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SOLENE-microclimate: a tool to evaluate envelopes efficiency on energy consumption at district scale.

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Abstract

The building simulation tools available to evaluate energy consumption are numerous. Nevertheless, the main lack of the majority of these tools is the ability of consider the environment where the studied building is. Moreover, some of them impose strong constraints such as the choice of walls composition limited to several predefined walls or the value of the convection exchange coefficient which can not be modified.

The 3D numerical tool SOLENE-Microclimate takes into account the unsteady building thermal behavior using the SOLENE thermo-radiative model, which can (or not) be coupled with the outside airflow computed with the CFD tool Code_Saturne. The main advantage of this tool is the representation of the whole urban environment which can modify both radiation exchanges (short- and long-wave radiation) and meteorological condition outside the building. The urban planning impact can also be evaluated by taking into account green soil, walls and roofs or trees influences. Thanks to all these abilities, building envelopes efficiencies can be evaluated in realistic urban configurations.

After a presentation of SOLENE-Microclimate, three examples of projects dealing with the influence of considering or not the environment on envelope balance are exposed:

- A study of the VegDUD project evaluates the influences of green walls and green roofs on building energy consumption.
- The project Merrubi studies the influence of both thermal radiation exchanges with environment and wind distribution.
- The project EVA aims to quantify of the modification of the albedo values several districts.

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Keywords: SOLENE-Microclimat ; urban simulation, building thermal behavior.

1. Introduction

The building simulation tools available to evaluate energy consumption are numerous. Crawley et al. [1] and Attia et al. [2] propose a review of respectively twenty and ten tools which are able to evaluate energy consumption of buildings. In addition to these studies, Attia [3] presents the advantages and inconveniences of ten of them considering a separately architect and engineers needs. The main lack of the majority of these tools is the ability of consider the environment where the studied building is. Moreover, some of them impose strong constraints such as the choice of walls composition limited to several predefined walls or the value of the convection exchange coefficient which can not be modified.

The 3D numerical tool SOLENE-Microclimate takes into account the unsteady building thermal behavior [4] using the SOLENE thermo-radiative model, which can (or not) be coupled with the outside airflow computed with the CFD tool Code_Saturne [5]. The main advantage of this tool is the representation of the whole urban environment. Both short-wave and long-wave radiation through their direct and indirect contribution (after inter-reflexions) are taken into consideration. In case where the coupling with Code_Saturne is activated, urban environment influence on the wind distribution on the buildings walls is also considered. As a result, the temperature distribution on each walls of the buildings is calculated using these radiation and wind distributions. This knowledge of the distribution of the boundary conditions is the second major feature of the tool in order to evaluate energy consumption of buildings. The third major aspect is the integration of green soil, walls and roofs models [6].

After a presentation of SOLENE-Microclimate, three examples of projects dealing with the influence of considering or not the environment on envelope balance are exposed:

- A study of the VegDUD project evaluates the influences of green walls and green roofs on building energy consumption through their direct and indirect impact. These influences are compared with those of trees and lawns considering different kind of building envelopes: high/low insulated building with low/high glassed rates.
- The project Merrubi studies the influence of both thermal radiation exchanges with environment and wind distribution for three districts in French cities (Paris, Nantes and Strasbourg). In this study, the variation of the influence of these physical phenomena with the building density is prime of interest.
- The modification of the albedo values for an entire district and its influence on energy consumption in comparison with other UHI mitigation solutions (use of vegetation, street humidification,...) is a part a the work lead in the project EVA. This study considers two different districts in Lyon, France: a modern residential one with quite small buildings and an old residential one with 50 meters high block buildings.

1. The SOLENE-microclimat model

1.1. Radiative model

SOLENE is a simulation tool which was first developed at the CERMA laboratory in order to assess radiation process in urban situations from a 3D surface mesh. A hemispherical geometry represents the sky vault (Fig. 1), which has also been meshed to take into account the anisotropy of diffuse solar radiation. The tool computes sky irradiance (direct and diffuse fluxes, Fig. 2) which can be evaluated from measurements data or from a sky model [7].

