URBAN COMPLEXITY AND COUPLED CFD / THERMO RADIATIVE MODELING: A REVIEW OF CASE STUDIES

Merlier, Lucie (1,2,3); Kuznik, Frédéric (1,2); Rusaouën, Gilles (1,2);
Roux, Jean-Jacques (1,2); Salat, Serge (3)

1: Université de Lyon, 69 631 Lyon cedex 01, France;
2: INSA Lyon, CETHIL UMR 5008, 69621 Villeurbanne cedex, France;
3: CSTB, Urban Morphlogy Lab, 75 016 Paris, France

ABSTRACT

Recent computational improvements allow for wind and thermal simulations on more complex urban configurations. Their thermo-aeraulic features can now be investigated by more sophisticated CFD models, coupled with energy ones. By assessing more accurately micro-climatic conditions, their suitability for both human comfort and building energy consumption prediction is increased.

Such coupled studies already exist but are still scarce. They highlight the impact of urban morphology and its complexity on induced flow phenomena and radiative exchanges. They enable parametric investigations but also uncover new research tracks.

This paper reviews and analyzes some of them from three complementary aspects: their urban model, their physical and numerical hypothesis and their validation method. Then, improvements enabled and sensible aspects stressed by such approaches are discussed.

INTRODUCTION

In the context of global warming and natural resource depletion, building designs and systems have been tremendously improved over the past twenty years to reduce building energy consumption. Consequently, the relative impact of urban context on the building thermal behavior has become of uttermost importance. Indeed, energy needs are strongly correlated to local microclimate, which is itself defined by complex interactions between buildings, open spaces, the urban inner atmospheric boundary layer and the sun.

At the meso and city scales, researches have been carried out on urban climatology and on the urban heat island (UHI) (Oke, 1988). The canopy, roughness and inertial sub layers were investigated. They highlight the importance of the surface thermo-radiative balance, as well as air flow contribution on the urban micro-climate. Some numerical tools, such as TEB (Town Energy Balance)[1] have also been developed, to compute heat and water exchanges between cities and the atmosphere.

For smaller spatial scales, numerical tools have been developed and validated as well. They enable detailed investigations of short and long waves radiative exchanges, and more particularly of the solar availability or multi-reflection between buildings in street canyons or urban blocks (see (Kämpf and al., 2010) for instance). Concerning air flows, and considering the experimental difficulties, numerical simulation and more particularly computational fluid dynamics (CFD) methods seem to be a very powerful investigation technique to study mostly wind fields, turbulence and buoyancy effects within the urban roughness sub layer (Blocken and al., 2011). Those thermo-radiative and wind numerical tools are able to model urban local micro-climate, given the simultaneous use of building energy simulation (BES) tools which compute building energy balance. Each specific simulator provides boundary conditions for the others.

Up to now, in most radiative and air flows studies, detailed simulation tools were used for simple geometrical cases. Reciprocally, on more complex configurations, simplified models were applied.

Fundamental studies on generic configurations provide interesting information about physical phenomena. If cuboids immersed in a turbulent urban boundary layer already lead to complex flow recirculations, heat transfer inclusion increases this physical complexity. However, urban 3D heterogeneous and rough structure implies even more complex flows and energy exchanges. Thus, to study more accurately both complex urban configurations and their associated physical phenomena, extensive simulations are needed. Due to computational power improvement, such comprehensive coupled studies are emerging. They aim at evaluating building energy performance or user outdoor comfort, but they also underline open questions relative to boundary conditions, spatial scale imbrications, coupling strategies relevancy and uncertainties.

To highlight actual research practices on urban micro-climate and energy issues, this article reviews some research works. Due to the computational cost

[1] http://www.cnrm.meteo.fr/spip.php?article199, accessed on 30/01/2013)

and studies objectives, their fields are mostly limited to the block scale. The aim of this paper is not to be exhaustive on the related works, but is rather methodological. It points out the contribution of such methods on urban physics comprehension while underlining identified improvement ways.

Thus, this paper begins with a contextual section dealing with urban micro-climate specificities, the main principles of coupled thermo-radiative / CFD simulation and its principal advantages compared to the common practices in BES.

