Comparison between Real Energy Consumption, Italian APE and Dynamic Energy Simulation

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Abstract

The most important challenge of energy modelling is certainly to guarantee that the energy consumption predicted by the simulation during the Design phase reflects the real consumption of the building once built. With the increase in energy consumption monitoring, in recent years it has been realized that there is often a substantial difference between expected and actual energy consumption; this difference is called the "Performance Gap" or "Energy Gap". Furthermore, the energy classification of buildings according to methodologies recognized by Italian regulations is becoming increasingly important, in order to have access to economic benefits or building bonuses. The scope of this work is to compare the energy consumption estimated through dynamic energy simulations and through the Italian regulation-based software with the real consumption of the building, evaluating the reliability of the calculation procedures and calibrating the dynamic model with the real usage schedules (post occupancy evaluation). This study is based on a large recent office building, with high national and international energy performance standards (LEED certified).

1. Introduction

The building sector is a major contributor to the emission of greenhouse gases into the atmosphere since it consumes about 30% of the world's energy to which corresponds the emission of about 40% of direct and indirect CO_2 globally (IEA, 2022). Energy consumption by buildings is also continuously increasing. Although all phases of a building's life produce carbon dioxide, 80-90% of the building sector's emissions occur during the "operational" phase, thus, they mainly depend on the energy used for heating, cooling, ventilation, pumping, lighting, and power appliances.

From these premises, it can be deduced that the building sector is by far the sector with the greatest potential for improvement in reducing greenhouse gas emissions.

A building is a complex system, and the energy phenomena that develop within it are different and continuously related to each other. Simulating the performance of such a system makes it possible to analyse the energy consumption of buildings according to their actual use.

However, it has been noted that these simulations often do not reflect the actual performance once the building is constructed (Turner et al., 2008) and they differ from the energy consumption estimates derived from calculations according to the Italian regulations.

2. Calculation Methodologies

Simulating the behaviour of a building and its energy needs creates a level of awareness that leads to a transparent real estate market geared toward improving the energy efficiency of our heritage.

Dynamic energy simulations are an advanced calculation methodology used to analyse and optimize the energy efficiency of buildings. This technique is based on the use of mathematical models to simulate the thermal behaviour of a building over time, considering dynamic variations in external and internal environmental conditions.

Unlike a static system, which can be described by direct, instantaneous equations that are not affected by time, a dynamic system evolves over time and therefore must be described by equations that link past variables with present variables, since the state of the system depends on the previous state.

Therefore, this article aims to analyse the impact

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these methodological differences have in the evaluation and prediction of a building's energy consumption.

2.1 Building Description

The building subject of this article is located in the northwestern of Italy; it has a sinuous shape that stretches along the north direction and is mainly for office use; it has an area of 15,000 m^2 and houses about 600 employees. The building has seven floors on one side, while on the other floor it reaches 4 floors.
A portion of the building is also dedicated to reception, gymnasium, relaxation room, cafeteria and open spaces.
The façade of the building is entirely composed of glazed surfaces alternating with opaque "spandrel" panels. The glazed surfaces are composed of two types of frames: one used for the flat surfaces, and one used for the curved surfaces of the building. The glazing surface used in the flat facades is triple glazing with double chamber of 22 mm filled with 90 percent argon gas; the total thickness is thus 74 mm. In contrast, the glazing surface used in the curved facades has a triple glazing with 12 mm double chamber filled with 90% argon gas, reducing the total thickness therefore to 54 mm.
The facade of the building's elevated floors features a series of shading both inside and outside to reduce incident solar radiation in summer and avoid the phenomenon of Glare (glare from the sun). On the exterior facade there are vertical and horizontal baffles of about 30 cm for the entire extent of the wall.
The main thermophysical characteristics of the building's envelope are shown in the Table 1.

Table 1 – Thermophysical characteristics of the building's envelope

Description	Thermal Trasmittance	Solar Factor (for windows)
Opaque exterior wall	0.19 W/m²K	-
Opaque panel	0.3 W/m²K	-
Roof	0.186 W/m²K	-
Window	0.75 W/m²K	0.26

Within the building there are activities and machinery that, in addition to consuming energy electricity, generate, along with people, a certain amount of heat and thus affect the energy balance and heat load of a building.
Table 2 shows the main values considered.

