Toward an EnergyPlus decision tool for evaluation of energy performances during early-stage building design

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Abstract

The paper analyses the benefits of energy analysis application in early-stage design. The research highlights the barriers that prevent this early integration and finally proposes the development of a simplified software tool tailored around the optimization of energy efficiency during early-stage design. Generally, the research aims to identify (a) the accuracy in results obtainable through progressive simplifications of the building model, (b) the most significant building parameters with respect to the output accuracy and (c) the maximum level of simplifications able to ensure the respect of time requirements dictated by early-stage building design and to maintain an acceptable level of accuracy.

Here, a single case study of a large multi-storey office building is modelled starting with a detailed simulation performed through EnergyPlus and Openstudio software. The detailed model is then analysed and progressively simplified. At each progressive simplification step, a comparison with the detailed model is given in terms of building energy loads and power curves of the system.

Total differences between detailed and simplified models are analysed to determine the quality of the results of the simplified model.

1. Introduction

The daily operation of commercial and residential buildings comprises roughly one-third of the world's primary energy consumption. Because buildings are typically operated for many years, there is great potential for reducing global energy needs through improved building design (Urban et al., 2006).

Most of the energy consumed in buildings is the result of fossil fuel combustion, either directly or in the generation of electricity. One major path to reduce human impact on global warming is to design buildings and building renovations that have minimal energy demands and meet those demands with renewable energy rather than fossil fuels (Utzinger et al., 2009).

Computer modelling and simulation is a powerful technology for addressing interacting architectural, mechanical, and civil engineering issues in buildings. Building performance simulations can help in reducing emission of greenhouse gasses and in providing substantial improvements in fuel consumption and comfort levels, by treating buildings and their thermal systems as complete optimized entities and not as the sum of a number of separately designed and optimized sub-systems or components (Hensen, 2004).

Many existing energy simulation tools for buildings are very sophisticated and promise a high level of accuracy. Popular tools such as Energy Plus and DOE-2 are quite effective at simulating final building designs and are typically used for demonstrating compliance with performance standards such as LEED.

However, despite the proliferation of many building energy analysis tools in the last ten years, architects and designers are still finding it difficult to use even basic tools (Punjabi et al., 2005). Findings confirm that most BPS tools are not compatible with architects' working methods and needs (Attia et al., 2009; Gratia et al., 2002).

Although building energy simulation is a useful tool for predicting performance and comparing design options, most energy simulations occur too late in the design process (Ellis et al., 2008). In the traditional design process, the energy engineer uses simulation, if at all, as a tool for equipment sizing and code compliance only after the architect has completed the architectural design. Part of the problem is that existing simulation tools are not practical for the design process. Experience with real buildings has shown that low-energy design is not intuitive and that simulation should therefore be an integral part of the design process (Torcellini et al., 1999; Hayter et al. 2001).

In conceptual design it is important to be able to evaluate multiple concepts, and to quantify, rank-order, and even to be able to semi-automatically generate design alternatives. Qualification and quantification of variant solutions is here more important than detailed assessment of a single case. Therefore, in this approach the level of resolution can be generally low.

These initial concept decisions are critical as they can determine the majority of a building's energy use profile. Unfortunately, energy modelling is rarely leveraged in the concept phase to provide information that could drive these critical decisions. This is a missed opportunity, since energy modelling in the concept phase can be a very powerful tool for the entire design team (Tupper et al., 2010).

Needs related to the design process can be easily identified as time and accuracy. Accuracy is an essential prerequisite for every analysis used for decision making, in every field. If the analysis is not accurate the results could be misleading and the decisions made based on those results could be non-optimal or even completely wrong. The problem becomes significantly more relevant during the design process of buildings, where decisions taken can concern a large amount of energy and can affect the building for many years. To worsen this issue is the difficulty to modify wrong decisions made early in subsequent design phases or even during the management of the building.

Accurate energy analysis requires time, up to several weeks in more complex cases, and the more accurate the analysis must be the more time it will require. This is in contrast with the necessity to minimize the time requirements to make it compatible with design times, but to do so simplifications to the building model and simulation tool are needed, with the drawback of a loss in accuracy. Another way to reduce time requirements could be the introduction of default values and databases for inputs, with the possible risk of reducing the model detail level and degree of freedom, themselves influencing the accuracy or relevance of the final result.

