Building Simulation

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CFD AND ZONAL APPROACHES : COMPARISON AND VALIDATION

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FRANCE

ABSTRACT

This paper deals with comparison between the CFD method and the zonal one, and also model experimental validation. The zonal method consists of a dwelling decomposition in several isothermal air zones, in contact with walls.

This work comprises two parts :

- comparison between zonal and CFD approaches : the studied case is a heated and ventilated room. Two zonal models are achieved : isothermal and non isothermal, using ALLAN.®Simulation software. The CFD model is a low Reynolds number k-ε type using CFX code,

- comparison between non isothermal model calculations and experimental data : tests took place in a 2-rooms apartment.

INTRODUCTION

Thanks to computers improvement, CFD techniques are nowadays extensively used in building physics, even for natural convection modelling. A CFD approach is very useful when an accurate knowledge of flow characteristics proves to be essential ; however, it often needs a huge CPU time. As an alternative or at least a complementary method, the zonal approach can be implemented to carry out heating, ventilation and air-conditioning systems modelling and this, either in dynamic or static mode.

The presented work deals with comparison between the CFD method and the zonal one, and also model experimental validation.

The zonal modelling tool used is ALLAN.®Simulation 3.3 [1]. It's a general purpose model description and management software. The current application of ALLAN aims to simulate technical systems. So, it's possible to model, for instance, a boiler, a hot water tank, a heating distribution system and heat transmitters. All of these models can be linked with a building model. Then, an energetic system representing all or part of an accommodation is obtained.

Within zonal dwelling modelling, there are two variants. In the first one, each room air volume is assumed isothermal, in the second one, this volume is broken down into ten zones taking into account heat transmitters (radiators in this instance) and ventilation inlets and outlets location. A unique discretisation method is applied to the walls for both zonal models.

The CFX 4.3 code is also used [2]. It's a flow modelling software dedicated to the prediction of laminar and turbulent flow, and heat transfer. This code is based on a finite-volume method and it resolves the Reynolds-Averaged Navier-Stokes equations for each control volume. Several turbulence models are available and the radiative transfer is also considered.

The turbulence model is a low Reynolds number k-ε type. The solution algorithm is a velocity-pressure coupling one called SIMPLEC. Radiation is treated by the Discrete Transfer Algorithm.

The first part of this study deals with comparison between zonal approach and CFD one in a steady state. CFD results have previously been compared to experimental data in a satisfying way [3]. The test case is a climatic engineering room intended for real scale heat transmitters testing.

The second part presents non isothermal modelling results and compares them to experimental data. The tests took place in a Gaz de France Research Division 2-rooms apartment described below.

MODELLING

Both zonal and CFD models are detailed in this paragraph.

Zonal modelling

All transfer modes are taken into account in the building model and are described below.

Conductive transfer

Conduction is supposed to be unidimensional. Dwelling walls are broken up into isothermal layers according to their inertia (figure 1). A wall is known as light (heavy) if its first time-constant is lower (higher) than two hours. The light (heavy) walls include two (four) capacitive nodes and two surface nodes [4].

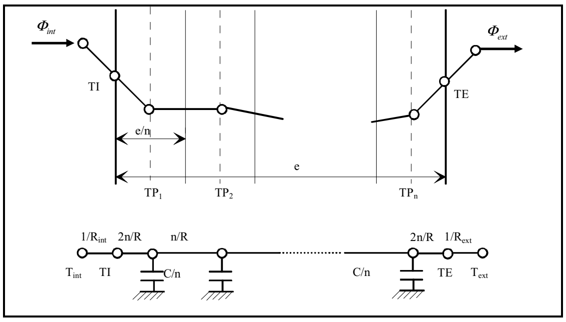

Figure 1 : conductive transfer modelling

Radiative transfer

Radiative calculations are based on the concept of Mean Radiant Temperature. This temperature is an average temperature of the walls balanced by their respective surfaces :

$$T_{mr} = \frac{\sum_i A_i TI_i}{\sum_i A_i}$$

Heat transfer between walls are calculated thanks to the mean radiant temperature by writing the radiative net flux in linear form and by introducing a radiative transfer coefficient. The net radiative flux between the radiator and the walls is :

$$\Phi_R = \varepsilon_r \, \sigma \, A_r \left[\left(T_{sr} + 273{,}15 \right)^4 - \left(T_{mr} + 273{,}15 \right)^4 \right]$$

Temperature difference between the radiator and the cell can reach 60 °C. Linearity assumption would not be accurate. Mean radiant temperature expression becomes :

$$\sum_i h_R A_i \left(TI_i - T_{mr} \right) + \Phi_R = 0$$

Convective transfer

In this transfer treatment lies the difference between isothermal and non isothermal zonal model. In the first one, the whole air volume is considered isothermal. In the second one, dwelling air volume is broken down as shown on the figure 2. This breaking down looks like previous ones [5, 6] even if the equations are pretty different [7].

