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Challenges in Decarbonising Space Heating in the UK Case Study

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The British climate means that space heating is an important element of the national energy budget and is therefore a significant part of the challenge to meet the UK legal target of zero carbon by 2050. One of the solutions to this challenge is the widespread deployment of heat pumps to replace gas fuelled heating systems in buildings. Heat pumps are electrically driven and can be highly efficient. The increase in renewable sources of electricity has made electricity comparable to gas in terms of carbon intensity. However, this method of heating buildings places greater strain on the National Grid. This study examines a heat pump installation in an existing educational building previously heated by gas. Temperatures and heat outputs were logged for a typical space within the building for a defined period when weather conditions imposed a large load. Data indicated that the heat pump system coped with abnormally low outside temperatures, though further fine-tuning of controls and refinement of other services is necessary to limit the increase in electrical demand.

Key Words: decarbonization, space heating, heat pumps, national grid, energy monitoring

Introduction

The UK government has set a legal target of reaching net zero carbon by 2050. Though this refers to the whole UK economy, an important element of this strategy is the energy involved in buildings and in particular, the energy required to provide heating. Heating accounts for 37% of UK carbon emissions (Catapult Energy Systems, 2022) of which 17% is for space heating, 4% is for hot water and 2% for cooking. Decarbonising UK heating is therefore a significant part of the net zero challenge. The Department for Business, Energy and Industrial strategy has identified heating as "arguably the most difficult of the major energy consuming sectors of the economy to decarbonise". (2018). This paper considers one attempt to reduce carbon by replacing a fossil fuelled system.

Net Zero for Operational Buildings

Part of the proposed decarbonisation strategies for UK heating systems is to eliminate the use of natural gas as a heating fuel. The Committee on Climate Change (CCC) predicts that, by 2050, all domestic heating will be provided by heat pumps (52%), district heating (42%), hydrogen (5%) and direct electric heating (1%). An electrically powered solution using heat pumps for heating appears to be the presently preferred option, particularly as modern (5th generation) proposals for heat networks also involve heat pumps transferring energy from ambient loops. Although heat pumps are attractive because they can operate at high efficiencies (Coefficients of Performance), widespread use will place increasing demands on the electrical system. Crawley and Price (2022) have identified that “if most households start to use a heat pump, the “peak” winter electricity use grows to more than double the current peak winter demand”. Some work by the UK Energy Research Centre (Wilson, et al., 2018) examined UK gas and electricity demands during winter of 2017/18 (figure 1). This illustrates that meeting heating demand by replacing gas with electrical power may reduce carbon emissions but will require careful consideration of its effect on UK electrical power supply.

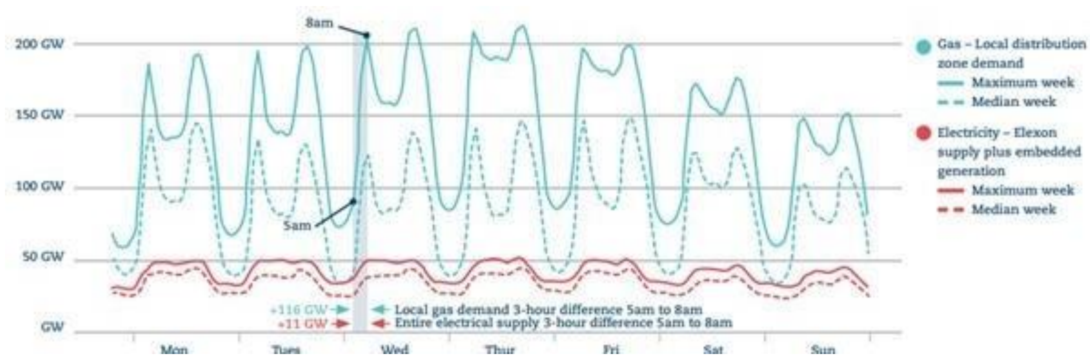

Figure 1. Britain’s local gas demand and electrical system supply - median and maximum demand weeks (source: Wilson et al)

