SIM_ZONAL: A SOFTWARE TO EVALUATE THE RISK OF DISCOMFORT: COUPLING WITH AN ENERGY ENGINE, COMPARISON WITH CFD CODES AND EXPERIMENTAL MEASUREMENTS

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ABSTRACT

The software Sim_Zonal is a tool for evaluating indoor temperature and air flow distributions for residential and office buildings. The aim of this EDF (Electricity of France) software developed in collaboration with LEPTAB (University of La Rochelle) is to evaluate comfort problems and specifically risks of discomfort (risk of draught, indoor gradient temperature, etc..) with taking into account the coupling with the building envelope. The objective is to obtain a simple software for rapid appraisals, which is complementary to the CFD codes. This version makes it possible for the users to achieve dynamical and parametric simulations with variable configurations of rooms, different emitters (electric heaters, heated or cooled floors, heated or cooled ceilings) and variable boundary conditions (meteorological conditions) with a one hour time step. The final aim is to calculate comfort criteria as PMV or UCRES (comfort criteria developed by CSTB).

INTRODUCTION

Sim_zonal is based on a rough partitioning of the room which is divided into a small number of "cells": they are rectangular parallelepipeds. (The number of cells is usually on the order of 10 to 100, compared to 100 000 or more for typical CFD calculations). The cells are coupled to the wall equations. Mass balance and heat balance equations are applied to the cells and the exchanges are calculated between them. It is an intermediate approach described in Inard et al. (1996), Musy (1999), Wurtz et al. (1999) and Wurtz et al. (2001) between one-node models (that consider a homogeneous temperature in each room, and, for that reason, do not permit to predict the thermal comfort in a room) and CFD models (that require great amount of simulation time). Sim_zonal can take into account plumes or jets with empirical laws. In low velocity domains, flow rates are calculated in respect to the pressure distribution. This airflow model is coupled with a building envelope model including the calculation of conduction through the walls, convection between inside wall surfaces and cells, and long-wave and short wave radiant interchange among the inside wall surfaces in Walton (1980). The zonal model is coupled with an energy engine in order to control the power of the emitters. These features allow assessing the risk of discomfort into a room.

First, we present a graphical interface which is a very easy way to describe a simulation. This presentation shows the necessity to propose a low level of complexity is the tool has to be used by non specialists.

The second part describes a comparison of Sim_zonal results with CFD codes predictions. As CFD tool, we use AIRPAK which is a dedicated version of FLUENT to the building field and which integers a zero-equation model for indoor airflow. To do this we study the cases of a heated floor and we propose some amelioration to get a better description of temperature field and air circulation.

In the last part, we propose a comparison with experimental measurements in case of a room solicited by a fan cooler. First we describe how the fan cooler model has been built with experimental data and in a second time we present the first results obtained in a room and show what kind of results can be obtained with this intermediate approach.

SIMULATION

A graphical interface is used to describe the simulation. To explain possibilities of our software we propose to show the different steps that have to be done to describe a simulation. We first the grid density on each direction and the grid dimensions as indicated on Figure 1. The principle is to ask very few information because this software has to be used by non-specialists and the input concern the geometrical conditions but no physical variables are required.

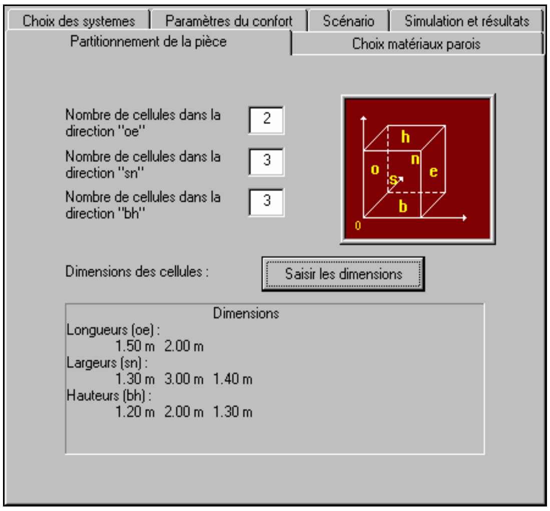

Figure 1: geometrical description

The second table concerns types of building elements used (wall constitution, glazing) and their location in the simulation domain as described in Figure 2. A material file contains all description variables about a wall that means for example radiative and modal coefficient (conduction in a wall is described with Moore method). For this reason the user has only to choose the type of each wall, window or door and specify their location in the room.

