Introduction of a new Dynamic simulation screening tool to support early stage building design

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Abstract

The paper introduces a newly designed dynamic building energy simulation screening tool to help integrate the use of advanced simulation techniques to early stage building design and feasibility studies. The tool will help the design process to move toward an integrated design approach, including energy analyses and expertise from the first stages of design when time constraints and information requirements are still a hindrance for the use of other existing simulation tools. The paper focus on the integration of the user input and output interfaces and automatic model generation algorithms while referring to previously existing papers in term of model definition, case studies and validation. The tool is able to simulate building energy performances starting from a limited number of inputs received through a specifically designed user interface supported by databases and suggested values. Based on those inputs, a simplified building model is generated and simulated in EnergyPlus and results are post processed and visualized on the user interface. The tool is fully web based and can be used through any web enabled device as only the input and output interfaces are managed by the user device, with all other components being allocated to the server. The tool is able to run building performance simulations based on a simplified building model description with a limited number of inputs and in a short span of time, ranging from minutes to less than an hour. Nonetheless, the simulations are still returning results with an acceptable margin of accuracy compared to a detailed simulation, considered to generate useful information during early stage design and still higher compared to the use of traditional stationary models. The proposed tool will help the design process evolve toward an integrated approach and adapt to the foreseeable changes in regulations and market demand of low- and zero-carbon buildings.

1. Introduction

From many years, buildings have been identified as one of the major targets for reductions of energy use and greenhouse gas (GHG) emissions. Studies show how buildings are responsible for around 40% to 50% of the global GHG emissions (Chen, 2009; Economidou, 2011).

Consequently, a strong push toward more efficient buildings is currently ongoing on a world scale, with the aim of Zero Carbon (ZCB) or Zero Energy (ZEB) Buildings. Private initiatives such as LEED or BREEAM are already targeting those high goals, while national and supranational regulation are quickly settling for slightly less ambitious goals, such as Net Zero (NZEB) and Nearly Zero (nZEB) Energy Buildings to be mandatory in the next few years (Executive Order No. 13514, 2009; European Parliament, 2010).

Design process of buildings need to adapt to reach those standards, becoming more attentive to the energy and performance problem and moving toward an integrated approach, such as IDP. Building performance simulation can greatly help the design process by fuelling it with essential information on the building expected behaviour (Hensen et al., 2004), as well as feasibility studies, and is in fact already used in high calibre projects and design validation.

The constant push toward a new standard of highly efficient buildings such as nZEBs requires the creation of energy models during early design phases (Utzinger et al., 2009; Ferrero et al., 2015). However, such analyses require an high level of expertise and significant time commitment, in

addition to a significant amount of information, all usually unavailable during the first stages of building design or feasibility study.

The proposed simulation tool tries to solve this dilemma by providing a quick and easy way to perform simplified energy simulation with a limited number of essential user input, to be used as a screening tool to evaluate different design options. At the same time, to still being able to provide useful information to fuel the decision process, the simulations need to deliver an adequate level of accuracy. This need is strongly related to the time and information requirement previously cited and therefore the accuracy of those simulation can be still acceptable even if lower compared to more traditional detailed ones. This is granted by the tool through the use of specifically developed simplified models as seen below.

2. The Simulation Tool

2.1 The Idea

Research in the direction of a simplified simulation and screening tool stems from the need to overtake those well known barriers that are currently preventing or limiting the diffusion of advanced building performance analysis during the first steps of the integrated building design process or feasibility study of renovations.

The tool allows the dynamic simulation of buildings in a timeframe compatible with the needs of the design process while at the same time achieving an acceptable level of accuracy. Additionally, the tool is designed to be used on any web-enabled device, without the need of installing any specific simulation software from the user, although requiring an internet connection. Instead, the user will have access to the web interface and obtain the results as a service, in what could be considered as an automated consultancy delivery.

Through the use of this tool, the user only needs to input a limited number of details through the input interface on his device. Those details are then sent to the server were the simulation model is created and the simulation preformed, output from the simulation is then post-processed and relevant information on the performance of the building is sent to the user through the user result interface.

