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What is the required level of details to represent the impact of the built environment on energy demand?

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Abstract

A full coupling between a CFD code, a thermo-radiative model and a building energy simulation model enables *Solene-microclimat* software to calculate both building thermal behavior and urban microclimate with the retroaction of buildings on microclimate. However, this full coupling is time consuming and it is legitimate to wonder if it is always necessary to perform such detailed simulations. In the framework of the MERUBBI project, simulations were carried out to answer this question.

A set of simulations was designed to explore different kinds of configurations: three cities in France (Nantes, Paris and Strasbourg), three levels of density (from an isolated building to an implementation in the dense city center) and three kinds of buildings (an individual house in Paris, a residential building in Nantes and an office building in Strasbourg). To study the sensitivity of energy demand to the coupling detail, for each thermal flux at the external surfaces of the building, several levels of details were taken into account. For the impact of wind on convection, three modalities were considered: a constant convective heat transfer coefficient, calculated from the wind velocity at 10m; a convective heat transfer coefficient calculated from a vertical wind profile; a convective heat transfer coefficient calculated from the local wind velocity simulated with a CFD code. For the impact of air temperature on convection, two modalities are considered the use of the temperature measured at the nearest meteorological station; a local temperature calculated with the CFD simulation. For the impact of long-wave radiative exchanges, three modalities: the building exchanges with the sky without taking into account the masks of the environment and the long-wave radiative exchanges with the other surfaces; the building exchanges with the sky, taking into account the mask effects but not the exchanges with the surrounding surfaces; long-wave exchanges are taken into account with all kinds of surfaces in function of view factors. For the impact of short-wave radiations, two modalities: only direct and diffuse solar fluxes are taken into account; inter-reflections are considered. The results indicate that if the calculation of air temperature and convective heat transfer coefficient have few impacts in all the cases, the way of calculating long-wave and short wave radioactive fluxes has to be carefully considered, in winter as in summer. More detailed recommendations are given according to the density of the site in which the building will be implemented.

Keywords: energy demand; urban microclimate; urban form; long-wave radiation; convection; solar mask

1. Introduction

As Building Energy Simulation (BES) models have been improved, taking into account local climatic conditions and mask effects is becoming essential to conduct a proper assessment of building energy consumption in urban contexts. Indeed, many studies show that the urban microclimate has a significant impact on the energy consumption of buildings¹⁻⁵. Representing interactions between physical phenomena at various urban scales becomes an important step, and it is necessary to assess the relative impact of the environment on fluxes interacting at the building-environment interface.

Heat exchange by convection depends on both the near-wall air velocity and local variations in outside temperature⁶. Solar net irradiation depends on the masks, the albedo of the surfaces under study and the surrounding surfaces⁷. Long-wave radiation exchanges with the sky and surrounding surfaces depend on form factors, temperatures and emissivities of the considered surfaces and the surrounding ones⁸. Heat fluxes due to ventilation and infiltration depend on the pressure exerted on the building envelop⁹ and local variations in outside temperature.

Only a few physical models address both buildings and their urban environment. An approximate approach consists in evaluating the direct impacts of the environment (masks) on buildings, as the procedure implemented in *SUNtool* and *CitySim*¹⁰⁻¹¹, which takes into account the luminous and solar masking effects of the urban environment while calculating the energy consumption of buildings. In a more complete way, Yang *et al.* use the hourly 3D distributions of the microclimate (air temperature, air humidity, wind field and ambient surface temperature) extracted from ENVI-met simulation results as outside boundary conditions for the EnergyPlus model without retroaction of building on local climate⁵.

A more sophisticated approach entails evaluating the two-way interactions between buildings and their environment; this set-up requires to resolve scale compatibility issues, given the difficulty of accurately representing the urban environment as well as buildings and their uses. Two solutions call for reducing the studied urban land area (e.g., by focusing on a building in a canyon street^{3,12}) or simplifying the building thermal model¹³. This full coupling of buildings and the environment is very beneficial in that it allows for 1) the evaluation of both the impact of environment on the thermal behavior of buildings and buildings' impacts on the urban microclimate^{2,13-15}, 2) obtaining the direct and indirect impacts of the selected adaptation techniques^{16,17}; and 3) deriving a better estimate of charges associated with the human control of indoor spaces based on microclimate models³. It has been shown that the coupling of CFD and radiative models improves urban microclimate simulations because it enables a better assessment of external surface temperatures¹⁸. However, this full coupling is time consuming and it is legitimate to wonder if it is always necessary to perform such detailed simulations. To determine whether this level of detail is necessary for building energy simulation, several coupling techniques have been compared with different representations of airflow, outdoor air temperature distributions and radiative models. We carried out sensitivity analyses using the coupled simulation tool *SOLENE-microclimat*^{2,19,20}. The tool features Code_Saturne*, a computational fluid dynamics (CFD) software program, and *SOLENE*, a thermo-radiative simulation software program dedicated to the urban environment²¹.

