BIM-based building design platform - Local environmental effects on building energy performances

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ABSTRACT: For complex building projects, energy engineers, economists and other domain experts are usually integrated in the design team, to take part in the decision-making process starting from the beginning of the project. Within the current design practices, the iterative design process is difficult to implement, mainly because of the data exchange between the designers and the evaluators is far from optimized thus causing unacceptable delays. We present a BIM-based, on-the-cloud, collaborative building design software platform. This platform will account for all physical phenomena at the building level, while also taking into account external, neighborhood level influences. Within this platform, the paper presents the physical models developed to take into account local environmental effects on building energy performances. Several models are presented and applied to two building types (residential and office building). The results allow drawing some impact quantification of these new parameters in building energy consumption. The paper exposes the application of this platform as a tool to derive optimal building design under different constraints and gives perspectives for further works and developments.

1 INTRODUCTION

Recent urbanization has put the emphasis on the energy and environmental quality of urban buildings. For complex building projects, energy engineers, economists and other domain experts are usually integrated in the design team, to take part in the decision-making process starting from the beginning of the project. Within the current design practices, the iterative design process is difficult to implement, mainly because of the data exchange between the designers and the evaluators is far from optimized thus causing unacceptable delays. These problems and the neighborhood design approach and the BIM development lead us to review building design.

The goal is to design, develop, and demonstrate a BIM-based, on-the-cloud, collaborative building design software platform that enables the user to access, modify and test solutions under different constraints. The optimization of the building design is then based in different segments, i.e. energy, environmental, acoustic, renewable energy and economics.

The energy consumption patterns of buildings located in dense city centres are highly dependent on the surrounding urban neighbourhood, compared to the low density, suburban/rural regions, where the building energy consumption patterns are similar to an isolated building energy consumption patterns. The design of sustainable neighbourhoods and restoring communities require a full scale modelling of urban neighbourhoods that is not consistently replicable with the current computational approaches.

In this paper, we deal with the question "How to take into account the local environmental effects on building energy performances?". The building design is often focused in the building itself, discarding the occupants behavior, surrounding environment and its microclimatic context.

One example is the use of an average meteorological weather file from an airport or from a rural area next to the city where the building is.

The building interacts with the environment through the exterior temperature, solar radiation, wind, etc. The effects of these parameters can have a high impact in the building consumption (Francisco Sanchez de la Flor, 2004).

The simulation of the neighborhood-level parameters is made by taking, in one hand, in statistical and Stochastic modeling for occupant behavior and, on the other hand, measures-derived models to simulate the building surrounding environment. The tools developed must be adapted to the different building design actors constrains, i.e. low number of inputs, fast-computing time and be compatible with the existing software.

In detail, this paper presents an accurate and simple method to take into account local air temperature and wind variations, the impact of albedo and masks for energy evaluation. These environmental parameters impact are analyzed by taking into account two examples.

2 BIM-BASED, ON-THE-CLOUD, COLLABORATIVE BUILDING DESIGN SOFTWARE PLATFORM

Within the current design practices, the iterative design process is difficult to implement, mainly because of the data exchange between the designers and the evaluators (i.e. based on 2D or 3D drawings and text-based specification documents) is far from optimized thus causing unacceptable delays. The development of a platform that account for all physical phenomena at the building level, while also taking into account external, neighbourhood level influences could solve these problems. The HOLISTEEC project[1] is developing this platform. The design of this platform will rely on actual, field feedback and related business models / processes, while enabling building design and construction practitioners to take their practices one step forward, for enhanced flexibility, effectiveness, and competitiveness.

In more detail, this platform is a holistic multi-physical simulation engine, able to capture and assess in an integrated way building performances in various dimensions at building and neighborhood level: energy, environment, acoustics, and lighting.

Each design phase can be seen as an iterative loop over three distinct activities, as shown in the picture below:

- design activities, creating more detailed information concerning the future building and the way it will be constructed,
- simulation activities, updating the user defined objectives forecast values based on the available project information,
- project evaluation activities in which the user defined objective checklist is used as a criterion to decide whether to accept the current design and to move on to the next project phase, or on the contrary, to launch a new round of design/simulation activities.