Table 2 – Internal loads, lighting power density and occupancy

End Use	Plug Loads	Lighting Power Density	Occupancy
Office	12 W/m²	11 W/m²	14 m²/persona
Meeting Room	12 W/m²	11 W/m²	14 m²/persona
Stairs and Toilets	2 W/m²	7 W/m²	unoccupied
Data Room	120 W/m²	5 W/m²	unoccupied

The building is also equipped with a daylighting control and dimmable artificial lights according to the following set points:

- Office and meeting room: 500 lux
- Corridors, stairs and toilets: 200 lux
- Reception: 300 lux.

The building uses multipurpose groundwater heat pumps for its conditioning.

2.2 Real Energy Consumption

Knowledge of actual building consumption was possible through the monitoring of the simulated building (in this case, the reference report is related to the year 2019). One of the main difficulties comes from the fact that the measurement of electricity consumption was carried out on cabins common to several buildings in the complex, and therefore some of the meters represent not only the consumption of the modelled building but also those of two adjacent buildings. To compare the results, it was necessary to estimate the share attributable solely to the modelled building through information present in the monitoring report.
The report divides consumption into the following items: Air conditioning, lighting, FEM (electrical

equipment), Fans, Pumping, ACS (domestic hot water), UPS (lighting), UPS (FEM) and CED (Data Room). UPS (lighting) and UPS (FEM) are the consumption related to lighting and electrical equipment connected to a UPS (Uninterruptible Power Supply) system, i.e., a system of batteries that manage to power these loads even in the event of a power failure, e.g., in the event of a blackout; since the batteries themselves do not consume any current other than that required by the loads, the consumption of these two items was added up to those of lighting and FEM, respectively.
The following figures show the monthly trends (Fig. 1), the energy use intensity (Fig. 2) and the percentage distributions of the main electric consumption items (Fig. 3).

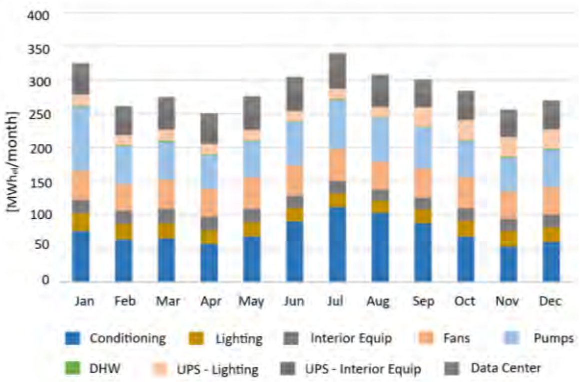

Fig. 1 – Monthly consumption trends

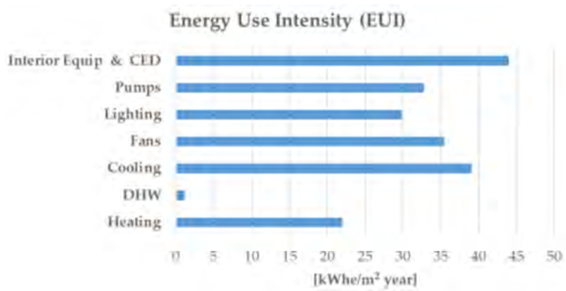

Fig. 2 – Energy Use Intensity for different items

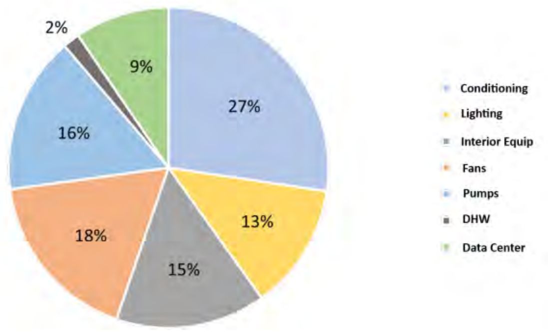

Fig. 3 – Percentage distributions of electric consumption items

2.3 Dynamic Energy Simulation

The tool used to simulate the building is the simulation software in DesignBuilder version v7 that uses the simulation engine EnergyPlus but with a user-friendly interface that allows users to enter geometry and useful data for simulation intuitively and quickly.
The weather data comes from the software Meteonorm, a global standard and a powerful tool for solar energy applications and building design.
As mentioned, one of the main problems (and at the same time one of the main challenges) of dynamic energy simulations is the energy gap, i.e., the difference between estimated and actual energy consumption.
This project also showed this issue, and by monitoring real consumptions, it was possible to calibrate the energy model to make it as closely aligned as possible with real usage conditions.
The Fig. 4 shows the difference between pre and post occupancy simulation.