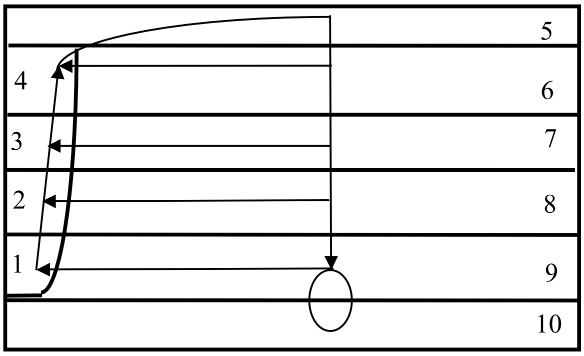

Figure 2 : zonal model

The main convective transfer phenomena are between :

- *ambient air and walls :* to describe such phenomena, standard natural convection correlations involving Nusselt and Rayleigh numbers are used ($Nu = CRa^n$),
- *horizontal air layers :* two factors induce these transfer :
    - temperature difference between air and walls,
    - temperature difference between horizontal layers,

  More information about these factors modelling will be found in another author's paper [7].
- *ambient air and incoming one :* Colburn's forced convection correlation is used to calculate convective transfer coefficient between dwelling air and cold air jet [8] : $Nu_{D_h} = 0{,}023 Re_{D_h}^{0{,}8} Pr^{1/3}$,
- *ambient air and radiator :* net convective flux is given by [7] : $\Phi_c = 2{,}63 \eta_r L_r H_r^{0{,}75} \left(T_{sr} - T_\infty \right)^{1{,}25}$.

Building components

ALLAN.$^{®}$Simulation modular approach allows a decomposition of any studied physical system into macroscopic isothermal elements. Applied to such elements, energy balance is :

$$P_{stored} = P_{in} - P_{out}$$

or : $C_i \dfrac{\partial T_i}{\partial t} = P_{in} - P_{out}$

Pressure drop of hydraulic network elements is calculated by the following formula :

$$\Delta P = \left(\lambda \frac{L}{D_h} + \zeta \right) \cdot \frac{\rho u^2}{2}$$

Building components modelling comprises a writing phase where technical elements (pipe, valve, boiler...) are described within simple models and a assembling phase of these models in a global one. Hydraulic network modelling has previously been detailed by the authors [9].

CFD modelling

It is a finite-volume method with a Reynolds Averaged Navier-Stokes equations approach. The turbulence model is a k-ε type (using an eddy-viscosity hypothesis) with wall function concept (internal boundary layer is divided into viscous and logarithmic sub-layers). SIMPLEC, the solution algorithm is a velocity-pressure coupling. It is an iterative process resting on a non-staggered grid (all variables are stored at centres of scalar mass control volumes). Radiation is treated by the Discrete Transfer Algorithm which lies on the discretisation of the radiative transfer equation along rays. It is a simplified version of the Monte-Carlo algorithm because of the fixed sampling and ray discretisation.

The main hypotheses of our study are :

- air is assumed transparent and incompressible,
- flow is turbulent, steady,
- buoyancy is modelled through Boussinesq approximation : $\rho = \rho_{ref} \left(1 - \beta \left(T - T_{ref} \right) \right)$.

EXPERIMENT

Gaz de France Research Division has among others an experimental building in which full-scale testing of energy system can be conducted (heating system, air conditioning, sanitary hot water). This building is composed of 25 apartments (studios, 2-rooms, 3-rooms) in 5 floors. Its North-South orientation permits to study the influence of the exposition. With the 2000 sensors, it is possible to follow a lot of parameters like : air temperature, wall temperature, flue gas temperature, hot water temperature, CO2 emission...

Validation tests took place in a 2-rooms apartment. As seen on the figure 3, heating water is provided by a boiler located in the kitchen and passes through four radiators. The apartment is surrounded by others dwellings. Its northern and western faces, which include all the glazed area, are exposed to the outside conditions (temperature and solar fluxes).

