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On the impact of local microclimate on building performance simulation. Part II: Effect of external conditions on the dynamic thermal behavior of buildings

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Research Article

Building Thermal, Lighting, and Acoustics Modeling

Abstract

Most of the building energy models are not suited to properly integrate local urban ambient conditions; thus, this study initiates a sensitivity analysis of the heating and cooling needs and operative temperature of buildings to local radiative, thermal and aeraulic external conditions. These conditions were estimated using the possibilities of a building energy model (based on the BuildSysPro Modelica library) or derived from microclimatic simulations (SOLENE microclimat) for generic isolated or urban buildings. The thermal behaviors of both energy-inefficient and energy-efficient buildings in summer and winter are examined. The results show major effects of short- and long-wave radiative heat transfers as well as aeraulics. According to present results, and given current urban growth and climate change challenges as well as the development of energy conservative buildings, this last point may become particularly critical in the future.

Keywords

building energy simulation,
urban environmental variables,
power needs,
thermal comfort,
heating and cooling,
ventilation

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1 Introduction

Due to their basic scope of application, modeling heat transfers in a building, common building energy simulation tools are generally not suited to accurately integrate building external conditions. This fact is even truer when considering urban buildings as simulations generally use typical weather files to specify external boundary conditions. Such weather data generally characterize open terrains and do not correspond to urban conditions. Indeed, the 3D structure and the material composition of cities as well as the anthropic activities that develop in urban areas generally tend to locally heat up the urban atmosphere, which often produces an urban heat island effect. At the smaller urban block scale the urban structure substantially affects building external conditions in terms of short-wave radiation fluxes air and radiant temperatures and wind-related fluctuations (Sun et al. 2011; Merlier et al. 2019a). In addition, regarding, more specifically, building energy simulation, empirical correlations or generic surface averaged quantities are generally used to specify building boundary conditions (Cóstola et al. 2010; Mirsadeghi et al. 2013). These different assumptions or simplifications of the local environmental conditions as well as their effects on buildings can lead to substantial uncertainties and errors in the modeling.

As these biases become very challenging given the current urban growth and the development of energy conservative buildings in the context of climate change, several studies have been developed during the last decade. These studies evaluate urban effects on building energy behavior at different scales. In particular, based on measurements of external conditions around urban buildings, Zinzi et al. (2018) and Salvati et al. (2017) highlighted a decrease in heating needs and an increase in cooling needs compared to rural conditions, especially in hot regions. Considering complementary numerical studies, Pigeon et al. (2014) used an urban canopy

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List of symbols

h	convective heat transfer coefficient [W m^{-2} K^{-1}]	T	temperature [K]
K	air permeability [m^3 h^{-1} Pa$^{-2/3}$]	ϕ_{conv}	convective heat flow [W m^{-2}]
P	pressure [Pa]	ϕ_{LW}	long-wave radiation flow [W m^{-2}]
Q	airflow rate [m^3 h^{-1}]	σ	Stefan–Boltzmann constant [≈ 5.67·10^{-8} W m^{-2} K^{-4}]

model (TEB (CNRM 2015; Masson 2000)) to estimate the external building conditions of different types of Parisian buildings and evaluated their effects on building energy loads using the embedded building energy model. The results showed that considering adjusted long-wave radiative heat exchanges between urban surfaces may increase cooling loads by 18% and decrease heating load by 6%. Using more detailed approaches to model urban environments but on smaller scales, i.e., using microclimatic models such as SOLENE-microclimat or ENVImet, internally or externally coupled with a dynamic building energy model, Bouyer et al. (2011); Yang et al. (2012); Malys et al. (2015) evaluated the impact of adjusted external conditions due to the presence of a specific urban environment on building energy needs. Solar loads, infrared exchanges and convective heat transfers were more particularly analyzed. The results highlighted the substantial influence of the urban radiative environment on building energy needs. Solar masks were shown to reduce cooling loads and increase heating loads respectively by 18.8% and 0.8% in Yang et al. (2012), and long-wave radiative heat exchanges generally constituted heat gains for buildings. More particularly, urban thermo-radiative environments were shown to increase the cooling needs of a newly built highly glazed office building by approximately 20% in Bouyer et al. (2011). The alteration of convective heat exchanges by surrounding buildings was shown to be less influential and even negligible for well insulated buildings (Malys et al. 2015). The effects of aeraulics appear to be rarely studied; however, Yang et al. (2012) showed that an increase in outdoor air temperature by approximately 1 °C on average during the daytime may have an impact on the cooling needs of buildings through air renewal by approximately 10%. However, to accurately estimate aeraulic-induced thermal loads, pressure contribution should be considered as well, as it determines the wind-driven infiltration and natural ventilation potential of buildings. Indeed, dedicated studies show that the natural ventilation potential of buildings strongly decreases with urban density, potentially by more than 50% (Ramponi et al. 2014), which strongly limits natural free cooling. Therefore, urban environments can substantially influence the energy behavior of urban buildings by modifying external conditions and, thus, radiative, thermal and aeraulic exchanges between a building and its built environment compared to a rural configuration. Nevertheless, studies rarely simultaneously consider aeraulic, radiative and thermal conditions. Therefore, the present study develops a methodology to discuss and improve current knowledge on the influence of urban boundary conditions on the thermal behavior of buildings by highlighting their dynamic and coupled effects. For this purpose, different sets of building external conditions were derived from state-of-the-art approaches for the cold and hot seasons. These conditions were more particularly assessed using (see Part I (Merlier et al. 2019a) and Fig. 1):