2. Strategy for the decision tool

The present study is part of a research framework for the development of a tool that targets the early-stages of the design process: a time when design details are often sparse and uncertain, simulation time is limited, and major decisions are not yet finalized. Most tools are overly complicated for this task and do not provide an easy way to compare the trade-offs between design options (Urban et al., 2006). The aim of this project is to provide a fast way to assist designers in the decision making process during the first hours of design.

By restricting the input space to the most critical design parameters a tool could rapidly predict a design's performance. The primary objective is not an exact performance prediction of the final building design. What is important is that the user is able to identify which design factors have the highest impact on energy use and thermal comfort relative to the others.

Although restricting the detail in the inputs, the computational model is still quite sophisticated, being based on the energyPlus simulation engine.

It is also interesting to note that, by using a complete simulation engine like energyPlus, it is possible to generate an IDF file of the simplified model, which can then be integrated and expanded in the subsequent design phases.

In particular the research concentrates on the analysis of large commercial buildings in Italy. The main field of application of building performance simulation during design should be on large buildings as total costs better justify the inclusion of this kind of studies. Commercial buildings are also generally more energy intensive, leaving more room for the implementation of energy saving solutions, and less suited to standard energy saving solutions compared to residential structures.

As previously mentioned, the proposed tool will not directly perform any energy calculation, instead, based on the data inputs required, it will generate an energyPlus input file leaving energy calculations to the standard EnergyPlus simulation engine.

It is crucial to identify the adequate level of accuracy needed at each design phase and develop a corresponding model/tool of the building sufficiently simplified not to require data not yet

available, to be run and evaluated compatibly with the corresponding design phase times and meanwhile complex enough to guarantee an adequate level of accuracy so that obtained results can still be relevant.
Exactly this relation of accuracy and time needed is the basis of this study, analysing the gradual simplification of a complex building model evaluating changes in time and input needed to build the model and run the simulation and the gradual loss in accuracy in relation to the complete model, to find the optimum level of simplification of the model needed to apply energy analysis at each design phases with adequate time and accuracy, particularly focusing on the conceptual phase.
The research is developed in three main phases, first a simulation protocol is written, able to create an energy model of the building starting from general inputs available during conceptual design, in the second step the protocol is tested and improved through its application to an adequate number of case studies and lastly the protocol is to be implemented into a design tool able to generate the building model and run simulations with a limited number of input data.
All the case studies will be developed following the same pattern as seen in figure 1: a complete building model will be implemented in EnergyPlus and assumed as the “base case model”; from there a given number of simplification steps will be applied, each analysing one major aspect of the simplification protocol as detailed in the next section. For each step, output differences from the base case in term of energy and power loads are analysed to identify the total difference generated by the simplified model.
In the following section the first of those case studies is implemented and analysed also describing the major aspects of the simplification protocol.