Then, five reference case studies based on coupled simulations and carried out on urban configurations are presented. One focuses on a generic street canyon and the four others deal with genuine neighborhoods. Three of them are located in France, more precisely in the cities of Nantes, Lyon and Toulouse. The other one takes place in Shenzhen, China. The aim is mostly to probe their urban model, physical and numerical hypothesis but also their validation method and outcomes.

Finally, hypothesis and results extracted from those research projects are discussed. Improvements enabled by such studies, sensible points underlined and the relative influence of the physical features modeled are highlighted.

URBAN MODELLING AND COUPLED SIMULATIONS

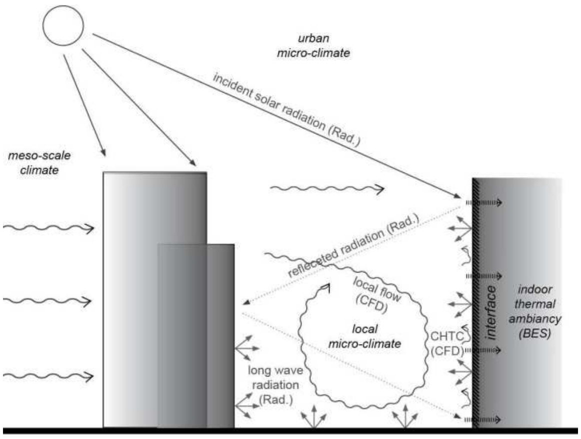

Figure 1 Urban fluxes and associated numerical applications

Geometrical and physical urban complexities

Unlike for open rural areas, urban mass and energy balances are greatly determined by the urban roughness, the thermal properties of construction materials, and the 3D urban structure characteristics (see Figure 1). Their complex interactions with the regional climate lead to the definition of local micro-climates, globally warmer and less ventilated than the rural one, and with extremely heterogeneous local features. These local specificities can be observed from the building to the whole city scale and wider, depending on the chosen spatial resolution. Those scaled features are not independent but are defined by their interactions and exchanges with smaller and wider scaled phenomena.

Therefore, when assessing building energy performance or pedestrian comfort in cities, commonly used airport meteorological data are not suitable. Nevertheless, they are often the only data available, and due to the specific local features of urban micro-climate, representative measurements are hard to obtain within cities. Consequently, corrections on those data are to be brought. Ideally, urban thermo-aeraulic ambiances are to be assessed by numerical simulations, including the different atmospheric spatial scales.

To improve modeling accuracy, and without considering neither water and moisture balance nor user, building properties and systems contributions, three main additional aspects are to be considered when studying urban local micro-climate and its correlated investigations (Allegrini and al., 2010):

- First, the scheduled UHI intensity, which changes the mean temperature and its daily temporal distribution. This can be dramatic in summer late afternoon and for free cooling purpose.
- Then, sun beams trapping and shadows in street canyons as well as multi-reflections between buildings. More generally, the consideration of the surroundings on radiative exchanges can greatly modify surface energy balances.
- Lastly, local flow features, which are almost totally defined by the urban conformation within the canopy layer. Extreme variations can occur over very short periods or spatial ranges.

Regarding those aspects, the multidisciplinary character of micro-climatic studies seems to be obvious. Nevertheless, existing numerical tools are mostly specific to an investigation domain: radiative exchanges, fluid dynamics or building heat and mass transfers for instance. Their specificities allow for a good accuracy in their application field, but to include urban physics complexity, all of them have to be mobilized simultaneously.

Coupled simulation principles

Two ways of coupling CFD and energy simulations exist (Djunaedy and al., 2005). The first is the internal coupling, for which an additional module of code is implemented in an already existing application and extends its capabilities. This method has the advantage of code unity and wholeness, while reducing potential compatibility problems. Nevertheless, depending on its implementation, the additional code package can sometimes be less evolved than a dedicated application should be.

The second way is the external coupling method which consists in interfacing two or more dedicated programs. Outputs of one are used as inputs for another. Without modifying the existing applications, it allows them to communicate and exchange data, but has to overcome their possible incompatibilities and respective limits. This procedure can lead to more performing simulations if each application called has been already specifically optimized and validated, and if their coupling is optimally implemented.

Depending on the number of data exchanges between programs at each time step, several strategies of static and dynamic coupling can be performed. Concerning the dynamic couplings, the onetime step, the quasi dynamic, the virtual dynamic and the full dynamic couplings can be defined (Zhai and al., 2002).

