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Evaluation of the Performance of a Real Building

Final Report

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Abstract

Previous works have shown that buildings may consume more energy than required for occupant comfort. The building sector is accountable for 35% of global final energy use and responsible for 17% of direct energy related CO_2 emissions. Researchers say that, currently there is a huge potential for energy savings in this sector because the technology presently available is highly cost-effective which can help to mitigate the global energy use by the building sector. This study focus on the difference between predicted (simulated) energy performance of buildings and actual measured energy use once buildings are operational. The methodology proposed consists on building performance evaluations where EnergyPlus is used as building performance simulation tool to investigate opportunities during the later phases of the design process and to research innovative applications for design support, with the goal to explore simple and economical energy saving measures that can contribute to mitigate the energy consumption from office buildings.

1. Introduction

Buildings are the largest consumers of energy. The buildings sector, comprising both residential and services sub-sectors, consumes 35% of global final energy use. It is responsible for about 17% of total direct energy-related CO_2 emissions from final energy consumers (IEA, 2013) [1], figure 1. The international community set clear goals regarding the reduction of CO_2 emissions and energy demand in the built environment. This drives research and building practice to search for solutions and new building concepts that contribute to achieve these objectives.

Even if emissions are stopped immediately, temperatures will remain elevated for centuries due to effect of greenhouse gases from past human emissions already present in the atmosphere. Limiting temperature rise will require substantial and sustained reductions of greenhouse gas emissions. Thus, the buildings represent the largest untapped source of cost effective energy saving and CO_2 reduction potential within Europe, yet the sector continues to suffer from significant underinvestment, following the Building Performance Institute Europe (BPIE, 2013) [2].

Buildings typically have a lifespan of several decades and therefore refurbishment of existing buildings is an important element of the EU energy and climate strategy. There is major potential for energy savings of up to 50-90% in existing and new buildings [3]. Many mitigation options are immediately available and highly cost-effective.

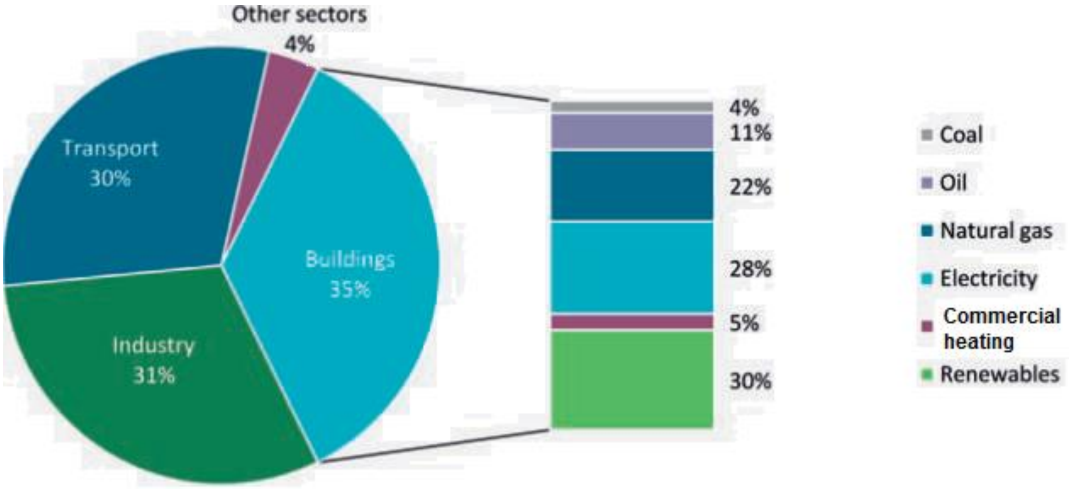

Figure 1: Final Energy consumption by sector and buildings energy mix, 2010

Taking all this into account, governments are currently implementing building energy regulation in order to establish a method of assessing, rating and certifying the sustainability of buildings. In the EU, whole building environmental assessment is voluntary, but energy certification is mandatory. The most well-known whole building qualitative assessment voluntary schemes are the Building Research Establishment Environmental Assessment Method (BREEAM), used in more than 60 countries including the Netherlands and U.K., and Leadership in Energy and Environmental Design (LEED) in the United States [4]. This two types of evaluation have the intent to raise awareness amongst owners, occupiers, designers and operators of the benefits of taking a sustainability approach. This type of building benchmarking is being used as a basis for specifying minimum building environmental performance, in order to help its users to successfully and cost-effectively adopt sustainable solutions, providing in addition some market recognition of their achievements.

There is often a significant discrepancy between the designed and real total energy use in buildings, this is often addressed as "the performance gap". Reports suggest that the measured energy use can be 2.5 times the predicted energy use [5]. In fact, building energy consumption is mainly influenced by six factors: climate, buildings envelope, building services and energy systems, building operation and maintenance, occupant activities and behaviour and indoor environmental quality provided [6]. A detailed comparative analysis on building energy data, concerning the six factors mentioned above, would provide essential guidance to identify opportunities to save energy.

A building performance evaluation has two main goals: to assess the building's performance relative to design intentions and to expose the challenges of meeting energy efficiency needs of our future. Building performance simulation (BPS) uses computer-based models that cover performance aspects such as energy consumption and thermal comfort in buildings [7]. Nowadays, it is primarily used in the design, operation and management of a building. BPS can help in reducing emission of greenhouse gases and in providing substantial improvements in fuel consumption and comfort levels, by treating buildings and theirs thermal systems as complete optimized entities and not as the sum of a number of separately designed and optimized sub-systems or components [8]. BPS is still not routinely applied in building design practice, despite nearly 40 years of research and development, methods for the design assessment are costly to implement, time-consuming or not applicable [9].