An explanatory infographic summarizing the structure of the proposed tool can be seen in Figure 1, highlighting each components that is needed for the process to work form when the user inputs the data on his device to the moment the results are visualized in the form of readily usable information.
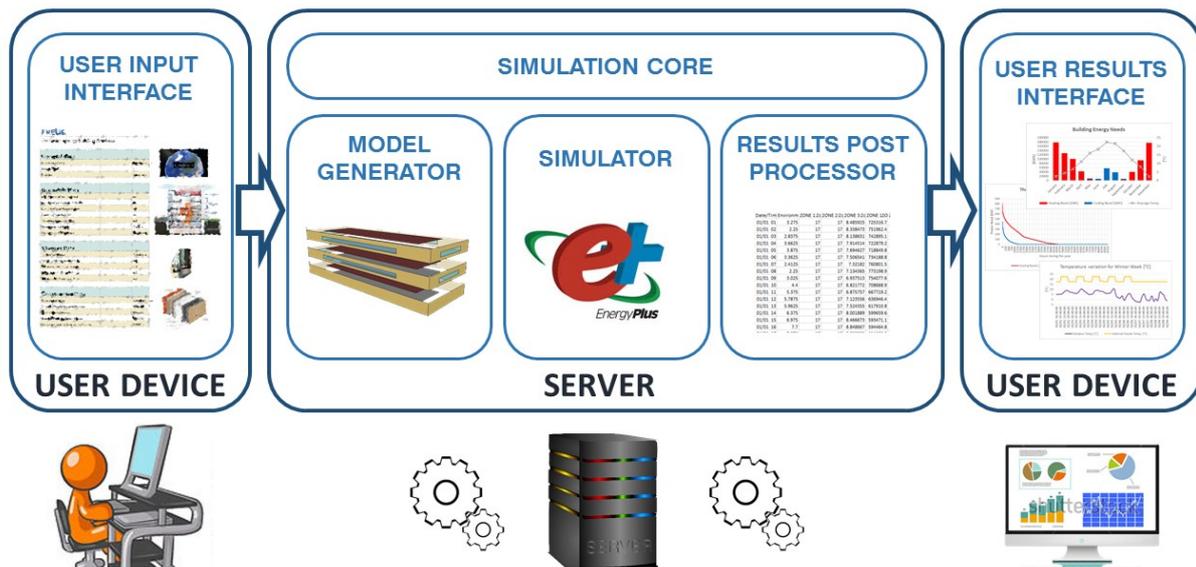

Fig. 1 – Structure of the proposed Simulation Tool

The tool is structured in three different blocks:

- The simulation Core
- The user input interface
- The user results interface

Each of the parts is discussed more in detail in the following paragraphs. Although the graphical aspect of the interfaces is currently under work and is not finalised yet, each element has already been defined and implemented in the tool.

2.2 The Simulation Core

The simulation core is composed by all the elements the user does not have direct contact with and is subsequently hosted on a server, only exchanging data with the user device through an internet connection.

The simulation core can be decomposed into three different elements:

- The simulator
- The model generator
- The results post processor

The simulator is, in fact, the simulation code that runs the dynamic performance simulation of the building based on the model received in input. For this application, the research team decided to use an already existing and reliable simulation code developed by the US Department of Energy named EnergyPlus (Crawley et al., 2004; Henninger et al., 2010). This allows to maintain the complexity and versatility of an advanced simulation code, while at the same time letting the research team focus on the other aspects of the tool, as highlighted previously and discussed in the following paragraphs. Not only this, but relying on an already existing calculation code will allow the final user to export the simulation model to EnergyPlus at any point if needed to extend the range of accessible features, if necessary, and easily allows for future expansions of the tool itself.

The model generator is where most of the research work form the authors focused. To be able to perform dynamic simulations, EnergyPlus requires a complex and specific input file containing the building model. As mentioned, this is one of the barriers for the extensive application of building simulation, as such models are normally time-consuming to create and require significant amount of information.

By applying the knowledge gathered during past research work and integrating the previously developed simplified building description model (Picco et. al, 2014), this pre-processor is able to collect the limited number of details provided by the user and automatically generate a fully functional, although simplified, building model that EnergyPlus can use to perform dynamic simulations.

Last element of the simulation core is the results post-processor, that automatically reads the output csv file obtained by EnergyPlus and process the contained data in usable information by the user in the form of tables and graphs, ready to be sent to the user interface, an example of such results can be seen in Chapter 4 of this paper.

2.3 The Input interface

The input interface is a web-based application that will be accessible by the user from a web-browser of any web-enabled device. Here, the user will be able to input the essential data required by the tool through a series of intuitive fields varying form value fields to database selection.

In its current state, a total of 25 inputs are required from the user, divided in 20 values and 5 database selections, once all the fields are filled the user will be able to send the data to the server, starting the simulation process.

