SIMSPARK PLATFORM EVOLUTION FOR LOW-ENERGY BUILDING SIMULATION

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To counter the world's mounting energy demands, the energy efficiency of buildings is a major control lever. Therefore, low energy buildings and passive houses are increasingly in the news. But what does this mean?
Beginning with a simulation platform (SimSpark) based on the solver Spark, we aim to describe the thermo-aeraulic behaviour in buildings. From this platform, we can easily integrate all types of system.
Using the environment's modularity, it is possible to estimate the gain contributed by various types of envelope or by the addition of different systems. We can also determine the interactions that give the most effective associations. In this article, the results of simulations on the effect of counter-flow ventilation on the heating demand and the effect of adding overhangs above windows on the building's thermal behaviour will be presented. We will also present a method to simulate the earth-to-air exchanger.

Keywords: solar buildings, high efficiency building, SimSpark, simulation, earth-to-air exchanger

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Introduction

In a context of sustainable development, it is becoming necessary to limit energy consumption. As buildings today require a great deal of energy, the notion of the low- and ultra-low-consumption building is coming to the forefront.
In the first section, we will quickly discuss these notions. Then we will see approach used to simulate these buildings with the simulation platform SimSpark by taking two concrete applications to show the possibilities of this environment. We will finally present a new method to simulate the earth-to-air exchanger.

Energy efficiency in buildings

In the energy efficiency of buildings, two performance levels are distinguished. For a heating demand of 30–60 kW·h/(m²·yr), "low-energy" or "low-consumption" construction is used. For an "ultra-low-energy" building (or "ultra-low consumption" or "passive"), a heating demand criterion of 10–15 kW·h/(m²·yr) must be satisfied. In this second type of house, it is no longer necessary to set up a conventional heating system.
The graph below (Fig. 1) helps understand why these two categories are advantageous.

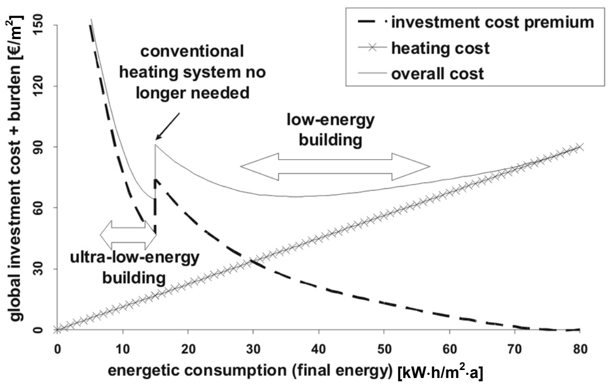


Fig. 1. *Global energy cost in a building [1]*

This graph shows that there are two economic optima: the first one for a consumption of approximately 40 kW·h/(m²·yr) and the second for a consumption of approximately 15 kW·h/(m²·yr). These two optima correspond to low- and ultra-low-energy buildings.
These two types of buildings are certified by two different companies in Europe: Minergie® (Switzerland) and Three Litters House (Germany), which certify low-energy consumption construction. Of the companies offering ultra-low-consumption buildings, the most widely recognized are Minergie-P® (Switzerland) and Passivhaus (Germany).
The maximal heating load required for a 150-m² ultra-low-consumption house is 1500 W, the power of a hairdryer.
According to a CSTB study [2], Germany has approximately 5000 passive houses and 12,000 low-consumption houses today. According to Minergie® [3], Switzerland has a total of 6000 low-consumption houses and 100 ultra-low-consumption houses. In France, there are only a few such homes and no operational ultra-low-energy building label exists at this time.
To describe high energy efficiency building thermo-aeraulic behaviour, simulation is necessary.

Numerical simulation with the platform SimSpark

To simulate building behaviour and use the experimental data, we chose to base our simulation platform, SimSpark [4], on the equation solver, Spark, developed by the Lawrence Berkeley National Laboratory. Spark is a general simulation environment in which a system of equations can be defined and solved by a robust algebro-differential solver according to Sowel et al. [5]. It is an object-oriented equation-based environment.