In this paper, internally and externally coupled simulation examples are presented. Three types of simulators are used: fluid dynamics, radiation and building physics/conduction. Based on specific inputs and hypothesis, each one is theoretically able to bring boundary conditions for the others. For example, radiation ones give the net amount of radiation arriving on a surface. CFD programs calculate flow and temperature fields for control volumes. Based on those results, building physics applications compute thermal balances of walls and building.

Given some iteration cycles to adjust reciprocally their boundary conditions, surface temperatures, convective heat transfer coefficients (CHTC), wind and turbulence fields can be accurately computed. Nevertheless, the effective reliability of exchanged data and of the whole coupled simulation depends on each model hypothesis, on their respective simplification level and on their interface parametrization.

REFERENCE CASE STUDIES

Case 1: A generic street canyon - Basel, Switzerland

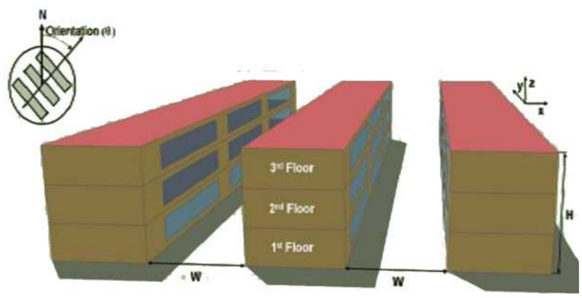

Figure 2 Allegrini's street canyon model, Basel climate. Source: (Allegrini and al., 2010)

This first study differs from the others by the fact that it does not model a real urban configuration and that it does not explicitly use coupled simulations. This study aimed at quantifying effects of micro-climate on building heating and cooling loads, and focused on a theoretical street canyon (Allegrini and al., 2010). Simulations were performed using TRNSys17, and were carried out for three types of buildings and several canyon aspect ratios. Results were compared to the ones obtained for a standalone building.

Since TRNSys 17 does not model external multi-reflections, the street canyon has been modeled as an atrium, opened to the sky. UHI effects were also integrated by correcting scheduled meteorological data, thanks to one of the BUBBLE (Basel UrBan Boundary Layer Experiment) project outputs.

Wind urban properties have been taken into account trough the CHTC. Those ones are not standard empirical correlations used in traditional BES, but are extracted from a previously detailed work. Temperature wall functions (WF) for stand-alone building as well as several 2D and 3D street canyon configurations have been deduced from Low Reynolds Number Modeling (LRNM) simulations (Allegrini and al., 2012; Allegrini and al., 2012; Defraeye and al., 2011). LRNM necessitates a very high grid resolution next to building walls but also smooth walls. Computations were performed with RANS k-ε model for forced and mixed convection regimes. Then, adaptive temperature WF were built, leading to new CHTC correlations depending on the Richardson number, and including urban street canyon local specificities as well as buoyancy effect.

Three parallel and identical three storeys office and residential buildings were modeled to mimic an ideal street canyon (see Figure 2). The middle one was analyzed. Since the focus of this study was mostly methodological, the geometrical model was quite simple, but the computation methodology is suitable for more complex models.

Results show the strong influence of radiative exchanges but underline also the improvement enabled by the use of more accurate CHTC. Nevertheless, no feedback from buildings on their environment has been modeled. Indeed, this can be realized only with coupled simulations, as performed in the following examples. Nevertheless, in such cases, annual simulations are not achievable because of computational cost.

Case 2: An eco-neighborhood – Nantes, France

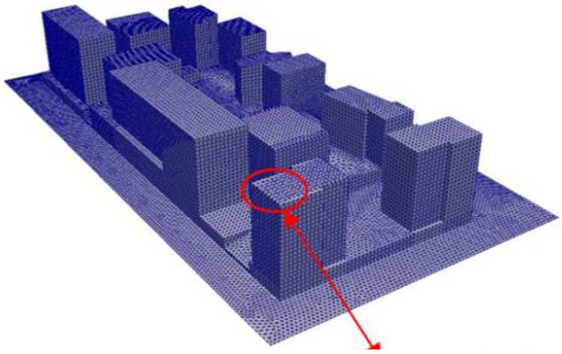

Figure 3 Geometrical model and mesh of the Tripode neighbourhood, Nantes. Extracted from (Athamena, 2012)

Athamena's PhD thesis (Athamena, 2012) deals with eco disctrict and their exterior comfort (Physiological Equivalent Temperature - PET) with regard to their morphological properties. Three French case studies were investigated: La Bottaie Chesnaie and Tripode (see Figure 3) in Nantes, and Confluence in Lyon.