In the framework of the MERUBBI project, a set of simulations was designed to explore different kinds of configurations: three cities in France (Nantes, Paris and Strasbourg), three levels of density (from an isolated building to an implementation in the dense city center) and three kinds of buildings (an individual house in Paris, a residential building in Nantes and an office building in Strasbourg). These buildings were designed by students in architecture with the aim of optimizing the benefice of natural resources in the different contexts, all sharing the same program and construction technics. They are new buildings and thus well insulated.

2. Method

To study the sensitivity of energy demand to the coupling details, for each thermal flux at the external surfaces of the building, several levels of details were taken into account.

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<http://researchers.edf.com/software/code-saturne/introduction-code-saturne-80058.html> Consulted on 2014 Sept. 4th

For convection:

- impact of airflow, three modalities: 1/ a constant convective heat transfer coefficient, calculated from the wind velocity at 10m; 2/ a convective heat transfer coefficient calculated from a vertical wind profile; 3/ a convective heat transfer coefficient calculated from the local wind velocity simulated with a CFD code;
- impact of air temperature, two modalities: 1/ the use of the temperature measured at the nearest meteorological station; 2/ a local temperature calculated with the CFD simulation;

For radiation:

- impact of long-wave radiative exchanges, three modalities: 1/ the building exchanges with the sky without taking into account the masks of the environment and the long-wave radiative exchanges with the other surfaces; 2/ the building exchanges with the sky, taking into account the mask effects but not the exchanges with the surrounding surfaces; 3/ long-wave exchanges are taken into account with all kinds of surfaces in function of view factors;
- Impact of short-wave radiations, two modalities: 1/ only direct and diffuse solar fluxes are taken into account; 2/ inter-reflections are also considered.

2.1. Case studies

Three case studies in three different cities and three levels of density were designed by students in architecture with respect to specifications related to the built surface and energy requirements. For Nantes, we decided to study a residential building, for Strasbourg, an office building and for Paris an individual housing. The buildings obtained for the Strasbourg case are given in Fig. 1. One can notice that due to the changes in context, the designed buildings have different forms. This will make our comparisons more complicated, but designing the same building in different contexts would be non-sense.

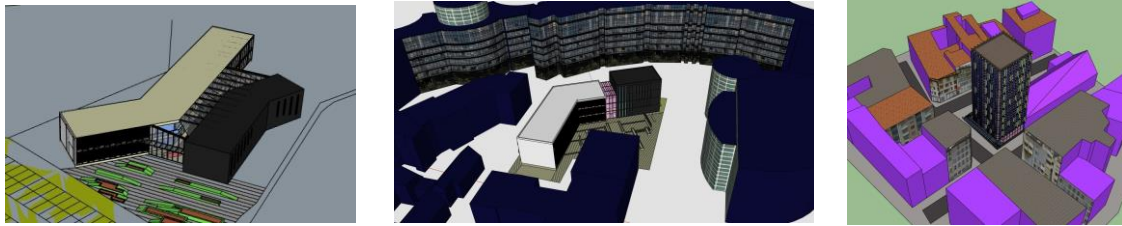


Fig. 1: case studies in Strasbourg from left to right, isolated, middle density and high-density contexts.

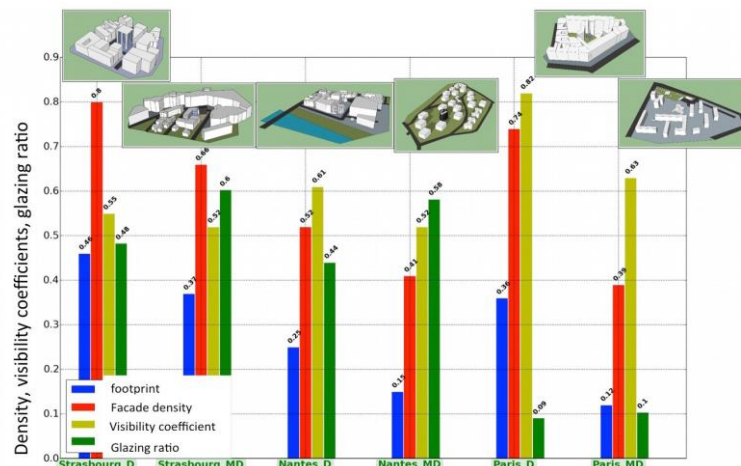


Fig. 2: footprint, façade density, visibility and glazing ratio indexes for the six urban case studies (D: high density, MD : middle density).

