Mathematical Modelling of a HVAC System Powered by Photovoltaic Panels Incorporated with a Seasonal Thermal Storage for a Single - Family Plus-Energy Home

ABSTRACT

Heating, ventilation and air-conditioning (HVAC) accounts for a sizeable portion of energy demand in today's society. Reducing the HVAC demand of a building will automatically reduce the energy carbon footprint. This thesis involves the conceptualization, design, mathematical modelling, and testing of an innovative photovoltaic powered seasonal thermal storage HVAC system (PVPSTS – HVAC system) to supply the all-year round energy needs of a single-family home. In conjunction with Prof. Arch. Anna Bać, a two-storey, single-family home has been designed to meet the latest simplified construction requirements by the "Polski Ład" of a building with ground area up to 70 m^2 and also in accordance with the Directive (EU) 2024/1275 of the European Parliament and of the Council on the energy performance of buildings (recast). The building energy analysis was carried out and a mathematical model was developed for it. The mathematical model of the innovative PVP-STS system is created on the basis of the Typical Meteorological Year data of Wrocław, Poland, after which a set of equations are derived and inputted into an electronic computing software to generate a simulation of the results. An algorithm for calculating has been developed using the "Trial and Error" method such that the results obtained at the end of the year on 31 December is equivalent to the initial data at the beginning of the year on 01 January to obtain a cyclical calculation algorithm. The required size of the storage stack was determined to be 1.6 × 1.6 × 0.3 m. The photovoltaic installation, which was integrated with the roof, can produce 48 GJ of electricity throughout the year. This is five to six times more than the building's heating needs, and any excess energy can be exported to the power grid, thus achieving a plus-energy home.

For the Seasonal Thermal Energy Storage System, different storage media and technology were evaluated and compared in terms of cost, life cycle and unit volumetric energy stored. The chosen solution of sensible heat storage in solid materials proved to be more efficient than conventional electric battery storage or even water tank storage. 12 stack-filling materials, and 9 high-temperature thermal insulation materials readily available in the local market were analyzed. 7 variants comprising of a combination of the stack's filling and thermal insulation materials were selected, and then grouped into 3 classes: advanced, medium and basic technology. Using a mathematical model, energy analysis of the year-round operation of the HVAC installation in the analyzed building was performed for each of the seven variants. The conducted analyses revealed that for each combination of filling and thermal insulation material, there is an optimal maximum temperature of the stack at which the volume of the stack is the smallest, or its costs are the lowest. It was proved that with the use of the innovative PVP-STS system proposed in this thesis, it is possible to achieve a plus-energy home standard, with costs as low as 17 times less than the traditionally used thermal energy storage in a water tank and as much as 400 times less than electric energy storage in batteries.

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