[1] - European Projet – Holistic and optimized life-cycle integrated support for energy-efficient building design and construction

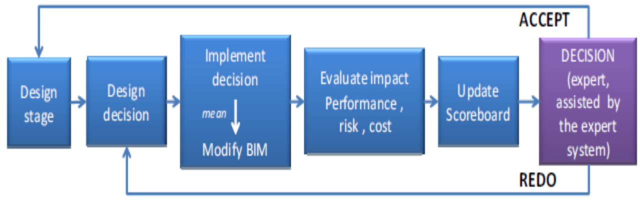

Figure 1. Schematic description of the early feedback loop HOLISTEEC approach

The innovation is that the shared information model (BIM+NIM - Neighbourhood Information Model) shall reflect at all time the status of the design, allow for updates as soon decisions are taken and for instant assessment of these decisions. This innovative design workflow will help fulfilling critical requirements from building design stakeholders, and actually support them in making the right choices at important decision points.

The present study represents one of the objects treated in this platform. A focus is made on how the local environmental effects influence the building energy performances. Next, we present the different analysed parameters.

3 BUILDING SURROUNDING ENVIRONMENT

With the aim of including neighbourhood environment parameters into the thermal simulation of buildings, we developed simple and outside-the-simulation-engine modules, so that these modules could be used with different building software's. Next we present the developed modules.

3.1 *Wind speed in urban canyon*

The wind flow inside canyons is driven and determined by the interaction of the flow field above buildings and the uniqueness of local effects as topography, building geometry and dimensions, streets, traffic and other local features.

The general idea of this module is to modify the wind conditions in order to take into account the canyon effect in building energy simulation.

The urban canyon module developed is based in works of Georgakis and Santamouris (Georgakis & Santamouris, 2008).

The computational methodology to calculate the wind speed in canyons is presented in the flow-chart below as a function of the wind speed and canyon geometry.

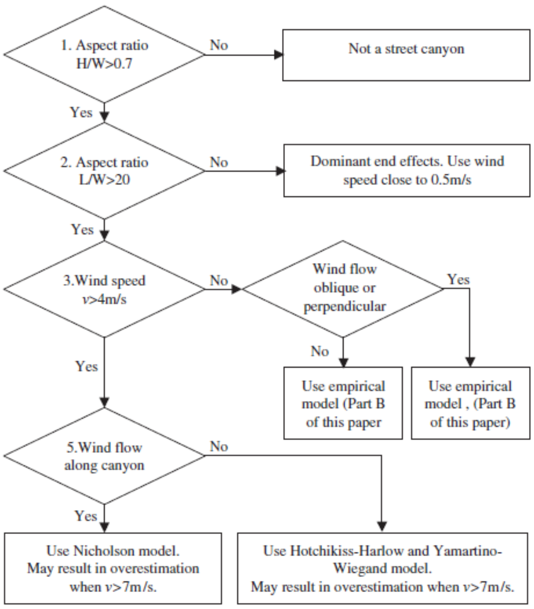

Figure 2 : Flow-chart of the algorithm for estimating wind speed inside street

For building energy simulations the energy impact of wind speeds lower than 4 m/s can be neglected. Thus, in this module the highly complex models ("Part B of this paper" in the flow-chart) were not used.

The next figure shows an example of the canyon wind effect on the wind speed.

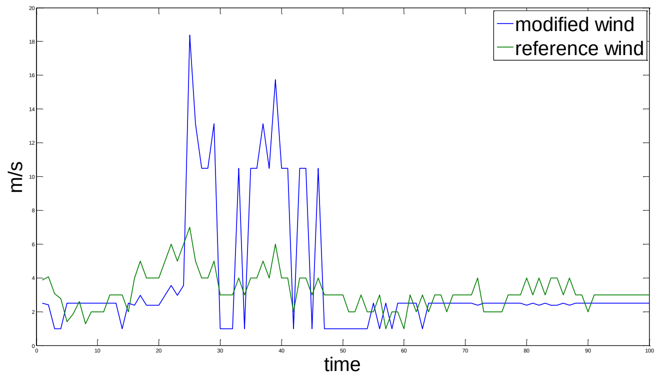

Figure 3 – Wind speed with and without a canyon effect

3.2 *Urban heat island effect*

Urbanization produces higher air temperatures in cities than in the undeveloped rural surroundings. This phenomenon, known as the Urban Heat Island (UHI) effect, is usually more intense under cloudless sky and light wind conditions and is mainly caused by the geometric and construction differences between the urban and rural surfaces and the anthropogenic heat released in the urban environment. The UHI effect can increase cooling energy consumption of buildings but can also reduce the heating energy consumption in winter.

As the major part of the meteorological data is obtained in rural areas, in order to take into account the UHI effect, a module was developed that modifies the external temperature of the meteorological file.

