HAL open science

Adaptation of building envelope models for energy simulation at district scale

Loïc Frayssinet, Frédéric Kuznik, Jean-Luc Hubert, Maya Milliez, Jean-Jacques Roux

To cite this version:

Loïc Frayssinet, Frédéric Kuznik, Jean-Luc Hubert, Maya Milliez, Jean-Jacques Roux. Adaptation of building envelope models for energy simulation at district scale. Energy Procedia, 2017, 122, pp.307 - 312. 10.1016/j.egypro.2017.07.327 . hal-01842356

HAL Id: hal-01842356

https://hal.science/hal-01842356v1

Submitted on 18 Jul 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 122 (2017) 307–312

Energy Procedia

www.elsevier.com/locate/procedia

CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Adaptation of building envelope models for energy simulation at district scale

Loïc Frayssinet[a,b,*], Frédéric Kuznik[a,b], Jean-Luc Hubert[a,c], Maya Milliez[a,c], Jean-Jacques Roux[a,b]

[a] *BHEE, joint laboratory CETHIL-EDF*
[b] *Univ Lyon, CNRS, INSA-Lyon, Université Claude Bernard Lyon 1, CETHIL UMR5008, F-69621, Villeurbanne, France*
[c] *EDF R&D - Département Enerbat*
Avenue des Renardières - Ecuelles - 77818 Moret sur Loing, France

Abstract

In order to reduce computational cost of district scale energy simulations, very simplified building envelope models are often used. However, the impacts induced by such simplifications, are not systematically validated, especially for instantaneous power demand, required for district energy network design and management, since those models are mainly designed for monthly or annual energy consumptions. This paper aims to analyse the impacts of usual envelope simplifications used at the district scale (such as conduction modelling, zoning, allocation of transmitted solar flux, controlled temperature modelling, etc.) on the building energy needs, and, consequently, to suggest relevant selections of adaptations according to the simulation focus, i.e. the temporal resolution.

© 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale

Keywords: Building model; district; simplifications; adaptations.

* Corresponding author.
E-mail address: loic.frayssinet@insa-lyon.fr

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale
10.1016/j.egypro.2017.07.327

1. Introduction

District scale studies require simulations of hundreds of buildings, and modelling hundreds of buildings with a technologically explicit formulation for computing power demand over a year, can lead to prohibitive computational cost (even more if considering interactions between them, as longwave heat exchange or microclimate impacts).

In order to reduce simulation cost, simplified approaches are often used in city energy simulations. Since simulating the conductive heat transfer is the most expensive part of building energy simulations, envelope model is the main target of simplifications. In particular, many building envelope resistance-capacitance (RC) analogy models were developed for district scale building energy simulation platforms: Kämpf and Robinson model for CitySim [1], Berthou et al. model for Smart-E [2][3], Perez et al. model for DIMOSIM [4] and specific envelope models of the Modelica libraries BuildingSystems [5,6], AixLib [7], OpenIDEAS [8], and BuildSysPro [9]. Other platforms [10–14], adapted for annual or monthly energy calculation, use quasi-static models. Otherwise, mathematical reduction technics are also used [15,16].

Furthermore, implicit simplifications relying on modelling assumptions of the building energy model (BEM) are usually used, as monozone model, geometry and meteorological loads simplifications. These simplifications are also used because of lack of suited data at city scale (e.g. glazing ratio, fabrics and the local micro-climate).

Thereafter, the term *adaptation* is used rather than *simplification* because the modifications (simplifications/adaptations) are performed with respect to a specific goal in order to reduce the computational cost and/or the number of parameters; the model is adapted to the outputs of the simulation which we need to focus on. This paper studies the impact of common adaptations used in BEM on the simulated building energy needs (heating and cooling) in order to determine which adaptations could be relevant with respect to the simulation goal. Power needs, at least hourly estimated, are particularly focused on since adaptations are usually validated with respect to annual or monthly energy consumption but not to power needs.

For this purpose, the paper is structured as follows: a first part (Sec. 2) details the methodology retained for the adaptation impact analysis; then, the estimated impacts are presented and analysed (Sec. 3); finally, the last part (Sec. 4) draws conclusions and perspectives.

2. Methodology

Two kinds of adaptations are studied: the first one relies on the level of discretization of the conductive heat transfer model, the second on usual modelling adaptations of BEMs.