- (i) possibilities of a building energy model, namely, BuildSysPro (Plessis et al. 2014; Schumann et al. 2016), for a building standing on a dark ground and alone given the lack of general guidelines relative to the modeling of urban conditions – *Default* approach;
- (ii) a microclimatic simulation – *Microclimatic* approach – performed using SOLENE-microclimat (Morille et al. 2015; Musy et al. 2015) for the same isolated building, assumed to be located on a mineral ground – *Isolated* configuration; and
- (iii) the same microclimatic approach but considering the building located in a theoretical urban environment composed of a regular array of 4 × 4 similar buildings – *Array* configuration.

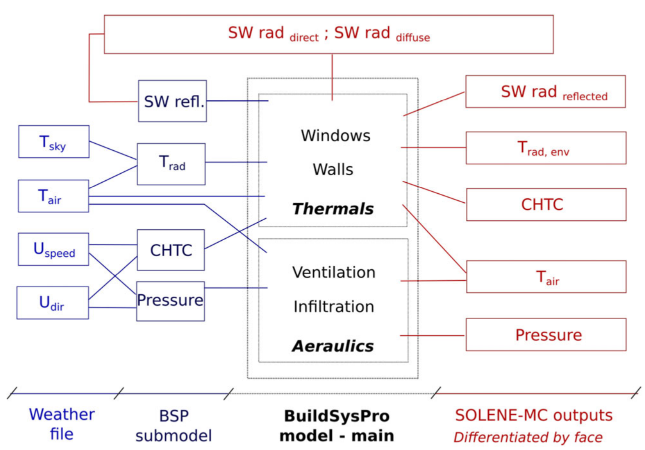


Fig. 1 Specification of building boundary conditions

Corresponding local external conditions were used to set boundary conditions to a detailed building energy model (Section 2) in order to compare winter and summer energy needs and summer comfort (Section 3). On this basis, the influence of adjusting the different external conditions due to (i-ii) changes in modeling approach and (ii-iii) urban environment on the dynamic behavior of the modeled building is discussed (Section 4).

2 Building model

2.1 General settings

A monozone 10 m high cubic building ($V = 10^3$ m^3) model was built using BuildSysPro, a Modelica library focusing on French building stock developed by EDF R&D (Plessis et al. 2014; Schumann et al. 2016) (for more details, see Part I (Merlier et al. 2019a)).

To relevantly integrate the contribution of the different boundary conditions, the building model includes two submodels (Fig. 2). First, the aeraulic submodel models infiltration and ventilation flow rates and the related heat transfers to the air node. Second, the thermal submodel models the convective, radiative and conductive heat transfers through opaque walls and windows and in the indoor area. The resolution of conductive heat transfers is based on a finite volume approach; each wall layer was discretized with more than 10 nodes per meter, depending on the thermal diffusivity of materials to relevantly study building dynamics (Frayssinet et al. 2017). The lower the diffusivity was, the finer the discretization.

The thermal properties of the building envelope were set to match TABULA indications (Rochard et al. 2015) for the most represented multifamily houses in France. This typology of buildings corresponds to uninsulated buildings built before 1915. This configuration is further referred to as *initial* building. These buildings could be renovated – *renovated* building –, thus substantially improving their thermal performance (see Table 1). The glazed ratio of these buildings equals 23%. In the model, glazed surfaces were assumed equally distributed over the four vertical faces.

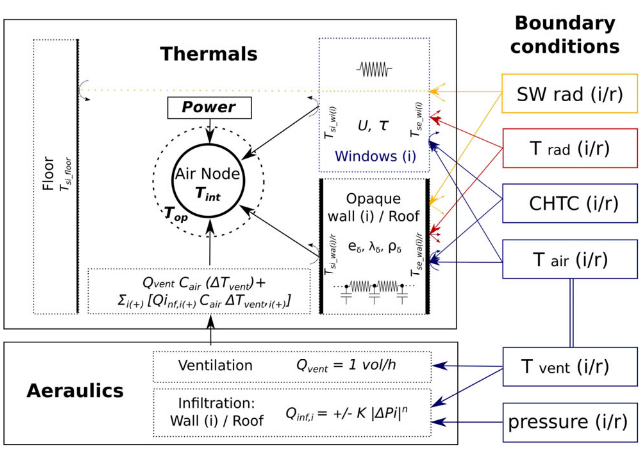


Fig. 2 BuildSysPro model

For simulation, either a heating set point equal to 19 °C, a cooling set point equal to 28 °C, or a floating temperature evolution in summer was specified. A ventilation airflow rate of 1 ACH was assumed, along with a wall permeability under a pressure difference of 4 Pa (reference infiltrated airflow rate per meter square of envelope Q_{4Pa}) equal to $Q_{4Pa} = 2$ m^3 h^{-1} m^{-2} for the initial building or ten times less for renovated building. No model for humidity was considered, as air moisture impact is assumed to be small in temperate climates. No energy system, internal gains, free cooling nor shading were considered in order to evaluate the intrinsic response of the building to its external conditions.

