A SIMPLIFIED COUPLED MODEL FOR THERMAL BEHAVIOUR AND AIR FLOWS SIMULATION IN URBAN SPACES

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ABSTRACT

The studies presented here aim at defining and setting out a calculation code allowing the prediction of outdoor ambient thermal quality Designers of urban spaces are expecting more specialized information such as skilled rules which may be achieved by the presented code, at present in process of development. The physical system is identified as being representative of the urban network of an average town like Saint-Denis, Reunion Island (about 60 000 inhabitants). The calculation code, made up by assembling different models, describes the thermal behaviour of the physical system.

INTRODUCTION

The evolution of town planning and of the incidence of today's way of life tends to confer more and more importance to outdoor meeting places such as squares public gardens, pedestrian streets, so on and so forth. The use of those urban spaces by city dwellers- demanding as far as the quality of their immediate environment is concerned- is liable to conditions of well-being and comfort felt by the users. If visual, auditory and olfactory comfort is but subjective and particular to each individual, the notion of thermal comfort for itself takes into account physical parameters linked to the micro climate prevailing in the given urban space.

In order to conceive more comfortable urban spaces since the quality of the pervading atmosphere, architects and planners must take into account in their building plans the physical processes which determine the micro climates in the vicinity of the buildings. And in order to do so, those town planners are looking for expert knowledge and skilled rules that may be achieved by the calculation code we are working out. This helpful conceiving tool which settling is in process allows from climatic factors (wind, sunshine, humidity) to determine the fields of temperatures prevailing in the ambience and to deduce the user's sensation of comfort. This tool particularly concerns humid tropical climate typical of Reunion Island. Moreover in tropical located buildings radiant and conductive effects play a primal part in the study of the thermal answer of the buildings have an influence on the thermal response of buildings.

The optimisation of the building climatic comfort is thus, strongly linked to a bioclimatic conception of the adjacent urban areas. Then, the question is how to take into account the most appropriately the physic parameters in use.

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THE CALCULATION CODE

Definition of the studied subject

The urban fabric of Reunion Island presenting a large cultural and historical diversity, the first purpose of our work was to define the subjects studied. Our first aim being to predict the thermal sensation felt by an individual, our choice has, then, been imposed by the scale of a study allowing the thermal modelling of a volume of the order of a man's height.

This is the reason why instead of dealing with the urban island as a whole, we have focused our study on the elementary urban units which compound it. Following a detailed town-planning study we have dealt with three types of basic urban elements i.e.:the street, the square and the building scheme.

In this presentation, we will deal with the case of a street as shown on the figure 1.

The description of the street component allows to create a descriptive data base. This one takes into account, on the one hand, the climatic parameters of the place in question(solar radiation, wind, temperatures and humidity) and, on the other hand, the physical parameters linked to the street itself that is to say: length and width, orientation, geometry and structure of the adjacent buildings: composition, surface as well as the presence of "foreign elements" on the pavement (shrubs, trees clusters, stalls...).

Our study, being based on few previous works, we have had to simplify the geometry of the street, and doing so limiting the number of parameters. The distance between the buildings (coefficient of empty space) or even their distance in comparison with the pavement are parameters that we have not integrated in our description. Other parameters such as strips symbolising arborized paths have been described in a simple way.

General structure of the calculation code

Our calculation code is shown as an assembling of units, each of them describing the thermal behaviour of a part of the physical system constituted by the

The prediction of the thermal comfort felt by a user depends on the output parameters of those units. This assembling of units should make possible the definition of essential and necessary inputs for this evaluation (Figure 2).

In our study, we consider that the user's sensation of comfort and the ambience are linked to six different but of equal importance thermo-physical parameters enabling to establish the balance of the of the human body [1].