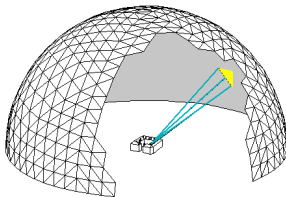


Fig 1. Hemispherical geometry representing the sky.

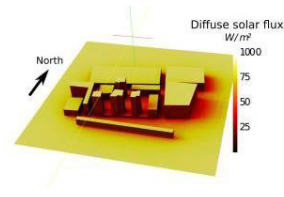


Fig 2. Diffuse solar flux computed bySOLENE.

Considering radiative proprieties of materials, solar beams interreflexions and infrared radiation balance, it estimates the whole solar flux reaching each urban surfaces using radiosity algorithm [8]. Radiation spectrum has been divided into two bands corresponding to solar radiation and infrared thermal radiation. Sky thermal radiation is assumed to be isotropic.

1.2. Thermo-radiative model

Thermal balances on each elementary cell representing walls and soil permit to realize dynamic simulations and to assess time evolution of surface temperatures [9, 10]. At each time step, absorbed solar radiation is computed as the result of direct and diffuse solar radiation received directly from both sun and sky, following reflection from all other urban surfaces in view, minus the reflected flux away from the surface. This computation also required the knowledge of convection exchanges, conduction and storage in built surfaces as well as the long-wave radiation exchanges. Thermal parameters of wall and soil material give access to the conduction fluxes in order to take into consideration material inertia [10]. The convective heat flux between the surface and to the atmosphere is computed using the surface-to-air temperature difference and a convective heat transfer coefficient (CHTC), which can then be assigned a constant value or a value dependent on wind velocity at a reference point [11, 12]. Lastly, long-wave radiation fluxes are evaluated from each thermal radiation emitted by each surface (depending on surface temperature) and the view factors between all surfaces. Since the external surface temperature of each elementary cell is tied to that of the next elementary cell via the long-wave radiation calculation, the system of equations is solved by iterative algorithm at each timestep.

1.3. CFD coupling

CFD coupling was first performed by using Code_Saturne (<http://code-saturne.org/cms/>). It firstly gives the velocity distribution (Fig. 3) on all the urban scene and permit to evaluate the CHTC in a more realistic way. By considering convective exchanges between each surface and air, and resolving equations of conservation (momentum, mass continuity, energy, species transport and using k-e turbulence model), air temperature and humidity distribution can be calculated [5]. The coupling principle used was detailed by Bouyer [13], who proposed an intermediate coupling whereby velocity and turbulence fields are pre-processed for each wind direction and velocity. Then, for each time step during iterative process, only transport equations for energy and moisture are solved. Computational cost is considerably reduced; this intermediate approach is tantamount to assuming that airflow is not disturbed by heat transfer at wall surface.

CFD coupling is also employed to compute moisture transfer and diffusion in the case of natural surfaces, as will be seen in the adaptation solution section 1.5 below.

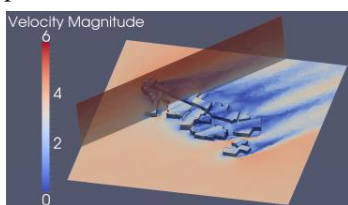


Fig 3. Wind velocity distribution in the district of Saint Michel street with an incoming wind from North-East.

1.4. BES coupling

A building thermal model [13] was developed in the tool in order to compute the real thermal variables inside the target building whose energy consumption shall be evaluated. The principle of this module is based on a multizone building nodal network model [14] where each storey corresponds to a zone. A free evolution of inside air temperature can be considered or energy needs can be evaluated.

1.5. Urban environment

As described in the previous sections, urban environment can be taken into account in order to evaluate the envelopes influence on both inside and outside environment. Urban form can influence various physical phenomena such as radiation exchanges and convective ones for instance. But the tool can also take into account the influence of urban planning and in particular the influence of urban vegetation since trees, grass, green roof or green wall can be considered in the simulations. Trees modify the radiative exchanges in the urban scene [15] but they also have influence on the wind speed distribution (they are considered as a porous media inducing pressure losses) and the air

and humidity ones since transpiration is evaluated [5]. Green wall and roof models are also integrated into the tool [6] which gives the opportunity to evaluate them in a realistic urban configuration and to study the influence of some specific parameters on building energy consumption for instance.