Table 1 Thermal properties of the generic test cases

	Wall	Window	Roof
Initial state			
Surface [m^2]	250	77	140
Materials	40 cm stone	Double glazing	13 cm plaster + 2 cm insul. + tile
U [W m^{-2} K^{-1}]	1.7	2.6	1.35
Renovated			
Materials	12 cm insulation	Triple glazing	12 cm insul. + 18 cm wood fiber
U [W m^{-2} K^{-1}]	0.24	1	0.2

2.2 Boundary conditions

Based on the three sets of data detailed in the introduction, the external conditions of the buildings were assigned by face in the building model. These conditions are the direct and diffuse short-wave radiative fluxes, radiant and air temperatures, convective heat transfer coefficient (CHTC) and relative pressure (see Fig. 1).

The developed methodology enables the different sets of conditions to be mixed in order to highlight the specific contributions of one or several external conditions on simulation outputs. Note that although being actually similar, air temperature for the thermal or the aeraulic submodels was differentiated to separately characterize the respective contribution of each type of transfer. In the following, T_{vent} stands for the temperature used as input to the aeraulic submodel and T_{air} refers to the input used by the thermal submodel.

In addition, to integrate and further evaluate the respective contributions of each external condition, different submodels were set or implemented in the building energy model to specify boundary conditions. Especially considering a wall

i in the aeraulic model, infiltration airflow rates ($Q_{\text{face},i}$) were estimated based on the mass balance of the indoor air volume assuming a uniform permeability (K_i) for the roof and walls and a power low function (Eq. (1)):

$$Q_{\text{face},i} = \pm K_i \times |P_{\text{ext},i} - P_{\text{int}}|^{2/3} \quad \text{and} \quad \sum_i Q_{\text{face},i} = 0 \tag{1}$$

where $P_{\text{ext},i} - P_{\text{int}}$ is the outdoor/indoor face pressure difference. Inlet T_{vent} used for ventilation was assumed equal to the average of T_{vent} estimated next to the four vertical faces of the building, while $T_{\text{vent},i}$ used for infiltration was differentiated for each face and used accordingly.

Regarding the thermal model, long-wave radiative heat transfers at the building outer surfaces (ϕ_{LW}) were evaluated based on the Stefan–Boltzmann law (Eq. (2)):

$$\phi_{\text{LW},i} = \sigma \times (T^4_{\text{rad,env},i} - T^4_{\text{surf},i}) \tag{2}$$

where σ is the Stefan–Boltzmann constant.

Convective heat transfers ($\phi_{\text{conv},i}$) were estimated using local CHTC and air temperature (Eq. (3)):

$$\phi_{\text{conv},i} = \text{CHTC} \times (T_{\text{air},i} - T_{\text{surf},i}) \tag{3}$$

where $T_{\text{surf},i}$ is the surface temperature estimated using the surface balance of wall i considered the conductive, convective and radiative contributions.

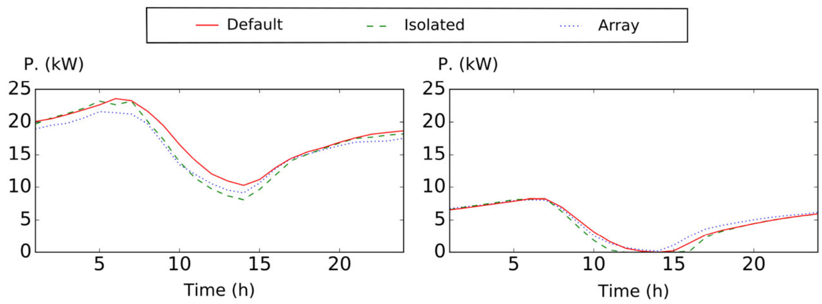
Short-wave radiation fluxes transmitted by windows were distributed over the floor.

Based on these different settings, simulations were run using the Dymola simulation environment, looping 10 times on the same day, i.e., 06 November for winter and 09 July for summer.[1] The results of the simulated tenth day were kept for analysis, and the nine first loops were used for the model initialization.

3 Results analysis

Considering the three sets of external conditions used to specify boundary conditions to the building energy model, i.e., (i-ii) the default and microclimatic approaches and (ii-iii) the isolated and array configurations, the following sections analyze the results regarding the following:

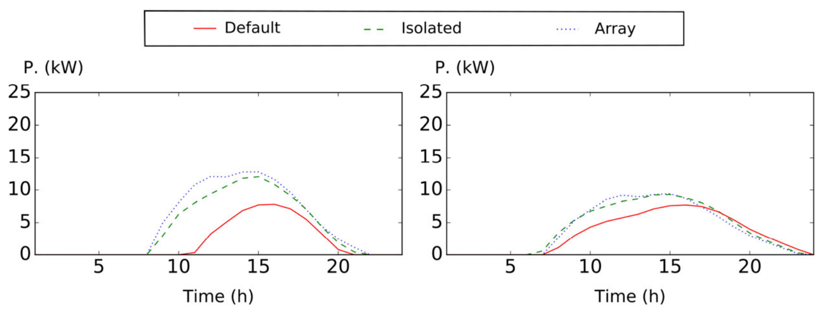
- The temporal evolution of the global energy needs and operative temperature (Figs. 3, 4 and 5). These results highlight differences induced by the different modeling approaches and configurations, i.e., considering one or another set of boundary conditions.



