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Decreasing the Load of Air to Water Heat Pump Systems on Electrical Grids

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***Abstract* – This article focuses on decreasing the energy taken from the electrical grid by air to water heat pumps in buildings that use renewable energy. Conventionally the majority of the produced renewable energy is not used directly to operate the heat pump. An energy management concept was developed, with a main new parameter – *RCOP* that enables to create an optimal working schedule that considers the renewable energy availability and heat pump coefficient of performance in relation to the weather. The concept was proven with computer models that use weather forecasts, renewable energy production, and heat demand. The achieved yearly savings in grid-electricity used by the heat pump were 14.3 %. The fluctuations in the grid load were decreased which as well were quantified by a lower standard deviation of the demand. In months with the best renewable energy availability, the grid electricity savings can reach up to 70 %.**

***Keywords* – Forecasting; HVAC control; heat storage; renewable energy coefficient of performance; self-consumption**

1. INTRODUCTION

There are many control methods to manage the heating systems of buildings. For example, PID and self-learning algorithms. The use of photovoltaics for heating buildings has been refined in several recent studies [1]–[3]. One of the main motivations for this research is to increase the hosting capacity of electricity grids for heat pumps and renewable energy producers [4]. The number and capacity of heat pumps as well as PV stations are rapidly increasing in electricity grids, this further accelerates the need for smart and integrated systems in electricity networks.

The increasing of self-consumption, as proposed in previous research, may not give the best results in terms of overall system performance and load to the electricity grid. By only viewing self-consumption as a key indicator, direct heating with electricity may be preferred too much, which is not reasonable in buildings with heat pumps and heat storage [5].

For example, even in a case commonly seen as ideal when 100 % of the renewable energy would be consumed locally, the current optimization approach for heating enables to decrease in the energy taken from the electricity grid. The renewable energy production from solar panels is highest during hours when the heating demand is the lowest. Air-water heat pumps nowadays have commonly inverter systems that follow the heating demand of the building directly. The lack of energy storage possibilities restricts the possibilities to optimize the energy use of heat pumps, especially complicated is this with intermittent wind energy [6].

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The addition of a thermal storage tank into the heating system of a building enables to optimize the energy use of a heat pump.

The current study proposes a new energy management logic for air to water heat pumps. By using weather forecasts it is possible to predict the COP of a heat pump and thereby optimize the amount of electricity used by the heat pump [7].

In all buildings equipped with renewable energy sources, it is economically sensible and environmentally beneficial to use as much renewable energy as possible for own consumption. This means that the aim of renewable energy systems is first and foremost to reduce the amount of electricity taken from the grid. One possibility to reduce energy costs is with local wind energy like demonstrated in previous research [8], the current study uses photovoltaics as an energy source. As the air-to-water heat pump can be one of the largest energy consumers in residential buildings, its operation must be based on two aspects at the same time: 1) Minimize the energy consumption of the heat pump; 2) Minimize the amount of energy taken by the heat pump from the grid.

The study aims to decrease the energy taken from electrical grids by air to water heat pumps. To achieve this aim, the information of renewable energy production and weather forecasts to predict the coefficient of performance are integrated into the control of heating systems with air to water heat pumps. To implement this methodology in the control algorithms, a new parameter is proposed in this research – Renewable Energy Coefficient of Performance (*RCOP*). *RCOP* combines both fluctuations in heat pump parameters due to changes in outdoor temperature and differences in grid energy demand due to renewable energy production.

The hypothesis is that when using *RCOP* to optimize the operation of a heat pump, the amount of grid electricity used by the heat pump is minimal compared to other methods.

2. METHODS AND METHODOLOGY

2.1. System Setup

Assuming the conditions of the humid continental climate zone (in this case, with a heating period of at least 6 months) and the use of an air to water heat pump with a heat storage tank in residential buildings. Further, an internet connection is necessary, a photovoltaic system to produce renewable energy locally, and controllers to manage the heating system and heat pump. The study used the following setup (Fig. 1).