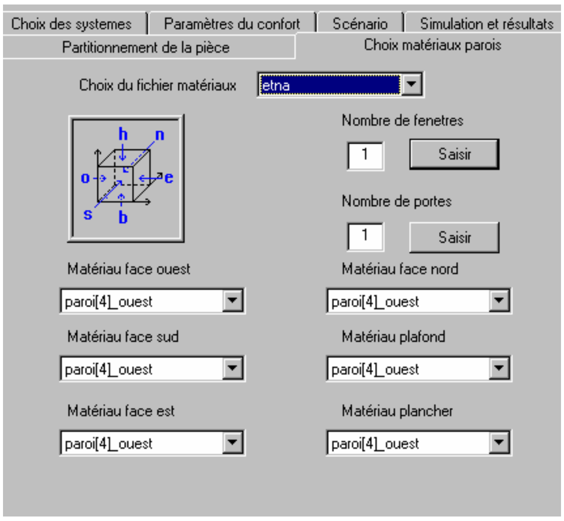

Figure 2: building elements

Next step consists of describing solicitations inside a room. As indicated in Figure 3 the different possibilities of systems are an electric heater, heated or cooled floors or ceiling and fan coolers. There is also a possibility to integrate a heat source to take into account a computer or human presence for example. A specific model has been built for each component with again the principle to limit complexity of data and propose default values for non specialists. In the next chapter describing applications we present an example of specific model in case of a fan cooler and we describe how this model has been built with experimental data help.

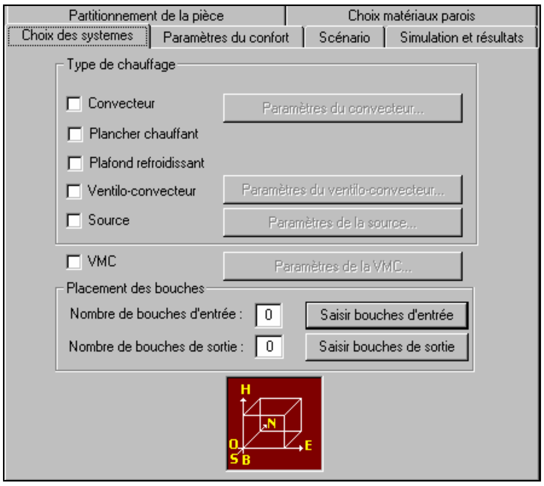

Figure 3: Integration of systems

The last information required consists of precising external conditions which can be external temperature (given by a weather file) or another room with imposed temperature. As presented in Figure 4 temperatures have to be given both on walls and apertures and we have the possibility to put initial values to obtain rapidly stationary conditions. In each case all data are written in data files so an expert user has always the possibility to add more precise information directly in these ascii input files. That is also an easy way to make few modifications on a problem description without using the graphical interface.

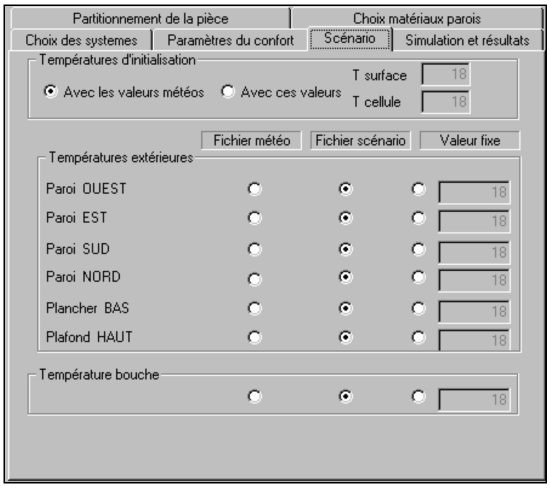

Figure 4: External conditions

At this stage one can run the simulation. For that, as shows Figure 5, we use a file which contain weather data (solar radiation and air temperature), and heat or cool power calculated with another software based on a one node model (energy engine). Then we give simulation's period and with this approach, we need only a few minutes to describe one year simulation what is very interesting to characterize risk of discomfort in a room.