A large number of scientific articles cover this subject. However the majority of these articles deal with the effect of the building materials in the heat/cooling consumption or with urban canopy models for atmospheric models. The urban heat island physical models are very complex due to the large number of parameters needed.

Thus, the developed urban heat island (UHI) module is based in field measures from the works of Oke, Kolokotroni and Giridharan (Giridharan & Kolokotroni, 2009) (Kolokotroni & Giridharan, 2008) (OKE, 1982).The UHI module does not take into account the thermal characteristics of the city like pedestrian pavements, tiles, road pavements to calculate an accurate albedo. The presence of green spaces is not taken into account in this study.

The works of Kolokotroni and Giridharan and Oke show that the UHI effet is correlated with the daily solar radiation, wind velocity and building position in the city (core, semi-urban and urban). The scheme presented below show the module procedure to modify the external temperature measured in a rural space next to the city.

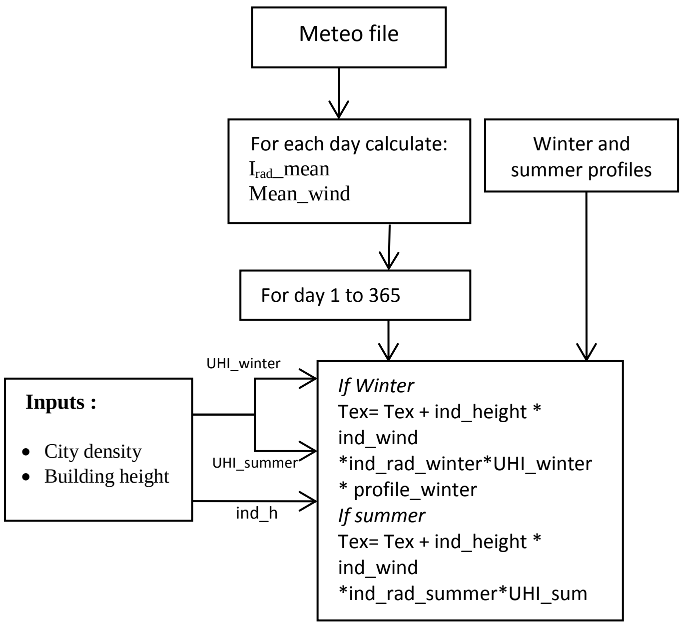

Figure 4 – Module calculation scheme

The radiation indices ("ind_rad") are derived from the mean global horizontal radiation.

Table 1 - sky indices used in the module derived from (Giridharan & Kolokotroni, 2009) (Kolokotroni & Giridharan, 2008)

Ind_rad	**Below 300 W/m² - sky covered.**	**Between 300 and 500 W/m² - sky partialy covered**	**Superior to 500 W/m² - clear sky**
Winter	0.4	0.5	1
summer	0.5	0.8	1

If the average wind velocity is lower than 5m/s the urban heat island are considered maximum. If the values for the wind velocity are higher the urban heat island effect is considered to be ¼.

The values of the building height are derived from OKE study. The coefficients for building height ("*ind_height*") are:

- *Average Building height < 50m – ind_height =1*
- *50 < Average Building height <100m – ind_height =0.5*
- *Average Building height > 100m – ind_height =0*

The measured values used to determine the UHI indicators and the daily temperature profiles are after the London city data from city centre to urban zones (Table 2). As no other measures where available, in this module we make the hypothesis that for other big cities the values are close to this ones.

Table 2 - Urban heat island intensity values

	UHI_winter	UHI_summer
Rural	0	0
Urban	1.2	1
Semi-urban	2	2.5
City center (core)	3	3.5

An example of the temperatures between rural and city center, when the UHI module is used, is presented in Figure 5.

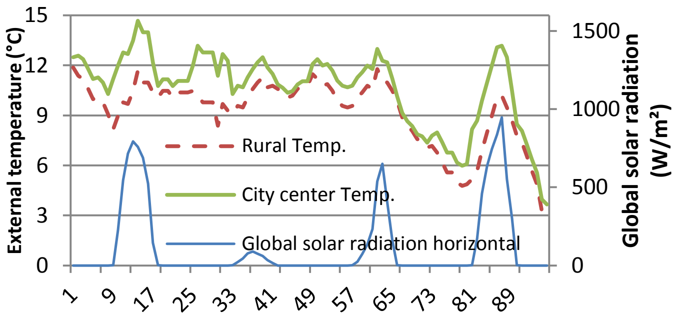

Figure 5 – Difference between rural and city center when using the UHI module

3.3 *Occupants behavior simulation*

The occupant behavior has a high impact on building the energy consumption. However, it is very difficult to predict the occupancy and the related activities. In order to take a more profound approach, we used a stochastic model 'Qiriel-Croniq' based on French national studies (Ansanay-Alex, Abdelouadoud, & Schetelat, 2016). This model alows the simulation of the occupants profiles and their activities (household equipements heat losses). This model was only used in the simulations of residential buildings as the office buildings section is under developpement.