Coupled simulations between the thermo-radiative software Solene and the CFD code Code_Saturne were used. Solene computes direct and diffuse radiative fluxes using shapes factors and radiosity. Wall thermal balance is calculated thanks to the integration of a 1D wall model based on the electric analogy, with two layers and five nodes.

The coupled model was validated previously thanks to the EM2PAU (Etude Micro Météorologique sur la Propagation Acoustique en milieu Urbain[2]) field experiment. The model was then a street canyon geometry shaped with two rows of containers, located in a vegetated area in Nantes suburb.

In order not to interpolate, the volume mesh of Code_Saturne fitted Solene's surface one. At the model core, surface cells were 0.18m². CHTC were expressed with the Rowley empirical relation:

$$CHTC = 11.8 + 4.2\,U, \qquad (1)$$

where U is the wind velocity next to the wall. T int was set on the basis of measurements performed by the CSTB in a renovated apartment (HUMIRISK project). A full dynamic coupling was performed. Solene gave surface temperatures, Code_Saturne T ext and CHTC.

Because of computational costs, initializing simulations were neglected. Two statistically representative days were simulated, for Lyon and Nantes climates, respectively on july the 30th and 19th. Meteorological data were extracted from Meteo France stations measurements, on airport locations. Input meteorological data were corrected to correspond to theoretical urban ones.

[2] Micro meteorological study on the acoustic propagation in urban context

Simulation results enabled a comparison between the three case studies in terms of mean wind characteristics, surface and air temperature, sunlight and solar energy potential. Those parameters enabled user outdoor comfort evaluation under the selected climatic conditions.

Case 3: An eco-neighborhood block - Lyon, France

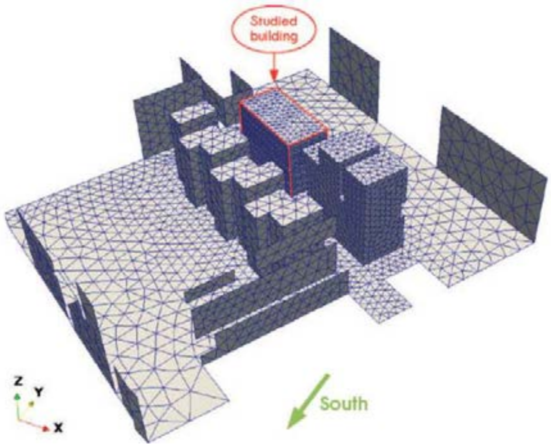

Figure 4 Geometrical model and mesh of the Confluence block, Lyon. Extracted from (Bouyer and al., 2011).

This study aimed at assessing cooling and heating loads for two weeks (one in summer and another in winter), for an office building located in an eco-neighborhood called Confluence, in Lyon, France (see Figure 4). It was based on a coupled simulation between Solene and Ansys Fluent (Bouyer and al., 2011).

Solene building thermal sub model was based on a multi-zone nodal network model, itself relying on the electric analogy. An occupation scenario was set as input. The full dynamic coupling was not performed, only energy and humidity transport equations were resolved for each iteration, whereas velocity and turbulence fields were computed only once during initialization. Moisture transfer was thus taken into account. The RANS k-ε model with two standard equations was used, considering that it is able to provide averaged variable satisfying enough for urban wind investigations. Forced convection was assumed, and the linear correlation of Jayamaha:

$$CHTC = 1.444\,U + 4.955 \qquad (2)$$

was used to model convective heat transfer at building facades.

In order to obtain a suitable temperature field, thermo-radiative simulations were realized for two weeks before the coupled run. Reference meteorological data used as input parameters were taken from Lyon meteorological station. They were then modified in terms of velocity, which was modeled with a power law, and turbulence parameter to mimic a theoretical dense urban environment fetch.

Fluent returned CHTC, air temperature and moisture mass rate while Solene rendered global radiation absorbed by the virtual vegetation, and soil latent fluxes.

