SIMPLIFIED MODELLING OF AIR MOVEMENTS INSIDE DWELLING ROOM

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ABSTRACT

The need for increasingly sharp modelling of building energy behaviour allowing comfort to be evaluated within a heated, ventilated dwelling room leads Electricite De France ADE Department to develop an air interior movement simulation model. This is a simplified modelling which it could be possible to integrate into a global building science-of-heat software programme (CLIM2000). The design principle is the division of the air volume of the room into areas for wich mass and energy balances are computed.

Room areas where air flows at very low velocities (standard areas) and dynamic areas such as thermal plumes or jets are processed separately. An exemple of computation made using the first version of the model ie prior to the integration of plume and jet, evidences, the possibility of using simplified modelling to represent interior air movement.

NOMENCLATURE

E = Entrainment coefficient
$\Phi_{i,j}$ = Heat flow from area i toward area j (W)
$\Phi_{j,i}$ = Heat flow from area j toward area i (W)
Φ_p = Heat flow exchanged with the partition border (W)
Φ_{pi} = Well heat flow (taken from area i) (W)
Φ_{si} = Source heat flow (injected into i) (W)
g = Gravitation constant (m/s^2)
hs = Surface exchange coefficient ($W/m^2/C$)
K = Permeability of the border between areas i and j ($m/s/Pa^n$)
L = Width of the border between areas i and j (m)
n = Flow nature characteristic parameter
P = Air pressure (Pa)
P_{0i} = Air pressure at area i lower level (Pa)
q_{me} = Air entrainment mass flow rate in plume or jet (kg/s)
$qm_{i,j}$ = Arithmetical mass flow rate of air flowing from area i toward area j (kg/s)
$qm_{j,i}$ = Arithmetical mass flow rate of air flowing from area j toward area i (kg/s)
$Qm_{i,j}$ = Algebraic mass flow rate of air flowing area i toward area j (kg/s)
$Qm_{j,i}$ = Algebraic mass flow rate of air flowing from area j toward area i (kg/s)
Qm_{si} = Source mass flow rate (injected into area i) (kg/s)
Qm_{pi} = Well mass flow rate (taken from area i) (kg/s)
ρ = Air density (kg/m^3)
ρ_i = Air density in area i (kg/m^3)
ρ_j = Air density in area j (kg/m^3)
S = Surface of the border between areas i and j (m^2)
T = Air temperature (C)
T_i = Air temperature in area i (C)
T_s = Partition border surface temperature (C)
U = Maximum velocity inside the plume or the jet (m/s)
v_e = Air entrainment velocity (m/s)
z = Standard level of a area (m)
z_i = Standard level of the area i (m)
z_j = Standard level of the area j (m)
z_n = Neutral axis level (m).

1) INTRODUCTION

The numerical model became in a few years an ordinary, widely used tool in the building energy sector like in many other forms of energy. The model components whether for heating systems or for building casing (walls, windows, thermal briges,...) now form the object of complex modellings which were, in some cases, validated by experiment.

These models which often are developed to meet sizing and energy operating cost requirements, generally represent the final stage in its entire totality ie energy restitution to the room. This means that the space or the volume of air in a room in which one lives, is regarded as being fully homogeneous from temperature and concentration viewpoint (humidity, pollutant,...)

Should the software be used for evaluation or comparison of the different heating techniques according to criteria other than energy consumption, such a model would obviously be no longer appropriate. Thermal comfort requirements via temperature (vertical or horizontal) gradients or the air grade relative to pollutant distribution will certainly not be satisfied with a simple air node to typify the whole room volume.

This paper presents a modelling which provides response data upon the aeraulic behaviour of room environment while restricting the complexity of our software which should remain a building "general" code.

2) SIMPLIFIED MODELLING: "SAMIRA*"

Air movement inside a dwelling room is governed by continuity, NAVIER-STOKES, and energy equations and its modelling is generally clumsy. Such models (called field models) are actually complex from the viewpoint of data input (fine meshing needed) and restitution of results in terms of pressure, velocity and temperature fields.

Integrating these equations into a global building thermal software would entrail computation times inappropriate to long-term simulations like those we frequently have to make. This is why we had to turn toward a simplified modelling enabling us to understand indoor air movements and temperature distribution without using any field models.