The BPS tools are meant to provide prediction of the building performance based on a number of variables. The reliability of the prediction depends on vigorous quality assurance process. The International Energy Agency (IEA) has develop a practical implementation procedure and data for an overall validation methodology. The methodology consists of a combination of empirical validation, analytical verification and comparative analysis techniques. The BESTEST project was developed for systematically testing whole-building energy simulation programs and diagnosing the sources of predictive disagreement. The method consists of a series of carefully specified test case buildings that progress systematically from the extremely simple to the relatively realistic. Output values for the cases, such as annual loads, annual maximum and minimum temperatures, annual peak loads are compared and used in conjunction with diagnostic logic to determine the algorithms responsible for predictive differences.

In this study, it is intended to perform an energy performance evaluation of an existing building in order to develop methodologies to predict total energy use in buildings, with special concern to the heating and cooling consumption. Secondly, it aims at identifying and quantifying possible energy saving measures that can be easily implemented and will significantly reduce the energy consumption.

2. Literature Review

2.1 Building Performance Evaluation (BPE)

Building Performance Evaluation (BPE) is a tested and defined method that can be adopted to measure and monitor building performance before, during and after building projects. It is a process used to verify and understand the performance of a building, considering both the intrinsic performance of the building materials and services and the in-use, in other words the occupied performance of the building. Presently, there is a significant and growing evidence that buildings do not perform as anticipated at their project design stage, this is referred as "performance gap". These causes can be grouped in three main categories: causes that pertain to the design stage, causes rooted in the construction stage and causes that relate to the operational stage.

BPE provides the means of quantifying any performance gap and gives the key insights into its root causes, providing feedback on how and why buildings perform, identifying opportunities for improvement to the building design, facilities management, procurement and construction teams in order to improve the occupied performance of current and future buildings [10]. Thus, BPE is an assessment of how well the performance objectives for a building have been achieved and how well the built environment satisfies the needs of the users, owners and managers. The techniques and approach will depend on the project environment within which it is being applied, focusing on a range of technical performance criteria, and whether the evaluation is being conducted on a domestic or non-domestic building.

Ideally, when commissioning a building there exist five different phases to ensure the transition from construction to occupation occurs with least possible problems and that operational performance is optimised. This transition needs to be considered throughout the development of a project, not just at the point of handover. The five key stages are defined as, figure 2:

- Inception and briefing: ensuring that the client's needs and requirements are clearly clarified;
- Design development and review: reviewing comparable projects and assessing proposals in relation to facilities management and building users;
- Pre-handover: ensuring operators properly understand systems before occupation;
- Initial aftercare: Stationing the project team on site to receive feedback, fine tune systems and proper operation;
- Extended aftercare and post occupancy evaluation: it is suggested that this period last for three years. In year 1, problems are identified, training provided and systems adjusted, with regular previews. In year 2 and 3, performance is reviewed, and post occupancy surveys carried out, but with reviews becoming less frequent.

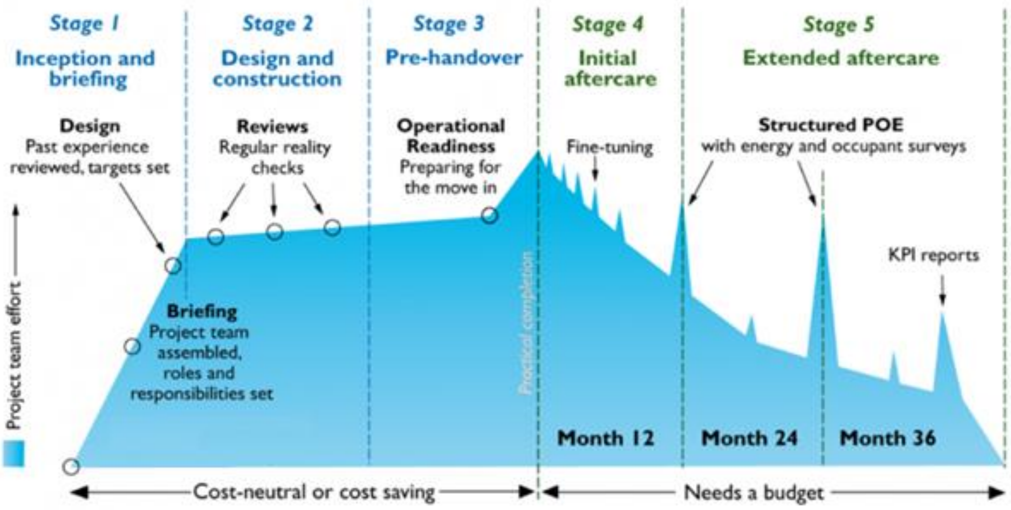

Figure 2: Diagrammatic representation of the five different stages during a BPE.