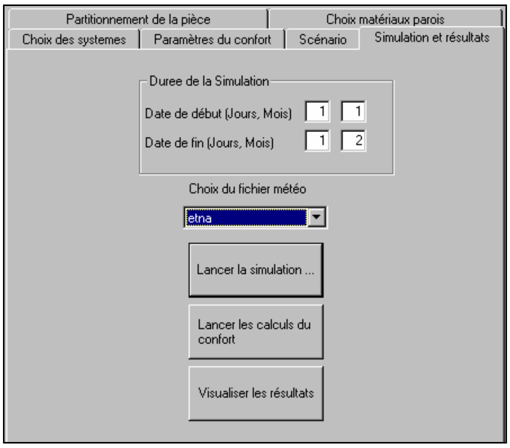

Figure 5: Weather data's choice and simulation's period

After this global description which permits to understand the principle of this software we propose to present different results obtained by comparison with experimental and CFD results.

APPLICATION

Two kinds of results will be shown which concern at first a comparison with CFD results in case of a heated floor and after an experimental study about fan cooler influence.

Comparison with CFD results

Our objective consists to establish a validity domain of our models. For this reason we compare results given by a CFD code with our intermediate approach based on Sim_zonal. For the CFD approach we use Airpack, an element of FLUENT toolbox which objective is comfort characterization. Figure 6 presents what kinds of outputs are given by this software, here in case of temperature field. The description is finely detailed with more than 100 000 nodes but we have to be very careful with this kind of software.

At first about the accuracy of results in a whole room because if results can be considered as valid in case of high velocity it's more difficult to trust results given by a CFD code when the airflow engine corresponds at natural ventilation effects. Another limitation of this approach is due to the fact that it's not realistic to give a PMV field in a local with more then 100 000 different values of PMV. This criterion has not been developed for that: The PMV is a unique variable calculated for a whole room in permanent conditions. For these reasons our simplified approach seems more reasonable even if we are not able to describe complex phenomena inside a room.

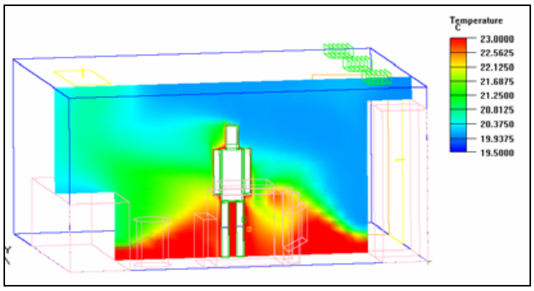

Figure 6: Temperature field obtained with Airpack

In our case dimensions of the room are 4 m x 7.5 m x 2.5 m. The room contains 2 windows (2.5 m^2) and inlet and outlet have same dimensions (0.2 m x 1 m). Walls with windows and ceiling are solicited by external temperatures while others walls are in contact with heated locals. Boundary conditions are shown table 1.

Table 1: Room solicitations

Emitter power	1000W
Outside temperature	5°C
Inside temperature	20°C
Mass airflow rate	0,5vol/h
Inlet dimension	0,2x1,0m

The first validation which has to be done is a comparison of global average temperature in the room for different heated floor powers. Table 2 shows that these differences are very small (The difference is always less then 0.2 degrees) that means the confirmation that energy balances are verified for both cases.