2. Evaluation of envelopes efficiency

The evaluation of various envelopes or at least of some of their characteristics is prime of interest of different research projects. Three of them are presented in the following sections.

2.1. The VegDUD project

The VegDUD project has dealt with the influence of the urban vegetation on various fields. The first part of the study quantify the direct and indirect influences of the green wall and roofs on the inside thermal comfort of a building. This study [5] considered the Pin-Sec district (Fig. 4) in Nantes, France. It demonstrates that the direct impact of green roof is strongly higher than wall on roof's indirect ones (Fig. 5).

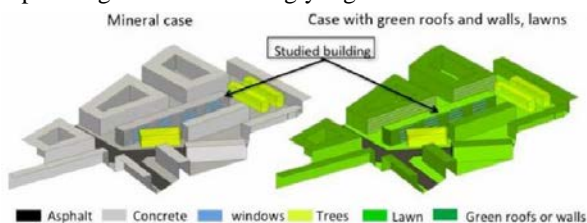


Fig. 4. Representation of Pin-Sec district considered in the VegDUD project.

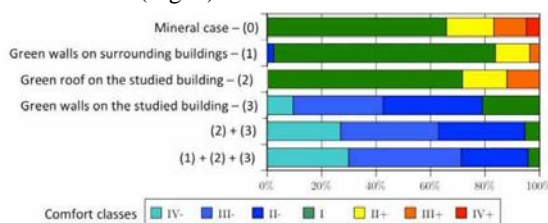


Fig. 5. Comfort on the second floor of the studied building during a summer day and relative to greening scenarios (from (EN 15251 2007))

In a second step, an academic canyon street situation was considered to compare the efficiency of green walls and roofs to reduce cooling needs in comparison with the efficiency of the trees or grass area. The study demonstrates that the green envelope efficiency is strongly depending on the kind of building considered. Insulation or windows rate have high influences on the green cover efficiencies (Fig. 6).

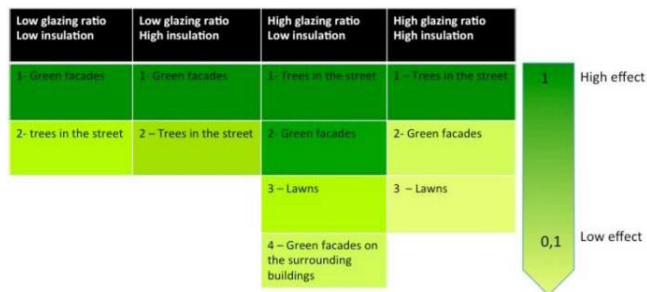


Fig. 6. Ranking of the effects of green facades, lawns and trees on buildings' energy consumption for not-insulated/insulated and few glazed/ highly glazed buildings (North-South street).

2.2. The Merrubi project

The Merrubi project raises the question of the phenomena which have to be taken into account to evaluate building energy consumption of new buildings in urban situation. Among these phenomena, wind speed distribution and long-wave radiation exchanges are prime of interest. In order to identify the situations where physical phenomena need (or not) be considered, three different kinds of buildings (individual house, collective dwelling and

5 office building) are considered in nine different districts with various densities in three different French cities: Paris, Strasbourg and Nantes. In each cities, a new building is integrated in a district with low, medium and high density.

First results are obtained on an office building in Strasbourg integrated in a district with medium density. They shows (Tab. 1) that considering the urban environment for the computation radiation exchanges in any other way than taking into account shadows of surrounding buildings leads to a 13.5% lower evaluation of the daily energy consumption for building cooling. The average long wave radiation losses (LWR) of the building are twice lower when urban environment is taken into account inducing a 3.7°C increasing of the average surface temperature (Tse).