2.2 Building Performance Simulation (BPS)

The primary purpose of an office building is to provide a comfortable environment to its inhabitants which will ensure their productivity. Prior to a simulation using a building performance simulation (BPS) tool it is essential to first understand the heat transfer mechanisms in a building. A building's thermal load is the amount of energy that must be removed or added to the system, to maintain a constant air temperature inside a room. So, a heat transfer analysis has to be made separately for each heat transfer mode: conduction, convection and radiation. In fact, all of the heat transfer modes occur simultaneously what takes the analysis much more complicated. The conduction can be simplified to steady-state conditions, quasi steady-state conditions or transient conditions. For nonlinear, time-dependent boundary conditions and wall and roofs that are not homogenous is not too easy to obtain a simple solution. Thus, to calculate the heat transfer there are a set of different methods, such as numerical methods, lumped parameter methods or Z-transform methods [11]. The Z-transform methods are the ones usually used in load condition and in building energy analysis because of its accuracy and its computational efficiency. In convective heat transfer the first stage is to distinguish exterior and interior because the first one is forced and the second one is free. Case the heating or cooling in a building is provided by an air system, the heat transfer to or from the space is affected by bulk convection. With respect to thermal radiation wavelength it can be divided in two categories: short wavelength radiation emitted by lighting and long wavelength radiation emitted by surface, people and equipment, and when analysing windows the solar radiation has to be divided in direct and diffuse radiation.

The combination of all this aspects have originated some models: heat balance model (maybe the most accurate), which ensures that all energy flow in each zone are balanced and involve the solution of a set of energy balance equations for the zone air as well as to the interior and exterior surfaces; the second class of models are thermal network models which is a form of heat balance models with the discretization of the building in a network of nodes; the third class, the transfer function methods, use transfer functions or response factors to relate current value of cooling and heating load to past values of heat and cooling load or heat gains. To have an accurate simulation it is also required apart from the control of the above mentioned aspects to take into account the weather data, time of the day, building geometry, construction type and occupancy. For this purpose, the decision related to the right time steps is crucial for the simulation because decreasing the time step not always improves the accuracy. Sometimes it is preferable to decrease the space step [12].

2.3 Uncertainty and Sensitivity Analysis

Currently, there are number of studies that focus on the analysis of computer models. This computer based models, usually are related to the building's geometry and characteristics as well as the shape of the building. The model does not need to represent as it is architecturally, but rather its thermal behaviour. For that reason, different types of uncertainty are emphasized, such as uncertainties in physical, scenario, and design parameters. De Wit [13] said, the modelling uncertainties arise from commonly applied physical assumptions and simplifications in a computer model. If a building simulation is considered as a decision support instrument, the determination of uncertainty in parameters is a very complex task, which arises from the consideration of systematic uncertainties, relating to methods and test conditions, and the random uncertainties between repetitions of experiments in the same test conditions. The uncertainty refers to the range of variation of a physical property, represented by a probability distribution. So, an uncertainty analysis (UA) takes into account uncertainties related to simplifications assumed during the development of the model and lack of information with respect to the input data. A common approach to conduct UA is to use a deterministic model but assign probability distributions to the uncertain input parameters, this distribution is described as degree of belief as where appropriate value of each variable is located.

On the other hand, sensitivity analysis (SA) consists on modifying model inputs in order to see their effects on model outputs. In other words, SA supports the decision maker in identifying the most sensitive parameters improving building performance understanding. UA and SA are usually applied to assess the risk of different energy conservation measures and as a help to support decisions. For instance, both analysis can provide information about reliability towards design parameters, respectively to the overall design [14].

2.4 Performance indicators

According to DOE a performance indicator is described as a performance metric which simplifies complex information and points to a general state of the building. Performance indicators are accessible numeric metrics of energy usage or observed building characteristic that indicates a certain aspect of the performance. They are intended to yield the best information for the least cost and analysis time using the available metered data and observable characteristics. An example of key performance indicators are the energy consumption of the building and thermal comfort of its occupants.

2.5 Validation

Validation of a model consists on making sure that the model simulations are providing accurate and reliable results about the building's performance. It is a process of assessing, by independent means, the quality of the data products derived from the system outputs, which is related to the simulation algorithms accuracy and correctness. There exists three types for validation of a building performance simulation software. The first is called comparative testing, in which a program is compared to itself or to other programs. The other two techniques are: analytical validation and empirical validation [15].

In the analytical verification, the outputs from a program or algorithm are compared to the results from a known analytical solution for isolated heat transfer mechanisms under very simple boundary conditions, in other words it test the numerical solutions of a software, but does not test the simulation model. It is based on very simple physic processes which are already established and well-known, making it only applicable to a limited number of situations, and if the results obtained with the software are correct they can be extrapolated to more complex cases, given to its simplicity it provides an exact standard for comparison. This method enables an easy and inexpensive way to understand the basic physics of a situation correctly but, for the more complex models where multiple building parameters and aspects need to be modelled, this technique is not useful.

In the Empirical validation, the calculated results from a program or software are compared to monitored data from a real structure or building, controlled test cells, or laboratory experiment. This technique requires detailed measurements of high quality, which make the gathering and monitoring of the data very time consuming and expensive. The characterization of some of the more complex physical processes (heat transfer with the ground, infiltration, indoor air motion and convection) treated by the building simulation programs are often excluded due to measurement difficulties and uncertainty. Because of this disadvantages only a limited number of case are economically practical. But at the same time, it also provides a rigorous and accurate test of the model and the solution process, making it applicable to any level of complexity.