Description of Spark simulations

The basic object in Spark is the equation, which is shaped in what is called an "atomic class". One equation can communicate with another one with its variables, called ports.
To program in Spark, these equations simply need to be ordered with each other. This requires using another type of object, the "macro-class", in which we call the equations and make them communicate with their variables. "System of equations" objects can also communicate with the other objects through their variables, providing an object hierarchical organization, from the simplest, which represents an equation (for example, the convection equation in a wall) to the most complex system of equations (for example, the complete thermal simulation of a building) by way of intermediate objects (such as objects modelling a wall).
When all the equations are connected through several levels of objects, the system's input and output are identified in a last object called "program".
This procedure allows connecting models at various levels very easily. For example, using their variables, a solar panel model can be combined with a floor heating model that is connected to a model of thermo-aeraulic air transfers of a building combined with models of the walls, providing a model of a building equipped with a direct sun floor.
Like the other object-oriented environments, Spark possesses the property of data encapsulation. This means that the characteristics of an object are localized within it, making it is easy to change a model in a simulation.
In Spark, the equations are not defined in a directed way. When the basic problem is defined, a variable is not an input or an output. Therefore, Spark inverts a model very easily by changing the status of a variable using a keyword in the program file. A variable which resulting from the simulation then becomes an input.

Examples of simulations

The house on which this study is based was built on two full floors. Its net floor area is approximately 100 m. There is 13.5 m² glazing on the south facade (i.e. 28 % of the total surface of the wall), 6.5 m² on the west (18 %) and 3.5 m² on the east side (9 %). The front faces the south. The climatic conditions are those of Chambéry, France.

The wall is composed of mass concrete inside and external insulation to take advantage of thermal inertia (we consider a classical insulation of specific conductivity 0.04 W/(m·°C)).

A nodal method with one node per floor was used for calculation. The thermal transfers in the walls were estimated by discretization of the heat equation by finite difference.

Radiation was calculated using the fictitious domain method. To determine the sun's contributions through the windows, we made a geometrical calculation of the area of the sun task on each window. Then we considered that the flow was distributed throughout the surface of the wall reached by the sun's rays. The value obtained is considered as a direct primary flow in the fictitious domain method.

Both very simple studies were conducted to show that the simulation platform is operational and easily gives results of dynamic simulations for different configurations.

More complex configurations are being developed and will be explained in a later publication.

Comparison of two types of ventilation

This section compares the effect of single-flow ventilation to that of counter-flow ventilation.

Let us note first that the counter-flow heat exchanger is shunted in the summer because of the low temperature gradient between indoor and outside. Consequently, in the summer, both types of ventilation have the same behaviour, which is why the comparison element chosen here is the heating demand [kW·h/(m²·yr)].

For both models, each floor possesses an air inlet, in which the mass flow is fixed, and an air outlet. For air exchange, the volume flow rate is normally 0.5 volume per hour. In the summer, during the night, when the outside temperature is lower than the indoor temperature, overventilation is obtained with a volume flow rate of 3 volumes per hour.

For the single-flow ventilation, the heat flow entering the room by the air inlet is calculated by the equation:

$$\Phi_i = \dot{m} C_p T_{ext}\,, \qquad (1)$$

where Φ_i – inlet heat flow [W], $\dot{m}$ – air mass flow [kg/s], C_p – air heat capacity [J/(kg·°C)], T_{ext} – external air temperature [°C].

The heat quantity going out via the air outlet is calculated by:

$$\Phi_0 = \dot{m} C_p T_{ind}\,, \qquad (2)$$

where Φ_0 – outlet heat flow [W], T_{ind} – indoor temperature [°C].

Counter-flow ventilation is simulated very simply by evaluating the air-supplied indoor temperature calculated with the efficiency of the exchanger:

$$T_{si} = T_{ext} + \eta(T_{ind} - T_{ext}), \qquad (3)$$

where T_{st} – air supplied inside temperature [°C], η – exchanger efficiency [-].

We then calculate the heat flow leaving the room using the same equation as for the single flow (2) and the flow entering using the equation:

$$\Phi_i = \dot{m} C_p T_{si}\,. \qquad (4)$$

After several annual simulations with a time step of 30 minutes, we can deduct the following result (insulation thickness varies) (Fig. 2):

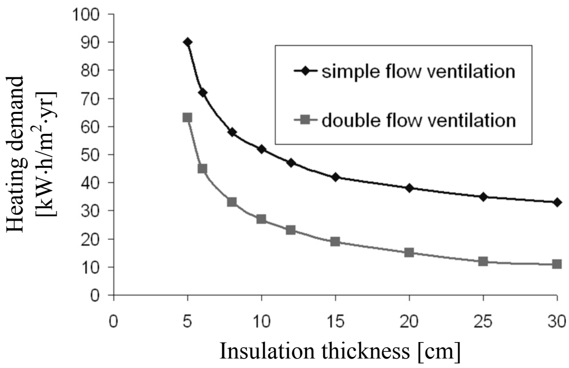


Fig. 2. *Heating demand for two types of ventilation*

On this curve, it should be noted that the difference in heating demand between the house equipped with single-flow ventilation and the one equipped with counter-flow ventilation is constant whatever the thickness of insulation. The value of this difference is approximately 25 kW·h/(m²·yr).