The challenge of zero carbon by 2050 has generated a range of research projects by government industry, and academia. The Net Zero Industry Infrastructure Coalition has produced a report, which sets out three pathways (2022). These are: an electrification pathway involving widespread deployment of heat pumps combined with the roll out of electrical vehicles; a hydrogen pathway in which most homes are heated by hydrogen combustion; and a hybrid pathway where heat pumps are supported by biomethane-fuelled boilers. National grid has set out four credible pathways to achieve a fully decarbonised electricity system by 2050. (2022). Both studies have some general agreement but differ in terms of emphasis and policy. However, a theme that is consistent in all proposals, apart from the introduction of greater energy storage, is the critical need for improved energy efficiency.

Research Method

This study is an examination the decarbonisation of a heating system for an individual building. It is recognised that some of the individual characteristics for this installation may not apply elsewhere, however, a case study can provide some real -life context. This study observed parameters (internal temperatures, electricity use) which indicate if the replaced plant, not only reduces carbon emissions, but is also operationally effective. Further investigation of similar projects can contribute to greater expertise in this strategy. Replacing Gas Boilers with Heat Pumps at Henry Cotton Building.

The Henry Cotton Building is part of the Liverpool John Moores University campus and is currently used for built environment and public health studies. Decarbonising the heating system for this building has been achieved by replacing gas-fired plant with electrically powered air source heat pumps. The original plant was rated at an output of 800 kW but has been replaced by heat pumps with a total output of 420 kW.

Air source heat pumps require more space than boiler plant as well access to fresh air. The reduced output has made this less of a space problem for designers. Another advantage in this case is that the original boilers were sized conservatively. Heat demand for this building was explored using dynamic simulation and revealed that satisfactory internal temperatures could have been achieved with smaller plant (figure 2).

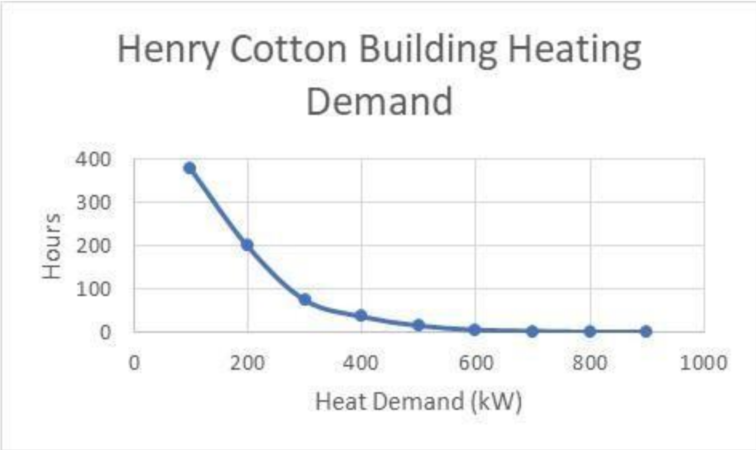

Figure 2. Heating demand Henry Cotton Building

Day (2021) considers that the relatively inexpensive cost of boilers and rules of thumb estimates has meant that historically, less emphasis has been placed on accurate sizing of boilers. Though this has, in the past, led to poorer efficiencies, increased capital costs and greater building areas and volume requirements, the original plant over-sizing has made heat pump installation easier. Images (figure 3) of the original boiler plant and new heat pumps indicate the comparative space requirements.

Figure 3. Space requirements for boilers and air source heat pumps Henry Cotton

Heat Pump Performance

To determine the effectiveness of the replaced heating plant, the heat pumps should achieve similar indoor temperatures to those provided by the original system. For carbon reduction, the heat pump should achieve a Coefficient of Performance (COP) that provides 2.5 to 2.8 kW heat output for every kW of electrical input, depending on flow and outside air temperatures (figure 4). The heat pump installation should also demonstrate elimination in gas usage for space heating and a reduction in carbon emissions.