2.6 Calibration

Kaplan [16] defines calibration as the process of adjusting the parameters of a model through several iterations until it agrees with recorded data within some predefined criteria. The definition of these criteria is a complex issue and, to date, it is impossible to determine how close a tolerance needs to be to fulfil the calibration process. The calibration of a building's model comprises two ideas towards quantitatively define the systems response to known, controlled parameters: Calibration Signature and Characteristic Signature. Characteristic Signature consists on the comparison between baseline uncalibrated performance simulation results and a modified baseline simulation, usually by a normalized plot that easily demonstrates the difference between them. The baseline uncalibrated model is based on information about the building design construction, occupancy profiles and systems control and management which may introduce some inaccurate results. These inputs are tested and changed (increased or decreased) one at a time, two characteristic signature plots are generated for cooling and heating energy demand as a function of the ambient air temperature. The main limitation of this method is that some parameters are independent of the ambient temperature and may not change accordingly, but still may have an important role in the building energy needs.

Calibration signature is very similar to Characteristic Signature, but this time the difference lies in the fact that this techniques shows the difference between the measured data results and the modified baseline model simulation by a normalized plot with the simulated energy consumptions as a function of the outside temperature. The objective is to verify the difference in input parameters with several model simulations in order to understand where the discrepancies in the building's performance are. This process has the advantage to perform faster calibrations because the users has a better idea about which parameter needs to be altered, instead of a trial and error technique that takes much longer [17]. To have an understanding of the accuracy of the model it is it is often calculated the RMSE (root-mean-square error) during calibration. When analysing a building's parameter, the RMSE can give an important help because it represents the standard deviation of the differences between the model simulated and the measured data. In contrast with the RMSE, the Mean Bias Error (MBE) is an overall measure of how biased the data is and is also a good indicator of how much error will likely be introduced in the annual energy consumption estimates, for MBE the positive and negative errors will cancel each other out. Figure 3 exemplifies the calibration process, previously described.

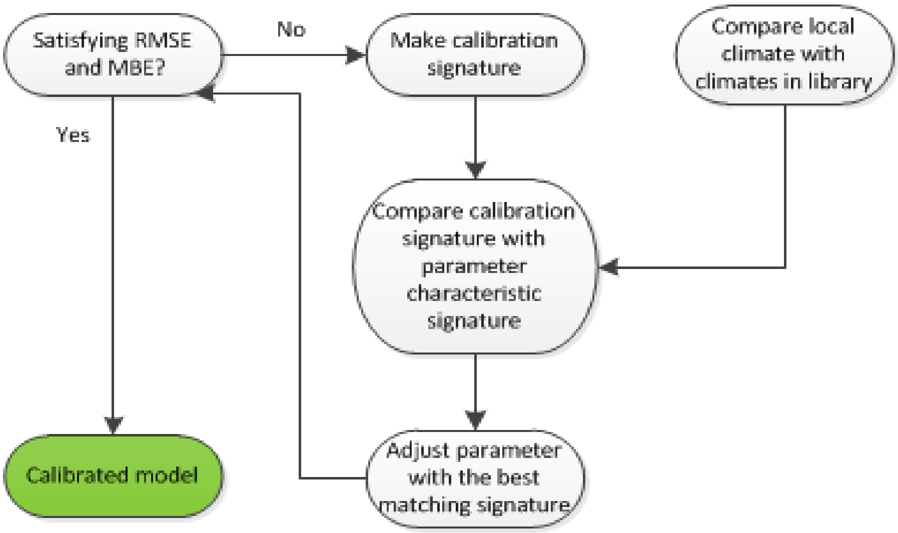

Figure 3: Diagram of the calibration process

3. Methods

For model based methodologies, there are two general approaches known as bottom-up and top-down. The bottom-up focus on the component or subsystem level, in this case a model is used to compare the real element to ideal operation conditions in order to detect the fault of the particular system element. The top-down approach is based on whole building level analysis, in which a model is used to compare the real-time measurements with ideal operation just as in the bottom-up approach [18]. The advantage of top-down approach is that the whole building analysis typically does not require large amounts of information regarding the operation of the building.

The methodology proposed is based on a post-occupancy evaluation by means of a top-down approach, in which building computer simulations are implemented using EnergyPLus for the assessment of the energy performance of a non-residential building. EnergyPlus is an energy analysis and thermal load simulation program normally used to estimate building energy performance. It is well-recognized, open-source and accepted building energy analysis software tool since it freely models heating, cooling, lighting, ventilating and other energy flows as well as water in buildings and many other simulation details that are necessary to verify that the simulations are performing as the actual building would. This simulation tool complies with ASHRAE 140-2004 standard, as the regulation obliges to. In addition to the Energyplus software, Openstudio is also used to assist and to support whole building energy modelling because includes graphical interfaces that facilitates users while programming.

The implementation proposed strategy proceeds according to the following steps, figure 4:

1. Analysis of the system and survey of operational variables. This step requires the description of the building's equipment or sub-systems in their interaction with the building. The conditions of the system's use and the operational requirements must be evaluated, including the analysis of the variables with the largest influence;
2. Creation of dynamic model that satisfactorily represent all of the involved phenomena related to variables with a significant influence on the analysed process;
3. Validation and calibration of the building performance simulation taking into account information about the building's energy consumption according to the measured data;
4. Evaluation and implementation of simple, but effective energy saving strategies to the energy simulation models;
5. Validation of the new simulation models with consequent calculation of gains.

