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Optimising Operational Energy in High-Rise Office Buildings in the UK The path towards Net Zero Carbon

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Abstract: A framework by the UK Green Buildings highlights three key steps to achieve this goal: reducing emissions through efficiency, on-site or off-site renewable energy and using offsetting schemes to address the remaining balance. The high-rise office buildings have experienced a considerable rise recently, spending 68% of total non-domestic electricity use in the UK. Such buildings have a high energy demand and renewable energy sources aren't well suited for those structures. The current energy and emissions assessment method in England is compliance modelling, which presents a performance gap. This study will evaluate the possibilities for optimising energy use in a typical high-rise building. The analyses go beyond the scope of compliance modelling, addressing the performance gap, followed by the integration of renewables to address the remaining energy demand. Design and climatic applicability synthesise the primary outcomes of this study.
Keywords: Operational Carbon, Energy Efficiency, Renewables, High-rise, Net Zero Carbon

1. INTRODUCTION

Approximately 40% of global carbon emissions are released by buildings and 50% of global material use goes to the building industry. Based on Sustainable Development Goals by the United Nations, global warming goes hand in hand with the quality of living infrastructure, well-being, and resources. There have been many initiatives, frameworks, and regulations in the UK which work as a vehicle to deliver the expected outcomes and reach the century's targets. The UK is aiming for a net zero carbon economy and this calls for offsetting carbon impacts from the built environment. In London, there is currently 6.7 million square footage of all office space in the capital, and over 50,000 commercial buildings in London, growing each year (Eurodita, 2022). The most obvious reason for the growth of high-rise buildings is the increase in population. On the other hand, the global agendas strive towards more sustainable solutions in the built industry. Based on previous research, the UK office buildings are one of the largest sectors in terms of energy consumption requiring 27.6GWh/year and 68% of total non-domestic electricity use. London offices cover approximately 300 million ft2 of office spaces and produce approximately 3 million tonnes of CO2 yearly and recently, the energy use in such typologies has increased due to building utilization (Mantesi et al, 2022). Based on the report by World Green Buildings, the whole-life approach is not established or required to bring forward at present due to the limitations in reporting the correct carbon values. Therefore, the buildings should aim for a net zero embodied carbon (construction) in new and major refurbishments and operational energy in both existing and new buildings (UK Green Building Council, 2019). Therefore, this study focuses on operational energy in a typical high-rise office building in the UK's climatic context. Previous research shows that achieving net zero carbon in a high-rise context is very challenging due to outstanding barriers. This is because the strategies applied to a specific climate are not applicable in another one. The renewables on-site generate energy, albeit with some limitations because the footprint area of the building is smaller compared to its vertical construction. In the UK, operational energy contributes to 30% of the total carbon emissions and its reduction is key to achieving scalable zero carbon (Zhigulina and Ponomarenko, 2018). Therefore, the aim of this paper is to elaborate on the approach and benchmarks set by multiple frameworks such as Advancing Net Zero, RIBA 2030 Climate Challenge, and the London Energy Transformation Initiative (LETI) Guide. The benchmark for energy consumption in commercial office buildings is 55 kWh/m^2. yr, set out by RIBA 2030 and the LETI Guide. The crucial considerations when aiming for net zero carbon building in operational energy are: reducing the energy demand and addressing the remaining balance by renewables. Therefore this study follows this path to net zero carbon, using indicative design measures set by the industry, such as the LETI Guide. Operational energy is the energy consumed by a building associated with regulated and unregulated loads. Regulated energy is the energy consumed by a building from controlled fixed building services, including installations for heating, hot water, cooling, ventilation, and lighting systems. Unregulated energy is the energy consumed by a building that is outside of the scope of Building Regulations, e.g. energy associated with equipment such as lifts, fridges, TVs, computers, lifts, cooking, and other 'small power'(CIOB, 2020). The regulated energy has been standardised and is used in compliance modelling Part L2. EDSL TAS – Part L Studio is widely used in the UK's industry and was the first dynamic simulation software approved for Part L2. However, the shortcomings of the Part L calculations and using this method have been widely recognized by the industry by now, therefore, it is not a representation of how the building will actually perform in operation. This has been leading to a performance gap that in theory achieves the desired performance but not in reality, consequently, buildings have been performing much worse than anticipated at the design stage (CIBSE TM54). Therefore, this study presents the attempts to close this gap by undertaking further simulations.