Table 2: Average temperature in the room

	Average room temperature (SimZonal)	Average room temperature (Airpak)
P=500W	18,38	18,22
P=1000W	21,87	21,93
P=2000W	29,12	29,19

In a second time we have compared temperature of each zonal cell with average of temperatures given by AirPack. We can see Figure 7 that these differences are small excepted for the particular zones near inlets or windows. To understand the reasons of these differences we can compare mass airflow in the two cases (AirPack and Sim_zonal). Figure 8 shows the complexity of air circulation specially in the right part of the room. This kind of phenomena can't be described with our intermediate approach because the little cells number avoid to obtain air velocity values in specific places.

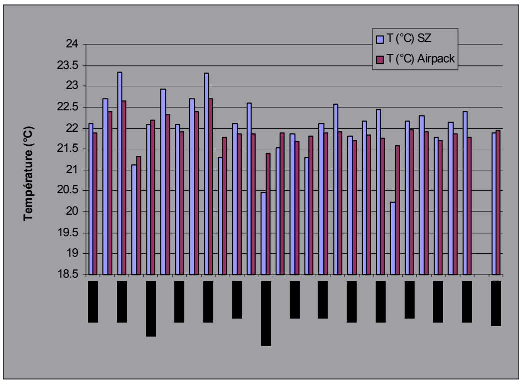

Figure 7: Temperature comparison between AirPack and Sim_zonal approach

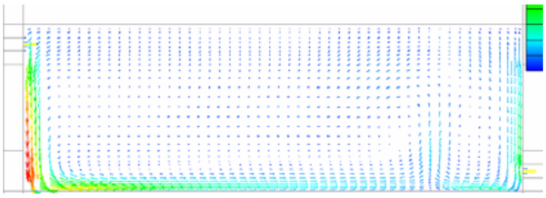

Figure 8: Mass airflow behavior obtained with AirPack

Figure 9 presents which kind of results can be obtained with Sim_zonal. We have seen that air temperature correspond to the values given by CFD approach except where velocity is high and we obtain the same results when we consider velocity. In this case (heated flow) there are no specific laws to describe mass air flow engine and pressure law are used to calculate mass air flow at each interface level.

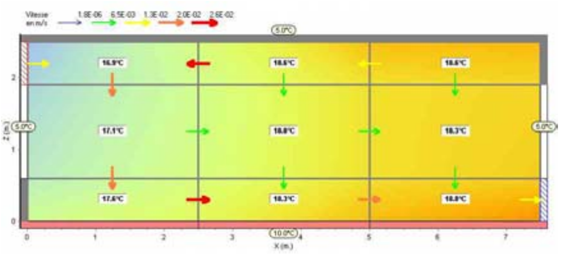

Figure 9: Temperature and mass airflow obtained with Sim_zonal

Where velocities are low air exchanges can be described with a pressure law issued from Bernoulli law like: $Q_v = k\, \Delta P^{\,n}$ where k corresponds to a discharge coefficient and is usually fixed to 0.83 while n represents type of airflow (1 in laminar cases and 0.5 in turbulent). This non linear model isn't really adapted to our simplification approach because convergence difficulties may happen. For this reason, we have tested a linear approach in Musy (1999) as indicated Figure 10.

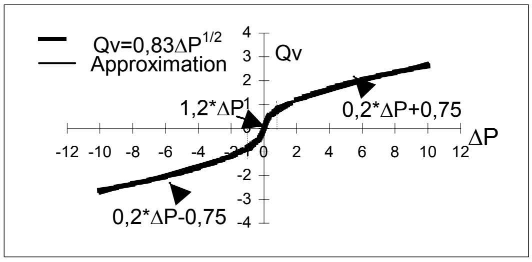

Figure 10: linear pressure law

Because of the very small pressure difference between two cells we need only a linear model at the middle of the curve to describe mass airflow that means we have obtained by this way a linear model. Nevertheless because of the too small pressure variation between two cells (less than *0.1 Pa*), it seams that the linear coefficient should be higher as 1.2. For this reason we have realized a parametric study for different discharge coefficients values with a variation from *1.2* to *5*.

