative studies, a simple algebraic model of turbulence is included (Patankar, 1979).

Boundary Conditions

SPCS thermal evaluation involves as boundary conditions heat fluxes in the entire envelope. Walls and roof surfaces heat transfer modes include absorbed solar radiation, convection due to wind and long wavelength radiative exchange between surfaces and sky. Therefore, time dependent functions of ambient temperature and global irradiance on oriented vertical and horizontal surfaces, daily average value of wind velocity, hourly average values of relative humidity, constant thermal and optical building material properties are used. Excepting convection due to wind, the heat transfer modes occurring in the building boundaries are no linear. They are linearised using the method of the tangent (Patankar, 1991). When regular roof and wall surfaces are considered, the net heat transfer on the external enclosure exposed to solar radiation and external environment is:

$$Q_B^{*}=h_w(T_{amb}(t)-T_B^{*}(t))+\alpha I_2+F_{s\text{-}sky}\varepsilon_s\sigma(T_{sky}^{4}(t)-T_B^{*4}(t)) \tag{2}$$

where h_w, denotes the film heat transfer coefficient due to wind; $T_{amb}(t)$ is the outdoor temperature, $T_B(t)$ is the boundary temperature; αI is the absorbed irradiance (α absortivity); ε_s is the surface emissivity; $F_{s\text{-}sky}$ is the surface-sky configuration factor; σ is the Stefan-Boltzman constant, and $T_{sky}(t)$ is the sky temperature in K. Sky temperature is determined as a function of the sky emissivity, which in turn depends on the atmospheric air dew point temperature. For an open roof pond with solar control and open roof pond shaded and ventilated, heat transfer by water evaporation and radiative exchange (water-sky or water-shading panel) must be added. When simulating solar-controlled SPCS, the building section has a configuration during sunshine different to that corresponding to the nocturnal period.

Validation of the Computational Model

Two experimental cells were specially designed and built for evaluating three SPCS based on roof thermal mass cooling by long wavelength nocturnal radiation and evaporation (González, 1997). In order to evaluate its thermal performance with the traditional constructive system used in Venezuela, they were built with identical external walls but different roofs. One of the cells, named Reference cell (CREF) has a well-insulated roof. The other cell named Experimental cell (CEXP) has an open roof pond. This roof pond is protected by a movable insulating panel of polystyrene with a glass fibre cover. It is located over the water surface allowing to expose the water to the sky and atmospheric air only during the night, or to shade and ventilate the water during all day. Temperature and relative humidity probes were placed into the cells, and instant analogical signals were recorded by a data acquisition system. All relevant climatic conditions were registered in a meteorological station. The CREF roof is made of 25 cm of polystyrene, followed by 5 cm of light concrete and 3 mm asphalt layer. The CEXP roof is a metallic reservoir full of water until 10 cm of height. The climatic variable values and indoor temperature of the cells are the average results of 21 days continuous period of measurements. The calculation domain is a 30x30 nodal point's grid. Comparison of numerical and experimental values of temperature are shown in Figures 1 to 4: Figures 1 and 2 correspond to the solar-controlled SPCS thermal performance, based on cooling by nocturnal radiation and by evaporation, for August 1996 and January 1997, respectively. They are named ESULIB.AC. Figure 3 shows the thermal performance of a SPCS which cooling is based only on evaporation (allowing 24 hours of ventilation but under shading), it is denoted as ESULIB.SV. Figure 4 shows the thermal performance of a SPCS where the cooling is achieved only with nocturnal radiation, denoted as ESUSE.AC. All these SPCS were evaluated without considering air infiltration to the interior volume and to the roof pond in the sunshine time (except in the ESULIB.SV). This was fulfilled in the experimental cells for the interior volume but not for the roof. This fact along with the clear sky assumption for nocturnal radiative cooling calculation is responsible for the deviations in the value of water temperature in ESULIB.AC and ESUSE.AC. It is worth to note that the corresponding simulation curves show practically the same experimental performance and the same average daily indoor temperature. CEXP indoor temperature values are almost coincident during the first 14 hours. Measured and numerical daily average temperatures are shown in Table 1, along with the values of a roof daily average global heat transfer coefficient (U), based on CEXP simulated indoor temperature. This is a cooling potential measure of each considered SPCS. Table 2 presents the absolute errors related to the experimental values with the relative maximum deviation shown in brackets. It can be observed a very good agreement even though it is a two-dimensional model. Regarding to indoor temperatures, a maximum deviation of 6% (1.85 K) and a maximum average error of 2%, was obtained for all the considered cases.

Table 1. Comparison of experimental and numerical results of daily average indoor temperature (°C).