The building is heated by an air-to-water heat pump and renewable energy sources (in this case PV panels) are used for the building. The heat pump receives the energy needed for operation from the grid and PV panels.

The heat pump supplies energy only to the buffer tank. The energy stored in the buffer tank is used by the heating contours regulated by the indoor controller. The indoor controller operates separately from the heat pump controller.

An internet connection is used to acquire weather forecasts for the scheduling of the operation of the heat pump. The heat pump controller is used to optimize the grid energy consumption of the heat pump.

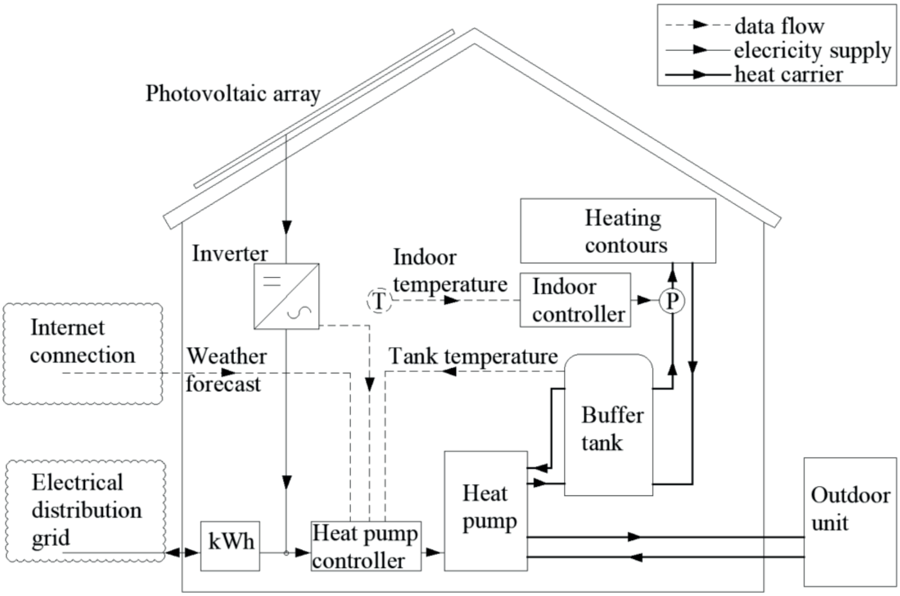

Fig 1. A heating system where the control algorithm can be implemented.

2.2. Heat demand and production

Some previous studies have considered covering separately the domestic hot water demand with heat pumps and ventilation heat exchangers [9], [10]. The current study used as an example the heating load of a building that has the following parameters:

- Heated floor area, A = 100 m^2;
- Indoor temperature setpoint, t_b = 20 °C;
- Outside temperature t, °C;
- The heating load of the building according to the minimum requirements for new residential buildings, Q_b = 0.75 W·m^2·K [11].

The heating load of the building $P_b(t)$ is characterized by the following equation:

$$P_b(t) = A \cdot (t_b - t) \cdot Q_b \,, \tag{1}$$

where

$P_b(t)$	the heating load of the building, kW;
A	heated floor area, m^2;
t_b	the indoor temperature setpoint, °C;
t	outside temperature, °C;
Q_b	the heating load of the building, kW.

The current study uses certified parameters from heat pump manufacturers (Table 1).

TABLE 1. HEAT PUMP PARAMETERS [12].

Temperature, °C	**–25**	**–20**	**–15**	**–7**	**2**	**7**	**15**	**20**	**25**
Consumed power, Pc, kW	3.85	4.95	4.88	4.28	3.4	2.51	2.18	1.98	1.88
Heating power, Ph, kW	5.82	9.89	10.8	10.8	10.8	10.8	10.8	10.8	10.8

2.3. Weather parameters and Renewable energy

The most frequent temperature range was in 2019 between 0 and 6 °C. Hourly average outdoor temperatures measured in Tartu, Estonia (58.3886874786409° N, 26.69390515955477° E) are used. The temperature distribution is shown in Fig. 2.

