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REFRIGERATION AIR CONDITIONING HEAT PUMPS

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The Journey to Net Zero

Heat Pumps

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Introduction

The electrification of space and domestic hot water heating is the most efficient use of our dominant renewable energy source i.e. wind. Heat pumps provide high efficiency, can be retrofitted directly into homes and are up to six times more efficient than the substitution of natural gas with green hydrogen. However, the electrification of heating has revealed challenges with heat pumps, i.e. their end-user acceptability, capital cost, operating cost, scalability, electricity network capacities, heat pump efficiencies and potentially higher temperature requirements for existing buildings. Thus, there are geographical factors that limit the just transition to heat/grid co-decarbonisation through addressing (i) inadequate building thermal quality; (ii) inadequate electrical network capacity to address electrification of heating; (iii) insufficient understanding of stakeholders and their needs to facilitate implementation; and (iv) insufficient understanding of the interaction between these three aspects. Therefore, improved Electric Heat Pump (EHP) technologies that address heat and hot water demands for buildings will be presented alongside the potential of EHP/thermal storage for buildings.

Refrigerants

Given the expected downward trend in single family home heat distribution temperatures (through hoped for insulation improvements and new builds), the heat distribution temperatures are expected to drop for such systems from over 60°C to 40°C or less. Regarding refrigerants, low global warming potential (GWP) is an important factor. EU F-gas regulations will reduce the current dominant hydrofluorocarbons (HFCs) and will challenge R410a, the prevalent residential heat pump working fluid. Reduced GWP R452B and R454B along with R454B show marginally superior coefficients of performance (COP) [1] while R32 is becoming popular. However, some R410A replacements with a lower GWP (<150) report COPs reduced by 4% to 14% so drop in alternatives with low GWP may not be feasible [2]. Natural working fluids e.g. R290 (propane) have similar performance in purpose designed systems [3] and there are several significant manufacturers. R744 (CO_2) is growing in popularity for water heating/air heating systems via a transcritical cycle but with only a small number of residential scale manufacturers. Regardless of the choice of fluid, in changing from R410a, it appears that a low GWP working fluid will be challenging to find. R466A (R32, R125 CF3I, or trifluoroiodomethane) with a GWP of 733 appears one of the most promising in terms of performance with a 5% increase in performance [4]. Therefore, specialist fluids (R744) requiring a significant system design shift or lower density refrigerants must be utilised e.g. R290 (flammability), R444B (lower flammable, GWP = 295) or R455A (lower flammable, GWP = 146). As previously stated, R290 is well known but the relative performances of the other lower GWP alternatives are less so. R444B shows a 4-5% increase in performance over R407C [5]. R455A will have a lower performance that R410A. So R290 may become the fluid of choice alongside a limited number of milder flammability low GWP mixtures as current refrigerant chemistry has been largely explored.

Heat pump components

Considering the main mechanical components of the heat pump, system noise through key legislation comes from the UK BS4142 for example. Regarding BS4142, 35 dB(A) to 40 dB(A) at night is “typical” suburban noise level. There is also a need to add 5 dB(A) for a “tonal” quality of fan and if the sound source is 10 dB(A) above background noise “complaints may be expected”. IEA Heat Pumping Technologies Annex 51 “Acoustic Signatures of Heat Pumps" sees over 60dB(A) for operation and defrost activities [6]. Therefore, selection of acoustic covers, fan types and operating speeds, compressor speeds, pipe sizing (velocity) etc. must be considered. However, variable speed drives (compressors, fans, pumps) are necessary components in energy efficiency and in demand side response roles (when accompanied by household heat distribution controls). The concept is simple in that the thermal inertia of the building can provide a portion of demand side response (through a heat pump "off" or "throttling" phase) with throttling of the heat pump leading to 40% to 65% load reduction depending on the building and outside air temperature [7].