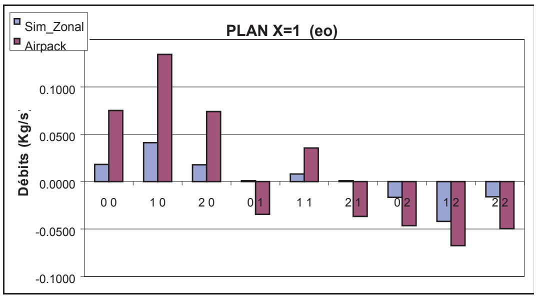

Figure 11: Mass airflow comparison between Sim_zonal and AirPack

Figure 11 shows that if we compare mass air flow obtained with Airpack, higher values of discharge coefficients permit to obtain a better air circulation representation. This result is interesting because it confirm a physical study about discharge coefficient. That example doesn't permit to propose any definitive conclusions but it indicates that the use of a pressure law needs to be very careful and avoid obtaining a complex airflow description. We have also shown that know that this coefficient should be function of meshing density because the different discharge coefficients characterize the global pressure lost in a room. For these different reasons we can conclude that a more precise study is necessary to determine the value of this coefficient in each interface function of meshing density, position in the room...

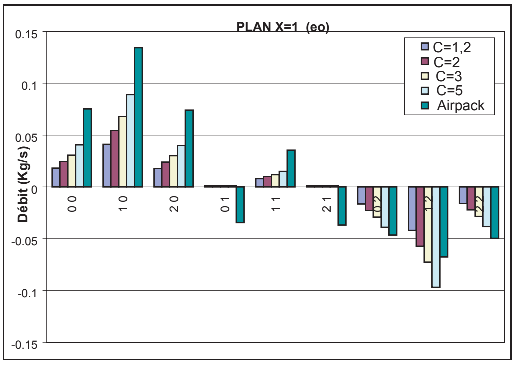

Figure 12: Mass airflow evolution with increasing of pressure coefficient

Nevertheless, to keep a simple approach there is no interest to propose a complex proposition and the first results show that even with these simplifications we get a good approximation of mass airflow behavior with low air velocities. We'll see that the situation is different when airflow engine doesn't correspond to natural ventilation.

Comparison with experimental results

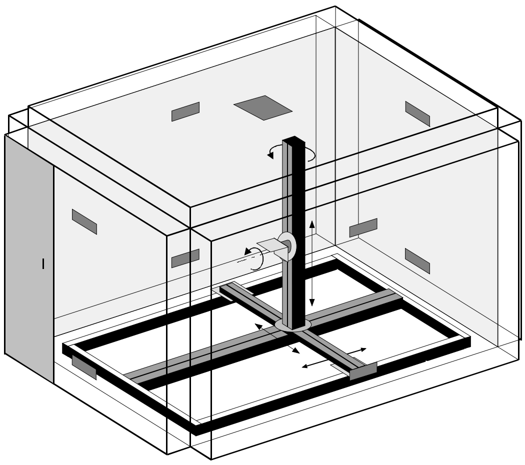

Figure 13: 3D view of Penates experimental room

The second case corresponds to evaluate influence of a fan cooler in a room and compare results with experimental data. The experimental study has been done in the EDF research center of Chatou and concerns a room called Penates described Figure 13 and solicited with a fan cooler. This cell is interesting for an experimental comparison because every boundary condition is measured or controlled.

Table 3 presents every boundary condition in case of a 1200 W power fan cooler.

Table 3: Conditions in room Penates

Emitter Power (W)	1200
Control temperature (°C)	20
Wall temperature where near fan cool (°C)	15
Others walls temperatures (°C)	15,3
air flow rate (ach/h)	0,7
Inlet temperature(°C)	20

A graphical tool, Figure 14, has been developed to represent geometric characteristics. We can see the global room meshing, presence of two windows, inlet and outlet and fan cooler disposition.