The isolated cases will serve as reference cases. The district morphology has been characterized for the six urban cases with the idea to further verify if our conclusions are related to density and urban form. Footprint is calculated as the ratio of built ground area to total ground area of the district. Façade density as the ratio of façade area to the sum of façades', roofs' and free ground's areas. Those two index are calculated at the district scale while the two others are centered on the studied building. Visibility is the mean sky view factor of the building and glazing ratio is the ratio of glazed surfaces of the façades. These indexes for the six urban case studies are given fig. 2.

2.2. Method for the sensibility analysis

The impact of the way we take into account four phenomenon will be studied: wind velocity, outdoor air temperature, infrared exchanges and irradiation. The two first are related to convective flux, ventilation and infiltrations.

2.2.1. Wind velocity

The sensibility study is directed toward convective flux, thus, the impact of method to calculate wind velocity will be applied through the calculation of the convective heat transfer coefficient (CHTC). In each point of the meshing, CHCT is calculated from eq (1).

$$h = 5,85 + 1,7 * v \quad (1)$$

v , which represents wind velocity, will be successively calculated with respect to one of the three modalities:

- **h_constant:** Meteorological wind velocity (wind velocity at 10m), taken constant over the building envelop
- **h_profil:** Wind velocity calculated in function of the altitude:

$$V(z) = v_{meteo} (z/z_0)^{0,3} \quad (2)$$

- **h_simulationCFD:** Wind velocity calculated in the contiguous cell using Navier-Stokes equations (code-saturne).

Fig. 3 gives the spatial distribution of CHTC for the Strasbourg Medium Density case. The variation ranges are similar, but spatial distribution differs.

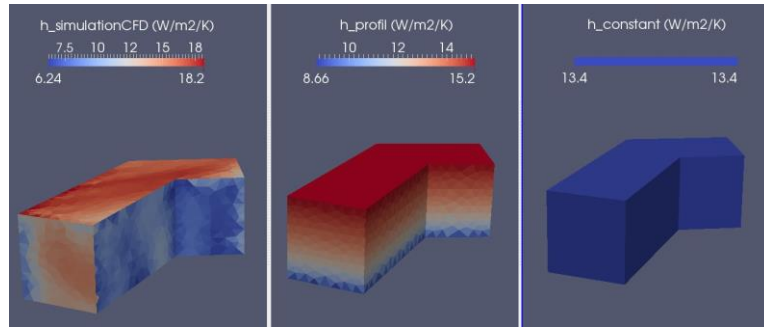


Fig. 3. Spatial distribution of CHTC on the Strasbourg Medium Density case

2.2.2. Infrared exchanges

Calculating exchanges between all the elementary surfaces of the meshing is time consuming, thus, the second sensibility analysis was applied to the modeling of infrared exchanges. The three studied modalities are:

- **Whole_sky:** Calculation of the exchanges that occur between each surface and the sky, without taking into account the masks.
- **FF_sky:** Calculation of the exchange that occur between each surface and the sky, taking into account the masks. Exchanges between city surfaces are neglected (as if they were at the same temperature)

- **FF_sky+scene:** Calculation of all the exchanges between the surfaces and with the surfaces and the sky. These three levels are schematized in Fig. 4.

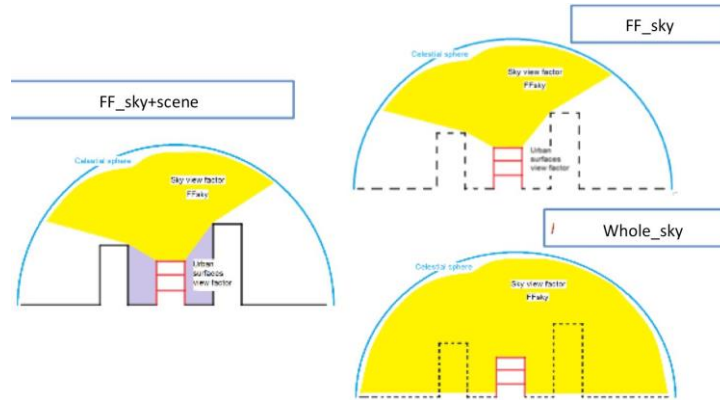


Fig. 4. The three levels of infrared exchanges modeling

2.2.3. Solar flux

Concerning solar fluxes, our aim was to assess the impact of calculating inter-reflections. Thus, two modalities were studied:

- **No_refl:** without calculating inter-reflections (applying the diffuse and direct solar fluxes coming from the sun and the sky)
- **Refl:** with calculating inter-reflections.