Though different types of simplified models exist, they all rest upon a division of the reference room and they differ in the mode of computation used for inter-area mass and heat exchanges [BOUIA 1990].

The exchange laws may deduced from serial experiments, and from a degrading of conventional fluid mechanics equations as is the case for our SAMIRA model.

2.1) Model hypotheses

The model is based on the drafting of mass and energy balance equations for each area. Inter-area mass transfers are computed using BERNOULLI's equation assuming that the velocity is zero within each area. Therefore, no quantity equations are available for movements, which means assuming that kinetic energy is entirely dissipated by turbulence within each area.

Such hypotheses which is adapted to the room still areas is erroneous when applied to plume and jet areas corresponding to the flow above a convector and perpendicularly to an air intake. Plume and jet models have been introduced to take account of the specific characteristics in the behaviour of the areas considered.

Both temperature and pressure vary in each point of a heated, ventilated dwelling room. The differences may be high between an area near to the source or an air extractor, and middle of the room. Dividing the room consists in suitably splitting it into parallelepipedic sections with vertical or horizontal generating lines. The arrangement of heating and ventilation systems and that of the opening elements involve the selection of a given meshing taking account of the area nature (figure 1).

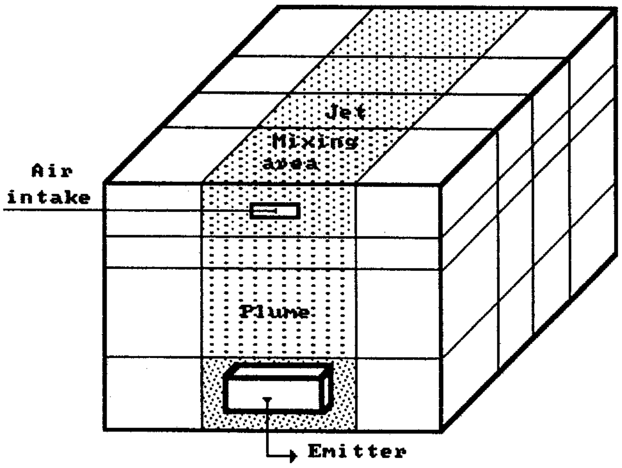


Figure 1

There are different types of areas:

- Areas which belong to a plume every time a source of heat exists: **Plume areas**,
- Areas which belong to an air jet in the case of air intakes: **Jet areas**,
- The other areas will be called: **Standard areas.**

Each standard area is supposed to be still at temperature **T** constant and with a hydrostatic pressure profile **P**, P_0 being the pressure at the lower level.

The borders between areas are assumed to behave as fictitious and fully permeable partitions. The volume flow rates between two standard areas **(i)** and **(j)** comply with a power behaviour law resulting from

***S**imulation **A**éraulique des **M**ouvements **I**ntrazones en **R**égime **A**nisotherme

BERNOULLI's relation. They are function of pressures (P_{0i}, P_{0j}), temperatures (T_i, T_j) and area dimensions. The flow conveyed from a standard area toward a plume or jet area, complies with an empirical entrainment rate law.

2.2) Balance equation

An area exchanges air volume flow rates and heat flows through its six borders, four vertical and two horizontal.

Mass and energy balances under steady-state operating conditions read as follows for each area respectively:

$$\sum_{j=1}^{6} Qm_{i,j} - Qm_{si} + Qm_{pi} = 0$$

$$\sum_{j=1}^{6} \Phi_{i,j} - \Phi_{si} + \Phi_{pi} = 0$$

where $Qm_{i,j}$ (resp. $\Phi_{i,j}$) is the algebraic total mass flow rate (resp. total heat flow) from the area **(i)** toward the area **(j)**. Indexes **s** and **p** represent the source and well terms.

The expression of these mass flow rates varies depending on whether these are a transfer between two still areas or between a plume are and the adjacent areas (figure 2).