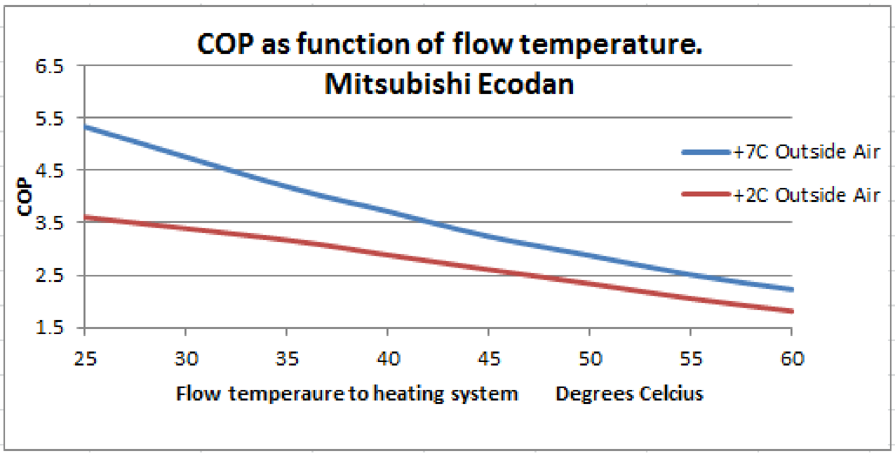

Figure 4. The relationship between heat pump flow temperature and outside air temperature (Source: CW Consulting)

An assessment of indoor conditions was made by selecting a typical space and monitoring indoor and radiator flow and return radiator temperatures over a period of seven days (9th to 15th December). This period represented a severe cold spell for the Liverpool area with consequent heat load for the Henry Cotton Building. A room temperature of around 250C (figure 5) was measured for all plant operational periods. Flow and return temperatures to radiators were steady at around 40 0C and 370C.

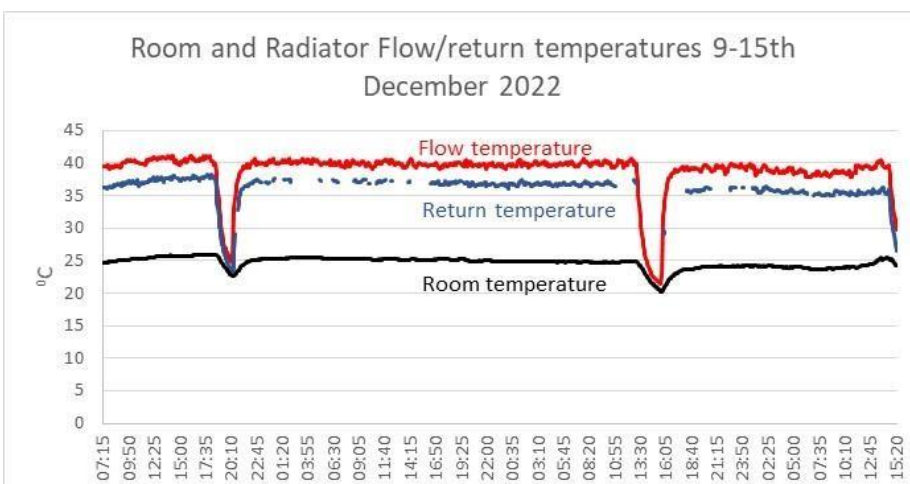

Figure 5. Room and radiator temperatures (Source: HOBO temperature monitor)

The campus building management system logged outside air temperature for the study period (figure 6). Outside air hovered around freezing temperature for much of the period and dropped as low as -50C at night.