2.2.4. Outdoor temperature

Using CFD simulation leads to detailed air temperature that account for the convective effects occurring between the urban surfaces and air. We studied two modalities:

- **Tmeteo:** in this case, we don't perform CFD simulation and use the meteorological temperature as boundary condition
- **TCFD:** we perform CFD simulation so that we dispose of local air temperatures that are used to calculate convective heat fluxes as well as ventilation and infiltration.

2.3. Simulation data

- Meteorological data are obtained from Meteonorm, ten days will be studied in summer and in winter
- Building materials: wall made of 10cm concrete and 10cm glass wool; roof made of 10cm concrete and 15cm glass wool; double glazing windows.
- Albedos : walls= 0.3, roofs=0.2 ; windows=0.35 (transmittance 0=65), streets=0.15, lawns=0,25
- Indoor loads: the analyzed result will be the building energy demand per square meter (thus we assume that in winter indoor temperature is set at a minimum of 19°C and in summer at a maximum of 26°C. There are no other internal loads, so that to have results independent from the occupation.

3. Results

3.1. Wind velocity

One can notice fig. 5 that there are few differences between the results, whatever the density. The distribution of CHTC doesn't impact the calculation of buildings' energy demand. Two hypothesis can be made: either the value of

this coefficient itself as few impact or it is its distribution on the building's envelop that is not worthy of been calculated. Indeed, in this case, when the mean CHTC is $13,4 \text{ W/m}^2.\text{K}$ in the constant case, it's variation range is :

- from 6.2 to $18.2 \text{ W/m}^2.\text{K}$ in the $h_{\text{simulationCFD}}$ simulation, with a mean value equal to $12.5 \text{ W/m}^2.\text{K}$;
- from 8.7 to $15.2 \text{ W/m}^2.\text{K}$ in the h_{profil} simulation, with a mean value equal to $13.5 \text{ W/m}^2.\text{K}$.

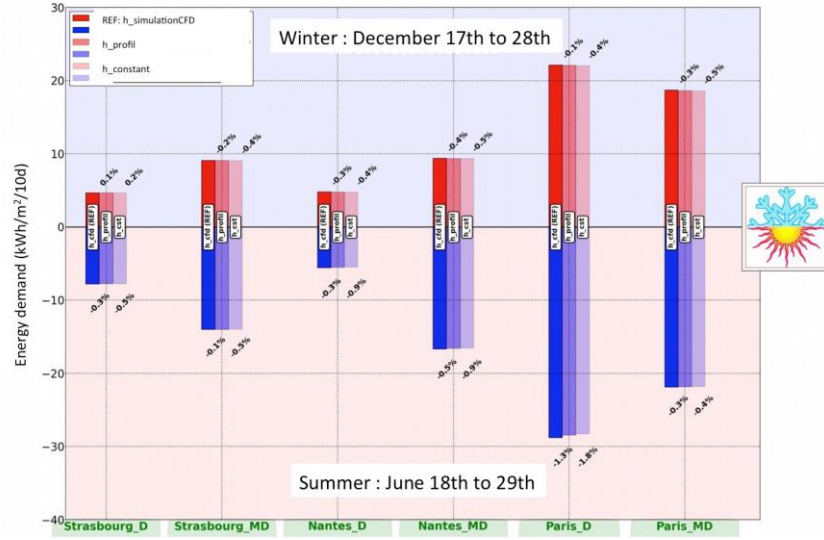


Fig. 5. Comparison of wind modalities for the six urban cases

3.2. Infrared exchanges

From the results presented in Fig. 6, one can notice that the intermediary modality (neglecting exchanges with the other surfaces but taking into account precisely the exchanges with the sky) is more comparable to the reference one than the third modality, which consists in doing as if the building was built in an isolated site. The differences are low, in summer as in winter, except for the Paris high density case, for which one can observe a difference up to 12% in winter. Indeed, this case consists in an individual house build in high courtyard, thus, the latter barely exchanges with the sky. In this case, a detailed calculation of infrared exchanges must be carried out.