For both mineralized and vegetated configurations, five situations were studied to assess the relative influence of the additional physical phenomena modeling on outputs and computation time. The consideration of theoretical or real solar heat fluxes, of the thermo-radiative balance and of the convective heat fluxes were compared to the stand-alone case simulation. It led to building energy load evaluation in each case, and provided quantitative information on the relative influence of the modeled parameters on building energy needs predictions.

Case 4: An apartment block - Shenzhen, China

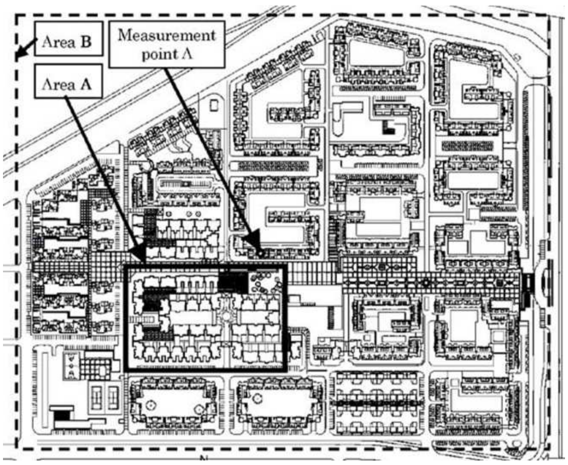

Figure 5 Map of the simulated areas of Shenzhen, China. Extracted from (Chen and al., 2004)

In order to assess outdoor pedestrian comfort for an apartment block, coupled radiative, convective and conductive simulations were performed (Chen and al., 2004). The urban model is located in Shenzhen, near Hong Kong, in China (see Figure 5). Calculations were realized for a summer day, using the k-ε standard model. It was improved by the inclusion of buoyancy effects and the Kato Launder modification to control an excessive production of turbulent kinetic energy on the windward façade of obstacles.

This study was carried out together with field measurements, which enabled the input meteorological data definition and results comparison. Meteorological data were recorded at 30.5 meters high. The target block was composed of 4 to 5 storey buildings. Surrounding ones were higher, with 7 to 9 floors.

3D CFD was used to compute steam and convective exchanges. 3D radiation model was based on Monte Carlo method and shape factors computations. A 1D heat conduction scheme was used for the calculation of ground and outer wall heat balance. Air conditioned loads were taken into consideration. Thermo-radiative calculations provided surface temperatures as well as convective heat and latent transfers as parameter for the CFD simulation which would theoretically give a feedback. However in this study, due to the computational cost, no feedback on radiative results of convective calculation was modeled.

To initialize the coupled simulations, radiative and convective computations were performed, beginning two days before the targeted date. An isothermal CFD simulation was also performed on a wider area to obtain an initial flow field which took into account the urban context of the target block. Boundary and initial conditions defined, the coupled simulation was performed for a summer day at noon. Computations were performed in two steps for each area.

Surface temperature and horizontal wind velocities as well as horizontal distribution of relative humidity, mean radiant temperature (MRT) and standard effective temperature (SET) were calculated and compared with field measurements. Some improvement schemes on urban configuration were tested in order to show how such numerical tools could be advantageously used for urban design.

Another study of the same kind was carried out on urban blocks in Tokyo, Japan, to quantitatively figure out the effective efficiency of mitigation measures to reduce the UHI intensity (Chen and al., 2009).

Case 5: An urban block – Toulouse, France

Figure 6 Geometrical model and mesh of Toulouse CAPITOUL area, France. Extracted from (Qu, 2011)

A 3D atmospheric model was implemented in a CFD code Code_Saturne (Qu, 2011). It was compared to Solene (based on surface meshing) to highlight its suitability.

The coupled code had been previously validated in the MUST (Mock Urban Setting Test field experiment) project context. Using the container arrays of MUST as model, sensitive studies were carried out to see the influence of the material albedo but also of the convective flux on surface temperatures. It highlighted the importance of considering the local flow parameters, and thus the profitability to use more detailed CHTC formulations in micro-climatic simulations.

This coupled numerical study of a real urban fragment was realized in order to validate the coupled code for a realistic case, using CAPITOUL (Canopy and Aerosol Particles Interactions in Toulouse Urban Layer) field experiment dataset. The target area is thus located in Toulouse, France (see Figure 6). The force restore method was used to model the ground temperature evolution. A wall thermal model was implemented for building thermal balance modeling. T int was computed using a temperature evolution equation. Input meteorological data were extracted from measurements realized on site, by a pole located above a roof.