(a) Initial building
Mean power needs: Default = 17.4 kW, Isolated = 16.5 kW, Array = 16.2 kW

(b) Renovated building
Mean power needs: Default = 4.5 kW, Isolated = 4.2 kW, Array = 4.7 kW

Fig. 3 Influence of the modeling approach: modification of the heating needs induced by the adjustment of boundary conditions

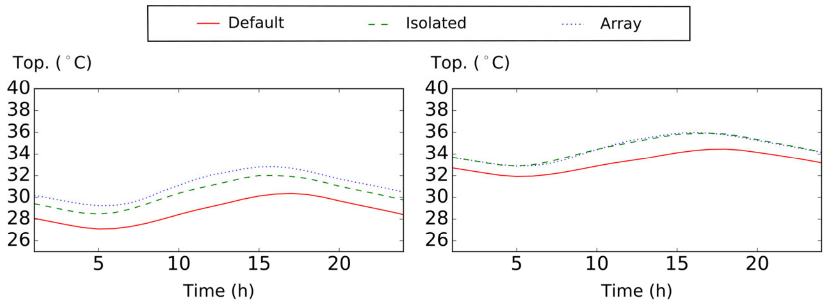


(a) Initial building
Mean power needs: Default = 2.0 kW, Isolated = 3.9 kW, Array = 4.6 kW

(b) Renovated building
Mean power needs: Default = 3.2 kW, Isolated = 4.0 kW, Array = 3.9 kW

Fig. 4 Influence of the modeling approach: modification of the cooling needs induced by the adjustment of boundary conditions

[1] Individual annual simulation lasting between 1 and 2 minutes on a 2.5 GHz processor and 8 GB of RAM computer.



(a) Initial building
Mean operative temp.: Default = 28.7 °C, Isolated = 30.3 °C, Array = 31.1 °C

(b) Renovated building
Mean operative temp.: Default = 33.2 °C, Isolated = 34.5 °C, Array = 34.5 °C

Fig. 5 Influence of the modeling approach: modification of the indoor operative temperature induced by the adjustment of boundary conditions

- The dynamic contribution of each external condition on heating and cooling needs as well as operative temperature (Figs. 6, 7 and 8). These results highlight the impact of each distinct external solicitation on the building thermal behavior.

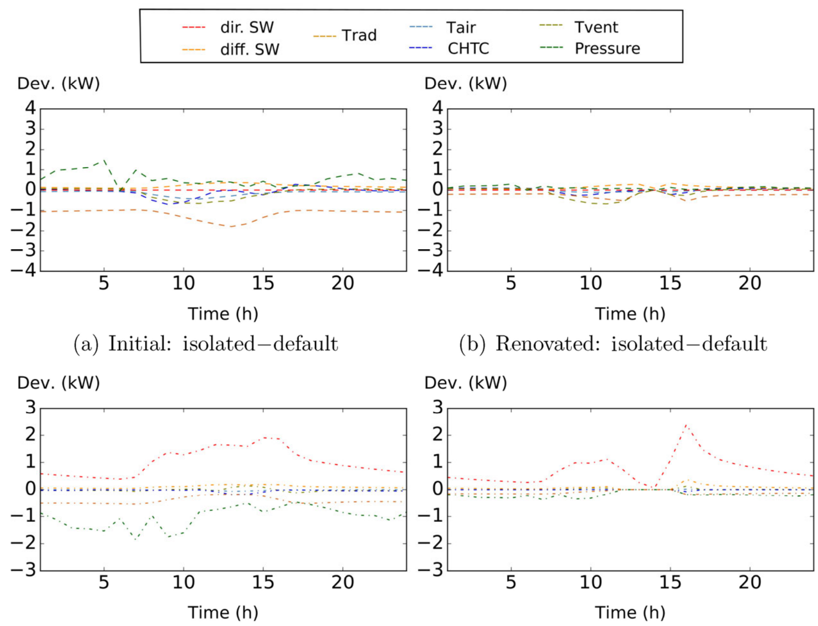
Tables 2 and 3 complete Figs. 3–8 by precising the mean and maximum differences of heating and cooling needs as well as operative temperature induced by the different types of heat transfers, i.e., short-wave and long-wave radiative, convective and aeraulic-induced heat transfers.

3.1 Impact of the modeling approach

3.1.1 Heating needs

Considering a stand-alone building, Fig. 3 shows that renovation induces an averaged reduction of heating needs by a factor of four due to the improved thermal insulation and air tightness. As a consequence, renovation also tends to reduce the influence of the modeling approach on heating needs. More precisely, using the boundary conditions derived from the microclimatic approach induces lower heating needs than what is estimated based on the default approach: the averaged difference equals 5% and 7% for the initial and renovated buildings, respectively. The difference is mostly due to the contribution of the environmental radiant temperature, which is higher in the microclimatic approach, especially during the daytime. This higher temperature decreases heating needs by 7% and 6% for the initial and renovated buildings, respectively.