	• Air temperature	T_a
Ambience	• Air Speed	V_a
	• Humidity of Air	H_a
	• Average Radiant Temperature	T_r

	•Clothing Thermal Insulation	R_v
User	•Activity Level of the User (his Metabolism)	M
	•Heat Perviousness of the Clothing	R_w

The determination of the state of thermal comfort can be performed thanks to a model of thermo-sensorial answer quite similar to the one developed by FANGER[2].However, the code structure being modular, our process is not based upon a particular model of human body's response. The input data being the sole requirement for the model, their choice doesn't allow models of a biological type as the one developed by STOLWICK [6]. We thus begin our work on the assumption that the model of comfort prediction appears as the following general statement

$\vec{A} * \vec{I} = s$

in which s is a number representing the user's thermo-sensorial answer as for FANGER's model, s represents the "Predicted Mean Vote "(PMV).

The thermal modelling of the urban space should allow the determination of the vector $\vec{A}$'s components. Vector $\vec{I}$ including the problem's data and Vector $\vec{A}$ being clearly defined, the modelling of the main exchanges between the user and the ambience (symbolised '*' by the operator) therefore leads to the determination of the thermal sensation s. It follows a general organisation of the code as shown on figure 3.

These two sequences of calculation are not coupled together, insofar the thermal interactions between the user's body and the urban space are not considered. This simplification can be explained by the fact that the thermal emission of the human body is considerably inferior to the one of the urban environment or surroundings.

Description of sequence 1

Sequence 1 brings up the most complex problems of the modelling of the system. It must allow the simulation of thermal and aeraulic exchanges within the urban space. Regarding the structure and the organisation of the tool, the analogy between figures 2 and 3 shows that sequence 1 is compound of "ENSOL", "SOL", "BATIMENT" (i.e. building) and "THERMAL" units, which will be explained thereafter.

Flow and sunshine calculation units

•**"ENSOL"** unit thanks to a meteorological and to a descriptive data base, allows the determination of sunny areas and the calculation of the direct Φ_D and diffuse Φ_d flux on a surface. These results will serve as input data for the calculation of the surface temperature of the buildings and pavement. The fluxes F_D and F_d will each be directly taken into account as a regular flux reaching the human body in sequence 2.

•**"FLUENT"** unit is a fluid mechanic's software allowing the simulation of fluid discharging(laminar like or turbulent). It has seemed interesting to us to use FLUENT for the simulation of the discharging (turbulent one) of the wind in urban area and in order to determine speed profiles. In such cases, in which the wind has an impact on the urban space, FLUENT allows to simulate the air flow in the street, assuming that this forced discharging is nearly isothermal. A phenomenon of forced convection (on façades and pavements) appears and with it a coefficient of convective exchange $h_{c,j}$ (in which j represents the surface index) (Figure 4).

The calculation of the speed field by FLUENT allows the determination of the convective coefficients hc of each surface. In order to do it we ill use a correlation of $h_c = a + b V^n$ type in which V represents the speed of the wind at the considered point. The coefficients a, b and n are experimentally determined, particularly by "tunnel effect" [3].

Thermal answer calculation units

•**"SOL"** and **"BATIMENT"** units. The description of these units is made simultaneously since the principle of calculation is similar in both cases. From the results achieved thanks to the previous units (hc, Φ_D, Φ_d) those SOL and BATIMENT units allow the respective calculation of the surface temperature of the pavement and buildings.

An energy balance on the surface, including the radiant (short and long wavelength), conductive and convective flux, enables to dynamically determine the evolution of the surface temperature.

$$\frac{\partial T_s}{\partial t} = h_c \left(T_s \quad T_a\right) \quad K\left(T_s \quad T_{int}\right) + \sum_j \sigma \varepsilon F_{ij} \left(T_s \quad T_j\right)$$

(Eq. 1)

The calculation of the ambient temperature Ta can be made thanks to the "THERMAL" unit which will be described afterwards.

The indoor temperature of buildings (Tint) takes place in the formulation of the conductive flux. This indoor temperature will be calculated by a simplified version of CODYRUN, a software for thermal and aeraulic conception of multizone buildings[4].

The surface temperatures calculated in this way will be used as limit conditions in the calculation of Ta.

• **"THERMAL"** unit allows the calculation of the ambient temperature in the street. Actually, the temperature of the volume of reference, as a result of the phenomenon called "Urban Heat Island" , is higher than the air temperature read at the nearest meteorological station.