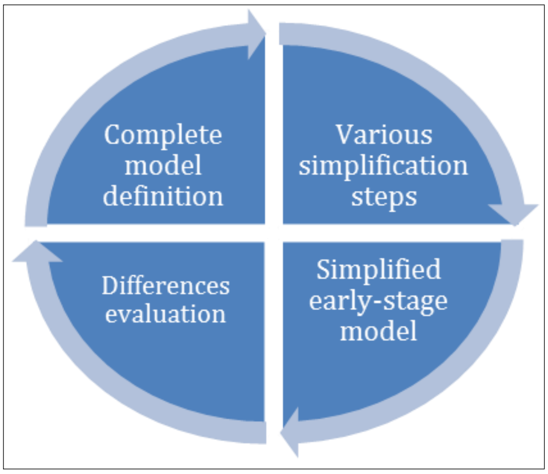

Fig. 1 – Simplification process

3. Case study simulation

The case study in exam is an office building built in 1954, fully renovated in 2007, situated in Bolzano, Italy, and certified as Klimahaus Gold with a calculated energy demand of 7 kWh/m²y according to Klimahaus calculation. The heated surface amounts to 2,841 m² for an inner volume of 12,817 m³ (Troi et al., 2008).
The building shell is designed as an ETIC system with 35 cm of EPS insulation, reaching a U-value of 0.08 W/m²K. The facade arrangement mirrors that of the existing structure, with a 16 % window-to-wall fraction. The windows are of the 3-pane type with plastic frame, insulated in the sunscreen plane with polyurethane. The result is passive-house suitable windows with a U-value of 0.79 W/(m²K).
On the system side, the building is provided with mechanical ventilation handled by a central AHU which provides refrigeration and dehumidification of the intake air. The AHU is also equipped with an high efficiency enthalpic heat recovery system with a 90% sensible effectiveness and 75% latent effectiveness. The refrigerant circuit is powered by an air-to-air electric chiller with a 3.5 nominal COP and 87.5 kW capacity.
Air heating is handled by re-heater coils in the air system and additional fan-coils, all connected to a water circuit powered by one central condensing boiler with 60 kW capacity and estimated 100% efficiency.

3.1 Detailed model

As a first step in the analysis a complete and exhaustive building model (figure 2) is created using energyPlus and its interface plugin Openstudio.
The model consists in thirty-five homogenous thermal zones, fully describing all conditioned rooms, underground semi-conditioned spaces and

all accessory non-conditioned volumes like deposits and interspaces. The vertical effect of staircases is also taken into account, modelling the two existing stairwells as an unique thermal zone each.
Twenty-three construction types are identified to characterize the construction in its entirety, of which two are transparent, triple glazed Krypton windows for above ground and double glazed air windows for underground spaces. To do so twenty-five different "material" objects are modelled.

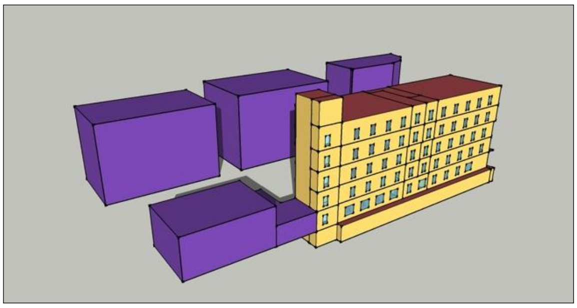

Fig. 2 – Overall view of the complete model

Each window is modelled individually for a total of 198 fenestration surfaces, of which forty-five are inter-zone surfaces modelled in the underground interspaces. All the relevant shadowing objects have been modelled comprising all the adjacent structures, in this case situated to the north-west of the building, and the building specific solar obstructions, consisting only in canopies above the two main entrances of the building as there is no individual shadowing for the various fenestrations.
Four zone archetypes are defined to characterize the various zones, each one defined in terms of occupancy, lights, electrical equipment and air infiltration, each defined by a design value function of the zone area and an appropriately written time schedule. Temperature and humidity set-points and set-backs are also defined for each archetype following the real behaviour of the building thanks to monitored data.
The system has been modelled as a VAV system with humidity control comprised of a central AHU with cooling and heating coils and reheat coils for each zone. Additional fan-coils are not modelled limiting the conditioning system to the coils in the airstream. Nonetheless obtained results are in accordance with available monitored data. All coils are connected to hot and cooled water circuits respectively powered by a central gas boiler and an electric centrifugal chiller. Heat recovery is also modelled as previously described.
Standard monthly mean ground temperature reported in the weather file have been modified to better represent actual conditions of the case study.
The simulation is performed for the duration of one solar year, starting January 1st and ending December 31st, under conditions provided by weather file "Bolzano 160200 (IGDG)" of the energyPlus database, identified as being the closest to the real building location.
Results of the simulation are then calibrated based on actual measured data available for the building mainly in terms of internal set-points to better represent the behaviour of the real building.
Six points of comparison are identified in simulation results to evaluate the accuracy of subsequent model simplifications. Those reference data are identified based on the concept of evaluating the accuracy of the model in reference to the most useful data typically used during early design stage.
The six points of comparison are defined as the annual building energy loads for heating and cooling, the peak power requirement for both heating and cooling systems and the power-time curves for heating and cooling.
The first two reference points are deemed the most relevant for comparison of different building design, therefore extremely useful during concept design. The last four points are more useful in system sizing so to know the required equipment size and use of the system over time.
Following, the simplification process is analysed defining each step singularly on a general standpoint and detailing its application to the case study in exam.