The input interface is divided in 5 categories:

- General Data: Contains general information on the building, for a total of 1 value and 2 database selections;
- Geometric Data: containing details on the shape and size of the building for a total of 6 values and 1 database selection;
- Windows Data: containing details related to the transparent surfaces, for a total of 4 values and 1 database selections;
- Construction Data: containing details on the materials and structure type used within the building, for a total of 1 database selection and 4 values;
- HVAC Data: giving basic details on the HVAC configuration and HR for the simulation, for a total of 5 values.

As the amount of input is extremely limited, and the tool could be used by professionals with limited expertise on the topic, it is particularly important that every field is clearly defined and accompanies by an acceptable amount of details allowing the user to correctly utilize the tool.

For this reason, in the final version of the tool, every field will feature a comprehensive explanatory tag and will include both visual help and recommended values for different situations.

At the same time, the databases cover the important role of delivering all the information required to the model that, in general, is not available at the required level of detail during the stages in which the tool is potentially being used.

For this reason, a significant level of thought has been and will be devoted to the definition of comprehensive and suitable database entries able to effectively cover most if not all the possible cases with limited assumption and approximation.

2.4 The Output Interface

Lastly, the output interface is constituted by a web-page where the results from the simulation are visualized after being elaborated into readily usable information. The data containing relevant graphs and tables is sent directly by the server and visualized on the user device.

Although this could be considered the least research intensive part of the tool, it is still essential to identify and convey the useful information in a comprehensive and clear way for the final user to understand it. At the same time the information needs to be concise and specific to avoid the risk of less expert users to lose themselves in an unmanageable amount of data.

The authors identified list of useful information that has been included in the interface and is directly visualized on the user device in the form of tables and graphs. An example of those results is shown in Chapter 4 and can be summarized in 3 groups:

- Monthly Energy Needs for Heating and cooling: useful to immediately understand the performance of the building in term of consumption and compare different design options;

- Thermal power curves for heating and cooling needs: essential as a starting point for plant design and feasibility analysis of different plant options;
- Hourly temperature variation for Winter and Summer Typical week: useful to form a qualitative idea of the internal comfort conditions and compare different design choices in term of user comfort.

Lastly, both the output csv file obtained from the EnergyPlus simulation and the idf file containing the model used for the simulation are given to the user as an optional download. The user is therefore able to perform more detailed analysis either by post-processing the already generated output from the simulation or, for more expert users, adding elements to the simulation itself to perform more detailed analysis, e.g. by following the development of the building design while new information becomes available. The option of generating an automated report including all the results in a readily presentable form is currently under evaluation. The option to visualize internal comfort chart for the building is currently under discussion as simplified nature of the tool can only allow for qualitative evaluation of comfort conditions and cannot consider localized effects that could greatly influence it, nonetheless even a qualitative information on comfort condition could be of great use while comparing different design choices to identify the best option not only in term of energy use but in term of building performance in general.

3. Validation and case studies

As mentioned at the beginning of the paper, one of the most important aspects of this research has been the focus on accuracy, although limited by the necessity of using simplified models. As mentioned, a simplified screening tool such as the one proposed here, still needs to assure an adequate level of accuracy, although lower when compared to a detailed building simulation due both to its nature and its purpose, being used when a detailed simulation is not possible or feasible due to time and information constraints.

Validation was therefore approached in two different phases: validation of the simplified model and validation of the simplified tool. A third phase associated with the validation of the simulation code is deemed unnecessary thanks to the use of EnergyPlus, a well--known and reliable simulation code (Crawley et al., 2004; Henninger et al., 2010).

The validation of the simplified model has been performed following its definition and extensively discussed in previous publications (Picco et al., 2015). During this process, three different buildings have been selected and modelled, both through the use of the simplified model and a detailed model using all available information. The detailed model was calibrated thanks to the use of historic data and for each analysed case, the difference in results in term of heating and cooling energy needs and heating and cooling peak power was verified to be below the threshold of 20%. This threshold has been derived by the authors based on market expectation and, although not directly related, the recommended acceptable value of mean bias error for detailed and calibrated simulation models as presented in the Measurement and Verification guidelines from DOE (DOE, 2008) equal to 10%.

Following the initial validation, the simplified model has been applied to a number of other buildings to evaluate their energy performances. When suitable, a detailed model has also been simulated, for validation and research purposes. For each case, difference between simplified and detailed model, in term of heating and cooling energy needs and peak power needs always resulted under the aforementioned 20% margin, further confirming the validity of the simplified model.