The air flow modelling of the air volume will be different whether the dominant type of convection will be natural (no wind) or forced (normal wind).

In the case of natural convection, the thermal gradient between the surfaces the surfaces and the air will create upwards movements of the mass of heated air (near the walls).

The coefficient of convective exchange hc will depend on this gradient of temperature. The calculation of the air temperature is made by only taking into account the diffusion of the heat in the air

$$\frac{\partial T_a}{\partial t} = a \frac{\partial^2 T_a}{\partial x_i} \qquad \text{(Eq. 2)}$$

We consider two models : the first one concerns the iterative calculation of the coefficient hc which is function of the temperature difference between the air and the surfaces.

The second model, based on the works of NOILHAN [5], considers the natural convection in the thermal diffusion coefficient a, by calculating this last one in function of the hour, the co-ordinates of the place and the atmospheric stability.

In the second case the air speed field is calculated by the "FLUENT" unit. As a result of the forced discharging, on the one hand, the coefficient of convective exchange will depend on the air speeds and, on the other hand, only a boundary layer close to the wall will become heated. Thus, a thermal balance will enable us to determine the air temperature in this boundary layer, whereas the mass of the air outside this boundary layer will be considered as isothermal.

The units that are described here, concern the calculation of the thermal response. We obtain a differential equations system that allows us to calculate the temperatures of the system in dynamic behaviour :

$$\begin{cases} \dfrac{\partial T_s}{\partial t} = h_c\left(T_s - T_a\right) - K\left(T_s - T_{int}\right) + \sum_j \sigma \varepsilon F_{ij}\left(T_s - T_j\right) \\ \textit{for the n points of surface} \\ \dfrac{\partial T_a}{\partial t} = a \dfrac{\partial^2 T_a}{\partial x_i} \\ \textit{for the m points of ai} \end{cases}$$

So, we can write the following formulation, called the state equation of the system:

$$[C]\{\dot{T}\} = [A]\{T\} + \{B\}$$

$[C]$ represents the matrix of specific heats.

$\{T\}$ represents the temperatures vector, called state vector.

$[A]$ is the evolution matrix. It traduces the thermalexchanges between the different components of the system.

$\{B\}$ represents the vector of solicitations.

RESULTS OF SEQUENCE 1

The results we are presenting here affect the thermal modelling of an urban space as it was shown in sequence 1.

The studied shape represents a stretch of a E/W road of a simple geometry : in this case, pavement lined with two identical buildings.

Simulation results are given for the 18^{th} March. There is no wind.

Surface temperatures

The surface temperature field Ts represents the most important factor in the formation of micro climate in the vicinity of buildings. The figure 5 shows the surface temperature evolution.The maximal value is reached at 2 P.M. : 60°C for the ground, 43°C for the sunny surface and 36°C for the shadowy surface.

Air temperature

Figure 6 shows the comparison between the meteorological air temperature and the temperature in the volume of reference. Because of the " urban heat island"'s effect,-due to the proximity of the buildings; the lack of wind and the radiant flux, there is a difference between the meteorological air temperature and the air temperature in the street. ΔT is maximal (about 8°C) at 3 P.M..

The influence of the walls on the air temperature is shown on figure 7. At x= 4 we are near the left façade and at x = 12 near the right one. The temperatures are more important near the walls (ΔT ~ 0.5 °C to 2 °C). The difference between the temperatures at point x=8 and x=12 increases after 1 P.M. because the right façade becomes sunny in the afternoon.

CONCLUSION

The numeric calculation code that is developed in the present work allows us to study the characteristics of built space filled with sunshine, to define the whole energy solicitation (atmospheric radiance, to calculate the aeraulic parameters that concern the buildings when the urban unit is exposed to an air flow, and at least to determine the thermal response of the whole system concerned by simulation. If those different parameters are known, we can deduce the climatic comfort characteristics of the studied urban space.