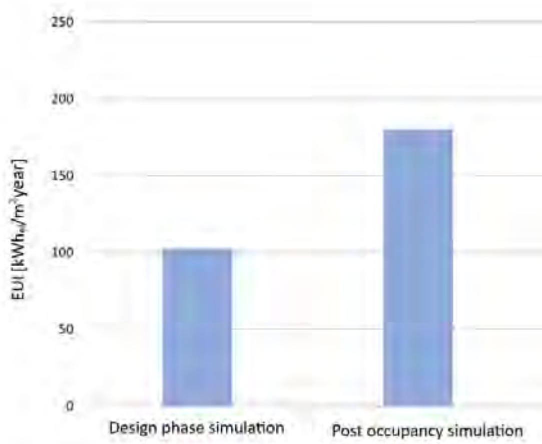

Fig. 4 – Pre and post occupancy simulation results

The main discrepancies between the two models were:

- The evaluation of the internal loads
- The occupancy profiles
- The real set point temperature in the building
- The value of the temperature of the air supplied by the Air Handling Units
- A more accurate calculation method of the energy consumption of the ground water pumps, thanks to a new version of the simulation software. With this new approach, it was possible to recreate the actual operation of groundwater (Fig. 5) heat pumps by "simulating" with district cooling/heating the effect of groundwater in summer operation (condensation) and winter operation (evaporation).

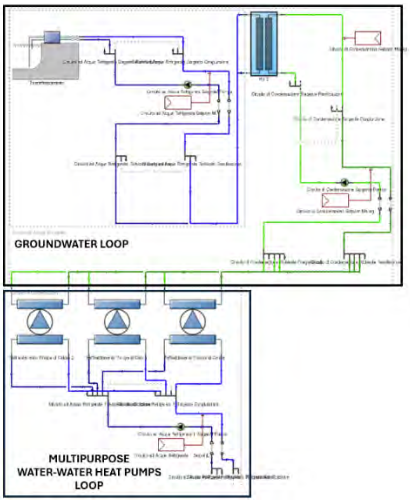

Fig. 5 – Detailed simulation of the groundwater loop

The EUI for different items of the post-occupancy simulation is reported in Fig. 6, while Fig. 7 shows the percentage distributions of the electric consumption items.

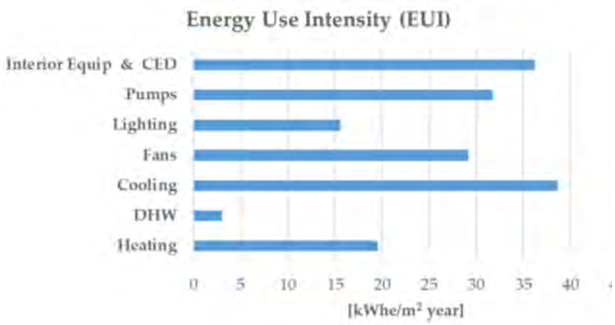

Fig. 6 – Energy Use Intensity for different items

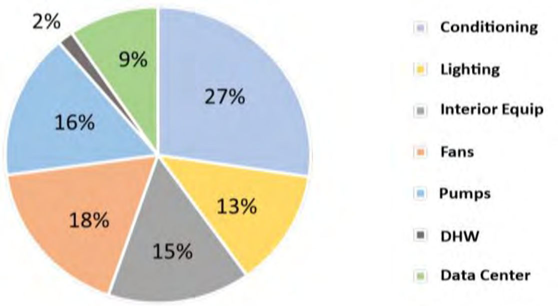

Fig. 7 – Percentage distributions of the electric consumption items

Fig. 8 highlights the gap between the two simulations and real consumptions.

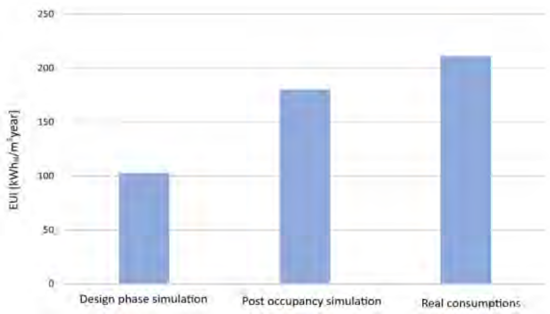

Fig. 8 – Gap between real and simulated consumptions

2.4 Italian Regulation

When assessing energy performance to ensure compliance with current regulations, it is crucial to use a standardized calculation method. This involves a clear procedure with standardized values, as outlined in the UNI TS 11300 standards (transposition of the European ISO 13790). Such calculations are mandatory for new constructions and are required for property transactions like buying, selling, or renting. The results are documented in an Energy Performance Certificate. This calculation should be streamlined, efficient, and accessible to a wide range of professionals with foundational knowledge of energy principles.