The second part of the validation process focusses instead on the tool itself, verifying that the automatic model generator is able to correctly recreate the simplified model of a building starting from the data from the input interface, and at the same time the output post processor is able to correctly recreate useful information both in numerical and graphical form.

This phase f the validation is currently undergoing, in parallel with the finalizing and improvement f the user interface, although initial results can be seen in the following chapter through an example of application of the tool, proving both the model generator and output post-processor are working correctly, as expected.

4. Example of Application

As an example of the application of the presented tool in its current form, the Castelli clinic building has been selected. The building is one of the case studies used during the definition of the simplified model; we are therefore able to verify the tool is correctly creating the simplified model and compare the obtained results to the ones of the detailed model, developed for the validation of the simplified model results.

The building, located in Bergamo, is considered a medium-large building with an approximate floor area of $5000m^2$ on a total of 5 floors. Built before the second great war and currently used as an hospital, the building is characterized by poor thermal performances of the envelope and old plants.

The building data summarized in Table 1 is inputted in the simulation tool's user interface through relevant database selections and direct input of values. The simulation is then launched from the same interface. Following this, as previously detailed, the information is sent to the simulation core, where the pre-processor generates the EnergyPlus input filed and performs the simulation. Results from EnergyPlus are then loaded by the post-processor and elaborated to generate readily usable information.

Although the amount of data that could be obtained from EnergyPlus is extremely large in size and variety, a series of essential details have been identified as the most important ones to be directly shown to the user through the output interface.

Figure 3 to 6, shown below, exemplify the current visual output obtained by the user through the output interface following the execution of the simulation.

Figure 2 shows a monthly summary of heating and cooling energy needs from the building through staked bars, coupled with the monthly average outdoor temperature as a reference. This graph,

coupled with optional tabular data gives a good representation of the energy performances of the simulated building.

Table 1 – Input data for example of application

Entry	Value	Unit
Location	Bergamo [IT]	-
Orientation	-70.8	°
End Use	Hospital	-
n. of floors above ground	4	-
Length of south/north front	53.4	m
Length of east/west front	83.5	m
Floor to floor height	3.5	m
Average floor surface	1124	m²
Underground Floor	Yes	-
Underground floor use	Hospital	-
Type of windows	Double Clear	-
Total north facing surface	59.1	m²
Total east facing surface	230.4	m²
Total west facing surface	130.3	m²
Total south facing surface	125.0	m²
Structural type	Masonry	-
Ext. walls transmittance	1.60	W/m²K
Roof transmittance	1.65	W/m²K
Ground Floor transmittance	1.21	W/m²K
Und. Walls transmittance	1.65	W/m²K
Therm. heating set point	22.5	°C
Therm. cooling set point	28.0	°C
Therm. heating setback	18.0	°C
Therm. cooling setback	28.0	°C
Heat-recovery efficiency	0.0	%

Figure 3 shows the Thermal power curves of the system, for both heating and cooling, this is a useful information to select the optimal plant configuration and size and estimate the annual hours of activity of different plant equipment.

Figure 4 and Figure 5, respectively, show the hourly temperature variation for a zone within the building for a typical winter and summer week, coupled with the outdoor temperature. Those graphs are useful to the user to immediately have an idea of the thermal conditions within the building and the operation of the systems.
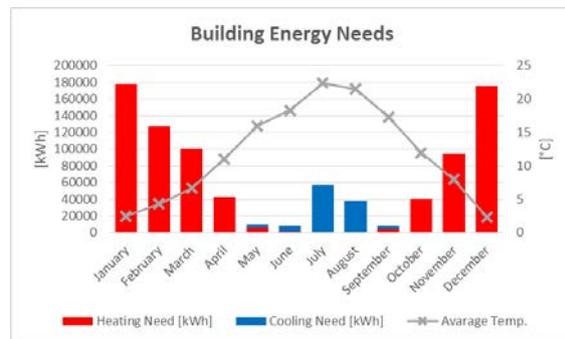