With respect to other boundary conditions, the sensitivity of the renovated building to the modification of wind-



(a) Initial: isolated−default

(b) Renovated: isolated−default

(c) Initial: array−isolated

(d) Renovated: array−isolated

Fig. 6 Influence of the built configuration: modification of the heating needs induced by the adjustment of boundary conditions

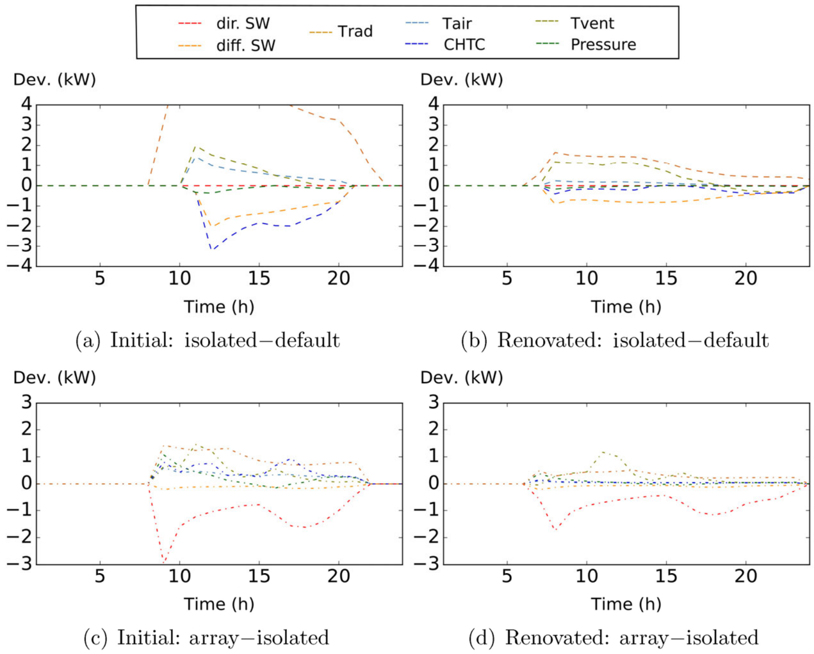


Fig. 7 Influence of the built configuration: modification of the cooling needs induced by the adjustment of boundary conditions

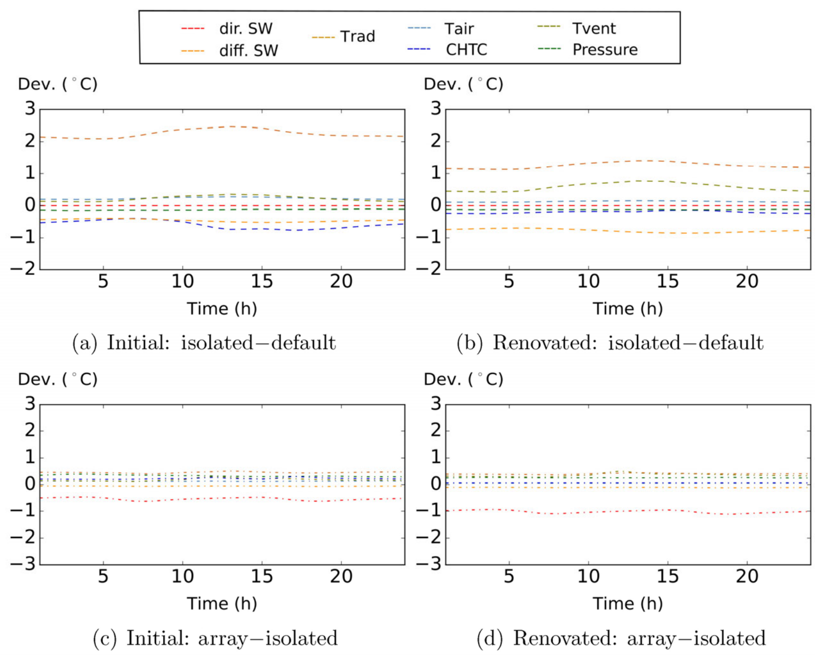


Fig. 8 Influence of the built configuration: modification of the indoor operative temperature induced by the adjustment of boundary conditions

induced heat transfers is rather negligible. These effects are more substantial in the initial building, for which modifying the aeraulic fluxes increases the daily heating needs by 3% because of higher infiltrated airflow rates, which are not compensated for by the slight increase in air temperature. Conversely, convective heat losses are reduced by 2% when based on the microclimatic rather than the default approach, probably due to higher air temperature. Using the smaller short-wave solar reflections derived from the microclimatic approach instead of the default flux slightly increases the heating needs by 1% and 2% for the initial and renovated buildings, respectively.

