A Study on Modelling Energy Performance in Buildings

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Abstract
The UK property industry needs to verify its energy usage; without this, the market cannot achieve the performance improvements necessary in order to achieve net zero carbon by 2050. In the UK, there is a stock of buildings with 'performance gaps'. This means that the energy performance of a modelled building does not equate to its actual operational performance. Design focuses on theoretical performance under standard conditions instead of paying attention to how buildings perform in reality. In this study, TAS software was used to perform conventional dynamic thermal simulation and advanced simulation for the chosen building. The aim of the dynamic simulation is to verify compliance with Building Regulations. The advanced simulation focused on the HVAC plant and its predicted energy use. The results of these two simulations were compared and analysed, and demonstrate that there are strong drivers and a coherent rationale for establishing a scheme to support Design for Performance. Dynamic simulation models include simplifications and assumptions compared to how a real building operates and underestimates the real energy consumption of the building.

Keywords: building simulation, HVAC

1. Introduction

The landmark piece of UK legislation on climate change is the 2008 Climate Change Act [1], which states that the government is committed to reduce carbon emissions by at least 100% of 1990 levels by 2050.

In the UK, carbon emissions from operation of buildings accounts for around 30% of total carbon emissions [2], mainly resulting from electricity usage, heating and cooling. In order to achieve net zero carbon buildings by 2050, buildings should target reductions in energy consumption and demand to cut down the total electricity supplied. The most cost-effective way to minimize the new infrastructure required to achieve a zero-carbon energy system is to invest in energy efficiency and demand reduction.

The design of new buildings in the UK is based on regulations that require delivering energy efficiency. However, these regulations are not achieving the intended outcome. They focus on the theoretical performance of the building's design under standard conditions instead of paying attention to how the buildings will perform in operation.

The building's operational performance is not expected to be measured and this reinforces the design for compliance culture. The real energy consumption of the building is never compared against the original predictions. Across the industry this has led to a 'performance gap' between the building's actual performance and its theoretical performance.

There is a need to change this approach, to one where designers can improve and anticipate the performance of the building's systems in use and there is a clear and transparent way of measuring the actual building performance providing feedback for future considerations. This would shift the current design from compliance culture to a 'Design for Performance' culture and will drive continual improvement and influence market behavior.

Design for Performance aims to address the operational energy efficiency of a new office building, focusing on the 'base build' services [3]. This study will assess how the Design for Performance can be implemented on educational buildings. This study deals with a new 13-storey educational building which is located in London and was constructed in 2019. The key aims and objectives of this study are to develop and validate a comprehensive and detailed model of an educational building and provide evidence for the performance gap between the dynamic thermal model (compliance model) that complies with Building Regulations Part L2A [4] and the advanced simulation model for Design for Performance. In this study, firstly, the design conditions were specified; secondly, the building services systems were reviewed; thirdly, the dynamic thermal model and advanced simulation model were constructed, and results were analyzed. It was found that the dynamic thermal model underestimated the energy consumption as it did not include the loads for fresh air and therefore undersized the heating and cooling requirements.

2. Methodology

In order to accurately estimate the annual energy consumption of the building, both the dynamic thermal model and the advanced simulation model were developed to gain a more detailed understanding of the energy usage of building services systems such as heating and cooling. Analysis of each model incorporated the building's design criteria and building services system design.

2.1. Design Criteria

The design criteria for the internal and external conditions are essential for designing the building services system. The external design criteria are 1) 31.2°C of dry bulb and 20.8°C of wet bulb in summer and 2) -4.4°C of dry bulb and wet bulb in winter [5]. The internal design criteria for typical rooms are taken from CIBSE Guides A and B [5, 6]. The design criteria of public health system are in accordance with BS 8558:2015 Guide to the Design, Installation, Testing and Maintenance of Services Supplying Water for Domestic Use within Buildings and Their Curtilages and the Institute of Plumbing (IoP) Loading Unit Method [7].

2.2. Description of Building Services System Design

A 225kW Low Temperature Hot Water (LTHW) thermally-led biofuel-fired combustion CHP engine is used to generate electricity whilst also capturing usable heat that is produced in this process. Two 650kW UltraGas 1300D high efficiency low NOx floor standing twin module boilers were specified as working in a duty/standby arrangement. The boilers operate alongside the CHP. The primary boiler LTHW heating circuit operates with a nominal flow temperature of 80°C and a return temperature of 50°C (ΔT of 30°C), and is scheduled on a demand-dependent basis.

There are two water-cooled chillers with a cooling capacity of 260kW based on the cooling load calculation from Royal Institute of British Architects (RIBA) Plan of Work Stage 4.

Hot water services are provided by centralised unvented semi-storage calorifiers. The heat generated from the central gas-fired boilers and CHP is supplied to the integral plate heat exchangers inside the calorifiers.

Mechanical ventilation systems are provided for the basement up to the second floor while floors 3 to 12 are naturally ventilated. The ventilation system of the building consists of 10 air handling units serving the different areas of the lower levels and 4 fans providing extraction for cleaners' cupboards, toilets and common rooms.

The electrical supply for lighting and small power items was distributed through multiple split load metered MCB (miniature circuit breaker) distribution boards located in the building's dedicated electrical riser cupboards.

2.3. Dynamic Thermal Model

A Building Regulations Part L dynamic thermal model was produced using EDSL TAS Engineering Version 9.4 to deliver the RIBA Stage 4 building design. This model was then used to generate the advanced simulation of the HVAC systems using TAS Systems. This software is capable of performing dynamic thermal simulations and allows the designer to predict energy consumption, CO_2 emissions, occupancy comfort and operating costs.