3.2 STEP 01. Simplified Constructions

The first step in the simplification process concerns the building constructions. The simplification is based on the identification of a single construction type for each kind of surface present in the model. The simplified constructions scheme is based on the identification of six construction types: exterior walls, exterior roof, exterior floor, fenestrations, interior walls and interior floors. Of those, in the suggested tool, only the first four will be required to the user as input data, the last two will be derived by the software based on the input data provided for the other constructions.

In more detail the first three constructions, regarding opaque surfaces, are to be characterized by a single thermal conductivity value, in W/m²K, of the complete construction package for each surface type and one global information regarding the construction mass for the entire building, by which the two interior constructions will also be deduced. Starting by those values a fictitious construction is to be reconstructed by the tool in the form of material and construction objects required by energyPlus resulting in construction packages with the characteristics inputted in the data. A construction mass information, in the form of database selection, is required to properly account for thermal inertia of the building. The fourth kind of construction references transparent surfaces, windows and fenestration in general, and is believed not to be properly represented by a limited amount of data, therefore this construction will be selected by a provided database for which energyPlus itself already provide various entries.

This simplification step constitutes a relevant reduction in the input data required by the model, going from a complete description of each construction present and all the materials that compose it to a total of three input data for conductivity and two database selections.

In the case study here analysed, for each construction type previously mentioned, a weighted mean, function of the total surface area, of the conductivity of all construction present is done and an average conductivity is identified. Based on the known structural type of the building the six reference constructions are identified. For fenestrations the construction is identified by the only relevant type of windows present, triple glazed windows with insulated plastic frame.

3.3 STEP 02. Removal of external obstructions

The second simplification step is identified in the removal of all external obstructions modelled, like external buildings or other external elements, consisting in the removal of any shadowing surface implemented in the complete model but not specifically planned as an obstruction for the single fenestrations. Shadowing surfaces for fenestrations can be simplified requiring the vertical distance by the window and the horizontal length of the overhang.

This step is not dictated by the unavailability of needed information, as the position of the building and its surroundings are one of the first information known, but by the observation that the modelling of external obstruction would be a too cumbersome and detailed work for this stage and is in fact one of the most common simplifications applied in practice without noticing; conversely shadowing of fenestrations can be a specific design choice with significant impact on energy needs and so needs to be modelled but exact dimensions of each shadowing element are probably not yet known.

3.4 STEP 03. Zones Lumping

Lumping of zones for each floor consists in the characterization of each floor of the building with one single thermal zone. This, with the simplification of constructions, permits to define an entire building floor with a really limited number of building surfaces and therefore a limited number of input needed. Also limiting the number of zones on floor to one impacts on the need for defining zone archetypes, eliminating all accessory zones and characterizing each floor, and therefore the building itself, by its dominant intended use. This is a relevant simplification hypothesis and is expected to greatly impact the model behaviour.

This simplification is greatly in accordance with the available data during the initial design phases as zone distribution and characteristics are typically not known, or only generally assumed, during early-stage design.

In the case study each floor is represented by a new single zone, losing the modelling of staircases, and each zone-floor is characterized by the zone archetype considered dominant in the complete model. The result is the selection of the office archetype for each floor with the exception of underground and top ones, consisting of a small storage room, characterized by the deposit archetype.

3.5 STEP 04. Simplified transparent surfaces

This simplification step is meant to reduce the data input to fully model transparent surfaces of the entire building. It requires the previous simplification step, namely the lumping of zones for floor to be performed. The idea underlying this step is to model the sum of all transparent surfaces on each floor with only four transparent surfaces, one for each relative cardinal direction. For each building floor and for each direction only one transparent surface is identified with the purpose to model all the surfaces oriented in that direction.

Two solutions have been identified as the most adequate for the purpose: the modelling of one single surface with total area equal to the summed area of all surfaces in the complete model and generated based on a reference fenestration height for a total of two data inputs for each surface and a total of eight for each floor, and the modelling of one reference surface representative of one single fenestration of the complete model then multiplied through a surface multiplier to obtain the total area of the fenestration, thus requiring three input data for each direction.