Thermal storage optimisation

Thermal storage sizing will be dependent on several factors including integration of household variable non-dispatchable renewable energy (e.g. solar), weather/climate, integration of local electricity network variable non-dispatchable renewable energy (e.g. wind), the impacts of a weak electricity network in terms of the electrification of space heating and the electrification of transport. In addition, for thermal storage, there are challenges of compactness in retrofitting air-source heat pumps and thermal stores in existing single-family homes and potential acceptance of aggregation control of operations in terms of electricity network capacity management. Regarding building integrated renewable energy e.g. solar, the challenges are to potentially increase self-consumption in terms of electricity (Photovoltaics) for personal economic purposes and/or limiting export to the local electricity network. The latter has ramifications for local electricity network capacity and for electricity voltage transformer sub-station abilities to reverse flow. Heinz and Rieberer [8] simulated a retrofitted single-family home in Zurich, Switzerland with PV, an air-source heat pump, and thermal storage options (water) ranging from 500 litres to 2000 litres. The proposed retrofit reduced the heating demand by 27% and concluded that "existing" radiators were a better mechanism for addressing PV integration. Thus, 5 kWp PV and a 1 m^3 thermal energy store was the most economic for a 185m^2 single family home. Insulation is important and its inclusion reduced the needs for buffer storage while battery inclusion serves the role of local building self-consumption of PV generated electricity. Shah et al [9] successfully operated a higher temperature cascade air-source heat pump and 600L of water based thermal storage responding to wind availability in a detached family home without fabric retrofit and utilising the existing hot water radiator system originally designed for a gas boiler with flow and return temperatures of 80°C and 60°C respectively.

Discussion and Conclusions

When considering the electrification of heating, actions that mitigate negative impacts on the electricity network must be prioritised. Therefore, reduction of thermal demand (e.g. building insulation) will reduce air-source heat pump electricity demand and it has been shown that it also reduces thermal storage size [9]. The electrification of heating in areas of weak electricity network will need to consider diversity factors, aggregation and potentially their role electricity network ancillary services. However, demand forecasting and status of individual heat pump and thermal energy storage systems to meet that demand is not well established, as are the relevant communications and demonstration of revenues e.g. against infrastructural upgrade deferral for example.

References

[1] *Drop-in Performance of the Low-GWP Alternative Refrigerants R452B and R454B in an R410A Liquid-to-Water Heat Pump*, Applied Thermal Engineering16 September 2020, Jaime Sieres, Ignacio Ortega, Estrella Álvarez

[2] *Evaluation of Low-GWP and Mildly Flammable Mixtures as New Alternatives for R410A in Air-Conditioning and Heat Pump System*, International Journal of Refrigeration 28 September 2020, Binbin Yu, Hongsheng Ouyang, Jiangping Chen

[3] *Vapour Compression Heat Pumps with Pure Low-GWP Refrigerants*, Renewable and Sustainable Energy Reviews 28 November 2020, Di Wu, Bin Hu, R. Z. Wang

[4] *Energetic Performance Analysis of R466A as an Alternative to R410A in VRF Systems*, Engineering Science and Technology, an International Journal, Volume 23, Issue 6, December 2020, Pages 1425-1433, Atilla G. Devecioğlu, Vedat Oruç

[5] *Low GWP R22 Replacement for Air Conditioning in High Ambient Conditions*; International Journal of Refrigeration, September 2015, Ankit Seth i, Elizabet Vera Becerra, Mark W. Spatz

[6] https://heatpumpingtechnologies.org/annex51/wp-content/uploads/sites/59/2020/11/iea-hpt-annex-51-d22-v1.pdf

[7] *Large-Scale Demonstration of Precise Demand Response Provided by Residential Heat Pumps*, Applied Energy 8 February 2019, F. L. Müller, B. Jansen

[8] *Energetic and Economic Analysis of a PV-Assisted Air-to-Water Heat Pump System for Renovated Residential Buildings with High-Temperature Heat Emission System*, Applied Energy, 27 April 2021, Andreas Heinz, René Rieberer

[9] *Energy and Economic Optimization of Solar-Assisted Heat Pump Systems with Storage Technologies for Heating and Cooling in Residential Buildings*, Renewable Energy 1 May 2020. Maria Pinamonti, Paolo Baggio