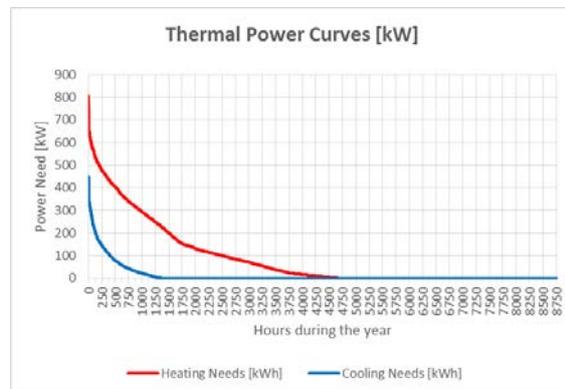Fig. 2 – Output: Monthly Energy Needs

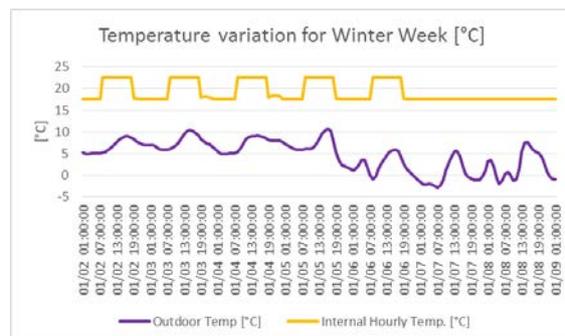Fig. 3 – Output: Thermal Power Curves

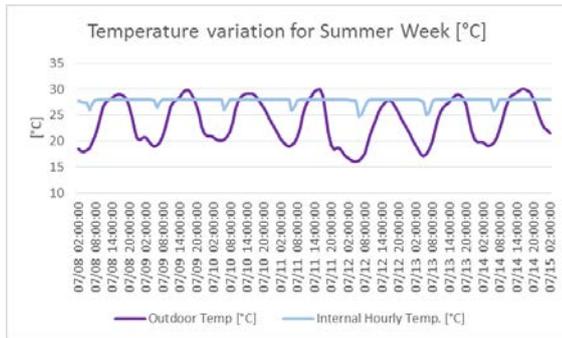Fig. 4 – Output: Hourly Temperature Variation for Winter Week

Fig. 5 – Output: Hourly Temperature Variation for Summer Week

Finally, the results in term of total heating and cooling needs are reported in Table 2 below to compare results obtained by the tool with the ones obtained from the Simplified and detailed model previously developed and discussed in previous papers.

Table 2 – Comparisons between models

Model	Heating [kWh]	Cooling [kWh]
Tool	769473	110219
Simplified model	774493	126788
Detailed Model	791075	128102

As evident by the table, the tool is delivering the same results as the simplified model, confirming the model generation and post-processing algorithms have been implemented correctly in the tool and starting from the input data, the generated model is equivalent to the manually created simplified model.

5. Conclusions

As we are moving toward a carbon free future, our buildings are becoming increasingly more complex, due to the always increasing performances requirements and new surfacing technologies. As a consequence, the design of those building is becoming an increasingly complex process, always requiring additional expertise and attention to energy and performance issues.

Building performance simulation could be considered a possible solution, however, a gap is still present between the available tools and the needs of the design process during the first stages of building design, due to the lack of available time and information.

The proposed screening tool aims to fill this gap by providing a quick and simple way to perform simplified dynamic performance simulations with minimum time commitment and information required to identify preferable design choices during early stage design and feasibility studies. Thanks to the use of validated simulation code EnergyPlus and a purposely developed simplified description model, the tool is able to deliver results within an acceptable margin of difference compared to detailed simulations, within the 20% difference on all evaluated case studies.

The tool is currently being delivered in its initial form focusing on the most essential design parameters such as the envelope, materials and basic HVAC parameters. Once the first version is fully operational, various possible developments are under evaluation, such as including specific building features, expanding the plant side of the model and inclusion of renewable technologies. Also inclusion of optimization techniques such as genetic algorithms is under evaluation. Meanwhile databases will be constantly expanded to cover for a larger range of options.

The authors believe, based on the obtained results, personal experience in the field of building performance simulation an expectations from the market, that the proposed tool will have a significant impact in the integration of computer simulation during early stage design and feasibility study, providing useful information and fuelling the constant improvement in building performance.

6. Acknowledgements

7. Nomenclature

Symbols

GHG,   Greenhouse Gas;
ZCB,   Zero Carbon Buildings;
ZEB,   Zero Energy Buildings;
NZEB,   Net Zero Energy Buildings;
nZEB,   Nearly Zero Energy Buildings;
EPBD,   European Performance of Buildings Directive;
IDP,   Integrated Design Process;
BPS,   Building Performance Simulation;
HR,   Heat Recovery;
SGHC,   Solar Heat Gain Coefficient
CSV,   Comma Separated Value
IDF,   EnergyPlus input data files

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