As a result, for a house with 5-cm-thick insulation, the energy savings gained from installing counter-flow ventilation is 30 %, while for a house with 30-cm-thick insulation (order of magnitude for German passive houses), the energy savings is roughly 70 %.

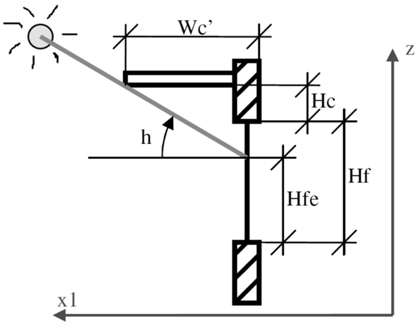
Thus, to obtain high energetic efficiency, counter-flow ventilation is completely warranted.

Passive treatment of summer comfort

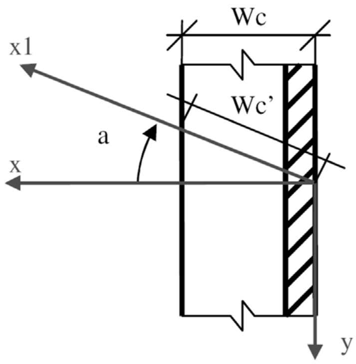
In this section, we attempt to determine the effect of window overhangs on summer comfort and their impact on heating demand.

Summer comfort is estimated by the number of hours when the indoor air temperature exceeds 27 °C.

To model these overhangs, a geometrical calculation is made to determine at what height the window receives sunlight (Hfe) (Fig. 3).



a



b

Fig. 3. *View in the solar ray plan of the overhang (a), top view of the overhang (b)*

Here a − directed angle between the normal for the window and the projection of the sunbeam on the ground; h − solar altitude.
Other symbols are explicit geometrical characteristics of the problem.
We can deduce the expression of Hfe:

$$\text{Hfe} = \min(\text{Hf}, \text{Hf} + \text{Hc} - W_c \tan h / \cos a) \qquad (5)$$

With this value, the window surface area by which the solar flow enters in the room can be calculated.
Overhangs are placed 60 cm above the south windows and their length is variable.
The results obtained are illustrated in Fig. 4.

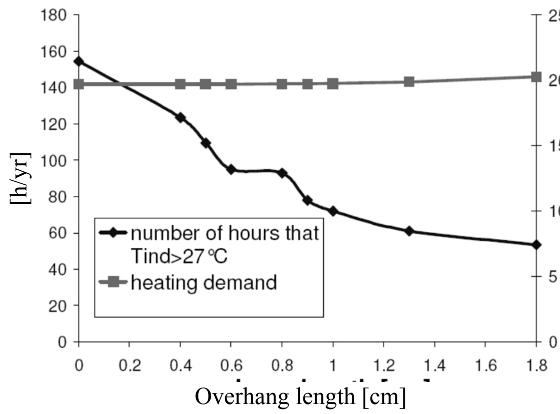
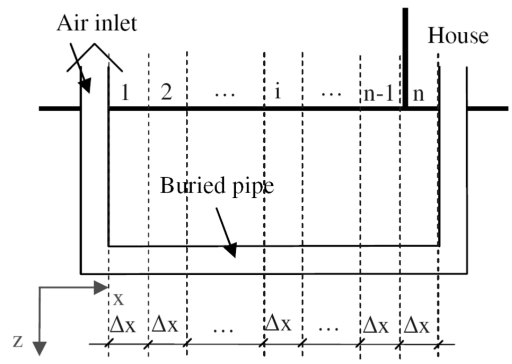


Fig. 4. *Effect of overhang length on heating demand and summer comfort*

According to the results, the number of hours that indoor temperature is over 27 degrees in the house can be divided by two with the south overhangs, without significantly increasing the heating demand.
This type of system is therefore very useful in a high efficiency building. Indeed, the problem of overhangs for classic houses is that between seasons, windows are shaded and energy consumption increases. Here, since heat is no longer needed between seasons, overhangs no longer have negative effect on the heating demand.

Earth-to-air exchanger simulation

The next stage of the simulation concerns systems used in high-efficiency buildings. Our first study concerns the earth-to-air exchanger.
The principle of the earth-to-air exchanger is very simple. Before being blown inside, the renewal air goes into a horizontal buried pipe. During the winter, air is preheated because the ground is warmer than the outside air and during the summer, air is cooled because the inverse phenomenon occurs.
The earth-to-air exchanger (Fig. 5) can be modelled in two different ways. In the first one, the pipe is submitted on its external face to a variable temperature calculated with its depth. The modification of the soil temperature is not considered. In the second one, the interaction between pipe and soil is considered [6]. The first simulation is not very realistic because it does not take into account ground depletion, which is why we chose the second category.
The 3D problem is divided into brackets of thickness: Δx.