The impact of each adaptation is analysed by comparing the power simulation results of the adapted model with the results of the un-adapted model. In order to do so, we focus on the time series differences between the two power curves. Two indicators are computed in order to analyse this time series: the mean and the absolute maximum (referred to *max.* in the following), in order to respectively discriminate impacts on annual energy needs (long term), and on power needs (estimated over a time step period). The rectified mean (*r. mean*), mean of the absolute values, is used as a second complementary indicator for quantification of long term period impacts without compensating effects between positive and negative differences.

The methodology is applied to a generic 10 m cubic building oriented towards the cardinal directions. Its characteristics is based on the French TABULA typology [17] for 'multi-family house built before 1915' category, as this category represents a key part of the French building stock. In addition, the case of an efficient-energy renovated building is also studied, in order to highlight the effects of the envelope performance on the impacts of the adaptations. Thereafter, *Init.* refers to the initial building according to the typology, whereas *Perf.* refers to the renovated building.

The models are built using the BuildSysPro Modelica library developed by EDF R&D [9] and simulated with Dymola for a whole year. A solver with an adaptive step size algorithm is used, but the output interval is set to 1 hour in order to match with the hourly Meteonorm weather data from the city of Lyon in France which is used. The setpoint temperatures are respectively 19°C and 28°C for heating and cooling. Main modelling assumptions are given in Sec. 2.2. No energy system is modelled, hence the power calculated corresponds to needs, not demand.

2.1. Conductive heat transfer modelling

Each layer of opaque walls of the BEM is discretized in a finite number m of equidistant mesh elements. For the analysis purpose, and for physical considerations, this number is defined as a function of the layer thermal penetration depth length, hence, as a function of the thermal properties of the layer:

$$m = \max(1, \text{floor}\left(\frac{e}{e_c}\right)); \; e_c = \sqrt{a \cdot \tau}$$

with 'floor' the integer part function, e the layer width and e_c the characteristic length of the layer (proportional to the thermal penetration depth length), a the thermal diffusivity and τ the characteristic time[1].

This characteristic time controls the level of discretization: the smaller the characteristic time is, the higher the mesh resolution is. For the analysis prospect, the building model is simulated for values of τ starting from 15 days to 59 s. The steps correspond to an increment of the number of mesh points of any layer of the building envelope model. For the comparisons, the reference is the model with the minimal characteristic time (supposed to be the most accurate).

Table 1. Number of points in wall layers for the two extreme value of τ (tau).

τ	Stone (40 cm)	Coating (2 cm)	(Perf.: Mineral wool (12 cm))
15 days	1	1	1
59 s	64	4	14

2.2. Building model assumptions

In order to analyse the sensitivity of the power needs to modelling assumptions, focused modelling assumptions of the BEM, detailed in Table 2, are alternately and individually modified.

Table 2. Analysed building model assumptions.

Item modelled	Reference model	Modified model [*key*][2]	Interest of the adaptation
External convective heat transfer	Linearized exchange coeff.	Coefficient linearly dependent of the local wind velocity [*DetailConv*]	Do not model external airflow
External radiative heat transfers	Linearized exchange coeff.	Stefan-Boltzmann law [*DetailRad*]	Linearize the equation
Infiltrations	Not modelled	Modelled with a power law [*Infil*]	Do not model external wind airflow
Distribution of transmitted solar flux	Only on the floors	All internal surfaces [*SolDistribAllS*]	Do not model solar patches and internal walls
Internal inertia	Modelled	Not modelled [*NoIntInertia*]	Do not model internal walls
Zoning	Monozone	Storeys (3 zones) [*StoreyZone*] Orientations (4 zones) [*OriZone*] Storeys & orientations (12 zones) [*AllZones*]	Do not model numerous thermal zones and respective internal heat transfers
Controlled temperature	Internal air temperature	Internal operative temperature [*TopControl*]	Do not model system control
Internal boundary condition for internal convective and radiative heat transfer	Internal air temperature	Internal operative temperature [*TopBCConvInt*]	Do not model internal walls and internal radiative heat transfer

[1] For τ-periodic harmonic load in a semi-infinite layer, the characteristic thermal penetration depth length is $\sqrt{a \cdot \tau / \pi} = e_c / \sqrt{\pi}$

[2] The *keys* are used in Figure 2 labels and in Sec. 3.2.