The current regulation uses a semi steady-state calculation method based on monthly evaluations (also in terms of weather conditions), then adding up the relative consumption to obtain annual or seasonal value.

The compilation of an energy performance certificate leads to a consumption index per unit area of non-renewable primary energy; however, it is possible to derive from the calculation software the

relative electricity consumption necessary for the comparison in this article.
This consumption, broken down by the different items, is shown in Fig. 9.

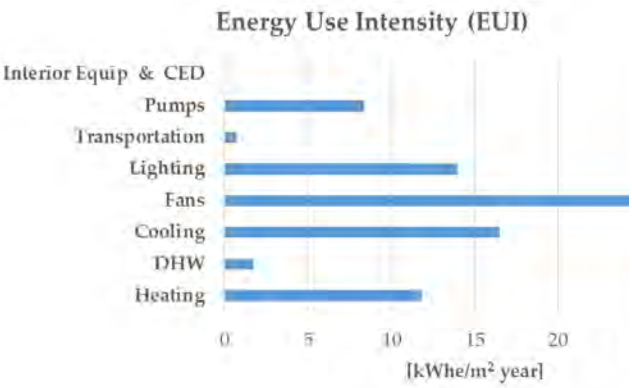

Fig. 9 – Energy Use Intensity for different items

2.5 Comparison of the Results

Two figures summarizing the results of the three different calculation procedures are shown below, first highlighting the ratio for each consumption item (Fig. 10) and then the overall results (Fig. 11).

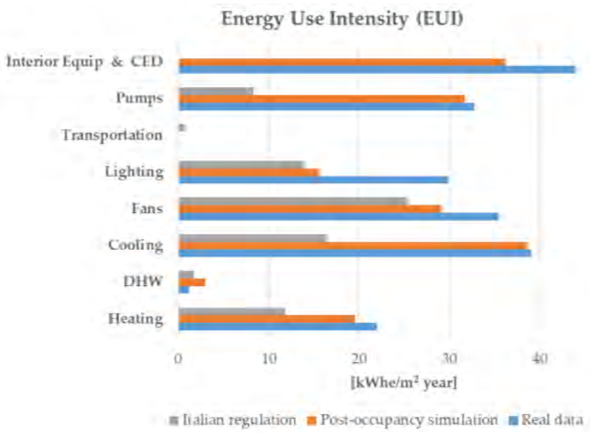

Fig. 10 – Comparison between EUI for different items

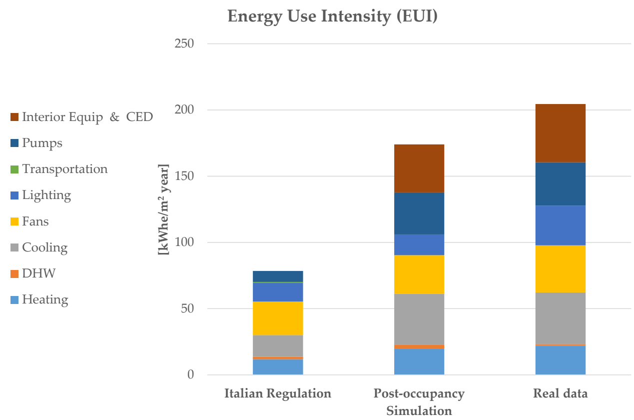

Fig. 11 – Comparison between Energy Use Intensity

2.5.1 Comparison between Post-Occupancy Simulation and Real Data

From an energy simulation, one should not expect an exact prediction of consumption, since the behaviour of a building is influenced by many factors that a simulation necessarily cannot predict and simulate accurately.
The Fig. 12 underlines how the calibration of the energy model as a result of the data provided after the occupancy of the building and the more accurate implementation of system part related to the groundwater system, leads to an overall difference between the two cases of 11 %, a result that can be considered satisfactory.