As with any building, architectural drawings in the form of plans, sections and elevations are essential for creating a true representation of the building. Fig. 1 shows a 3D image of the TAS Dynamic Thermal Model.

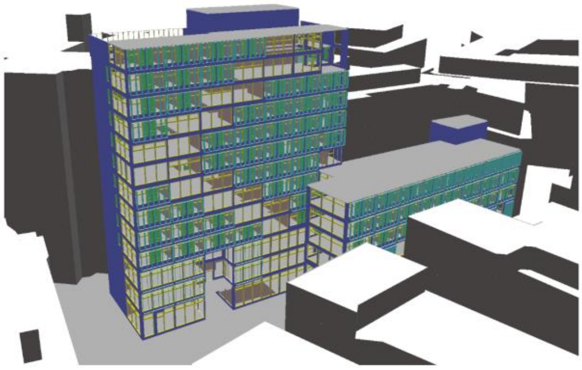

Fig. 1. Image of the TAS Dynamic Thermal Model ([8]

The methodology of how the heating and cooling loads are obtained in the dynamic thermal model is very important for understanding and validating the results from the advanced simulation. The Design for Performance model (advanced model) is linked to the building simulator so any change in the dynamic thermal model will affect the results of the advanced simulation. The attributes to be considered are weather, calendar, internal conditions and construction.

The dynamic thermal model was used to demonstrate compliance with Part L of the Building Regulations. The TAS calculation provides output in the form of a Building Regulations UK Part L (BRUKL) report. The breakdown of the energy consumption into heating, cooling, auxiliary, lighting, hot water and equipment in this document provides valuable insight into which areas have the greatest impact on the energy rating.

2.4 Advanced Simulation Model

TAS Systems was used for the advanced model. TAS Systems is a component-based plant modeler software which can be used to design, simulate and improve new and existing heating, ventilation and air conditioning (HVAC) systems. The systems can be edited to match real life designs or to test different potential options. Advanced simulation focuses on the HVAC plant and represents the proposed air conditioning, heating and air conditioning systems and controls with reasonable accuracy. This includes the specified number, capacity and configuration of plant and equipment – such as PV panels, chillers, boilers, CHPs, pumps, air handling units and fan coil units and terminal units. The results are calculated for every component for every hour of the year so yearly, daily, monthly and hourly values for temperatures, flow rates, demand and consumption can be obtained.

3. Results

A comprehensive and detailed advanced simulation model for the selected educational building was constructed and provides evidence for the performance gap. Predicted energy end-use consumptions were generated using the advanced simulation. These results were compared with the conventional dynamic thermal model for compliance with Building Regulations.

Table 1 demonstrates that there are strong drivers and a coherent rationale for establishing a scheme to support Design for Performance and summarises the differences in energy consumption by end use for the two models in kWh/m^2 based on 13,691m^2 floor area.

Table 1. Comparison of the Breakdown of Energy Use

End Use	Dynamic Thermal Model (kWh/m^2)	Advanced Simulation Model (kWh/m^2)
Heating	25.77	54.69
Cooling	4.51	12.74
Auxiliary	11.34	23.81
Lighting	10.02	21.63
Hot Water	19.88	28.50
Equipment	62.77	38.79
Lifts	0	5.16
Total	134.29	185.32

It is clear from Table 1 that there is a performance gap between the dynamic thermal model and the advanced simulation model. The dynamic thermal model underestimates the energy consumption of the building and is not representative. The total energy consumption in the advanced simulation model for this design is 185.32 kWh/m^2, while for the dynamic thermal model it is 134.29 kWh/m^2. The main differences are in the heating and cooling energy consumption, with both clearly being higher in the advanced simulation model. The dynamic thermal model calculates the heating and cooling demand for each zone, but it does not include the loads for the fresh air and therefore undersizes the heating and cooling requirements.

To model the mechanical systems in TAS Systems, technical inputs like specific fan power, efficiencies and load are required. This information is not needed to complete the dynamic thermal model and is the reason behind the lower auxiliary energy consumption.

Table 2 shows the electrical energy generated in the two models. The PV panels generate 16,285.4 kWh/year in the advanced simulation model, which is lower than the electricity generated according to the dynamic thermal model of 25,054.53 kWh/year. The technical details provided for this system in the updated model were based on the information provided by the contractor. The technical submittal stipulates a generation of 15,168 kWh/year and therefore the electrical energy calculated in the advanced simulation model is more accurate. The values obtained for the CHP generator are quite similar, at 165,053.9 kWh/year in the advanced simulation model and 176,340.08 kWh/year in the dynamic thermal model.

Table 2. Comparison of Electricity Production

Technology	Dynamic Thermal Model (kWh/year)	Advanced Simulation Model (kWh/year)
PV	25,054.53	16,285.4
CHP	176,340.08	165,053.9
Total	201,394.61	181,339.4

4. Conclusion

The model was produced as close to reality as possible using the HVAC technical information as built. It is clear that there is a performance gap between the dynamic thermal model used for RIBA Stage 4 and the advanced simulation model produced for this study. The dynamic thermal model underestimates the energy consumption of the building.

The advanced simulation model provides higher estimates for heating and cooling energy consumption. The dynamic thermal model does not incorporate the fresh air load and therefore underestimates the heating and cooling requirements.

Furthermore, technical information such as specific fan power or efficiencies are not required to complete the dynamic thermal model. In general, dynamic thermal models include simplifications and assumptions compared to how a real building operates. This means that they do not provide an accurate representation of the operational performance of the building. On the other hand, advanced simulation models focus on the HVAC plant, and so are able to represent the proposed HVAC system and controls with greater accuracy.

References

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