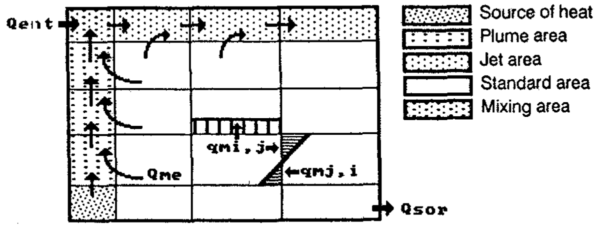


Figure 2

2.2.1) Mass and energy exchanges between standard areas

A statically balanced fluid complies with the law:

$$dP = -\rho.g.dz$$

In cases where the temperature is regular and variations in pressure, low, we have:

$$P = P_0 - \rho.g.z$$

The pressure differential between two adjacent standard areas **(i)** and **(j)** is:

$$\Delta P = P_i - P_j = P_{0i} - P_{0j} - (\rho_i.g.z_i - \rho_j.g.z_j)$$

There are two different cases:

- The border is vertical:

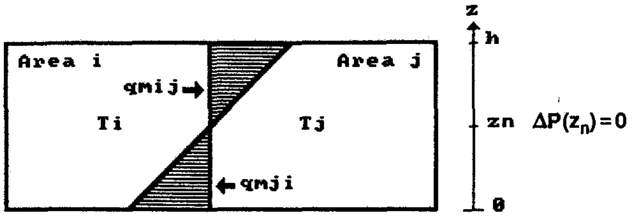
In this case the pressure differential reads as follows at level **z**:

$$\Delta P = P_{0i} - P_{0j} - (\rho_i - \rho_j).g.z$$

or

$$\Delta P = -(\rho_i - \rho_j).g.(z - z_n)$$

by introducing the level z_n of the neutral axis.



The elementary mass flow rate $dq_{mi,j}$ flowing through the elementary flow height dz is generally expressed as follows:

$$dq_{mi,j} = K.L.\rho.(\Delta P)^n.dz$$

Where ρ is the density of air in the upstream area, **K** the border permeability, **n** a coefficient which characterizes the flow nature ($n \in [0.5,1]$).

Depending on the position of the neutral axis z_n and the values of ρ_i and ρ_j, we have to break down the flow rate $Qm_{i,j}$ into a flow rate $qm_{i,j}$ entring the area **(j)** and a flow rate $q_{mj,i}$ entring the area **(i)**. Say after integration:

$$Qm_{i,j} = q_{mi,j} - q_{mj,i}$$

Where, for the case represented in the previous figure:

$$qm_{i,j} = K.L.\rho_i.[(\rho_j - \rho_i).g.]^n.\left(\frac{(h-z_n)^{n+1}}{n+1}\right)$$

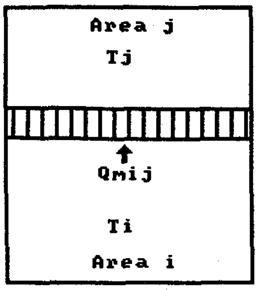
$$qm_{j,i} = K.L.\rho_j.[(\rho_j.\rho_i).g.]^n.\left(\frac{z_n^{\,n+1}}{n+1}\right)$$

The flow exchanged then becomes:

$$\Phi_{i,j} = q_{mi,j}.C_p.T_i - q_{mj,i}.C_p.T_j$$

- The border is horizontal:

In such a case, the pressure differential is uniform at the border level and there is only one through flow rate:



$$Qm_{i,j} = \rho.K.(\Delta P)^n.S$$

where S= The border geometrical surface and the flow exchanged is:

$$\Phi_{i,j} = Qm_{i,j}.C_p.T_i$$

If the standard area border represents a portion of a partition, a convective exchange take place which can be modelised by a coefficient h_s. The heat flow then reads:

$$\Phi p = h_s.S.(T - T_s)$$

2.2.2) Transfers between dynamic areas and standard areas

Given a border separating a standard area and a dynamic area, the mass flow rate is computed from semi-empirical global entrainment law. This approach due to MORTON, TAYLOR and TURNER [MORTON 1956] for plumes and ALPERT [ALPERT 1975] for jets, supposes that the entrainment velocity v_e is proportional to a flow characteristic velocity ie the maximum velocity inside the plume or the jet:

$$v_e = E.U$$

The entrainment flow:

$$q_{me} = 2.E.(b.\pi)^{\alpha}.\rho_e.U$$

where **E** = the entrainment coefficient
b = the plume radius or half-thickness
α = 0 (resp. = 1) given a flat plume (resp. axisymmetrical)
ρ_e = the entrained air density.