2. METHODOLOGY

The research was undertaken in collaboration with SOM, the firm that provided the case study for analysis. A typical high-rise office building in London, Broadgate tower, was used as a case study. The study was elaborated into step-by-step strategies, presenting the energy breakdown and how the building operates on different building fabric efficiencies and different systems. As anticipated in the introduction, EDSL TAS was used to evaluate energy use in the case study. Fabric efficiencies, g-values, glazing ratios, system and power efficiency measures were used following Part L and the LETI guide, as input in the building simulator (TBD. file). There are some prerequisites for using a TAS Building Simulator (TBD) file and importing it at the Part L Studio such as the following: The building should be zoned according to PartL2 methodology. The appropriate weather file to use is (CIBSE TRY). The TRY weather file contains data of 12 months each representing an 'average' and a typical weather year. It is used for making estimates of predicted energy and compliance with UK Building Regulations (Part L). The National Calculation Methodology (NCM) for non-domestic buildings is used in the TBD file. The building model should have the NCM calendar, the NCM activities applied to zones as internal conditions. Part L studio gives the option to change the infiltration rates for the building, U-value check (whether it is Part L compliant), lighting control strategies, HVAC setup where zones are grouped on Systems Groups to assign the air-sided HVAC configurations, set up the demand control ventilation, systems for heating, cooling, domestic hot water and renewables. Each system group can be further detailed in efficiency (SEER, COP, EER values). Moreover, the daylight studies were carried out using Climate Studio, renewables were added using EDSL TAS Part L Studio. However, the energy compliance modelling figures are standardised and do not show actual energy use and performance. The building was modelled in EDSL TAS, containing just one floor, that presents a characteristic floor, and the results are presented in kWh/m^2.

3. OPTIMISING OPERATIONAL ENERGY

The results present the annual energy demand, consumption and CO2 emissions for the base case and alternative cases. The energy breakdown represents the regulated loads in the building such as heating, cooling, lighting, domestic hot water, auxiliary and equipment.

– *Scenarios 1 & 2* were simulated as a fully glazed building. The assumptions of constructions were based on Part L fabric U-values, (External walls -0.18 W/K/m^2), double glazing windows with a 0.45 G-value, mechanical ventilation with heat recovery of 80% efficiency, and air tightness of 3.00 m3/h.m2@50Pa. *Scenario 1* was simulated as a mechanically ventilated building with no natural ventilation therefore it shows very high cooling loads. To reduce the cooling loads, *scenario 2* was tested with natural ventilation added with apertures modelled in a TBD file, on a mixed mode function control, thermostats set at 20-26ºC and a 0.25 openable proportion. The same system selection and efficiencies were applied to *scenarios 01 to 05*, besides a slight improvement in mechanical ventilation with heat recovery system where scenario 04 and 05 were simulated with a 90% of exchanger efficiency. The HVAC system was selected as fan coil system. The toilets used only extract fan with radiators on the zone providing heating as needed. The results on *scenario 2* show a 89% decrease of cooling loads (from 84.17 to 9.31 kWh/m^2.yr) from the base case, which result in lower energy consumption and less CO^2 emissions.

– The key difference between *scenarios 02 and 03* is the glazing ratio and daylighting control. Scenario 3 has a 60% glazing ratio and photocell control dimming. By this improvement, the heating loads decreased from 2.27 kWh/m^2.yr to 1.69 kWh/m^2.yr and the cooling loads decreased from 9.31 kWh/m^2.yr to 6.82 kWh/m^2.yr. The lighting demand was decreased by 46% by adding control demand.