The geometrical definition of the modeled area was increased along with the closing in to the model core. It evolved from roughness parameter to simplified blocks and 3D buildings with some architectural details. Thus, surrounding effects on the flow field and solar availability of the target location were modeled.

After some preliminary simulations, fully coupled convective and radiative simulations were performed. Despite a preliminary study conclusion, and due to the lack of wind data within the canopy, CHTC correlations were taken as a 1D linear function of the vertical wind velocity profile within the canopy:

$$CHTC = 11.8+4.2\ U(z)-4.0 \quad (3)$$

Results were compared to field measurement in terms of surface and brightness temperatures, as well as sensible and radiation fluxes and friction velocities. They were performed by infra-red measurements or at the pole. The importance of the building model parameterization (building composition and material physical properties) and, more particularly, of the modeled geometrical level of detail was underlined. Those modeling improvements are assumed to be able to sensibly improve the simulation accuracy and the full scale data fitting.

Synthesis

The following table 1 sums up the main characteristics of the coupled studies presented in this paper in terms of urban model, study objectives, used codes, coupling methodologies, boundary conditions, initialization strategies, CHTC correlations and validation methods.

DISCUSSION

Coupled simulations on more or less realistic urban models presented in this paper show different levels of complexity and completeness, in terms of radiative, thermal and convective exchanges computation.

As especially highlighted in the third case, taking into account the radiative and convective context when assessing urban building energy loads, leads to significant changes in comparison with the traditional stand-alone building simulation. If radiative exchanges seem to be the most influent parameter in this work, the convective contribution is not negligible. Indeed, a 10% difference was found for the winter energy consumption in comparison with the case without CFD coupling. Moreover, wind field knowledge is also fundamental for natural ventilation purposes.

Nevertheless, modeling efforts are focused with regard to the study objectives and the suitability of available inputs. Considering computational costs, complexifying the geometrical model generally leads to physical model simplifications. For example, when aiming at assessing building energy consumption, as in case 1, an accurate BES was performed, using a multi-zonal transient building simulation code. Whereas, to assess outdoor thermal comfort, as in case 2, 1D wall thermal scheme was used.

Finally, when aiming at obtaining really accurate coupled thermo-radiative and CFD simulation for micro-climatic or building energy consumption

		Case 1	Case 2	Case 3	Case 4	Case 5
Generalities	Urban Model	Ideal street canyon	eco neighborhood	urban block	urban block	urban block
	Location	Basel - Switzerland	Nantes, Lyon - France	Lyon, France	Shenzen, China	Toulouse, France
	Main Author	Allegrini	Athamena	Bouyer	Chen	Qu
	Output	building energy loads	outdoor comfort	building energy loads	outdoor comfort	surface temperature
	Results time range	1 year	2*1 day in summer	1 summer + 1 winter week	one summer day at noon	1 summer day
Modeling	CFD code	(Fluent)	Code_Saturne	Ansys Fluent	home developped	Code_Saturne
	Turbulence model	(k-ε)	k-ε	k-ε	k-ε	k-ε
	Radiative code	TRNSYS 17	Solene	Solene	home developped	Code_Staurne
	Building energy	TRNSYS 17	Solene - 1D	Solene - zonal	home developped	Code_Saturne
	Coupling method	(manual)	full dynamic	partial dynamic	static	full dynamic
	CHTC correlation	From LRNM with AWF	linear - Rowley	linear - Jayamaha		linear - Martilli
Boundary Cond.	Meteorological data	Basel + UHI	Airport based	Airport based	field data, above roof	field data, above roof
	Urban model	adiabatic boundaries	immediate surroundings		surroundings	surroudings
Initialization	Thermo rad.		none	2 weeks	2 days	preliminary simulations
	CFD		none	velocity and turbulence field	1 isothermal on a larger area	preliminary simulations
Validation	Litérature			X		
	Simpler prev. study		EMPAU			MUST
	Field measurements				X	X

Table 1: Synthesis of the case studies main characteristics

purposes, model should theoretically integrate:

- Suitable geometrical and meteorological input datasets, as well as a validation one;
- A comprehensive numerical platform including detailed CFD, BES and radiative models, with compatible samplings in time and space;
- A full dynamic coupling;
- Reliable convective heat transfer correlations for forced and mixed convection regimes.

