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STUDYING INNOVATIVE CONCEPTS BY COUPLING SIMPLIFIED SIMULATION AND MULTIZONE AIRFLOW MODEL

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ABSTRACT

In order to respond to global warming and natural resources depletion challenges, industrials from the building sector need to propose an adequate offer. Energy simulation tools can support this process. In order to reach high performance level, e.g. primary energy consumption below 50 kWh.m⁻² per year (including heating, cooling, domestic hot water, lighting and ventilation), various studies and real cases show that, appropriate architecture, high insulation, free cooling and the use of a heat recovery exchanger for ventilation are needed. This last technology will be particularly affected by airflows across the building envelope caused by a low airtightness. Moreover, free cooling ventilation rate will highly depend on temperature difference between outside and inside. Thermal modelling tools need therefore to deal with those two issues precisely.

A multizone model has been developed to compute building airflows in order to evaluate them with a higher degree of precision in the frame of a simplified simulation tool that can be used in early phases of a project. This model is based on well-mixed zones and mass conservation principles. The air flow rate between two zones is expressed as a function of the pressure drop between those two zones. Wind pressure and buoyancy effects are the causes of pressure drops. Several types of connection are implemented: cracks, ventilation inlets, large openings. More types of connection will be added.

This model has been implemented in the thermal building simulation tool COMFIE [1]. The airflow model uses the temperatures of the zones as an entry and the thermal model uses the airflows as an entry as well. Both thermal and airflow model run at each time step until convergence is reached using a synchronous coupling method. An algorithm has been developed to ensure the convergence for each time step (from 1/10 to 1 hour).

Two case studies are presented. First, the case of a residential building, project of Vinci Construction France where the influence of air tightness on heating loads is being studied. Then the case of a concept building, Effibat, being developed by Vinci Construction France and MINES ParisTech. This building is an urban dwelling building including an atrium. Natural ventilation is used to cool the building at night in summer and the model aims at evaluating the resulting comfort level.

INTRODUCTION

In order to respond to global warming and natural resources depletion challenges, industrials from the building sector need to propose an adequate offer. Energy simulation tools can support this process. In order to reach high performance level, e.g. primary energy consumption below 50 kWh.m⁻² per year (including heating, cooling, domestic hot water,

lighting and ventilation), various studies and real cases show that, appropriate architecture, high insulation, free cooling and the use of a heat recovery exchanger for ventilation are needed. This last technology will be particularly affected by airflows across the building envelop caused by a low air tightness.

Moreover it is important to fulfil a satisfactory level of summer comfort, passively or mechanically. Simulation tools have therefore to evaluate this performance precisely, and must be sensitive to the corresponding design parameters (e.g. free cooling). A precise ventilation rate evaluation is then needed to create ventilation strategies that will allow the building to reach his consumption and comfort targets.

Dynamic yearly thermal simulation tools are used to evaluate heating loads and room temperature for different thermal zones in the building. The building envelope is precisely described: architecture, materials thermal properties. Solicitations from inside (occupation, electrical equipment dissipation) and outside (temperature and solar solicitations) are taken also into account.

In a multizone ventilation simulation tool, the building is idealized as a zone network linked by airflow components such as cracks or windows [2, 3]. Airflow rates are calculated as a function of pressure drop between two zones that will depend on wind pressure around the building and temperature difference of the zones.

Those two models are treating complementary issues that are highly inter-dependent. A coupling of those two kinds of models seems therefore needed to design high performance buildings.

METHOD

Airflow Model

The model is based on the assumption of well-mixed zones: each zone is assigned a reference pressure point and a temperature. Driving forces are variable surface pressure caused by wind on the building, stack effect caused by temperature differences and supplied and extracted air by the mechanical ventilation system. Pressure difference between two points *i* and *j* located in zones *m* and *n* is expressed :

$$\Delta P = P_i - P_j = P_M - P_N + P_T + P_V$$

Wind pressure P_V depend on wind speed at the building site, V_h . Pressure coefficients (C_p) allow a distribution of the wind pressure around the envelope:

$$P_V = \frac{\rho V_H^2}{2} C_p$$

Pressure difference P_T due to buoyancy effect between two points *I* and *J* located in zones *M* and *N* is expressed as a function of zone air densities and relative elevation:

$$P_T = \rho_M g(z_M - z_i) - \rho_N g(z_N - z_j)$$

Air circulates between the zones via different kinds of airflow components. The air flow rate is then expressed as a function of the pressure drop between two zones.