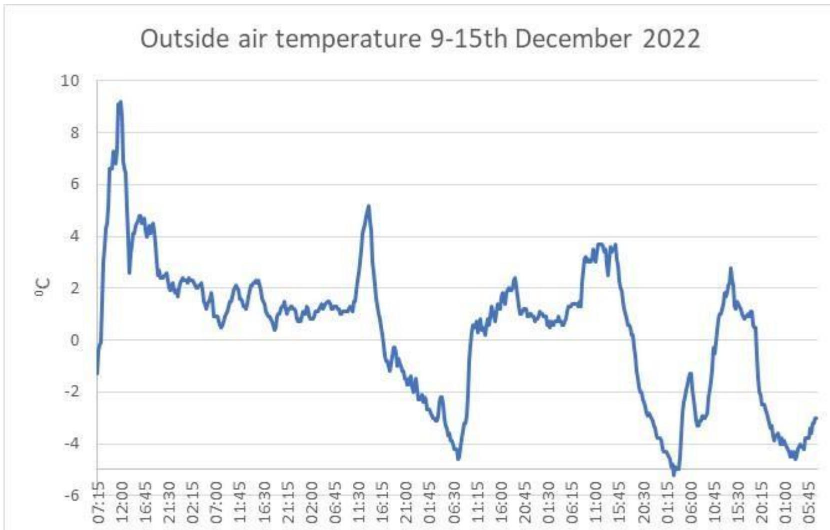

Figure 6. Outside air temperature in Liverpool (9th -15th December 2022) (Source: LJMU Campus BMS)

The campus building management system also logged heat pump flow temperature and heat delivered. The heat pump flow temperature averaged 54.50C (figure 7).

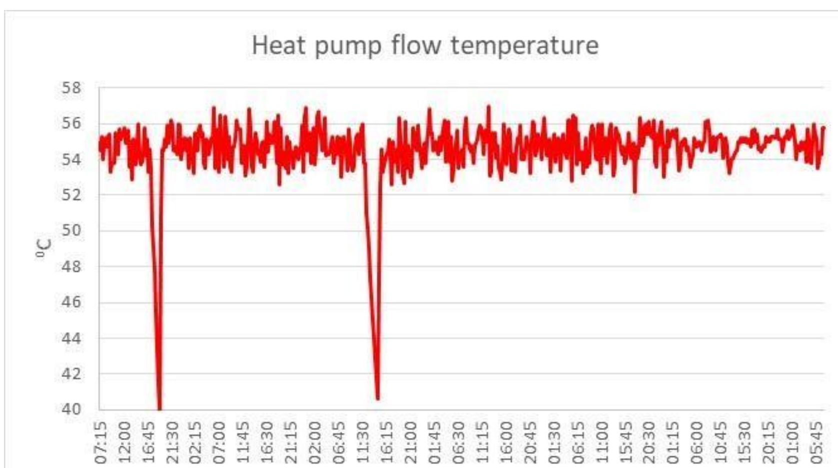

Figure 7. Heat pump flow temperature (9th to 15th September) (Source: LJMU Campus BMS)

The heat pumps delivered 23 509 kWh of heat energy and heat pump flow temperature averaged 54.50C. This figure is based on space heating to those areas heated by low pressure hot water radiators (classrooms and offices). Lecture theatre air conditioning plant was not used during this period.

Results and analysis

Room and radiator temperatures.

Low-pressure hot water heating plant in the UK has typically delivered hot water to radiators at around 800C, with a return temperature of 700C. A similar flow temperature for a heat pump system would have an adverse effect on the coefficient of performance and the design flow and return temperatures for Henry Cotton are 500C and 400C, which equates to a radiator surface temperature of approximately 450C. This lower radiator surface temperature would reduce heat output by around 54% ((Radiators, 2022)). To offset this reduction in heat output additional radiators were installed in rooms. Some over-sizing of the original installation may have assisted here. Although the actual radiator flow/return temperatures indicate a reduction in radiator heat output of 65%, the monitored room temperature was around 250C. CIBSE recommend a comfort temperature for a teaching space of between 19 and 210C (2006). For this space, the system is over-performing. The additional radiators may contribute to this effect, but it is more likely that the heating controls require some fine-tuning.