This last point constitutes a real issue for the building and urban energy research community. Indeed, quite simple empirical correlations use to be employed in micro-climatic models and in BES. These correlations were originally not defined for urban purposes. Moreover, their applicability is mostly limited to relatively high wind speed conditions, which is not necessary the case in urban context: wind field features are spatially very heterogeneous, and are often driven by buoyancy effects.

Increasing the physical completeness of micro-climatic models with comprehensive coupled simulation should then imply to keep the same accuracy degree to model exchanges at the building (but also applications) interfaces. As shown in previous studies, the CHTC choice can lead to significant differences in terms of surface thermal balance. It can be the consideration of local features as thermal stratification or friction velocity for low speed urban winds instead of a unique value (Qu and al., 2012); or of buoyancy effects in temperature WF initially available for forced convection (Allegrini and al., 2012). The CHTC impact is even more important for glazed surfaces because of their low thermal resistance.

CHTC are commonly understood by the following linear formula:

$$CHTC = \frac{q}{T\,ref - Ts} \qquad (4)$$

Were q is the heat flux, $T\,ref$ the reference external temperature, and Ts the surface temperature.

Evaluating heat exchange at building surface, CHTC and, more precisely, surface heat transfers concern the wall boundary layer. Thus, to enhance its accuracy, recent research studies improve temperature WF using LRNM methods for urban configurations. The model used was the RANS k-ε method with two equations. If LRNM is assumed to be the most accurate method, because of the boundary layer resolution and not its modeling, it necessitates a very fine grid resolution. Hence, it is not suitable for integration in an urban model. Nevertheless, enhanced WF (customized (CWF) or adaptative (AWF)), derived from those LRNM simulations, allows for lesser than 10% error margins in comparison with LRNM, whereas standard WF with traditional law-of-the-wall shows a 10 to 60% error margin (Allegrini, and al., 2012).

Thus, such comprehensive coupled simulations raise the question of the relative impact of convective heat transfer modeling on building energy performance, as well as on outdoor thermal comfort predictions. Indeed, if radiative computation tools are already available to carry out relevant radiative studies, convective ones are still more limited for complex geometrical configurations. Indeed, because of the CFD computational cost, and its linked surface exchanges modeling issues, the convective contribution to the whole energy exchange is not yet as well known as the radiative one is.

CONCLUSION AND PERSPECTIVES

Considering simultaneously 3D radiative, conductive and convective transfers on an urban fragment constitutes a real improvement to building performance or outdoor comfort assessment. Indeed, the micro-climate is not defined by the sum of their individual contributions, but by their interactions.

Hence, the five case studies reviewed in this paper highlighted the potential of such coupled thermo-radiative / CFD simulations. It is a very promising tool, not only for urban energetic strategies improvements, but above all for the complex urban micro-climatic features understanding. However, it uncovers two series of questions:

- The first concerns the suitability of each model. For example, concerning CFD models: “Is the RANS k-ε effectively sufficient to model accurately urban flow fields?” “How to suitably model the approach flow?”
- The second is relative to the relevancy of the coupling strategy: “Is the surface heat transfer model relevant enough considering to the coupled model complexity?” “Are the initialization and the coupling method pertinent to reach sufficiently precise boundary conditions?”

Certainly, even for research issues, answers have to be provided with regard to the objectives purchased, and to the necessary resources to implement. Coupled simulations are very promising for even more accurate urban micro-climatic and building energy performance assessments. However, computing complex 3D flow and temperature fields questions the interface modeling, which is highlighted in this paper, to be of uttermost importance to preserve the coupled simulation outcome accuracy. Moreover, understanding the flow field in complex urban geometry will lead to a better use of natural ventilation.

NOMENCLATURE

1D, 2D, 3D = One, Two or Three Dimensionnal
BES = Building Energy Simulation
CHTC = Convective Heat Transfer Coefficient
CFD = Computational Fluid Dynamics
LRNM = Low Reynolds Number Modeling
MRT = Mean Radiant Temperature
PET = Physiological Equivalent Temperature
RANS = Reynolds Averaged Navier Stokes
SET = Standard Effective Temperature
T int = Internal Temperature
T ext = External Temperature
UHI = Urban Heat Island
U = Wind velocity
WF = Wall Function

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