Air infiltration through the building envelope is taken into account by a power law:

$$\dot{m}_{i \rightarrow j} = C_{in} \Delta P^n$$

C_{in} is the flow coefficient ($m^3 \cdot h^{-1} \cdot Pa^{-n}$), it is an indication of the size of the crack. n is the flow exponent (0.5 for a turbulent flow and 1 for a laminar one).

Most energy efficiency buildings labels require a minimum degree of air tightness (example: $1 m^3 \cdot h^{-1} \cdot m^2$ per façade under 4Pa for Effinergie, in France). This value is specified by the user. It needs to be distributed around the building. For instance, energy efficient architecture will tend to place more windows on the southern façade of building, this façade will then present more air tightness defaults due to windows than the northern one. Air leakage is distributed from fan pressurization test results according to [4]. n is supposed to be fixed, and the flow coefficient, found in the literature ($C_{Q_{i,lit}}$) is adjusted with the building coefficient given by the test.

$$C_{Q_i} = C_{Q_{i,lit}} \times \frac{[C_{Q_{test}} (\Delta P)^{n_{test}}]}{\sum C_{Q_{i,lit}} (\Delta P)^{n_{i,lit}}}$$

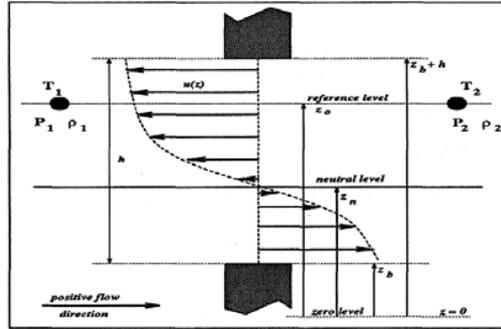


Figure 1: Air flow across a large vertical opening

The model also allows the user to implement vertical large openings. In such openings, multiple way flows are possible (stack effect can cause positive or negative pressure, above or under a neutral level, figure 1). An analytical solution, proposed by [2], has been implemented:

$$\dot{m}_{z_n, H} = \frac{2}{3} W C d \theta \sqrt{\rho} [2g(\rho_{01} - \rho_{02}) - bt]^{\frac{1}{2}} |H - Z_n|^{\frac{3}{2}}$$

And :

$$\dot{m}_{0, z_n} = \frac{2}{3} W C d \theta \sqrt{\rho} [2g(\rho_{01} - \rho_{02}) - bt]^{\frac{1}{2}} |Z_n|^{\frac{3}{2}}$$

W is the area of the opening, Cd a discharge coefficient and the neutral plan is expressed:

$$Z_n = \frac{P_{01} - P_{02} + P_{to}}{g(\rho_{01} - \rho_{02}) - b_t}$$

For each zone, mass conservation principle can be expressed as a function of the pressure:

$$f(P) = 0$$

Eventually, the system is resolved, using the Newton-Raphson Method to find the next approximation of the pressure vector:

$$P^{k+1} = P^k - X^k$$

With $J(P^k)X^k = f(P^k)$ (where J is the Jacobian Matrix)

Coupling with the thermal model COMFIE

COMFIE is a thermal dynamic multizone model. The core of the model simulates a building response to solicitations and can be linked to several objects that were developed independently (heat pumps, air to ground heat exchanger, photovoltaic and thermal solar , etc.).

The airflow model uses the temperatures of the zones as an and the thermal model uses the airflows as an entry as well.