Different expressions of **E** are proposed by several authors as a function of the configuration analysed. Expressions of **E** and **U** can be found in references [RONGERE 1986] and [INARD 1988].

Only the computations between standard areas are operational in our model at this time. The results given below therefore concern a pressurization modelling made before integrating any plume and jet models.

3) THE FIRST RESULTS

Below is an example of 2-D computation for a room equipped with a 1000 W source of heat and an air renewal rate of about 0.5 vol/h at 0°C. Conditions prevailing at thermal limits rest upon a scenario of distribution of surface temperatures derived from a radiating and convecting balance.

Figure 3 shows the air flow exchange between areas which were computed using SAMIRA model before the plume and the jet were integrated.

In the air flow global behaviour seems logical in the computation example, the hot plume area (on the lefthand side) is not suitably represented.

Laser tomography visualizations [AREFI 1991], in fact, allow us to assert that air is actually entrained with the plume over its whole length. Such an acknowledgement allows the need for integrating a plume model whith the associated entrainment into this type of global computation to be justified.

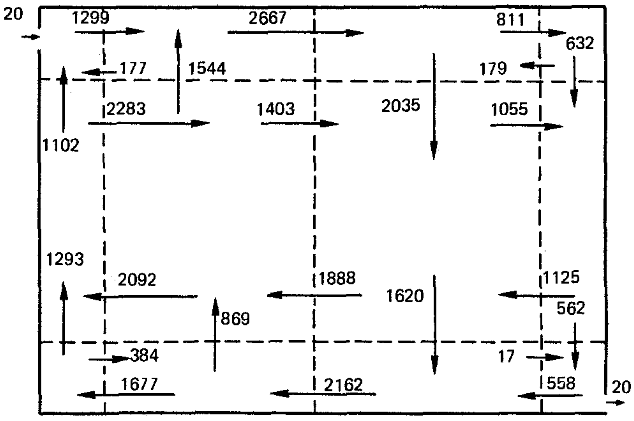


Figure 3 – Inter-area flow rates (kg/h)

Figure 4 allows the visualization of horizontal and vertical gradients for the air temperature distribution in the room. The temperatures should not be compared with the standard values derived from in-situ experimental observations inasmuch as the 2-D computation provides the hot source area with a low power per unit length and, consequently, under-rated plume temperature.

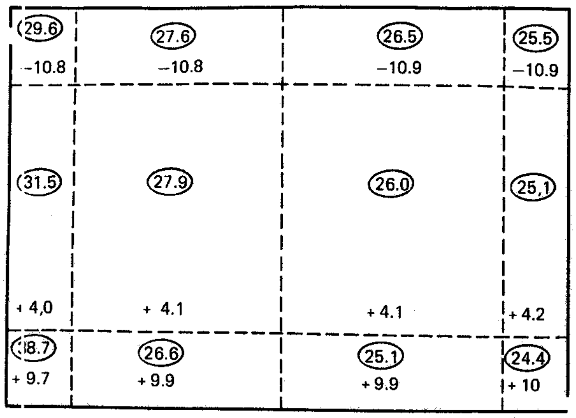


Figure 4 – The values in circles are air temperatures (°C), the other values are pressures relative to outside pressure (Pa).

4) CONCLUSIONS

These first computation results make it obvious that air movements and temperature gradients in room environment can be represented with the aid of a simplified model. It is also evident that a model under standard pressure does not suffice since the absence of representation of dynamic areas such as jets and plumes is damageable not only for the evaluation of inter-area flow rates but also for air temperature distribution.

We now are in the development phase for jet and plume models with their air entrainment, and we should be capable of improving the results owing to their incorporation into SAMIRA model.

Validation now is in progress and we will rest upon "academic" in-lab experimental measurements made on a reduced-scale (1mx1m x0.4m) cavity, and, then, on full-scale experiment. The validation work will be supplemented by an inter-software comparison with field models.

This model will be integrated into a building energy modelling global software programme (CLIM 2000). It will then be possible for us to represent its coupling with the other thermal phenomenons and to carry out comprehensive evaluation surveys of the comfort provided within a dwelling room heated by an electric convector.

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