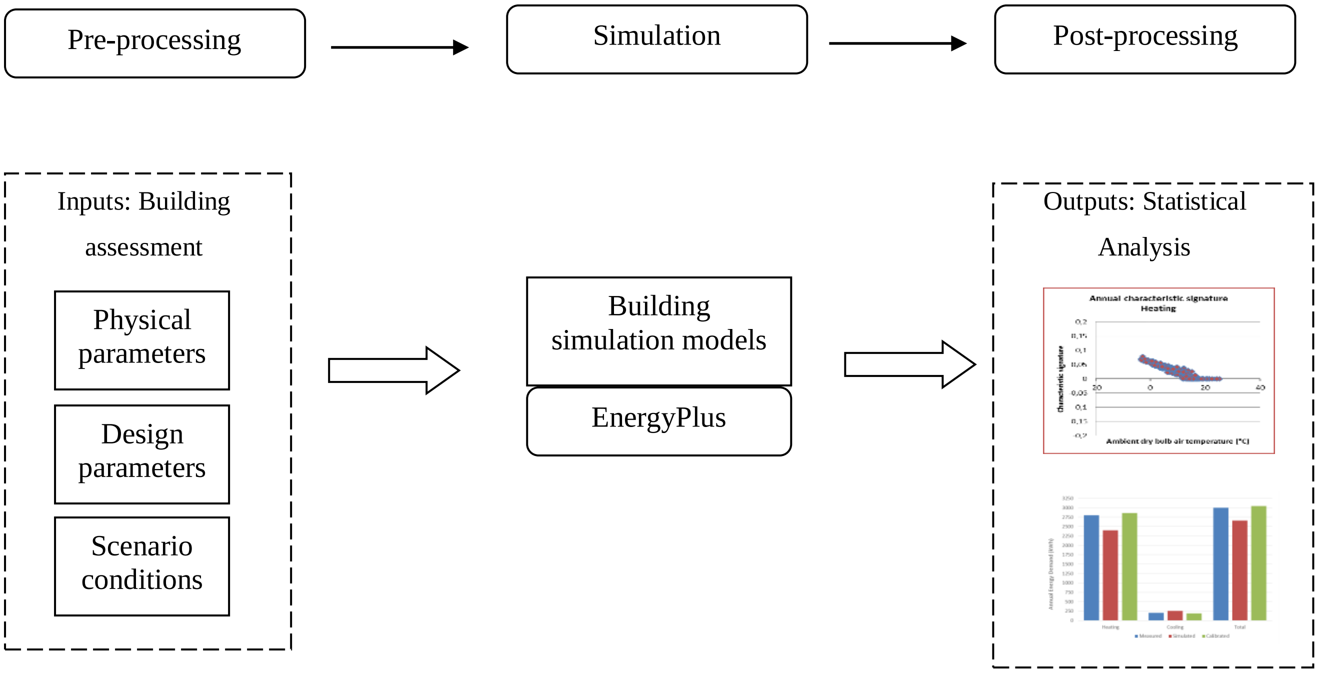

Figure 4: Overview of methodology process

3.1 Building Description and building system

The case study is an office building located in the Eindhoven University (Tu/e), frequently called as The Vertigo. The building was constructed on 1965 and underwent a major renovation in 2002. This building is a 26.000 m^2 building with a total of 12 floors, consisting of a high-rise seven-floor section and a three-story section with a larger floor plan, and two below ground floors. The top four floors comprise office spaces that share a central atrium that can be described as an open area. The rest of the top floors and the lower floors of the building consists of a mixture of classrooms, offices, and laboratories, figure 5. The below grounds house the mechanical systems. The Vertigo building is usually occupied from 08:00 till 18:00 on weekdays and is vacant on weekends.

The primary mechanical system consists of a heat pump located in the basement and two hot water natural gas boilers located on the roof. The heating and cooling is mainly provided by a district aquifer thermal energy storage (ATES) system connected to the heat pump. The basic idea of this storage system is to use the accumulated cold and/or heat to cool and/or heat the building and to store back the rest of heat/cold in the underground storage for later (next season) use. In addition to the storage system, additional equipment is added to the system in order to complement, should the capacity of the storage system be insufficient. The space conditioning is performed by a combination of four air handling units providing ventilation air, convective radiators along the perimeter of the building, a four pipe climate ceiling in the office spaces and ten fan coil units in unique spaces with high internal gains.

The heating demand is higher than cooling demand for the Vertigo building, as it happens during most of the year, mainly due to climate conditions. The temperature level in the cold storage is designed to be directly used for cooling HVAC equipment in rooms and air handling units most of the time. The heat pump is designed to heat up the water only up to 50 ºC that corresponds approximately to the heating demand at 5 ºC ambient temperature, for which the equipment is sized. When the heating demand is higher, the boiler is switch on.

The air handlers' heating is commanded off when the ambient temperature exceeds 16°C. The convective radiators are organized are controlled by two way valves set to maintain a room temperature of 22°C throughout the building. The radiators are commanded off when the ambient temperature exceeds 14°C. The climate ceilings located in the offices are locally controlled to maintain the room set-point [16]. As a result of not having any information about the heat pump operation relative to the heating or cooling mode, it was assumed that when the ambient temperature is below 15 ºC the system is cooling and when the ambient is below this temperature the system is heating.