Different simulations have been performed based on those two modelling hypothesis and no relevant differences can be noticed in term of result accuracy, with differences of ~0.1% in respect to each other and not significantly favouring one of the two solutions. Based on those considerations the first of the two solutions is preferred, presenting comparable accuracy results but a much simpler data input structure requiring less information with a simpler building model.

Like the previous ones, this simplification is greatly in accordance with information available during early design process.

3.6 STEP 05. Single floor standardization

The intention of this simplification step is to be able to geometrically describe one single floor element to represent the entire building, greatly reducing the number of input required for the model especially in the case of multiple storey buildings. This is attempted through the cancellation of all accessory spaces and by standardizing the different floor plans to a reference one.

In the case study this simplification step is performed by cancelling all the accessory zones, the deposit zones on the roof and the underground cavity interspaces, still considered in the model through the application of appropriate outside boundary conditions to the underground floor, this will be replicated in the final tool with the addition of one data input in reference to underground boundary conditions.

3.7 STEP 06. Zone squaring

In conjunction with the previous step this simplification is meant to allow the full geometrical description of the building with a really limited number of inputs. In particular this step intent is to describe the geometry of a single zone with a simple rectangular box.

The major geometrical aspect which impacts the thermal behaviour of a building can be identified in the area of the vertical dispersant surfaces, so maintaining them as near as possible to the detailed model is the first priority of the simplified model. The simplified zone box is therefore modelled equalling the relative south-north and relative east-west exposed surfaces area to the ones of the complete model.

The second major aspect which influences thermal behaviour is the zone floor area, which is a dispersant surface for the terminal zones and characterizes all internal gains and air changes. Modelling the zone as a simple box can lead to very large errors in the estimation of floor area, so an additional input is required for the medium floor area of the building.

The final simplified model is characterized by four data inputs: South-north face length, east-west face length, medium floor height and total floor area.

Like for the previous simplification, this one is also associated with the idea that an accurate geometrical model of the building is not needed during the first design stages due to continuous changes in building shape, therefore favouring an easier and faster modelling process to better suite integrated design process.

In the case study this simplification step has been applied, in a first stage, with three different floor area estimation methodologies to evaluate their effect. Floor area equal to the area of the box generated by vertical surfaces, floor area equal to the mean floor area of the building and floor area specified for each floor.

As expected, the first solution presents a relevant difference in results due to the significant errors in modelled floor area compared to actual floor area, in this case being the building quite regular in shape the output difference corresponds to 2.5%, which is considered relevant and can become a lot larger with different and more complex building shapes; the difference between the last two cases is instead considered marginal (<1%) and not influenced by building shape. The third option is the more accurate but the second one requires significantly less input data and is more suited for early design phases so it is favoured over the alternatives. The complete analysis is performed based on the second floor area estimation method.

3.8 STEP 07. Standardization of transparent surfaces

During step 04 the calculation of total area of transparent surfaces for each cardinal direction has been made singularly for each floor. In this simplification step this calculation is carried out for the entire building and then divided for the number of floors, obtaining the same surface area for each floor and therefore significantly reducing the number of inputs required by the model.

The simplification is also in accordance with the design process itself as, generally, the detailed dimension of the single windows are not fixed until the later design phases and therefore an accurate calculation of fenestration area different for each floor is not possible and easily subject to changes. It is therefore more useful to refer to a mean fenestration area for each direction.

3.9 STEP 08. Number of floors modelled

The last simplification step is meant to model a building through a fixed number of floors, and therefore thermal zones, regardless of the actual number of floors of the real building, reproducing them through the use of zone multipliers applied to the modelled zones.

This step does not have any relation with the design process in any of its phases as the number of floors is already known and is essential information which cannot be overlooked. Moreover the actual number is taken into account by this simplification, just not directly by modelling each floor with a zone. This also does not change the input scheme or reduce the number of inputs required for the creation of the model as the only input concerned by this step is the number of building floors, which is essential as previously mentioned.