That calculation code allows a variable description of the urban unit, that enables us to integrate any kind of configurations and any dimensions. A lot of phenomenon, which are linked to the environment must be considered firstly, because of the modular aspect of the calculation code architecture, and secondly because of the internal organisation of the units which allows a multi-model approach.

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FIGURES :

figure 1 : Definition of the studied subject: case of the street

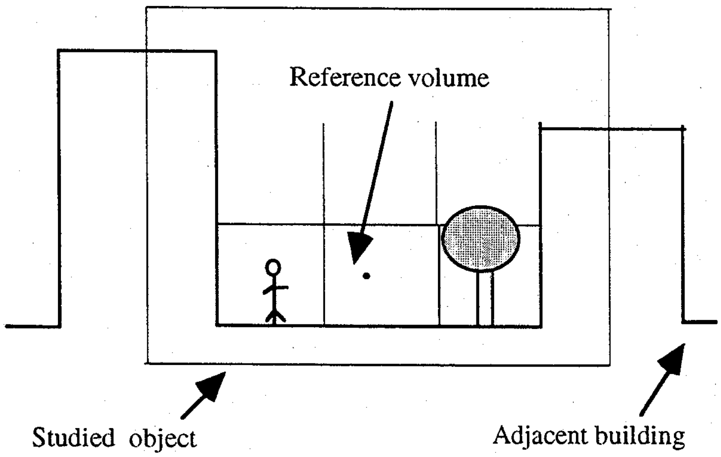

Figure2:Tool Structurre

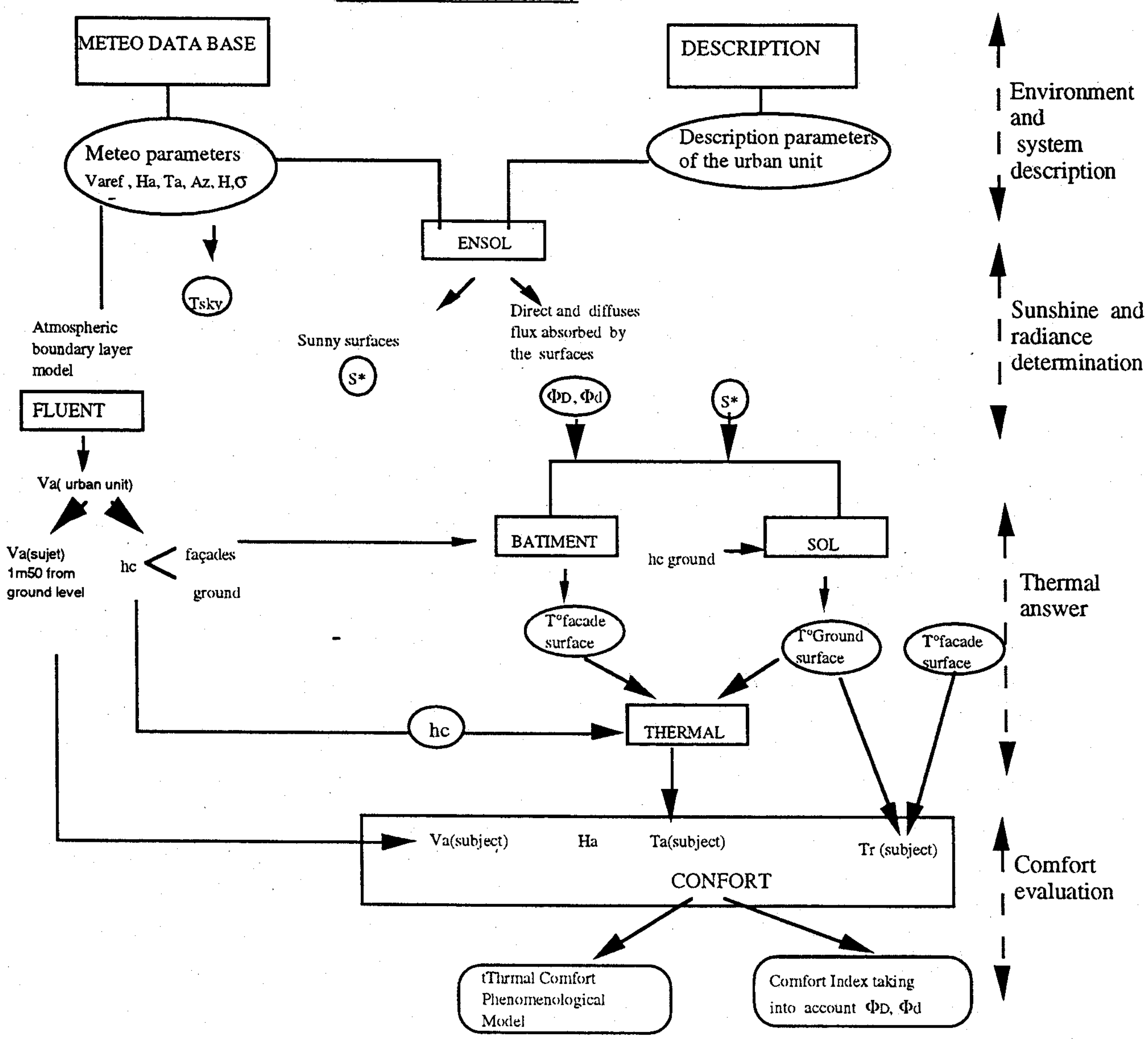

Figure 3 : General organization of the calculation code