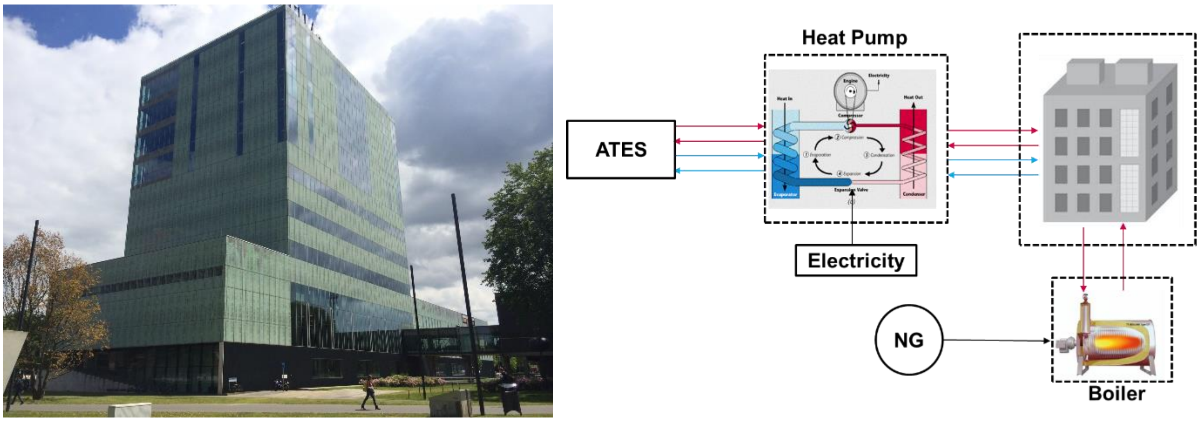

Figure 5: Picture of the Vertigo building on the left. On the right, a simple overview of how the building functions.

The number of independent variables during building optimization should be limited, since simulation of detailed building models may take several minutes in building energy simulation to several hours in computational fluid dynamics (CFD) simulation to complete, while the simulation-based optimization techniques often require hundreds or thousands of simulation evaluations. To overcome this, very simplifications are regularly assumed.

3.2 Base Case Scenario

Energy consumption for space heating and cooling, ventilation, electricity, lighting and office equipment is calculated separately. EnergyPLus is able to consider all outdoor and indoor parameters for running a complete simulation to access the building's energy consumption. The simulations were validated by comparing them with measured energy consumption data, which comes from five electrical meters located at the transformers, heat pump electrical sub-meter and a gas meter.

The first step in the simplification process regards the building constructions which are based on the identification of a single construction type for each kind of surface present in the model. The main characteristic of the building design of the base case are presented in table 1 and the key features of the building envelope are presented in table 2. The U-values of the external walls, roof and floor correspond to close estimates.

Table 1: Constructive characteristics of the base case Vertigo building

External walls	*Stucco, concrete, Wall insulation, plasterboard (outside layer to inside layer)*
Exterior Floor	Concrete, floor insulation, acoustic tile (outside layer to inside layer)
Roof	Asphalt shingle, roof insulation, roof membrane (outside layer to inside layer)
Interior Floors	Concrete, fiberglass batt, acoustic tile (outside layer to inside layer)
Windows and Glazing	Aluminium frame with double glazing

Table 2: Main characteristics of the building envelope

Construction	***U-value ($W/m^2.K$) (overall air-to-air)***
External walls	0,57
Floor	0,45
Roof	0,45
Interior Floors	0,45
Windows	2,8

The occupancy schedule for the building was assumed to be between 8 a.m. until 18 p.m., from Monday to Friday. The information concerning the office's equipment had to be calculated using the electrical sub-meters information related only to the consumption registered for these type of appliances. Regarding the work patterns of the building's occupants it was divided into floors occupation patterns. The top floors usually are more occupied than the lower floors. The main operating conditions related to this case on the subject of lighting, infiltration rate and set-point schedules is summarized in table 3.

Table 3: Main operation conditions of the base case

Occupancy hours	8-18h	Monday to Friday
Average density of occupation	0,025-0,079 (lower floors to higher floors)	Person/m^2
Metabolic rate	140	W/person
Clothing insulation	0,61	clo
Infiltration rate	0,2	l/s.m^2
Equipment density	4,44	W/m^2
Lighting density	12	W/m^2
Set-point heating	21	Celsius degrees
Set-point cooling	23	Celsius degrees

As described before, the Vertigo's HVAC system is a very complex system, in order to program the system some simplifications were assumed. It was considered that the building has a Variable Air Volume (VAV) system with reheat comprised of a central AHU (air handling unit) with cooling and heating coils and reheat coils for each zone. All systems are characterized by the same airflow rates and modelled accordingly to the equipment installed and the actual use of the building

The simulation is performed for the duration of one whole year, starting January 1st and ending December 31st. As a consequence of not having a proper weather file data from Eindhoven, the weather file used was from Beek, provided by the US Department of Energy (EnergyPlus database), for the reason that Beek has similar weather conditions to Eindhoven and was identified as being the closest to the real building (approximately 60 Km from Eindhoven to Beek).

Results of the simulation are then calibrated based on actual measured data available. Based on the results of the simulation four point of comparison are identified to evaluate the accuracy of subsequent model simplifications. The performance indicators identified are:

1. The annual energy heating demand of the building;
2. The annual energy cooling demand of the building;
3. The peak load demand for heating;
4. The peak load demand for cooling.

The data available for analysis spans from January 1st of 2009 through 31st December of 2012. The energy consumption data was taken from the building's system as outlined above.

3.3 Scenario 1, 2 and 3

As a comparative analysis, simulations are carry out considering the energy saving potentials for the Vertigo building in several scenarios. Apart from the simulation for the base case scenario, four separate simulations are also performed.