The intention of this simplification step is for a more standardized model that the tool needs to recreate. If the number of floors is fixed, the model needed to describe it has the same structure independent from the building itself, allowing for an easier development of the tool. Also, in the case of high-rise buildings or buildings with a great number of floors in general, this step is useful to avoid the generation of a too complex model from which long simulation times would originates.

In the case study this simplification is implemented by modelling a total of three zones, or floors, as seen in figure 3: one for the underground deposit, one for the top floor and one for the middle floors to which a multiplier of four is applied to fully model all the building floors. The zones are linked differently from the complete model to guarantee an appropriate behaviour of the model.

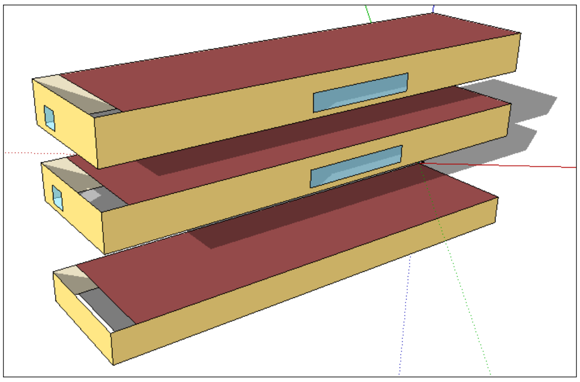

Fig. 3 – Overall view of the fully simplified model

4. Result analysis

A full year simulation has been performed for each simplification step previously detailed. For each simulation the results have been obtained and subsequently compared to those of the complete model in term of total annual loads, peak power loads and power curves shape for both cooling and heating in order to evaluate differences generated by simplification.

Table 1 reports the obtained results from the VAV model for total heating loads, results reported are, in order, the total estimated heating loads for the building, the percentage difference from the previous step, the total percentage difference from the complete model and lastly the cumulative absolute percentage difference between the complete model and all the previous simplification steps.

It can be seen that major difference generation occurs during simplification steps 03 and 08, which are respectively the zone lumping simplification step and the number of floor simplification step, with a 5.79% and a 4.81% difference increase from the previous steps. For step 03 this was expected as the simplification requires major changes in the model and a strong approximation in the operation of the building, also merging zones tend to mitigate extreme conditions. Differences in step 08 can be attributed to the humidity control implemented in the VAV system.

Relevant differences are also generated by floor standardization simplification step, due to the removal of semi-external unconditioned zones, and interestingly a difference of 3.0% is generated by the remove of external shadowing surface, which in this case study consist in the nearby buildings.

Total generated difference for heating loads for the whole simulation period equals to 15.55%.

In figure 4 a representation of the various heating power curves can be seen from which it is possible to notice that differences in terms of total peak power for heating are relatively small and only add to a total of less than 4% for all the simplifications. Also no major differences can be identified in the resulting curves, this is also confirmed by running statistic likelihood tests with the complete model results as the null hypothesis, for which the result is that there is no relevant difference in the two curves.

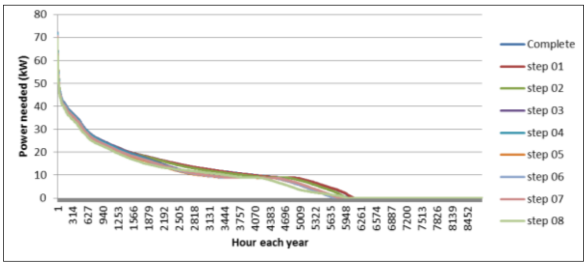

Fig. 4 – Heating power curves comparison for each simplification step

Similar analyses can be carried out for the cooling loads of the building (table 2 and figure 5) from which it is possible to notice that differences in step 03 and 08 becomes larger, due to the mixing of various zone conditions, and are still the most relevant for the same reasons mentioned above. Also difference in the shadow simplification step increases for the cooling period as differences for the other steps tends to decrease, reaching a total of 14.56% for all the steps.

In terms of cooling power curves no major differences can be identified as confirmed by statistical likelihood tests but this time the differences in power peaks become more relevant starting from the 141kW power peak of the complete model and decreasing at 129kW for the final simplification, for a total difference of nearly 9%, still below the total difference registered for total cooling loads.