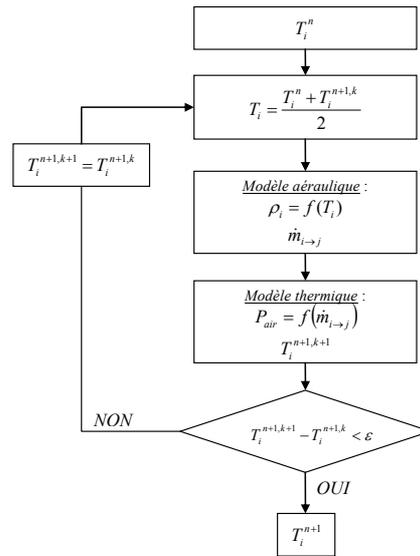


Figure 3: Coupling thermal and airflow simulations

Different approaches are found in the literature to proceed to coupling airflow and thermal models [5, 6]. First, sequential coupling which is an asynchronous method with no feedback between the models. Then synchronous methods where both models interact. Ping-pong (airflow model output is thermal model input for the next time step, this methods requires time steps shorter than 5 minutes) and onions (at each time step, both models iterate until convergence is reached). Onions method is chosen because it allows more freedom to the user who wants to use other modules from the program (e.g. ground heat exchanger).

To avoid convergence problems, temperature that is taken into account is the mean of the current iteration and the previous one (see figure 3).

RESULTS

Presentation of EFFIBAT

EFFIBAT is a dwelling building designed to reach the 50 kWh.m⁻² consumption target. This performance is made possible by a compact architecture, a high degree of insulation and heat recovery ventilation. Atria allow inhabitants to benefit from day lighting and the air is pre-heated in winter. In summer, atria are cooled by a natural ventilation. The purpose of the study is to evaluate the influence of the air tightness on the building load and the temperature in the atrium in winter and summer.

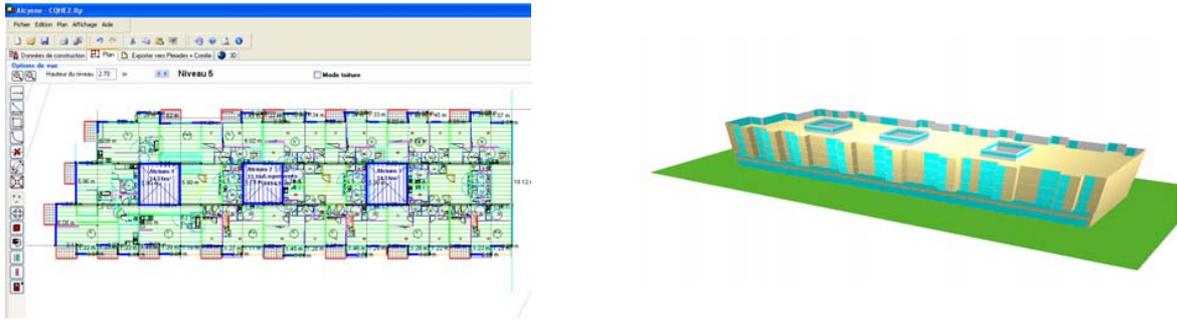


Figure 4: 2D and 3D representation of the project in COMFIE

Influence of air tightness on building heating load

The site meteorological station is Trappes, near Paris. The building envelope is insulated as described in table 1.

	Keynotes		Software presentation
External Wall	3cm fibered concrete +16 cm glass wool insulation+1.3 cm gypsum	Upper Ceiling	20cm concrete+10 cm polyurethane
Dwelling-Atrium Wall	1.3 cm gypsum +10 cm glass wool+1.3 cm gypsum	Floor	20cm concrete+10 cm polystyrene

Table 1: Envelope composition

The building is also equipped with low emissivity double glazing windows ($U_{\text{windows}}=1,3\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$)

Dwellings are supposed to be heated at 20°C . Ventilation rate is taken 0,5 vol/h, the heat recovery efficiency is assumed 80%.