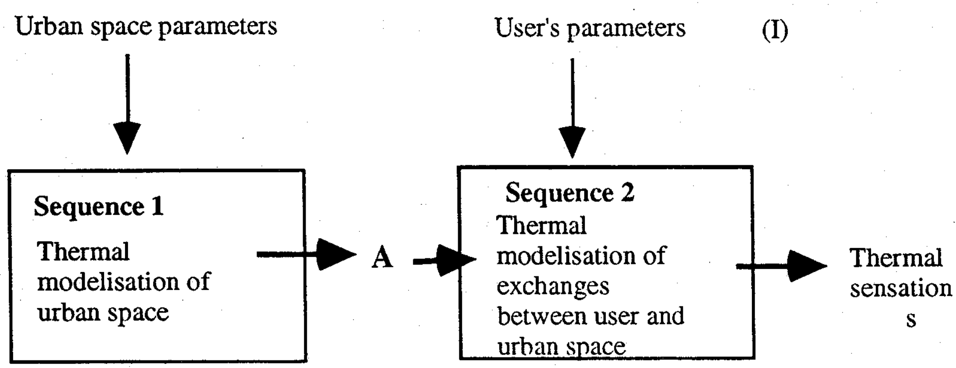

Figure 4 : Speed vector and convective coefficients

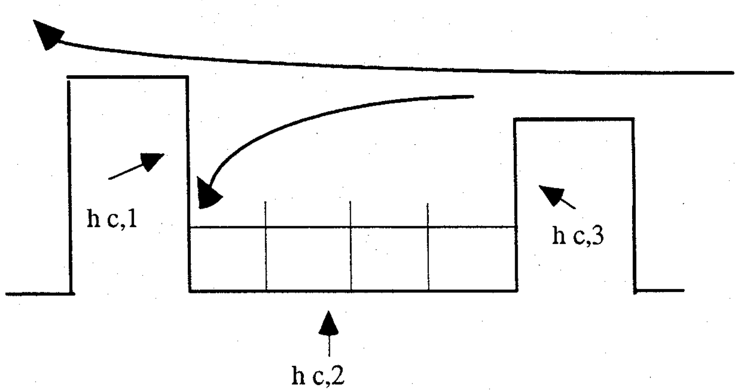

Figure 5 : Surfaces temperatures

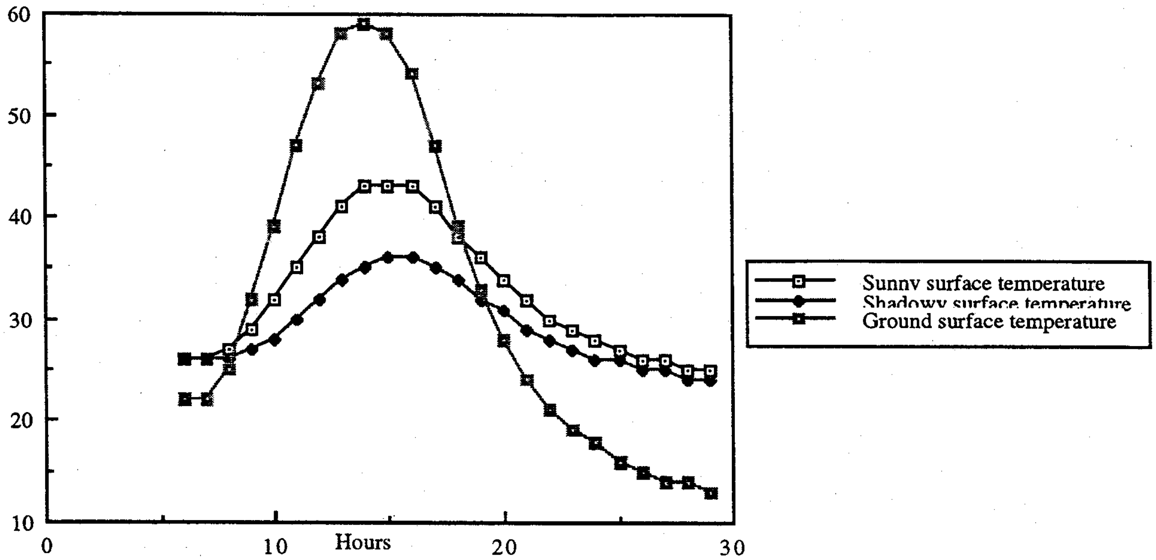

Figure 6 : Air temperature evolution

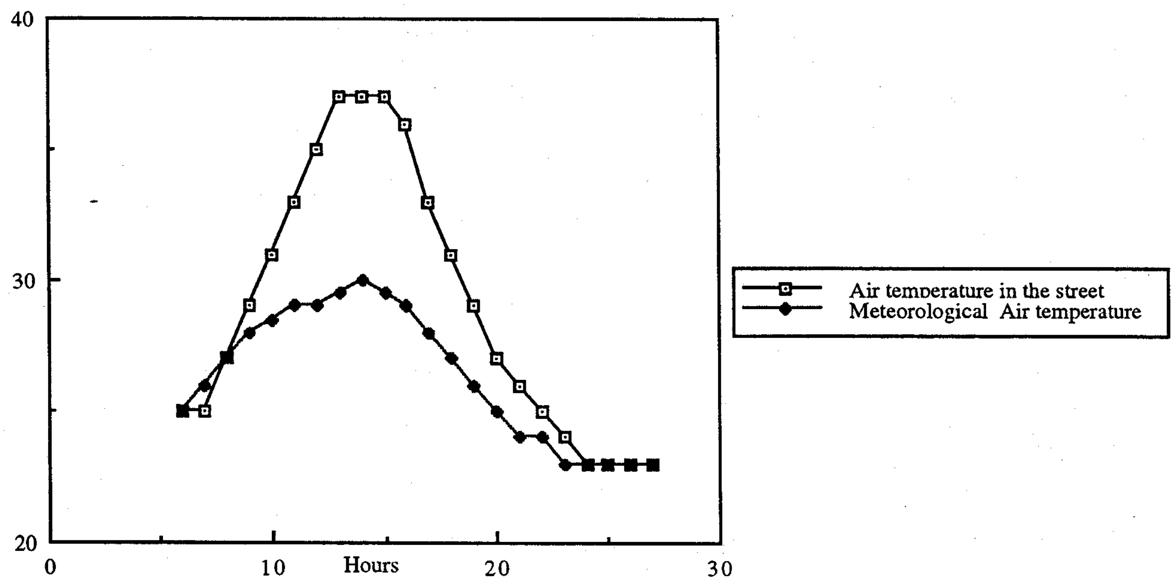

Figure 7 : Air temperature Evolution at different distance to the walls