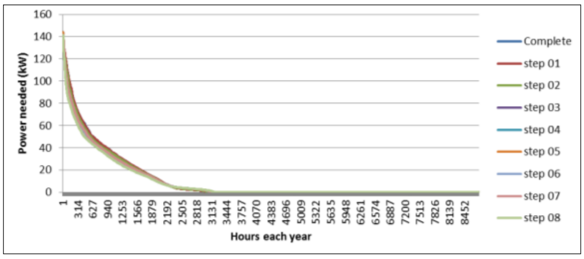

Fig. 5 – Cooling power curves comparison for each simplification step

Applying the simplification protocol on this particular case study for the "external obstruction" step, all the external buildings and canopies at the entrances have been removed. The building does not present any particular shadowing technology for single fenestrations, so this aspect of the simplification cannot be considered in the analysis as irrelevant in this case.

	FULL MODEL	SIMPLIFICATIONS							
		STEP 01	STEP 02	STEP 03	STEP 04	STEP 05	STEP 06	STEP 07	STEP 08
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
Total	94566	94387	91556	86255	85023	81911	83015	83903	79864
Diff %	0.00	-0.19	-3.00	-5.79	-1.43	-3.66	1.35	1.07	-4.81
Diff % tot	**0.00**	**-0.19**	**-3.18**	**-8.79**	**-10.09**	**-13.38**	**-12.21**	**-11.28**	**-15.55**
Diff% cum	0.00	0.19	3.19	8.98	10.41	14.07	15.42	16.49	21.30

Table 1 – Percentage differences on heating loads for each simplification step

	FULL MODEL	SIMPLIFICATIONS							
		STEP 01	STEP 02	STEP 03	STEP 04	STEP 05	STEP 06	STEP 07	STEP 08
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
Total	94022	94170	90365	85288	85130	85057	85397	87184	80331
Diff %	0.00	0.16	-4.04	-5.62	-0.18	-0.09	0.40	2.09	-7.86
Diff % tot	**0.00**	**0.16**	**-3.89**	**-9.29**	**-9.46**	**-9.53**	**-9.17**	**-7.27**	**-14.56**
Diff% cum	0.00	0.16	4.20	9.82	10.00	10.09	10.49	12.58	20.44

Table 2 – Percentage differences on cooling loads for each simplification step

5. Conclusions

Buildings are responsible for a tremendous amount of energy consumption also due to their long lifetimes and continuous operation. Efficient design is critical, especially at the early stages as poor decisions made early become difficult or impossible to correct later. Existing energy simulation tools fail to meet the needs of architects and building designers at the early stages of design due to the excessive complexity of the tools and amount of required information.

The proposed simplification protocol seeks to meet this need by providing a fast and simple way to perform building energy simulations and assist with the selection of appropriate building components and systems during early design stages.

It is believed that a difference of 20% between the detailed and simplified models is an acceptable result to provide useful information for the design process, taking into account the lack and uncertainty in information provided during early design phases.

Differences found between the simplified model implemented and a detailed model for this specific case study, are in the worst case equal to 15.6% for heating loads and 14.6% for cooling loads, in line with expectations. Even better results are achieved in term of heating and cooling peak loads, with the respective differences of -4% and -9% with respect to the complete model.

Although based on only one case study the presented results, featuring differences within the margin of 20% compared to a detailed model, bodes well that the simplification protocol and the expected tool can provide useful information for the design process, driving the research toward the implementation of new case studies able to improve the simplification protocol and generalize the obtained results, culminating in the creation of the proposed simplified design tool.

The application of the case study also allowed to evaluate various possible simplification techniques for specific problems like transparent surfaces and building floor area identifying the best solution in term of differences generated and inputs required.

It can also be noticed that many of the differences observed are concentrated on the lower tail of the two power curves when the loads become lower and discontinuous, typical of mid seasons and, for the heating power curve, humidity control during summer.

It can be concluded that the application of the described protocol can help reduce the time requirements for a dynamic simulation from up to several days to only 2-4 hours at the cost of an acceptable increase in result uncertainty. The expected simulation tool should increasingly reduce time requirements through automation of model creation to under one hour.

6. Acknowledgements

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