The scenario 1 considers the implementation of efficient and energy-saving office appliances and lighting system. On the other hand, scenario 2 examines the energy consumption differences when installing a constant air volume system instead of a VAV system. The objective is to analyse which of this two types of HVAC systems have the potential to save more energy. In theory CAV systems are somewhat rare in mid- to large-size buildings, due to fan energy savings potential while using VAV systems. However, in small buildings and residences CAV systems are often the system by choice due to their simplicity, low cost, and reliability. Another effective measured in terms of saving energy, as described in scenario 3 in table 4, is to make modifications on the set-point schedules of the building. By decreasing the heating set-point and increasing the cooling set-point, one can have the opportunity to save energy.

Table 4: Main operating conditions for the different scenarios

	Scenario 1	Scenario 2	Scenario 3
Equipment density (W/m^2)	3,5	-	
Lighting density (W/m^2)	10	-	
	-	Constant Air Volume (CAV) system	
Set-point heating (Celsius degrees)	-	-	20
Set-point cooling (Celsius degrees)	-	-	25

One last scenario will be performed after analysing which of these energy saving measures have the capability to save money as well as energy. This last scenario will consider all the previously mentioned measures at the same time in order to investigate how much can be saved, apart from the HVAC system that will need to be verified which of the both types of system is more effective for this building, and only after that this last scenario will be simulated.

Results are reported in absolute and relative values on an annual basis during the operation of the building. Energy consumption differences are calculated regarding the energy demand for the specific use under analysis as well as overall energy consumption of the office building. Annual costs are calculated based on the average prices of electricity during 2012, since there is only measured information relatively to the building's consumption until 2012, as previously mentioned. The cost saving values in this study should not be considered as exact values, but they are provided to give a relative idea of cost-effectiveness of the measure under study.

4. Results and Discussion

To have an idea of the building's consumption under evaluation, it is important to start displaying the measured information about the heating and cooling consumption of the building, as shown in figures 6 and 7, respectively. Since there is only viable data until the end of 2012, this year was considered as the reference year for validation and calibration of the simulation models.

