

## Performance Evaluation of a Pilot Apartment Building in Vaasa, Finland: Pathways to Low-Carbon Housing

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**Abstract** This study evaluates the performance of a pilot multi-apartment building in Vaasa, Finland, focusing on ventilation, renewable energy integration, and occupant engagement as pathways to low-carbon housing. In most apartment buildings, ventilation relies either on exhaust or centralised mechanical systems. Exhaust systems are inexpensive but compromise indoor air quality (IAQ) and increase energy use, while centralised systems maintain IAQ but lack flexibility for individual preferences. By contrast, decentralised apartment-level air handling units (AHUs) offer a better balance of efficiency, IAQ, and autonomy. The pilot building adopts such an advanced decentralised system, making it an ideal case for analysing and assessing the potential of distributed ventilation solutions. The 1113 m<sup>2</sup> building is equipped with decentralised AHUs, district heating with underfloor distribution, and an 11.6 kWp photovoltaic system that supplies about 25% of annual electricity demand. Its space and ventilation heating intensity is 34.5 kWh/m<sup>2</sup>, well below national benchmarks, thanks to a low specific fan power (1.6 kW/m<sup>3</sup>s), 82% exhaust heat recovery, and efficient system design. Domestic hot water remains the largest end-use (46.6 kWh/m<sup>2</sup>), highlighting the influence of occupant behaviour. To support behaviour change, tenants are provided with a mobile app to monitor water use, which has already shown potential to reduce demand. The performance assessment demonstrates a strong synergy between decentralised ventilation, renewable integration, and user engagement. The combination of low operational energy, high recovery efficiency, and partial on-site generation ensures both cost-effectiveness and environmental benefits. At the same time, the analysis points to opportunities for further optimisation through demand-responsive ventilation control, which will be explored in a future work on an AI-based demand-controlled ventilation strategy. A planned comparative study will test three AI-equipped apartments against 25 conventional units. A preliminary life-cycle cost analysis indicates that the proposed strategy could be implemented at relatively low investment cost, with energy savings enabling a reasonable payback period. Existing literature also supports the potential for substantial reductions in ventilation-related energy demand when compared with constant-rate systems.