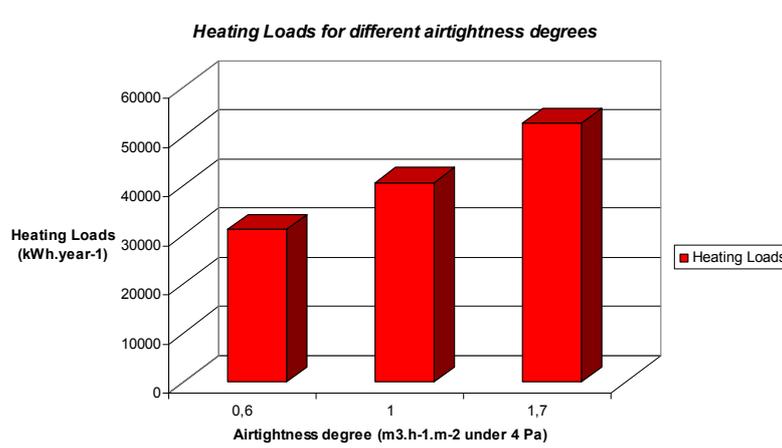


Figure 5: Heating Loads for different air tightness degrees

Three degrees of air tightness are considered: $0,6\text{ m}^3\cdot\text{h}^{-1}\cdot\text{m}^{-2}$ which is the project target, $1\text{ m}^3\cdot\text{h}^{-1}\cdot\text{m}^{-2}$ which is required by Effinergie and $1,7\text{ m}^3\cdot\text{h}^{-1}\cdot\text{m}^{-2}$, the default value from French regulation which is supposed to be representative French dwellings.

From 0,6 to 1, heating loads vary from 7 to 9 $\text{kWh}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ (+30%). It goes up to +70%, $12\text{kWh}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ for a building with noparticular air tightness preoccupation.

Summer temperature of the atrium

The atrium is a source of heat in winter but it needs to be well ventilated in summer to avoid over-heating problems. In order to evaluate summer comfort, as the building will be equipped by venetian blinds, it is assumed that inhabitants will use them. Windows solar factor is then reduced by 4 during this period. Eventually, 15 m² of facade opened windows is considered for each level (same surface is considered in the atrium).

Figure 6 shows the evolution of the temperature in the atrium and outside temperature during summer time. According to the study, temperature never reaches 26°C. Further work will consist in studying the atrium thermal comfort during the 2003 heat wave.

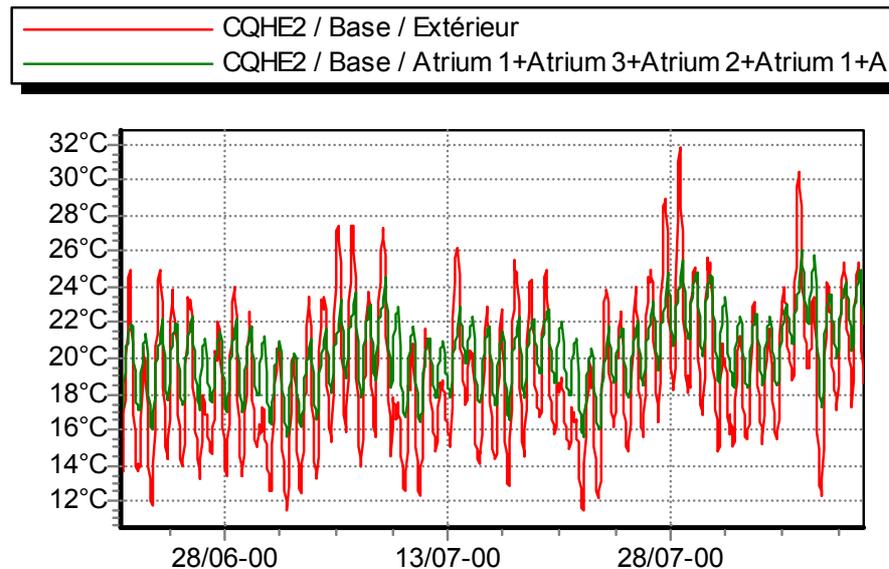


Figure 6: Atrium and outside summer temperatures

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