3.1.2 Cooling needs

Contrary to heating needs, renovation does not substantially reduce cooling needs. Indeed, cooling needs are about six

Table 2 Influence of the modeling approach: effect of boundary conditions

Mean (and max.) modeling effects (isolated – default)				
Building state	Phenom.	Heating [kW]	Cooling [kW]	Summer comfort [°C]
Initial	SW rad.	0.2 (0.4)	−0.5 (−2.0)	−0.5 (0.5)
	LW rad.	−1.2 (−1.8)	2.6 (8.1)	2.2 (2.5)
	Aero.	0.4 (1.6)	0.3 (1.7)	0.1 (0.3)
	Conv.	−0.3 (−0.9)	−0.5 (−1.8)	−0.3 (−0.5)
	Combined	−0.9 (−2.7)	2.0 (7.7)	1.6 (2.0)
Renovated	SW rad.	0.1 (0.3)	−0.4 (−0.9)	−0.8 (−0.9)
	LW rad.	−0.3 (−0.5)	0.7 (1.7)	1.3 (1.4)
	Aero.	0.0 (−0.7)	0.3 (1.2)	0.5 (0.7)
	Conv.	0.0 (−0.3)	−0.1 (−0.3)	−0.1 (−0.2)
	Combined	−0.3 (−1.3)	0.7 (2.5)	1.3 (1.7)

- SW rad.: short-wave rad. (dir. SW+diff. SW), - LW rad.: long-wave rad. (T_{rad}), - Aero.: infiltration+ventilation (Pressure+T_{vent}), - Conv.: convection (CHTC+T_{air}), - Combined: combined effects (all environmental variables).

Table 3 Influence of the built configuration: effect of boundary conditions

Mean (and max.) urban effects (array – isolated)				
Building state	Phenom.	Heating [kW]	Cooling [kW]	Summer comfort [°C]
Initial	SW rad.	1.1 (2.1)	−0.7 (−3.0)	−0.6 (−0.7)
	LW rad.	−0.4 (−0.5)	0.5 (1.4)	0.5 (0.5)
	Aero.	−1.0 (−1.9)	0.3 (1.6)	0.5 (0.6)
	Conv.	−0.1 (−0.2)	0.4 (1.3)	0.4 (0.5)
	Combined	−0.4 (−2.0)	0.6 (2.7)	0.7 (1.0)
Renovated	SW rad.	0.8 (2.5)	−0.6 (−1.9)	−1.1 (−1.2)
	LW rad.	−0.1 (−0.2)	0.2 (0.5)	0.4 (0.5)
	Aero.	−0.2 (−0.4)	0.2 (1.2)	0.6 (0.7)
	Conv.	0.0 (0.0)	0.1 (0.2)	0.1 (0.1)
	Combined	0.5 (2.3)	−0.1 (1.0)	−0.0 (0.2)

- SW rad.: short-wave rad. (dir. SW+diff. SW), - LW rad.: long-wave rad. (T_{rad}), - Aero.: infiltration+ventilation (Pressure+T_{vent}), - Conv.: convection (CHTC+T_{air}), - Combined: combined effects (all environmental variables).

times smaller than heating needs for the initial building, whereas they are comparable for the renovated building. Considering the default set of boundary conditions, renovation tends to substantially increase the cooling period, which leads to an increase in energy needs by 60%. The cooling period is also increased in the renovated building when considering boundary conditions derived from the microclimatic approach, but to a lesser extent. As the corresponding maximal power loads are decreased by 30%, estimates of energy needs are similar for both the initial and renovated buildings according to the microclimatic approach.

Regarding the contribution of the different boundary conditions, and similar to Section 3.1.1, the contribution of long-wave radiative heat transfers mostly explains the differences in the cooling needs observed when considering boundary conditions derived from the microclimatic instead of the default approach. This contribution explains both the earlier need of cooling and the increased power needs. As a result, the modification of the environmental radiant temperature increases cooling needs by 130% and 22% for the initial and renovated buildings, respectively. The simultaneous modification of all of the boundary conditions increases cooling needs by 100% and 23% for the initial and renovated buildings, respectively.

The modification of other external conditions and associated heat transfers induces more comparable deviations for both the initial and renovated buildings. The second most important change in cooling needs is induced by the modification of short-wave radiation fluxes. As the received reflected fluxes are lower in the microclimatic approach than in the default approach, corresponding cooling needs are reduced by 25% and 12% for the initial and the renovated buildings, respectively. Conversely, as the microclimatic approach estimates higher infiltrated airflow rates and local air temperatures, the aeraulic-induced heat transfers increases cooling needs by 15% and 9% for the initial and the renovated buildings, respectively, when based on corresponding data. Regarding convective heat transfers, considering the increased CHTC and local air temperature derived from the microclimatic approach induces a decrease in cooling needs by 25% and 3% in the initial and renovated buildings, respectively. This counterintuitive contribution can be explained by a higher solar heat removal rate at the outer surfaces of the building, which limits over-heating.

3.1.3 Summer comfort

Indoor operative temperatures are generally higher than the outdoor air temperature and show much smaller variation. Because of inertia, the operative temperature range in both the initial and the renovated buildings is of 3 °C, which is four times smaller than the range of meteorological air temperature. In addition, because of the improved thermal insulation and air tightness, the mean operative temperature is more than 4.5 °C higher in the renovated building than in the initial building. The indoor operative temperature even reaches 35 °C during the afternoon in this configuration which substantially exceeds summer comfort requirements.