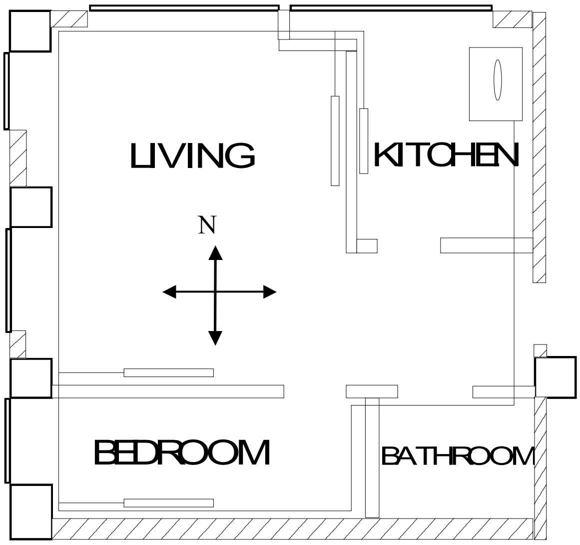

Figure 3 : 2-rooms apartment

Meteorological data, heat emission and ventilation are considered.

CONFIGURATION

In this paragraph, validation methodology will be detailed for each work part.

First part

This part concerns a climate engineering room modelling methodology. This room (5x3,9x2,7 m) comprises two air inlets (2,5x25 cm) which provide fresh air flow (0 °C, 1 vol./h). Air extraction (2x80 cm) is on the opposite wall, representing the gap between a door and a floor (figure 4).

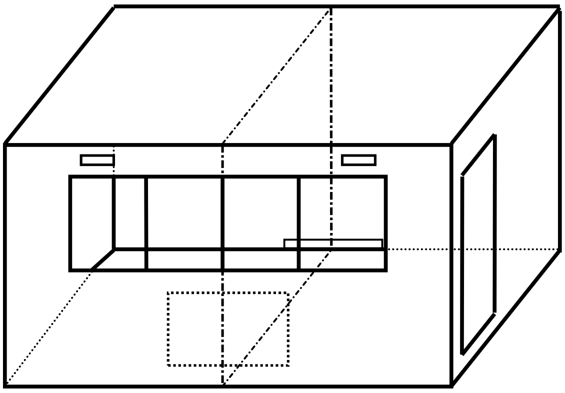

Figure 4 : climate engineering room

An isothermal surface representing a simple panel radiator is located in the inlets wall vicinity. The room is surrounded by compartments on its six sides.

Climate engineering room CFD model comprises about 80000 cells and has the following inputs : boundary conditions (cf. table 1 for surrounding compartments temperatures), radiator surface temperature (60 °C) and cold air mass flow rate (1 vol./h, 0°C).

Compartment	North, East and Floor	South, West and Roof
Temperature	20 °C	0 °C

Table 1 : compartments temperatures

The same inputs will be applied to the zonal model for comparison's sake.

Second part

This part is about a 2-rooms apartment model validation. Tests configuration is :

- generation : balanced-flued appliance located in the kitchen,
- distribution : double-pipe network,
- emission : four simple panel radiators,
- control : four thermostatic valves,
- ventilation : controlled mechanical one.

Input parameters are :

- extraction flow rates : respectively 105 and 30 m^3/h for the kitchen and the bathroom,
- adjacent apartments air temperature,
- outside temperature,
- solar flux,
- setting temperatures.

RESULTS

According to the above described configuration, carried out simulations gave the following results :

First part

Two important topics are evoked in this part, energy consumption through emitted fluxes and thermal comfort through vertical evolution of temperature.

Table 2 shows that global fluxes difference between zonal and CFD approaches is lower than 5 %. It must be noticed that zonal radiative modelling is particularly accurate.

	ALLAN	**CFX**
Φ_c (W)	258	230
Φ_R (W)	423	420
Φ (W)	**681**	**650**

Table 2 : emitted fluxes comparison

Figure 5 presents mean temperature evolution along vertical axis.