– *Scenario 4* was simulated using the LETI Guide design indicative measures such as: fabric U-values, (External walls – 0.12 W/K/m2), triple glazing windows with a 0.4 G-value, mechanical ventilation with heat recovery of 90% efficiency, and air tightness of 1.00 m3/h.m2@50Pa. As a result the heating, cooling, auxiliary and domestic how water energy demands were reduced.

– The glazing ratio was further reduced in *scenario 5*, by making it 40% and demand-controlled ventilation added to control the

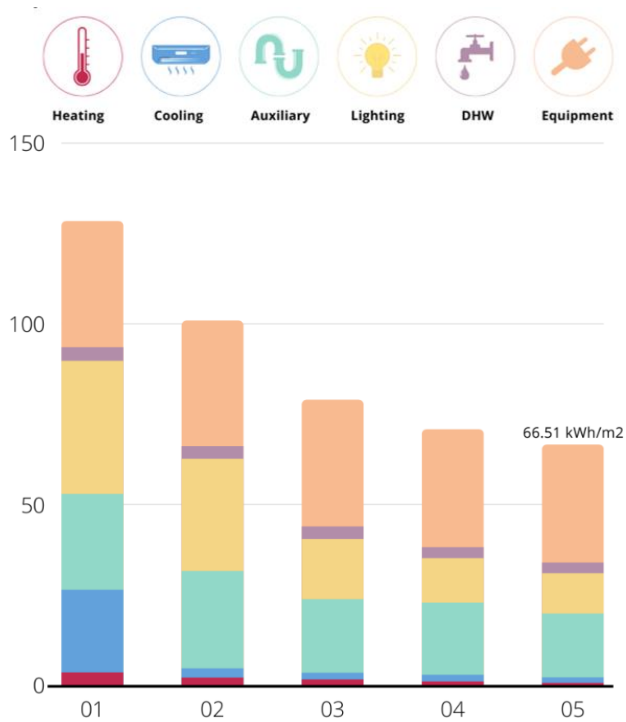

Figure 1. Scenario 1-5; Summary of the Reduction in Energy Consumption

amount of fresh air in the building based on the number of occupants and CO_2 levels, following CIBSE recommendations.

– Furthermore, heat pumps were added to scenario 06. The studies show that ground or water source heat pumps are more efficient with heating efficiency of 370% and cooling COP of 5.0 as shown in figure 2.

The inputs in the air-side configuration in Part L Building Regulations Studio as are follows:

Table 1. Air-side Configuration - Inputs in Part L studio

The heat source:	Heat pumps- ground or water source
The demand control:	Based on gas sensor
HVAC Heat Recovery:	Thermal wheel
HVAC Type:	Chilled ceilings
efficiency of exchanger:	0.8x
Extract and Supply Fan SFP:	0.7W/l/s
Terminal Fan:	0.3W/l/s
The fuel source:	Grid Supplied Energy with heat pump selected

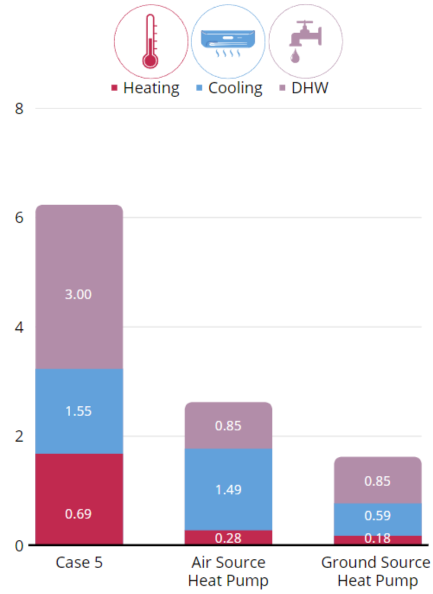

Figure 2. Heat pumps integrated in the case study - Comparative results

– Further improvements were required to reach the benchmark. Therefore, the plan layout was changed, positioning the meeting rooms near the South-East façade and providing them with natural ventilation and natural light. This presents scenario 07 and shows that by changing the layout, the cooling demand decreased by 67% and auxiliary by 25%. The energy demand was also decreased in heating and lighting as shown in figure 3.