Regarding the respective influence of boundary conditions, observed trends are comparable to Section 3.1.2 as external conditions and building properties are similar. Nonetheless, because of the buffer effect of thermal inertia, effects are almost constant over the simulated period. The contribution of long-wave radiation is the most important factor affecting the operative temperature. The higher environmental radiant temperature induces an increase in indoor operative temperature of 2.2 °C and 1.3 °C for the initial and renovated buildings, respectively. As a result, taking all of the boundary conditions derived from the microclimatic approach into account instead of conditions derived from the default approach tends to increase operative temperature by 1.6 °C and 1.3 °C for the initial and renovated buildings, respectively.

3.2 Impact of the urban environment

3.2.1 Heating needs

The general effect of the surrounding buildings on heating needs is inverse for the initial and the renovated buildings. In the initial building, the urban environment increases heating needs by 2% during the day and decreases them by 5% during the night. As a result, surrounding buildings decrease heating needs by 2% on average. Regarding the renovated building, the general effect of the urban environment appears negligible during the night, but its effect during the daytime leads to an average increase in heating needs by 12%.

This effect of surrounding buildings on heating needs is mainly explained by the sun shading induced by surrounding buildings, which is the most influential modification of external conditions affecting heating loads. This effect is greater during daytime, as the East and West and mainly the South faces are masked. Reduced short-wave fluxes increase the heating needs of the initial building by 7%. The increase is 19% for the renovated building, which is evidence to its higher relative sensibility to solar loads. Heating is even needed around midday in this configuration, which is not the case for the isolated configuration.

The influence of surrounding buildings on other external conditions counterbalances the effect of solar masks. In particular, aeraulic effects nearly compensate the effect of the reduced short-wave radiative flux for the initial building, which highlights a higher sensitivity of the building to other boundary conditions than the renovated building. The alteration of aeraulic-induced heat transfers and of long-wave radiative heat transfer by surrounding buildings is four times less influential in absolute value but relatively comparable for the renovated than in the initial building (−5% and −2% versus −6% and −2%, respectively). The contribution of convective heat transfers is negligible for both building states.

3.2.2 Cooling needs

On average, the general effect of surrounding buildings is an increase in cooling needs by 17% for the initial building. The effect of the urban environment is especially visible during the morning. On the contrary, the presence of surrounding buildings tends to slightly decrease the cooling needs by 2% for the renovated building.

As for heating, the modification of short-wave radiative fluxes due to surrounding buildings is the most influential contribution affecting cooling needs for both building states. Although being slightly modulated by increased reflection, solar masks reduce cooling needs by 17% and 15% for the initial and renovated buildings, respectively. This decrease in cooling needs is particularly due to two main gaps occurring in the morning and afternoon, which correspond to the shading of the East and West faces.

The modification of the other boundary conditions, i.e., the increase in environmental radiant temperature and the decrease in ventilation potential and convective heat transfers, are opposite the effects of the reduced solar loads. For the initial building, their combined effect is even higher than the effect of solar masks. This result is also the case for the renovated building, but only during midday. Indeed, in this configuration, solar effects remain dominant during the early morning and the evening.

3.2.3 Summer comfort

The results analysis highlights comparable trends for the operative temperature as for cooling needs. On average, the urban environment increases the operative temperature of the initial building by 0.7 °C, while the operative temperature of the renovated building remains similar in the array and in the isolated configuration because of compensations. The modification of short-wave radiation induced by surrounding buildings is the most influential effect on the building thermal behavior. It decreases the operative temperature by 0.6 °C and 1.1 °C for the initial and renovated buildings, respectively.

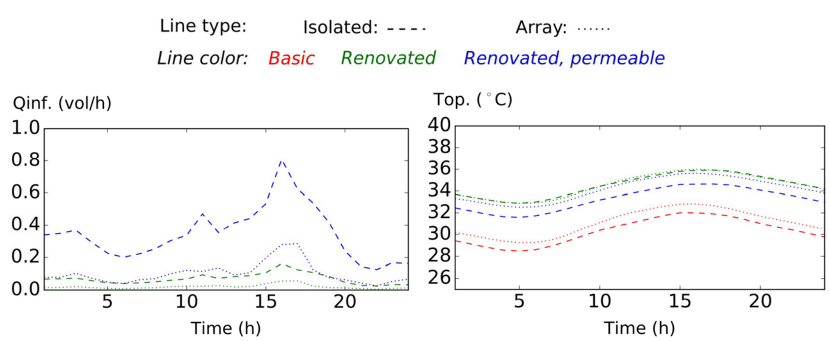
Regarding the effects of adjusting the other types of heat transfers on the floating operative temperature, it can be observed that the aeraulic contribution is equivalent to, and even more important than, the contribution of long-wave radiation for the initial and renovated buildings. The aeraulic contribution is the opposite but comparable to that of short-wave radiation in the initial building. It represents half of it for the renovated building. Hence, to address free-cooling issues, Fig. 9 further analyzes the free-cooling potential of buildings using natural ventilation, especially regarding the renovated building, which shows hot indoor temperatures. The results highlight that if decreasing the air tightness by a factor of 10 for the renovated building to simulate a volunteer overventilation, the operative temperature decreases on average by 1.3 °C in the isolated configuration. Such an effect is more important than the effect of solar masks in the array configuration. The decrease in operative temperature by volunteer overventilation is reduced down to less than 0.4 °C when considering an urban configuration. Indeed, because of wind masks, ventilation airflows are reduced by a factor of three in this configuration, which points out the prejudicial lack of cooling potential in urban environments.