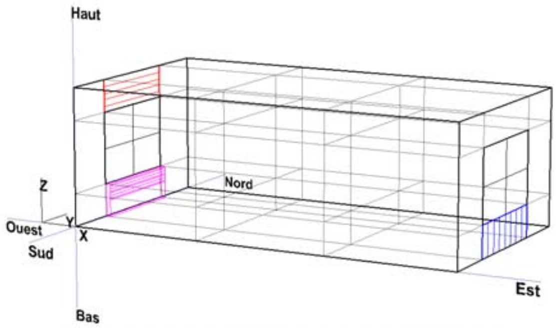

Figure 14: Geometrical disposition of Penates room

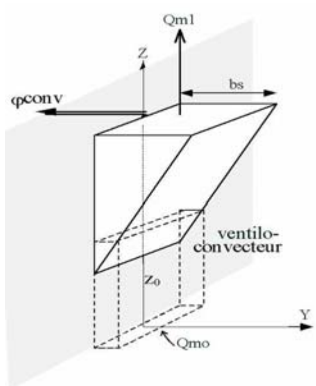

Figure 15: Fan-cooler description

To describe fan cooler influence we have first to build a specific model with experimental output mesured in Penates. Figure 15 present the kind of model which has to be used to describe the fan cooler in Wurtz (2000). The model has been simplified so the only empirical variable necessary is entrainment and initial mass flow. Mass and energy fluxes are then determined by conservations equations for this specific zone and linked to the equations set of the global model.

To evaluate the model validity we have compared all measured variables around the fan cooler, table 4, with simulation's results.

Table 4: Variables measured around the fan cooler

Room temperature (°C)	20
Temperature outside fan cool (°C)	23,1
Temperature for Z=900mm (°C)	22,7
Plume width for Z=900mm (cm)	16
Mass air flow outside fan cool (Kg/s)	0,14
Mass air flow for Z=900mm (Kg/s)	0,31
Entrainment (%)	56

Observing that the entrainment value doesn't change very much with variation of heat power or fan mass air flow, we have chosen to impose a fixed value of entrainment: 60 %.

A first validation consists to represent the average temperature variation obtained with Sim_zonal using heat power given by experimental study. Figure 16 shows that after 10 days (initialisation time) inside air temperature is higher than 19°C and after 3 weeks we obtain an average temperature exactly equal to 20°C which is the control value used in Penates. This simple case permits to confirm the energy balance conservation and we can study what happens inside the room.

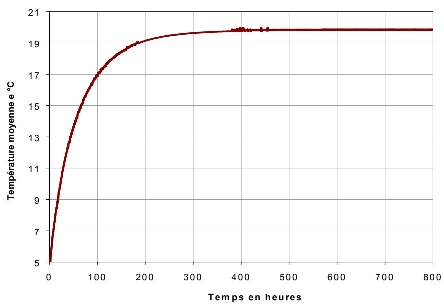

Figure 16: Temperature evolution in the room

We can see Figure 17 that we are able to describe with good precision temperature field in the room. The main error is due to the mass airflow which is going down due to the pressure model. In fact it should keep horizontal because of the hot temperature air above the fan cooler but for that a horizontal jet model should be paced at the top of the room.

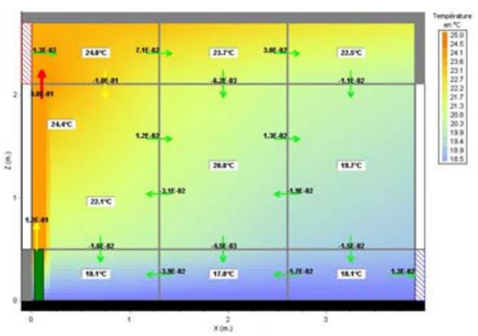

Figure 17: Temperature field in a room in case of fan cooler presence

CONCLUSION

In this paper we have presented software based on an intermediate method between CFD and one node model. The characteristic of this tool is mostly the description simplicity. In fact airflow models are often very complex and can only be employed by fluid mechanical specialists. This simplified approach should permit to architects or inhabitants to understand thermal and mass airflow behavior and consequently choose a heating system with a good knowledge of consequences on comfort characteristics. We have also shown the different simplifications which permit to obtain a very fast simulation tool while a correct choice of specific model permit to characterize comfort conditions in a room.

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