These modifications aim to model more accurately (or in a simpler way) a part of the BEM in order to determine if the adaptations are influential, and to estimate differences due to such adaptations, and hence, whether a detailed model is preferable or a simplified model acceptable.

The outputs of modified building models are compared with the outputs of the reference model (detailed in Table 2). Hence, a local sensitivity analysis is performed for the reference model. The modelling assumptions of the reference model are defined according to usual adaptations of city energy simulation BEMs. The interests of such adaptations are briefly explained in Table 2. The discretization of wall layers was defined for τ = 900 s (15 min) in order to reduce the computational cost while accurately simulating outputs (see Sec. 3.1.).

3. Results

This section presents and analyzes the results of the tests previously introduced. Power needs are divided into heating and cooling parts. For consistent comparisons between them, relative differences are plotted, relatively to the respective average non-zero power of the reference model, but minor axes giving absolute values are added (hence, the reference average values can be read in the respective minor axis at the 100% relative level).

3.1. Conductive heat transfer modelling

As expected, because of lower mesh resolution, the differences between simplified models and the reference model increase with the characteristic time.

Only max. differences evolutions are plotted in Figure 1 because the differences measured by this indicator are greatly higher than mean and r. mean differences. Indeed, these both last indicators have similar shape than max. but significant lower values: respectively lower than 0.2% and 2% for mean and r. mean. This observation confirms that high differences rarely occur, but could be important.

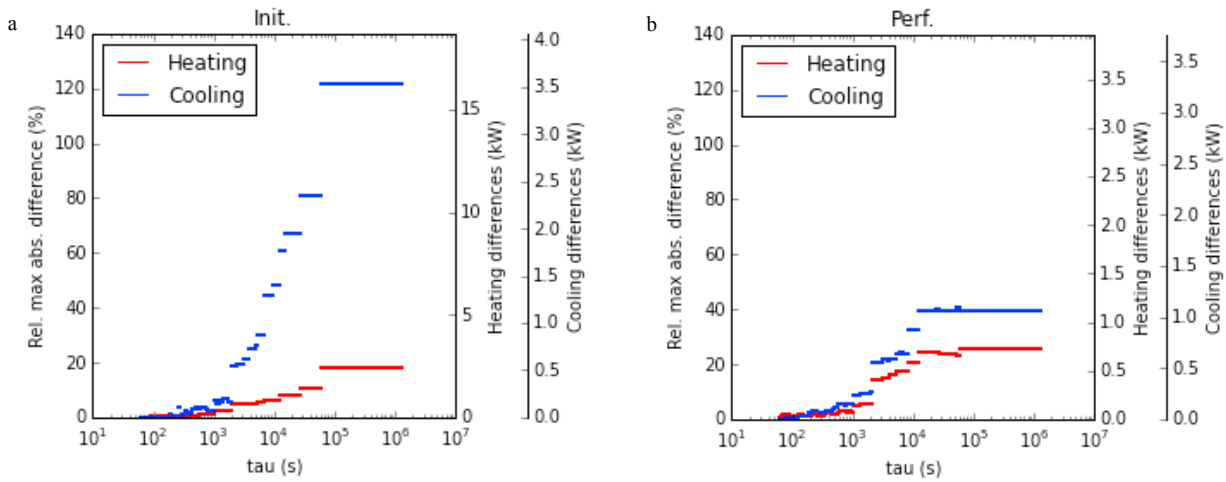

Fig. 1. Max. differences due to the mesh resolution for (a) Init. and (b) Perf. version.

The increase is not regular. It is worth mentioning that a gap is observed for a characteristic time of 2027 s for Init. and of 2131 s for Perf., that is about the half of the weather data time step (Δt). This gap may be explained by the fact that for higher τ, the mesh element width is higher than the thermal penetration depth length of the material for the highest meteorological loads frequencies (the maximal observable frequency is $(2 \cdot \Delta t)^{-1}$ according to the sampling theorem); i.e. the highest thermal loads frequencies are not diffused through the mesh element. Hence, after this gap, the higher the mesh width is (higher τ is), the more the highest frequencies are eliminated.