3.4 *Other building model parameters for urban environment simulation*

Some other parameters do not need the development of a complementary module as the building energy software's already take them into account. The list of the other parameters is presented below:

- the building height (low building=10m to very high building=80m) : just the building height parameter is changed (the building geometry remains the same) to determine the models sensitivity to this parameter.
- the azimuthal masks (in order to simulate surrounding buildings masks) : The buildings are simulated taking into account that the surrounding buildings have the same height and they are separated by a road. Note: The simulated buildings already present several shading devices.
- the exterior surfaces albedo (from albedo = 0.05 to 0.5).

4 SELECTED STUDY CASES

The objective of this study was to perform an analysis of different building model parameters to determine their significance on building energy consumption. All the calculations were made with the energy simulation software COMETh (Da Silva, et al., 2016).

Two different buildings (Table 3) have been selected to test the different modules and to perform a sensitivity analysis; a collective residential one and an office building, both are low-energy buildings (according to the French building regulation – RT2012). The meteorological file corresponds to the climate zone - H1a (in a rural area near to Paris).

Table 3 – Resume of building characteristics

	Residential Building	Office building
Area (m²)	2116	8755
Leaking air flow rate	1 m³/h/m²(under 4 Pa)	1.7 m³/h/m²(under 4 Pa)
Ventilation system	Single-flow mechanical ventilation by extraction (1595 m³/h).	Double-flow mechanical ventilation (14925 m3/h) and the a single-flow mechanical ventilation (1500 m3/h).
Heating / cooling system	collective condensing gas boiler with 95% efficiency (PCI) No cooling	Condensing gas boiler with efficiency of 96% / heat pump (cooling only) with EER coefficient of 2.8.
Total energy consumption (heat, cooling, light, ventilation)	55.42 kWh/m²	78.26 kWh/m²

The above system package is defined as “base case”. We have defined 2 additional cases (Table 4) for these buildings a “bad” case and a “good” case. These cases will allow seeing how the building responds to the different environmental conditions.

Table 4 – Bad and good cases for the two building types

	Residential Building	**Office building**
“Bad” case	Heating : conventional boiler	Heating: conventional boiler Cooling: EER=2
“Good” case	Heating : high efficient (97%) boiler (condensing)	Heating : high efficient (97%) boiler (condensing) Cooling: EER=3.5

5 RESULTS

The maximum individual impact of each variable (maximum variation of the results without signal) in building energy consumption is presented below.

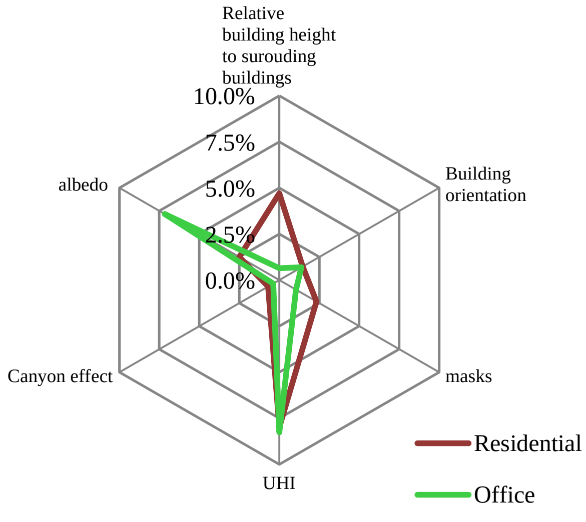

Figure 6 – Maximum impact on building consumption per building surrounding parameter

The impact of the canyon effect and of the relative height of the building is low for the two buildings because these parameters will principally affect the heating and cooling consumptions and it is dependent of the infiltration rate. The consumptions and the infiltration rates are low (Table 5) as these buildings are very efficient ones.