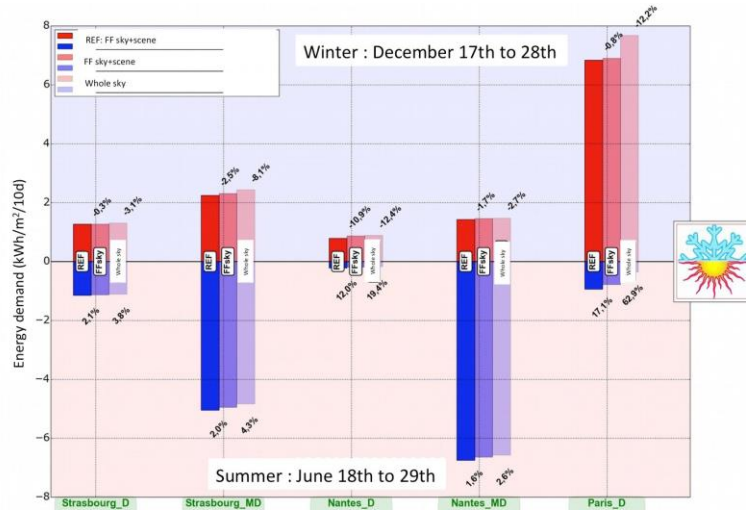


Fig. 6. Comparison of infrared exchanges modalities for the six urban cases

3.3. Solar irradiance

As expected, on Fig. 7, one can verify that when neglecting solar inter-reflections, heating needs are higher in winter and cooling ones smaller in summer. The order of magnitude of relative differences varies from 10 to 20%. Taking into account the inter-reflection inside the urban form is thus important when calculating energy needs.

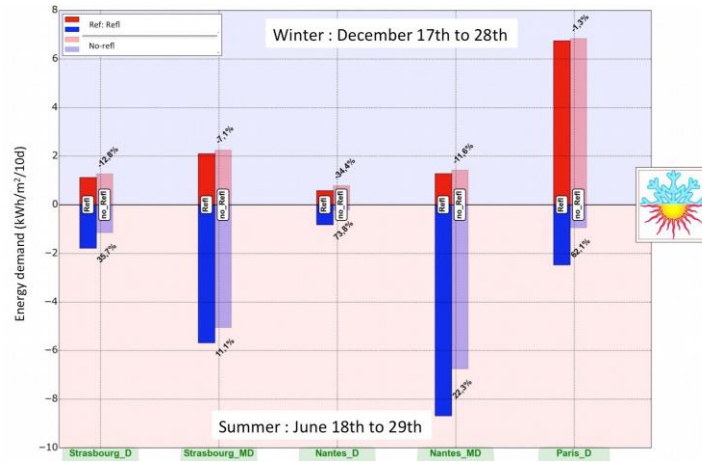


Fig. 7. Comparison of solar irradiance modalities for the six urban cases

3.4. Outdoor temperature

It is difficult to conclude from the results shown in Fig. 8. Differences are less important for the middle density case of Nantes, where the density is the lower. This could suggest that the higher is the density, the more important will be the impact of taking into account a locally calculated temperature.

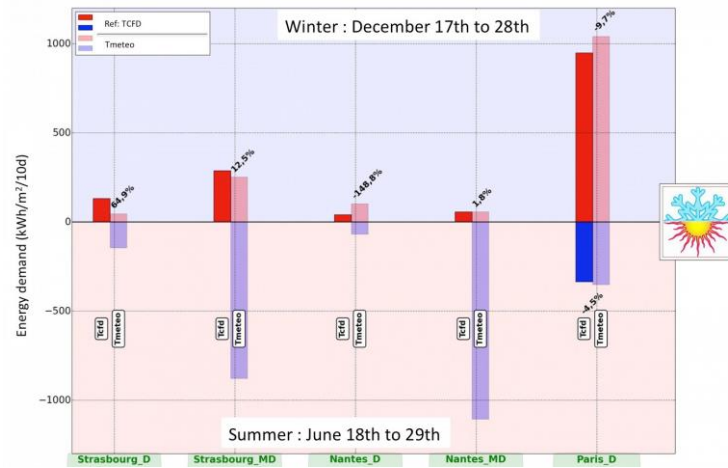


Fig. 8. Comparison of outdoor temperature modalities for the six urban cases

4. Conclusion

Even if the number of case studies is too small to have verified conclusion, this analysis leads to interesting results. First we can claim that calculating inter-reflexion is necessary to guarantee good energy needs assessment.

This is the external flux that is the easiest to calculate. Indeed, contrary to convection heat flux and infrared exchanges, this one doesn't depend on surface temperature and can be pre-processed. Depending on the configuration (density and glazing ratio), infrared exchanges calculation can also have a not insignificant impact on energy needs assessment. At least, sky view factor may be calculated and exchanges with the sky taken into account. This is a less expensive calculation than the complete calculation of infrared fluxed exchanges. Concerning the other parameters, it seems that they are less impacting results and quite simple solutions can be proposed.

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