	CREF		CEXP			U_{roof}	TLR %*	
	$T_{in,m}$	$T_{in,s}$	$T_{in,m}$	$T_{in,s}$	T_{amb}	$W\text{-}h\ m^{-2}K^{-1}$	TLR_m	TLR_s
ESULIB.AC August 96; 1.3 m/s	31.30	31.36	28.93	28.58	29.52	16.84	41.27	44.34
ESULIB.AC January 97; 1.9 m/s	29.57	29.03	26.63	26.28	27.49	20.22	65.64	70.72
ESULIB.SV February 97; 1.8 m/s	30.05	29.35	27.36	27.17	27.88	24.90	54.78	50.20
ESUSE.AC March 97; 2.3 m/s	30.50	30.54	28.60	27.90	28.47	9.60	36.68	47.70

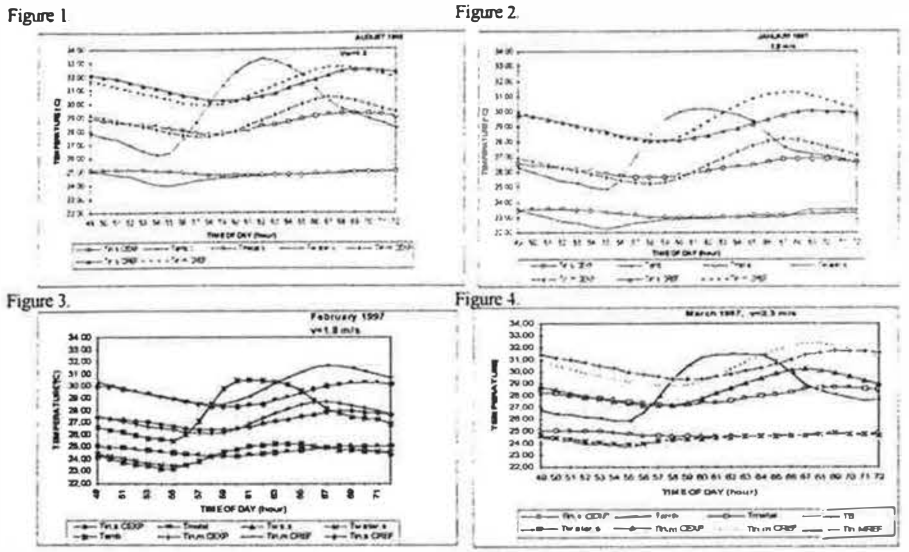
* Thermal load reduction percentage of CEXP with respect to CREF, using 25°C as comfort temperature

Table 2. Absolute errors of simulated indoor temperatures with respect to experimental values, in K (%)

	ESULIB.AC August 96		ESULIB.AC January 97		ESULIB.SV February 97		ESUSE.AC March 97	
	CEXP	CREF	CEXP	CREF	CEXP	CREF	CEXP	CREF
Maximum (%)	1.28 (4.2)	0.70 (2.2)	1.37 (4.9)	1.65 (5.4)	1.05 (3.7)	1.80 (5.7)	1.85 (5.8)	1.20 (3.7)
Minimum	-0.35	-0.60	-0.42	-0.15	-0.40	+0.05	-0.20	-0.80
Average	+0.35	-0.09	+0.37	+0.52	+0.19	+0.70	+0.65	-0.02

CONCLUSION

The computational code EVITA has been validated, comparing the numerical results with those obtained experimentally. A maximum deviation in indoor temperature of 6% (1.85 K) and a maximum average error of



Comparison of simulated temperatures and measured temperatures in CREF and CEXP for: 1 and 2 ESULIB.AC (August and January, respectively); 3. ESULIB.SV (February); and 4. ESUSE AC (March).

2% was obtained for all the considered cases, showing very good agreement. With the inherent limitations of a two-dimensional model, it allows to evaluate the thermal transient performance of a rectangular building section, for any walls, roof and floor material composition, under the local climatic conditions. Parametric studies and comparative evaluation of different SPCS can be carried out. These evaluations include thermal response, characterisation and optimisation, thermal load reduction percentage through the external enclosure, cooling potential and any other quantity related to the fluid and heat transfer process. Since it is based on CFD simulations, it is possible to obtain temperatures and velocity fields at a given time.

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MODELLING OF BUILDING RELATED EMBODIED PROPERTIES AND PROCESSES

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ABSTRACT

Since updating the NZ embodied energy data, the authors have been engaged in a project, the aim of which is to store in a computer database the data related to the processes involved in the production of building materials and the manufacture of building products such that their embodied properties may be estimated more readily and transparently than at present. © 1998 Elsevier Science Ltd. All rights reserved.

KEYWORDS

Embodied energy; database; graph theory; building materials; buildings

INTRODUCTION

During previous studies in which the computation of embodied energy coefficients was carried out manually (Baird and Chan, 1983; Alcorn, 1996) it became evident to the authors that entering data into some sort of computer database would give several benefits. Rather than having the data in a relatively inaccessible paper file, a computer database would provide better accessibility to researchers and allow the data to become widely available. It was also considered important that the computations of embodied energy coefficients should be audited for correctness, that the data be available to future computer-based analysis systems, and that references tagged to data items would enable efficient follow-up work. The embodied energy data has many inherent dependencies on other data, requiring recalculation if any one value changes - an ideal task for a computer-based system. Finally, the database would provide report generation and the ability to provide answers to ad-hoc queries on the data.

Although the current primary task of the authors is to calculate New Zealand specific embodied energy coefficients of building materials, it became apparent that the proposed data could be generalised to encompass all embodied properties of materials such as embodied greenhouse gases, embodied hazardous wastes, etc. In this paper, the authors describe their experience in developing software to store embodied energy data.

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