– Fixed external shading was added with a width of 0.70m. This results in increasement in heating, cooling and lighting loads. However, the daylight studies with internal dynamic shading show that shading devices are required to be open approximately 20% during 06:00-08:00 AM and around 40% during mid-day. There is more need for shading during mid-seasons and less during winter time due to the sun position.

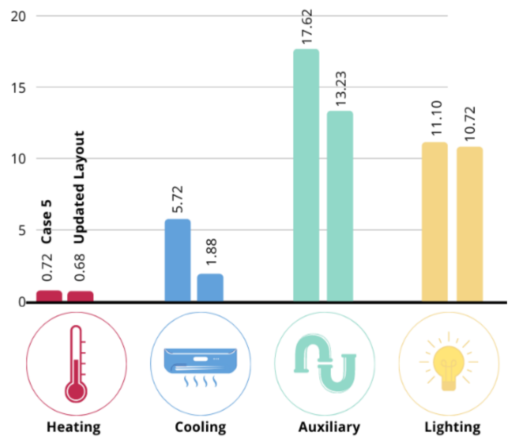

Figure 3. Energy demand (kWh/m2) Layout change

– As defined in the introduction, the unregulated loads are: lifts, plug loads and occupant density. Internal gains calculation was based on CIBSE Guide A (2016). The benchmark allowances for internal heat gains in general office building 12 W/m^2 , the occupancy gains 6.5 W/m^2, and in addition also accounting for equipment in idle mode. Only the working space is approximately 500 square meter, for around 50 people working in the area. The floor area per person/m^{-2} is 10. The energy calculation of lifts was based on the CIBSE TM54 methodology where (E_d) is the estimated daily energy consumption as a sum of the running consumption (E_{rd}) and the standing (Idle/standby) consumption (E_{sd}). ISO 25745-2 provides the energy performance classification for lifts. Therefore the total energy consumption by lifts was assumed to be 10 kWh/m^2 annually.

1.1 Renewable Energy Sources

PV panels were integrated on the roof area and on the façade where applicable, accounting for the useable space on the facade, based on a 40% glazing ratio. Considering that the only available space for PV panels in the roof area was 800 m^2, as the rest of the roof contains chiller plants and other systems, the proportional area used per one floor was calculated by dividing 800m^2 by the number of floors – 33. As a result, 800 / 33= 24m^2, a dedicated space per each floor. In summary, the total surface area for PV panels was assumed to be 20m2. An orientation of 180° (South) was assumed for the PV panels integrated into the roof area. The inclination of PV panels was assigned to 35.0° with a 20% efficiency profile, like most of the commercial panels. Moreover, the PV panels were assigned to the south and south-east façades, using 90° inclination. The results from Part L studio show that displaced electricity from the PV panels is 10.85 kWh/m^2 annually for floor the area of 1457m^2. This means the proportional space on the roof and the façade integrated PV panels generate 16,003 kWh per floor annually.

4. DISCUSSIONS

Comparing scenarios 1 and 2, the findings show the benefit of having natural ventilation in a building. In summary, the outcomes suggest that using Part L fabric U-values and efficiency measures are not sufficient. Moreover, the equipment loads, as shown in all scenarios, are approximately 32 kWh/m^2 of energy consumption, and these did not change throughout the alternative cases despite the improvements. This is because the NCM activities which also include the equipment gains, when applied to internal conditions, must not be changed when using the Part L Studio. Therefore this was covered in the unregulated loads calculation, reducing them to 12kWh/m^2.