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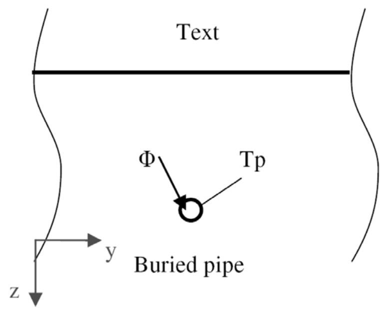

b

Fig. 5. *Earth-to-air exchanger: a − longitudinal view, b − cross-section view*

For each bracket, a simple power balance is made in the pipe:

$$\dot{m}C_pT_i = \dot{m}C_pT_{i-1} + \Phi\Delta x \qquad (6)$$

where $\dot{m}$ – air flow in the buried pipe, kg/s; C_p – air heat capacity, J/(kg °C); T_i – air temperature in the mesh, °C; Φ – heat flow brought to the pipe; Δx – bracket thickness, m.

To estimate the heat flow brought to the pipe (Φ), the response factor method is used on each bracket.

The problem is broken down assuming that soil is only submitted to two types of load: a temperature variation at the ground surface and a temperature variation of the external face of the buried pipe (linked to the temperature of air in the pipe).

On this 2D structure, the software Comsol will be used to determine the flow Φ (W/m) received by the stream for the following elementary load (Fig. 6):

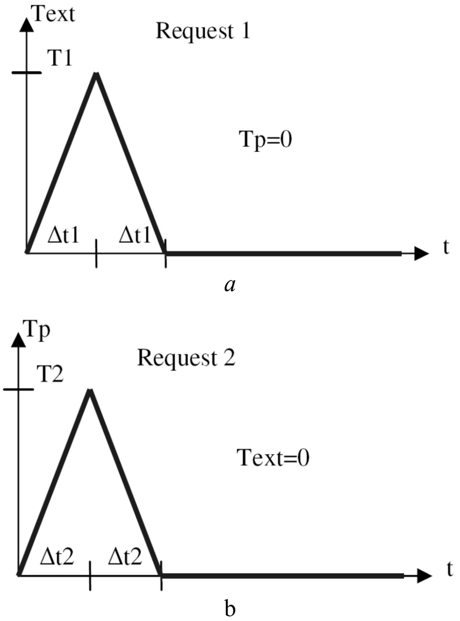

Fig. 6. *Elementary load: a – on the ground surface, b – in the pipe*

Δt_2 is lower than Δt_1 because the physical phenomenon is faster for the request 2.

Then response factors Y and Z are stored in tables to be input into SimSpark. For the first load, the response factor Y, which can be called transmittance, is evaluated by the expression:

$$Y = \Phi/T_1 \qquad (7)$$

For the second load, the response factor Z, which can be called admittance, is evaluated by the expression:

$$Z = \Phi/T_2 \qquad (8)$$

In order to determine the real heat flow received by the earth-to-air exchanger, both real loads must be broken down by superimposing elementary loads (Fig. 7).

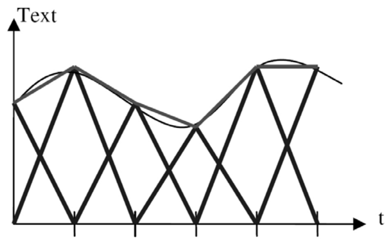

Fig. 7. *Breakdown of real load into elementary loads*

Then the superposition theorem can be applied and the heat flow received by the pipe can be deduced for each time step:

$$\Phi(t) = \sum_{i=i}^{\infty} Y_i T_{ext}\left(t - i\Delta T_1\right) + \sum_{j=i}^{\infty} Z_j T_{ext}\left(t - j\Delta T_2\right). \qquad (9)$$

With this expression, the temperature throughout the pipe can be estimated and the pipe air outlet temperature can be determined. The earth-to-air exchanger can be directly combined with the house's ventilation system (counter or single flow) to study the interactions. This simulation is in progress.

Conclusion

Finally, we have seen that it was possible to simulate the thermo-aeraulic behaviour of high-energy efficiency buildings with the simulation platform SimSpark.

Its modularity allows this platform to compare various types of systems easily, as well as various types of envelopes.

We showed that counter-flow ventilation is indispensable to obtain high energy efficiency; in that case, the heating demand is divided by 3 with regard to single-flow ventilation.

We also showed that adding overhangs above south windows greatly improves indoor comfort in summer without damaging the heating demand.

Finally a new method that will be integrated into SimSpark to treat the case of the earth-to-air exchanger has been discussed.

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