In addition, after this gap, it is observed that the differences mainly occur during increase or decrease of the power needs. This observation is confirmed with a high Pearson's correlation coefficient between the gradient of the power needs and the differences (higher than 0.8). This may be explained by the fact that in these cases, higher inertia is requested because of higher mesh width and consequently the thermal variations are longer. This may also explain why cooling, which is more intermittent, is more impacted on than heating.

3.2. Building model assumptions

As previously, mean differences are significantly lower than max. differences. Mean differences (not plotted here) are under 4%, excepted for *TopBCConvInt* for the Init. version which is 12%, and equal to about 1% on average. Even r. mean differences are under 8%, excepted for the previous exception which is nearly unchanged, and equal to about 2% on average...

However, max. differences are mostly in the order of magnitude of the average power needs, in particular for cooling. Nonetheless, heating is clearly more sensitive for the Perf. version than for the Init. version, probably because the majority of the adaptations modifies the solar heat gain internal distribution which plays a major role in energy efficient buildings. Among the modelling of other external meteorological loads, the radiative heat transfer adaptation seems to be the most relevant. It is important to notice that the infiltrations have a similar impact whatever the version whereas the permeability is ten times lower in the Perf. version. This trend may be explained by the higher part of the air renewal in the overall building energy balance in energy-efficient version than in energy-inefficient version.

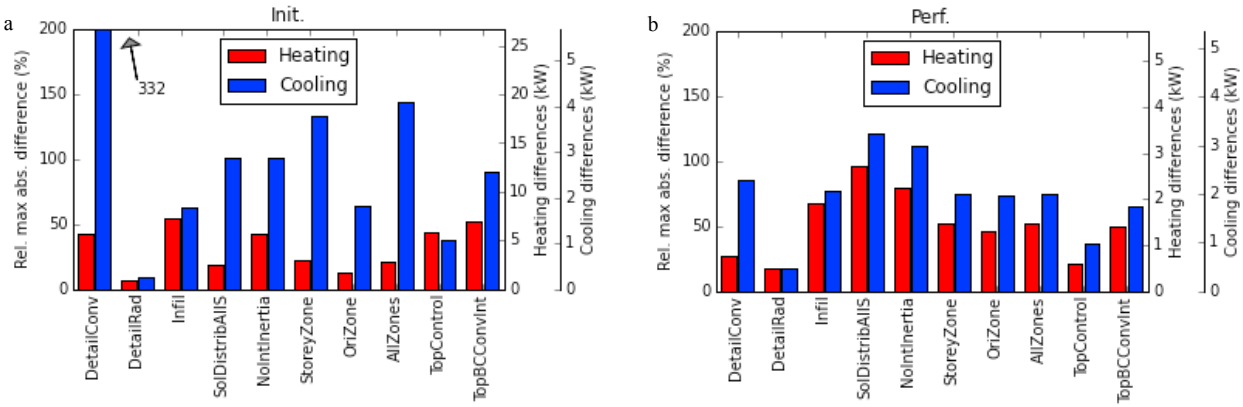

Fig. 2. Max. differences due to adaptations for (a) Init. and (b) Perf. version.

4. Conclusions and outlooks

The results of this study show that the majority of the adaptations is relevant when focusing on annual heating energy needs, but has significant relative impacts when focusing on power needs, especially for cooling and for the energy-efficient buildings case.

In particular, because of physical consideration, more detailed envelope meshing than usual reduce order RC analogy models[3] is needed when studying power demand (as for power grid management, including flexibility analysis), and even more the shorter the time step is. However, this effect is reduced by the energy system inertia, not considered here (difference between demand and needs).

[3] Note that the widths of RC-layers are generally optimized, leading to better simulating performance than the equidistant meshing used here. But physical limitations are identical.

Moreover, the analysis of some modelling assumptions shows that better knowledge of building characteristics would be advisable in order to detail models and hence reduce output uncertainties at short time step, especially regarding internal building structure information, and outdoor wind patterns (for convection and infiltrations).

However, the uncertainty of new parameters of a detailed model may also increase inaccuracy of the results. Hence, complementary uncertainty analysis should also be carried out before concluding about the potential suitability of an adaptation. In addition, the sensitivity analysis may be completed considering combined impacts of adaptations (global sensitivity analysis).