| Without Urban Environment | Considering Urban Environment | | | | | V_{cste} | V_{CFD} |
|--|-------------------------------|----------------|------|----------------|--|------------|-----------|
| Net LWR (W.m ²) at midday | 113.5 | Floor 1: 47.7 | 62.7 | Floor 1: -21.1 | Average CHTC | 12.0 | 9.11 |
| | | Floor 2: 49.4 | | Floor 2: -18.3 | Tse (°C) at midday | 41.5 | 45.6 |
| | | Floor 3: 175.9 | | Floor 3: 141.8 | Convective Flux (W.m ²) at midday | 210.8 | 255.8 |
| Tse (°C) at midday | 37.8 | | 41.5 | | Daily Cons. (W.m ² .day ⁻¹) | 338 | 348 |
| Daily Cons. (W.m ² .day ⁻¹) | 292 | | 338 | | | | |

Table 1: Influence of urban environment consideration on Long Wave Radiation and energy consumption.

Table 2: Influence of urban environment consideration: constant or distributed wind speed.

These preliminary results also demonstrates that the average CHTC (Tab. 2) varies by 24% depending on the calculation from a homogenous wind speed (V_{cste}) or a value deduced from CDF computation (Fig. 7) of outside air flow (V_{CFD}). This induces an increasing of the average surface temperature of the building by 4.1°C at midday. Both contribute to a rise of the average convective flux by 21%. Since the building is with high insulation, air conditioning consumption only varies by 3%. Both wind speed distribution and long-wave radiation exchanges finally induce differences higher than 16% for energy consumption evaluation. The complete results of this project are expected in 2017.

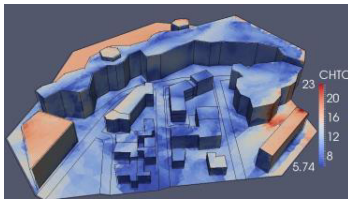


Fig. 7. CHTC distribution deduced from CFD computation on a medium density district in Strasbourg.

2.3. The EVA project

The aim of the EVA project is to compare various solutions to mitigate the impacts of the urban heat island on building energy consumption, indoor and outdoor thermal comfort. Three solutions are considered in two different districts (Fig. 8) in Lyon: the use of the vegetation, the use of street watering system and the modification of the albedo values. Various scenarios have been defined in order to compare impacts of each solution integrated alone in the district and then with other solutions in order to identify and quantify the interactions that it can have between them. The analysis of the impacts of the three solutions on the physical phenomena is coupled with an economic one in order to be able to have a critical understanding of the best solution that should be proposed by the urban planners.

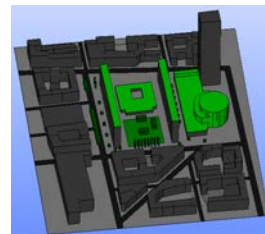
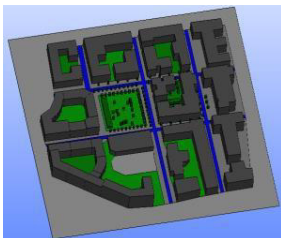


Fig. 6. Representation of the 2 districts considered in the EVAproject: evaluation of street watering system (in blue) in the Buire district (left), evaluation of green walls and roofs (in green) influence in Moncey district (right). By this way and with the methodology of the project, the efficiency of increasing albedo value of envelopes can be compared to those of the other solutions. The project is expected to give its results in 2016.

3. Conclusion

The most part of the tools that permit to evaluate the building energy consumption does not take into consideration the building environment in particular in urban situation where its influence can be sensible. Moreover, some of these tools have limitations that can hinder to evaluate the envelope efficiency.

The tool SOLENE-microclimat take into account a large majority of the physical phenomena that permit to consider the urban environment. The tool also lets the possibility to define freely the envelope materials and so to quantify the efficiency of a large amount of envelopes in a realistic urban environment.

The SOLENE-microclimat tool was firstly presented in order to present what are the physical phenomena that can be taken into consideration. In a second step, three projects was presented. In two of them, efficiency of specific envelopes or of some parameters of envelopes have been studied. In the third one, influence of urban environment on building energy consumption has been investigated.

The SOLENE-microclimat tool let a high flexibility that could permit to define new specific kind of envelopes such as wall with phase change material or production of solar energy systems and to evaluate their efficiency in an urban environment.

Acknowledgements

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