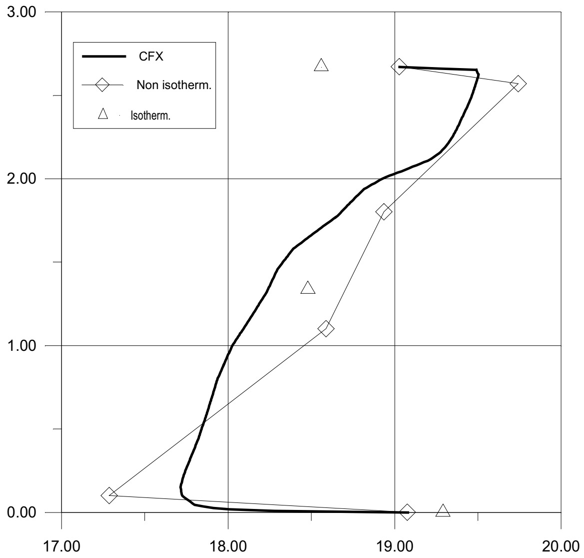

Figure 5 : temperature along vertical axis

It can be noticed that isothermal approach can obviously not represent temperature distribution. On the other hand, CFD and non isothermal simulated temperatures have a quite similar evolution (figure 5).

Second part

This part involves real scale testing in a 2-rooms apartment (cf. configuration).

Only air temperatures are of interest in this part, hydraulic network results will be found in [9].

Figure 6 shows air temperature comparison between simulation results and experimental data at 10, 110, 180 and 230 cm above the living floor in the room centre.

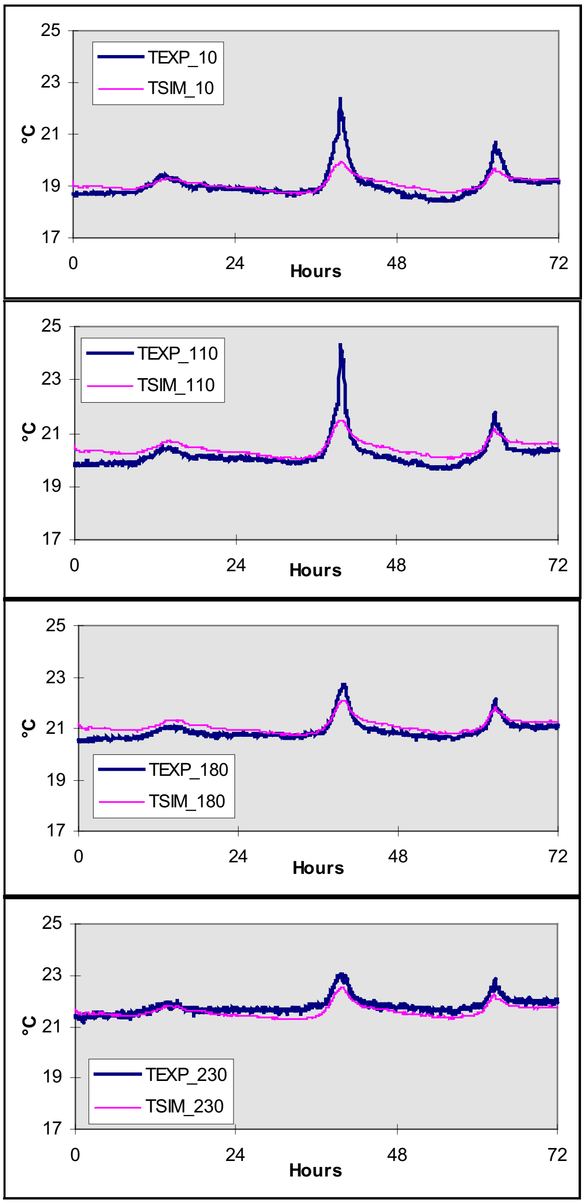

Figure 6 : simulated and experimental temperatures - Living

It can be seen from the figure 6 that difference between simulation results and experimental data is quite small (lower than 0,5 °C). In presence of solar peaks, sensor temperature is not equal to air one. Thanks to simulation, one can avoid this problem as seen on the figure above.

Figures 7 and 8 concern the bedroom and the kitchen respectively. They show both simulated and experimental temperatures at 10 and 230 cm above the ground.