Heat Pump Coefficient of Performance

The heat pump flow temperature for the study period has averaged 54.50C. This value is higher than the system design temperature (500C). The combination of a higher flow temperature and low outside temperatures will reduce the heat pump coefficient of performance. Manufacturer's information provides data for COP's and outside temperatures of between 2 and 70C but is not clear for lower outside temperatures. The average outside temperature for the study period was 0.4 0C.
From the theoretical COP thermodynamic equation (equation 1) for heat pumps and substituting flow and outside temperatures for condensing and evaporating temperatures, a comparison of theoretical COP's was estimated, At the logged operational conditions COP reduced by 9.7% compared to 2.5 at design condition.

$$COP_{heat\ pump} = \frac{Condensing\ temperature}{Condensing\ temperature - evaporating\ temperature} \quad \ldots(1)$$

Carbon Emissions

The heat pump system delivered 23 509 kWh (LJMU campus BMS) of heat energy to the Henry Cotton building during the week 9th to 15th December. If this level energy had been supplied by gas boilers at an efficiency of 90%, the primary fossil fuel energy input would have been (23 509/0.9) 26121 kWh. The Standard Assessment Procedure (SAP) (2019) carbon factor for natural gas is 210 g CO2/kWh. Therefore, the carbon saved by eliminating gas boiler plant (26121* 0.21) is 5485.4 kg or 5.485 tonnes. The electrical energy input, using a COP of 2.4 was (23 509/2.4) 9795.4 kWh. The SAP factor for electricity is 233 gCO2/kWh. Therefore. the carbon emitted during the study period was (9795.4* 0.233) 2282 kg or 2.282 tonnes. The net saving in carbon emissions was (5.485-2.282) 3.203 tonnes.

Annual Gas and Electricity Use

The annual gas and electricity used at Henry Cotton for the year 19-22 is demonstrated in figure 8.

Clearly, gas use has diminished considerably now that none is used for space heating. However, there is a corresponding increase in electricity demand. Though the carbon emissions trade off is positive, the increase in electricity use, if cumulative can have implications at grid level.

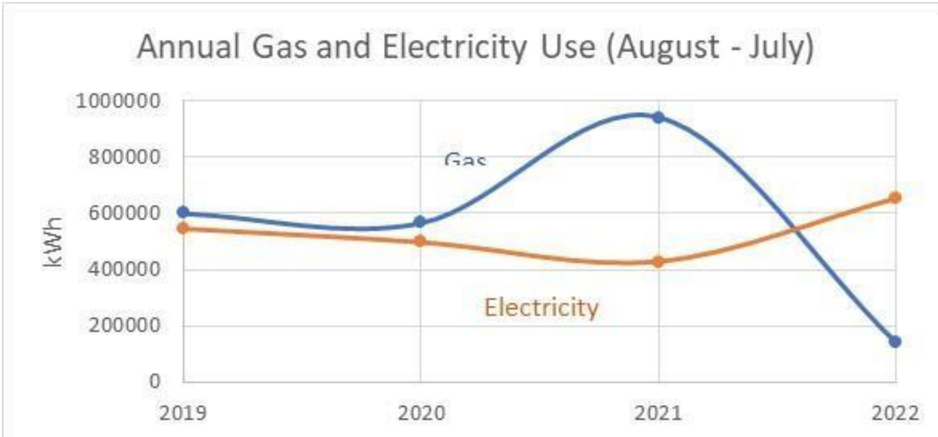

Figure 8. Annual Gas and Electricity (Source: LJMU Estates Dept.)

Conclusion

The monitored data for the study period suggests that the heat pump system effectively replaces the gas fired boiler plant by providing suitable internal temperatures and significantly reducing carbon emissions. Over a period of 7 days the heat pump system reduced carbon emissions from the Henry Cotton Building by over 3 tonnes, based on the UK Standard Assessment Procedure factors for carbon emissions. The data in this examination has been obtained from recently installed monitoring equipment and the LJMU campus building management system. While both facilities are extremely informative, further cross-checking of data with utility bills, energy meters and meteorological information will be necessary. Although the study looked at a period of high heat load, a deeper and longer monitoring exercise will be required to fully assess system performance. This exercise should also consider system control, occupant comfort, maintenance issues, potential refrigerant leakage, and running costs. The increase in electrical energy demand contributes to the load on the National Grid so it also necessary to find further efficiencies. Lighting and office machinery are candidates for reductions where co- ordination with occupancy has some potential for energy saving. Improved motor speed control measures can reduce pumping energy. The limited monitoring for this study indicates some potential over-sizing of the original design and this could be explored to find other reductions in electrical demand.

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