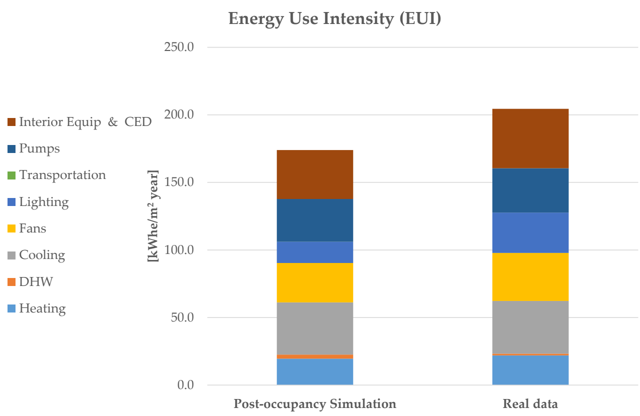

Fig. 12 – Comparison between Energy Use Intensity

However, the inevitable residual difference is mainly due to a series of factors such as:

- weather file: it probably represents the major impacts on building energy consumption, and the one used in the simulation is based on a TRY (Test Reference Year) that often fails to represent the large climatic variations that can occur from year to year and recent weather changes.
- habits of the occupants: people regulate their comfort level by interacting with the indoor environment and facility control systems. These interactions between individuals and the building influence both energy consumption (also for the interior equipment) and thermal/visual comfort. However, although the simulation was performed on a post-occupancy situation, it was not possible to obtain accurate information about people's actual behaviours.
- real data: as mentioned above, since electricity consumption was derived from values including other buildings, it is inevitable to expect a margin of error in estimating actual consumption as well.

2.5.2 Comparison between Post-Occupancy Simulation and Italian Regulation

Different reasons, on the other hand, underlie the difference between the consumption derived from the energy calculation according to the Italian standards and that obtained by the dynamic simulation.
Below are the main factors:

- Weather data: it is important to remember first of all that the monthly semi steady-state method implies that in the calculation of heat loss/input, the reference values are monthly averages, without taking into account the hourly variations that actually happen. In addition, the weather conditions used in the calculation according to the Italian standard is derived from UNI 10349:1994, since the building practice is prior to 2016 and therefore does not contemplate the updated data more similar to 2019, the reference year of real consumption.
- Software limitations: the calculation software according to the Italian regulations has limited possibilities to represent the actual system plant configuration; specifically in the software used, while in the heating plant it is possible to enter the real number of heat pumps, for the cooling plant it is possible to enter only one machine, with consequent inaccuracy in the calculation of the efficiency at partial loads; even the water pumps related to groundwater can be considered only as auxiliary consumption of the heat pumps, forcing a simplification that brings considerable inaccuracies with respect to the real operation.
- Operating period: the heating system is considered to be on 24 hours a day only during the period between October 15 and April 15, not considering any demands outside this time frame; similarly, the cooling system is operational only from April 15 to October 15, while the dynamic simulation shows demands outside this period since the high value of the Window to Wall Ratio of the building.
- Operation of the Air Handling Units: unlike heating/cooling systems, AHU are considered to operate for only 8 hours a day, unlike in reality; since energy consumption related to air handling is a major consumption item for office buildings, this aspect leads to a relevant divergence in consumption estimation; moreover, in the calculation according to the national standard, only the pre-heating coil is considered and the post-heating coil is left out, which could also be operational in summer; furthermore, the cooling coil cannot be implemented, resulting in the non-assessment of this consumption.
- Lighting system: lighting follows regulatory timetables and does not reflect the actual operating hours; furthermore, it is not possible to include a dimming system for lights according to the daylighting control as actually happens.
- Internal equipment: internal gains due to occupancy and different equipment, are normed according to UNI TS 11300 based on cadastral category and have well-defined time profiles. This represents one of the main critical issues since the real specific power is much higher and has a significantly different operating profile; however, these values do not contribute to the determination of the energy class of the building and consequently do not appear in the total energy consumption.

3. Conclusion

The building sector significantly contributes to global greenhouse gas emissions and energy consumption. While various phases of a building's life cycle emit carbon dioxide, the operational phase is responsible for the majority of the emissions, highlighting the importance of improving energy efficiency in buildings.

Through this paper, we wanted to share a comparative analysis between real consumption and estimated consumption at the design stage, with both a dynamic (pre- and post-occupancy) and semi steady-state analysis required by the regulations.

The results showed the importance of calibrating the dynamic model according to the real building use and at the same time its validity: the comparison between post-occupancy simulation and real data revealed a satisfactory alignment after calibrating the energy model, though residual differences persisted due to factors like weather variability and occupant behaviour; dynamic energy simulation could become a tool that can be used for energy analyses and evaluations of improvement interventions.

This paper also shows how the current method of calculation according to national regulations should be outdated because it cannot be a valid reference for estimating the real energy consumption of a building (because of weather data limitations, software constraints, operational periods, and assumptions about system operation and occupant behaviour), something that is increasingly required in the real estate field and in a view to the progressive and urgent decarbonization of the building stock.

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