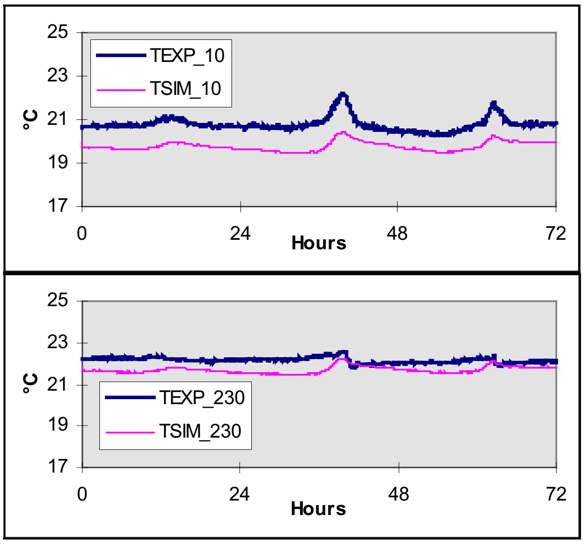

Figure 7 : simulated and experimental temperatures - Bedroom

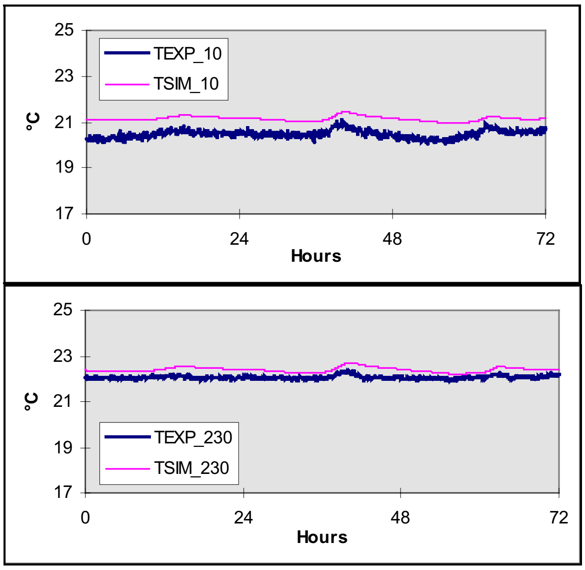

Figure 8 : simulated and experimental temperatures - Kitchen

In solar peaks absence, difference between simulation and experimentation is lower than a degree as shown on figures 7 and 8. This difference is due to the fact that experimental temperature is given in one point, so, even if it is in the middle of the room, it is not exactly the whole room mean temperature. On the opposite, simulated temperatures are mean ones.

CONCLUSIONS

It can be seen from presented results that zonal simulation is in good agreement with both CFD and experimentation data. A whole apartment behaviour can be represented with its thermal and control equipment.

The zonal method here proposed is shown to be an accurate and trustful approach for energy consumption and thermal comfort predicting. In addition, ALLAN.®Simulation software and CFX prove to be particularly efficient modelling tools.

CFX provides detailed information on flow structure while ALLAN.®Simulation allows a global approach taking into account the building as well as its equipment (production, distribution, emission, ventilation and control).

Next work will precisely consist in modelling entire building including its collective heating system.

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NOMENCLATURE

Symbols

A	surface	(m^2)
C	constant	($W.K^{-n}$)
C_p	heat capacity	($J.\ K^{-1}$)
D_h	hydraulic diameter	(m)
e	thickness	(m)
H	height	(m)
h_R	radiative transfer coefficient	($W.m^{-2}.K^{-1}$)
L	length	(m)
Nu	Nusselt number	( )
P	Power	(W)
Pr	Prandtl number	( )
R	thermal surface resistance	($m^2.K.W^{-1}$)
Ra	Rayleigh number	( )
Re	Reynolds number	( )
T	temperature	(°C)
t	time	(s)
TE	outside surface temperature	(°C)
TI	inside surface temperature	(°C)
TP	wall temperature	(°C)
u	water velocity	($m.s^{-1}$)

Greek letters

β	coefficient of thermal expansion	(K^{-1})
ε	emissivity for long length wave	( )
Φ	emitted thermal flux	(W)
φ	surface thermal flux	($W.m^{-2}$)
η	efficiency	( )
λ	linear pressure drop coefficient	( )
ρ	density	($kg.m^{-3}$)
σ	Stefan-Boltzmann constant	($W.m^{-2}.K^{-4}$)
ζ	singular pressure drop coefficient	( )

Subscripts

c	convective
exp	experimental
ext	outside
int	inside
mr	mean radiant
n	layer
R	radiative
r	radiator
ref	reference
s	surface
sim	simulated
∞	ambient conditions

Exponent

n	correlation exponent