Last but not least, specific attention should be paid at city scale to determine if maximal differences are concomitant or not. Indeed, diversity of building fabrics, building shape and occupant behaviour may de-synchronises maximal adaptation impacts of the different buildings, and thus modifies the aggregated impact of adaptations at city scale, compared to building scale.

Acknowledgements

The authors want to thank EDF (Electricity of France) R&D for its financial, scientific, and technical support in the frame of the BHEE joint laboratory.

References

[1] J.H. Kämpf, D. Robinson, A simplified thermal model to support analysis of urban resource flows, Energy Build. 39 (2007) 445–453.
[2] T. Berthou, P. Stabat, R. Salvazet, D. Marchio, Development and validation of a gray box model to predict thermal behavior of occupied office buildings, Energy Build. 74 (2014) 91–100.
[3] T. Berthou, B. Duplessis, P. Rivière, P. Stabat, D. Casetta, D. Marchio, Smart-E: A Tool for Energy Demand Simulation and Optimization at the City Scale, in: 14th Int. Conf. IBPSA, Hyderabad, India, 2015.
[4] N. Perez, P. Riederer, C. Inard, V. Partenay, Thermal Building Modeling Adapted to District Energy Simulation, in: 14th Int. Conf. IBPSA, Hyderabad, India, 2015.
[5] M. Lauster, J. Teichmann, M. Fuchs, R. Streblow, D. Mueller, Low order thermal network models for dynamic simulations of buildings on city district scale, Build. Environ. 73 (2014) 223–231.
[6] C. Nytsch-Geusen, T. Nouidui, A. Holm, W. Haupt, A hygrothermal building model based on the object-oriented modeling language modelica, in: Proc. Ninth Int. IBPSA Conf., 2005: pp. 867–876.
[7] M. Fuchs, A. Constantin, M. Lauster, P. Remmen, R. Streblow, D. Müller, Structuring the building performance Modelica library AixLib for open collaborative development, in: 14th Int. Conf. IBPSA, Hyderabad, India, 2015.
[8] R. Baetens, R. De Coninck, F. Jorissen, D. Picard, L. Helsen, D. Saelens, Openideas-an open framework for integrated district energy simulations, in: Build. Simul., 2015.
[9] G. Plessis, A. Kaemmerlen, A. Lindsay, BuildSysPro: a Modelica library for modelling buildings and energy systems, in: 2014: pp. 1161–1169.
[10] G. Agugiaro, Energy planning tools and CityGML-based 3D virtual city models: experiences from Trento (Italy), Appl Geomat 2015. (2015).
[11] J.-M. Bahu, A. Koch, A. Kremers, S.M. Murshed, Towards a 3D spatial urban energy modelling approach, in: ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci., Istanbul, Turkey, 2013: pp. 33–41.
[12] R. Kaden, Thomas H. Kolbe, City-wide total energy demand estimation of buildings using semantic 3D city models ans statistical data, in: ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci., 2013: p. W1.
[13] Q. Li, S. Jige Quan, G. Augenbroe, P. Pei-Ju Yang, J. Brown, Building Energy Modelling at Urban Scale: Integration of Reduced Order energy Model with Geographical Information, in: 14th Int. Conf. IBPSA, Hyderabad, India, 2015.
[14] R. Nouvel, K.-H. Brassel, M. Bruse, E. Duminil, V. Coors, U. Eicker, D. Robinson, SimStadt, a new workflow-driven urban energy simulation platform for CityGML city models, in: Proc. Int. Conf. CISBAT 2015 Future Build. Dist. Sustain. Nano Urban Scale, LESO-PB, EPFL, 2015: pp. 889–894.
[15] E.-J. Kim, G. Plessis, J.-L. Hubert, J.-J. Roux, Urban energy simulation: Simplification and reduction of building envelope models, Energy Build. 84 (2014) 193–202.
[16] E.-J. Kim, X. He, J.-J. Roux, K. Johannes, F. Kuznik, Is it possible to Use a Single Reduced Model for a Number of Buildings in Urban Energy Simulation?, in: 14th Int. Conf. IBPSA, Hyderabad, India, 2015.
[17] U. Rochard, S. Shanthirablan, C. Brejon, M. Chateau le bras, Bâtiments résidentiels - Typologie du parc existant et solutions exemplaires pour la rénovation énergétique en France, POUGET consultants, 2015.