4 Discussion and challenges

Contemporary challenges linked with the energy performance of urban buildings, such as the design of passive strategies, integration of renewables, grid management or performance guarantee, require the use of appropriate external conditions and boundary conditions for numerical simulations. Such inputs are critical for urban planners and building engineers because of global warming and urban growth issues. However, building energy models were basically not designed to address such problems. Thus, the present study is a first step towards the evaluation of the local microclimate effects on building energy performance simulation. It is worth mentioning that the novelty of our work is the methodology rather than the results, as the latest are very configuration-dependent.

The implemented methodology highlighted the importance of accounting for comprehensive sets of appropriate boundary conditions, including radiative, thermal and aeraulic conditions, to address current building energy issues. Indeed, not only are the thermo-radiative conditions dependent on the chosen modeling strategy, but the wind-related heat transfers by convection and ventilation are as well. Both heat transfer modes are shown to clearly influence the numerical thermal behavior of buildings, but differently depending on the building environment and thermal performance and season. The results also differ depending on the studied output quantity.

Such results appear especially useful for building engineers and city planners. However, to move further into the analysis and generalize the approach, some developments should be further addressed. In particular, one of the main limitations of this study is the short period of simulation. This restriction is induced by the use of a rather computationally expensive approach, i.e., steady CFD RANS simulations. Indeed, although CFD effectiveness for urban applications is currently rapidly growing, making it an appealing technique even considering detailed turbulence modellings such as Large Eddy Simulation (for instance, using the Lattice Boltzmann method with the immersed boundary method (Obrecht et al. 2015; Jacob and Sagaut 2018; Merlier et al. 2018, 2019b)), computational time and turbulence modeling challenges still generally prevent its use for most building energy problems. Therefore, the



(a) Infiltrated air flow rates (b) Operative temperature

Fig. 9 Effect of pressure on free-cooling potential present study only focused on a couple of days, while energy engineers generally develop whole-year studies. The accuracy of the developed simulations would also certainly benefit from the development of a full dynamic coupling between the microclimatic and building energy simulations (Zhai and Chen 2005) at the neighborhood scale, as well as a more detailed conductive and convective heat transfer modeling. This would enable estimation of more accurate surface temperatures and thus long-wave radiative heat transfer. However, such a detailed coupling would also substantially increase the computational cost.

On the whole, the present study also only focused on generic geometries. This choice has the advantage of easing results analysis and is consistent with the methodological aim of this study. Nevertheless, it does not integrate the complexity of real urban morphology, which should be now considered if aiming to simulate a real urban building. Additionally, active system, internal heat gains or user behavior was not explicitly taken into account.

Finally, it is worth mentioning that current results were not validated against reference experimental data. Validation requires reliable and usable experimental data. This point arises another important challenge for urban and building physicists: the production of such data for complex real urban configurations that include intricate and coupled phenomena. Indeed, the production of such data is facing two notable issues: (1) the measurement of relevant external conditions as well as buildings/occupants/systems behavior and (2) the reliable description of geometric and thermophysical parameters.

5 Conclusion

The objective of this study was to highlight the influence of the modeling approach and of the urban environment on the dynamic thermal behavior of typical urban buildings. For this purpose, radiative, thermal and aeraulic conditions were derived from two state-of-the-art modeling approaches for two built configurations and used as input for a detailed building energy simulation. On this basis, typical time integrated and dynamic behaviors of an old or a thermally renovated buildings for typical sunny and windy summer and winter days under temperate climatic conditions were discussed.

Comparing the results obtained for a stand-alone building but considering boundary conditions derived from a building energy or a microclimatic model, the results highlighted the importance of accounting for the temperatures of surrounding surfaces. Adjusting the environmental radiant temperature was found to be the most influential modification of external conditions on power needs and operative temperature. Nonetheless, this major effect has to be related to the substantial difference estimated between the air and environmental radiant temperatures highlighted in Merlier (2019a).

Comparing the results obtained for an isolated or an urban building, the results pointed out the major effect of solar masks on power needs and operative temperature, as they decrease heat gains. This effect was generally found balanced by the modification of other boundary conditions. In particular, effects of aeraulics were shown substantial, especially with respect to the summer comfort in urban environments. Indeed, in this configuration, the absolute influence of wind sheltering was found comparable to that of solar masks, and the small urban natural ventilation potential was shown particularly prejudicial for free cooling.

The different abovementioned effects were shown dependent on the thermal performance of building envelopes. Because of its insulation and air tightness, the renovated building appeared mostly impacted on by the modification of solar fluxes as well as, to a lesser extent, by the environmental radiant temperature and aeraulics. On the contrary, most of the different boundary conditions significantly altered the thermal behavior of the initial building.

Hence, although the general methodology developed in this study could be extended to further improve the accuracy of results and better fit current building energy simulation issues by performing sensitivity studies and an entire yearly analysis, this study proposed a framework to discuss usual urban building energy simulation practices. Towards the design of energy-efficient and comfortable urban buildings both in winter and summer, the conclusions identify important modeling challenges to be addressed when aiming to properly integrate the effects of the urban environment of a building in dynamic simulations.

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