The use of the indicators from the LETI guide was proven to work in terms of energy use reduction. Furthermore, the positioning of the meeting rooms near the façade is encouraged as the results show improvements and lower cooling loads and this proves that changes in design layout highly impact the energy use in the building. The efficient use of space, natural light, and natural ventilation are important indicators. The results comparing air source and ground or water source heat pumps, prove that the latter are more efficient. Therefore, using efficient heat pumps with heating efficiency of 370% and cooling COP of 5.0 in the last scenario, combined with more efficient design layout, provided a further reduction of energy consumption. The results in figure 5 show that the LETI benchmark (55kWh/m^2.yr for energy consumption) was achieved and surpassed. The total energy consumption in the case study was calculated and it is reduced to 45.21 kWh/m^2 as shown in the figure 5. From the base case of total of 198.96 kWh/m^2 energy consumption, there was a 77 % decrease in energy consumption in the last scenario. By

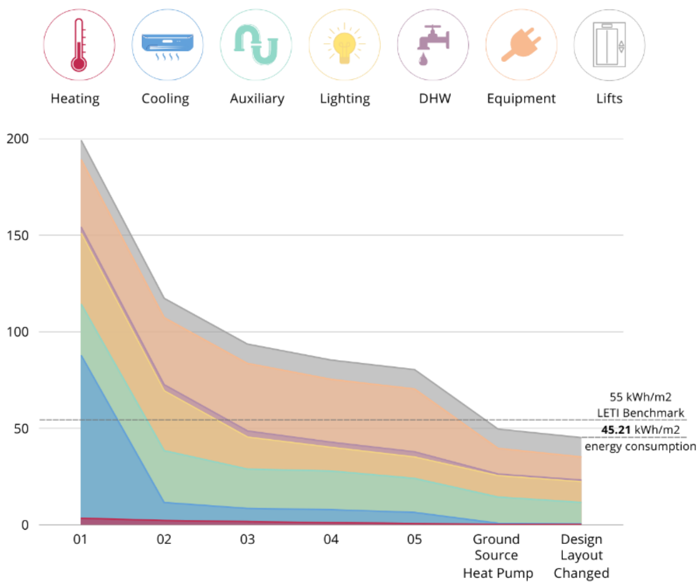

Figure 1. Annual Energy Consumption (kWh/m2) - Base Case & Alternative Cases

meeting the industry benchmark, a milestone was passed, as the building energy demand was highly reduced. The remaining energy was addressed integrating renewables into the roof area and facade. The energy generated from the PV panels on the roof area only accounts for only 16.7 % of the total energy generated. This shows the benefits of having the PV panels integrated into the façade as they have the highest contribution in this case. According to current frameworks, the remaining energy should be offset using in-site renewables, and as proven from the results, the high-rise structures are not well fit for renewable energy sources due to the insignificant surface area for installation. Additionally, the studies showed that addressing one issue in the design process, could create a challenge for other aspects of the design. A case in point is the external shading insignificantly increasing the heating, cooling and lighting loads. This could imply that shading should be carefully considered, and suggests looking for options such as internal, external adaptive shading, or kinetic facades. The whole-life approach is the final goal of the current industry frameworks, however, embodied carbon assessment is outside the scope of this research. Furthermore, the changes in the building materiality and glazing ratios impact the embodied carbon. Having a glazing ratio of 40% means that there is lower embodied carbon from the glass, and more area on the external walls. The industry suggestions vary from using biobased materials, reusing the materials, using carbon sequestering materials such as hemp or straw insulation, timber, and highly recycled materials.

5. CONCLUSIONS

In summary, the evidence suggests that achieving net-zero carbon in a high-rise context is very challenging. Based on the analytical work, a high-rise building integrating good design, efficient systems, and renewable technologies, could become net zero if it lowers the energy demand to the point that the balance by the renewables could be met by on-site or off-site renewables. This would also include the benefits a naturally ventilated building, but only in locations where there is climatic applicability of passive cooling. Furthermore, net-zero offsetting schemes and carbon offsetting trends will be the loophole for the built industry to claim their net-zero title and not achieve the standard. For this reason, future work could include the investigation of more efficient systems and up-to-date renewables. This way remaining balance would be offset by renewables and not through offsetting contracts. This study followed the current industry compliance modelling, which puts the study in the industry's context, and the analyses go beyond the scope of compliance modelling, using the CIBSE TM54 guide to evaluate the energy use in the case study.

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