Table 5 – Heating and cooling consumptions

	Heating consumption	Cooling consumption
Residential (infiltration = 1 m3/h.m² under 4 pa)	24.3 kWh/m²	NA
Office (infiltration = 1 m3/h.m² under 4 pa)	7.1 kWh/m²	12.2 kWh/m²

The impact of the infiltration rate is very important. For example, if the infiltration rate of the residential building is set to 4 m3/h.m², the impact of the canyon effect is 14.5% of the total building consumption. For buildings where the major consumption posts are related with heating and cooling, the canyon effect can have an even higher impact.

The other parameters albedo and masks will also impact the lightning calculation so this phenomenon is reduced.

For the residential building the most sensible parameters are the UHI (with -7.97%) and building height (with -4.71%). As it is an efficient building the values of the UHI impact show that the heating is highly modified.

The results for the office building show that only the UHI effect (with 8.25%) and the albedo (with 7.50%) have a significant effect in building energy consumption. The albedo impact is due to high consumption of lightning of the building. The UHI effect is even higher than the residential building because of the cooling consumption.

As the residential building is not equipped with a cooling system, we analyzed the maximal reached operative temperature in the building.

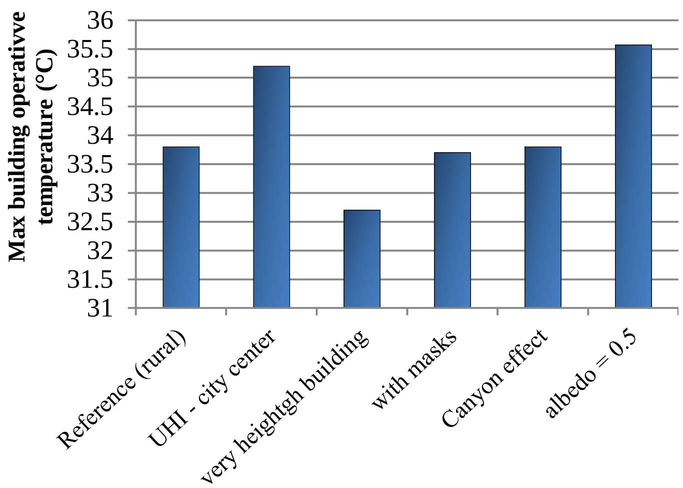

Figure 7 – Maximum building operative temperatures for the different configurations

The maximum operative temperature can be modified of -1.5 to +1.8 °C for the different simulated configurations.

6 DISCUSSION

The impact of shading by other buildings is small. However the tested buildings present several shading devices. As the tested masks do not shade the sun during summer (high solar altitude angles), the effects in summer comfort and energy consumption (cooling in the office building) are low. The BIM-Based platform should be able to take into account the surroundings geometry.

In the presented case the building orientation and design were fixed. Despite, the low effect of building orientation, this variable should be retained, as during the building design the window position can influence the building consumption.

Regarding the canyon effect, its impact in energy consumption is very low for these two buildings. However further tests should be made especially for building with different infiltration rates and high heating and cooling consumptions.

The impact of the UHI, albedo and building height are related. The surrounding albedo will disturb the UHI effect. If the building height is very different from surrounding buildings the UHI will be lower. The UHI model allows a simple quantification of the building position in the energy consumption. The developed model is based on a measure campaign done for the city of London (UK). Thus, to ensure the reliability of this model, it should be compared with more detailed models and measures in different conditions to validate / improve the current model and enable a correct building design evaluation.

Examples of the integration of these simulation modules to the BIM-based platform should allow deriving optimal building design in a neighborhood environment.

7 CONCLUSION & PERSPECTIVES

This paper presents a new design platform that allows a multi-domain building design optimization, where during all the design status updates to the project are taken into account directly. The platform includes different domains of study (energy, economics, environment…). The paper develops a part of this platform which concerns the influence of the environmental effects on the building energy performance.

Several modules where developed to represent the building environment and applied to two buildings. The impact of the building surrounding environment is majorly due to the UHI effect and to the albedo of the surrounding. The canyon effect does not have a high impact for these two buildings due to low infiltration rate. However, a special attention should be made to this phenomenon for buildings with high infiltration rates. The results show that the impact of each parameter is very different for the two building types. The results also show, briefly, that the impacts on summer comfort can also be non-negligible.

Due to the platform structure, these modules should be very flexible and simple. However, to correctly estimate the energy consumption, validation / improvement of the current modules should be done.

An example of the application of this platform will allow deriving optimal building design for different project objectives (economical and/or energy and/or environmental…).

8 ACKNOWLEDGEMENT

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