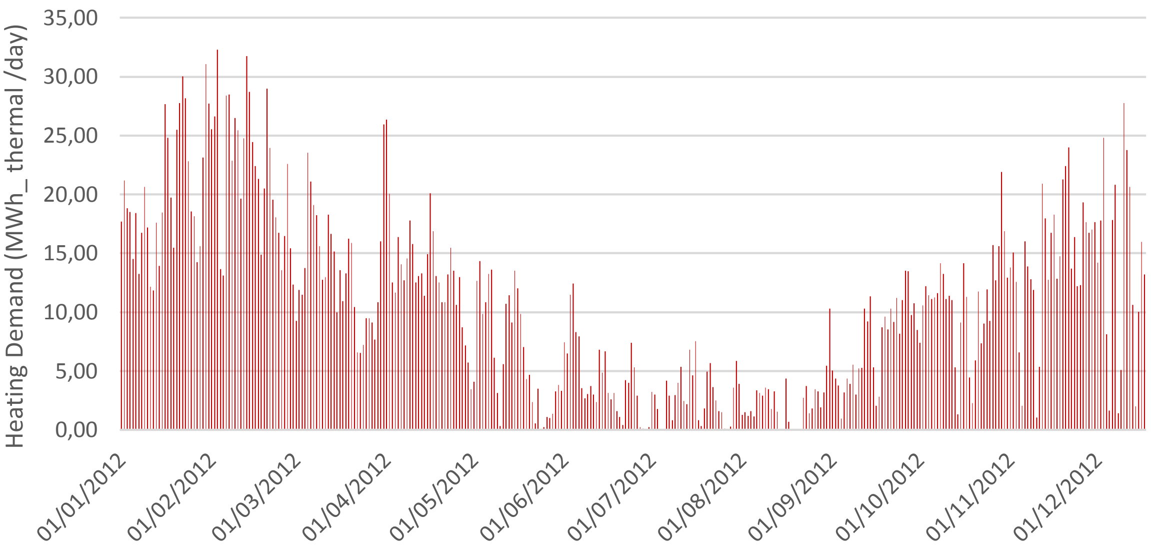

Figure 6: Vertigo building annual heating consumption from measured data

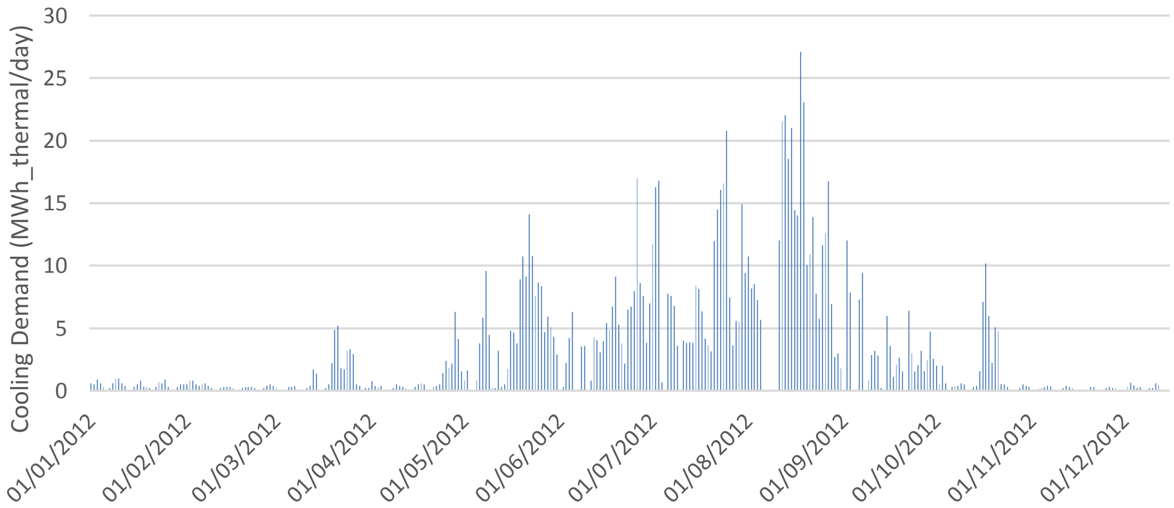

Figure 7: Vertigo building annual cooling consumption from measured data

These are the results to presume from the simulation models concerning the heating and cooling consumption of the building. One can see in figure 6, as expected that during the Summer the heating demand is lower, having the highest resuts during the Winter. On the contary, in figure 7, the cooling demand is lower on the cold months having the highest values of consumption for the duration of the hot months. One can easily notice that for this building the heating demand is higher throughout the year when compared to the cooling demand.

So far the results obtained are related to the EnergyPlus programming of base case scenario. But it is intended to perform a full year simulation for each scenario previously detailed. For each simulation the results are obtained and subsequently compared in terms of annual consumption, peak loads for both cooling and heating in order to evaluate differences generated by the different scenarios. Unfortunately, up until now there are not results related to the simulation models due to some simulation problems. But nonetheless, it is important to show what has been obtained relatively to the model simulation. Figure 8, demonstrates the building’s geometry using OpenStudio Plugin for

Sketch Up. This software facilitates the user in making the building geometry thanks to the graphical interface of this tool, which can then be exported to EnergyPlus software.

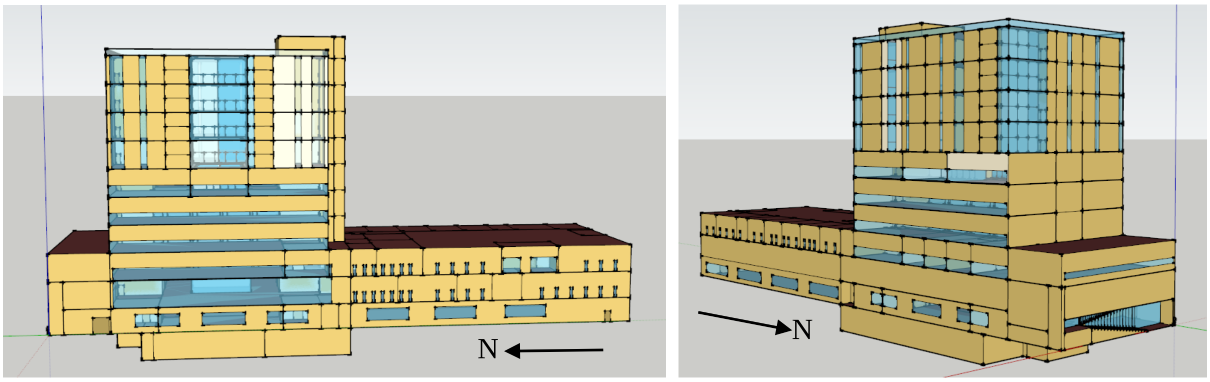

Figure 8: Vertigo building geometry

Figure 9 presents the building HVAC system using Openstudio software tool, that simplifies and is more user-friendly than EnergyPlus in making the the building's mechanical system. The image on the left shows the chilled water loop, the image from the center illustrates the hot water loop and the one from the right displays the VAV system with reheat. The main problems of the model reside here because there is not a easy way to simplify this step which requires some level of input data and also knowledge about how the mechanical system functions.

Figure 9: Vertigo building HVAC system.

5. Conclusion and Future Work

One of the most significant barriers for achieving substantial building energy efficiency improvements is the lack of knowledge about the factors determining energy use. Therefore, one of the main objectives of this work is to investigate the methodologies and techniques for simulating total energy use in an office building in order to demonstrate how the resulting information can be used to provide meaningful advice for better building energy performance. Buildings represent complex systems with high levels of interdependence in many external sources. The design, analysis and optimisation of modern building systems may benefit greatly from the implementation of building performance simulation tools at all stages of the building life-cycle. However, studies have found discrepancies between modelled and measured energy in many cases where BPS tools have been used in to model real buildings. Work in the areas such as POE, uncertainty and sensitivity analysis is essential for bridging the gap between the measured energy use and the predicted energy performance, this is why is crucial to start BPE in the initial stages of conception. Simulation-based optimization is undoubtedly a promising approach to achieve many building design targets, opening a new era of design to architects and engineers. Building design optimization is inherently a complex multi-disciplinary technique which involves many sciences. Nevertheless, 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 required technical knowledge, one this examples is Energyplus.

The main reasons for a building to have a performance lower than expected are the budget cuts and time constraints during construction and delivery, poor communication and transfer of work between involved actors, disinterest of building performance by owners and management and overall absence of incentive and knowhow of energy performance assessment. So, this is why it is so important to apply the methodology presented in this work to the other stages in a building's life cycle, not only after the building has been commissioned and began to be occupied.

In this case, according to the data information the annual electricity consumption is 2,1 GWh/y, but no further results related to the simulation models were not accomplished derived from the fact that when tried to simulate some errors and problems appeared in the software, preventing from obtaining further results. Due to the lack of time and inexperience at the beginning time of the project, the project was not concluded. However, it is intended to be finished in the following months as described in the previous sections. One final remark for further work is to accomplish an uncertainty and sensitivity analysis in order to determine the robustness of the Vertigo building.

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