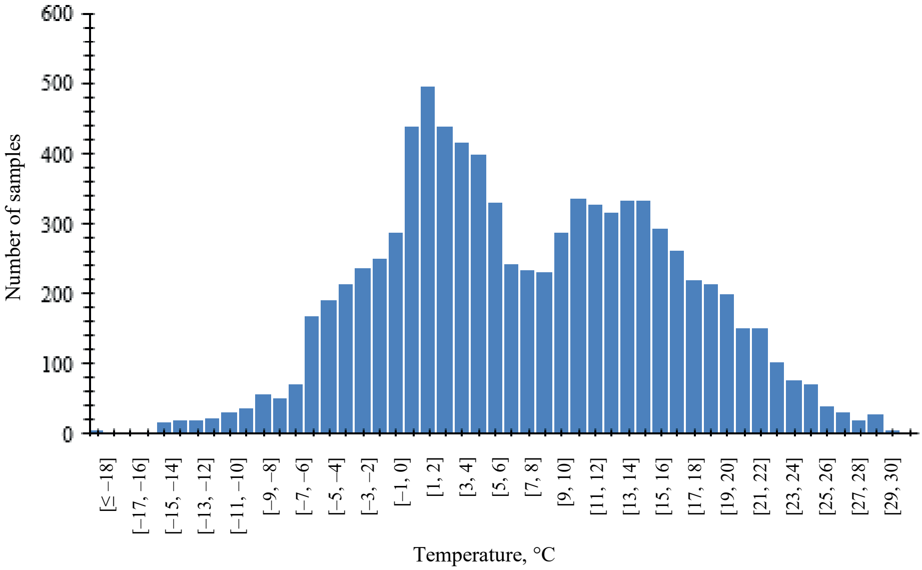

Fig. 2. Temperature distribution 2019 in Tartu.

Fig. 3 shows monthly energy production from the PV park used for modeling. Data of 2019 energy production is acquired from the PV park in the Technical Institute of the Estonian University of Life Sciences.

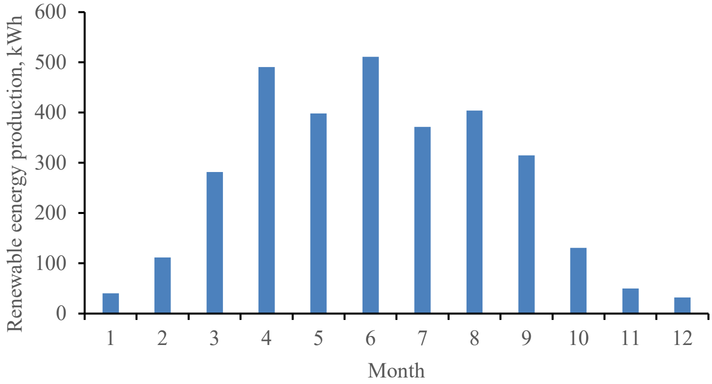

Fig. 3. Renewable energy production by months.

In practice, the weather for renewable energy availability can be forecasted with physical models, statistical models, artificial intelligence based models, machine learning and deep learning based models [13].

2.4. Methods

It is assumed that every hour when the pump is running, the maximum amount of renewable electricity available in that hour is used. The amount of grid electricity used by the heat pump is then calculated in two different approaches:

1) The operation of the pump is not optimized; it works according to the heat load of the house using the maximum available renewable energy. It is presumed that the heat pump works only at full power (on-off regime). Energy is not stored in an accumulation tank and the pump works according to demand. The electrical energy consumed hourly by the heat pump (P_{ci}) can be calculated with the following equation:

$$P_{ci} = \frac{P_b(t)_i \cdot P_c(t)_i}{P_h(t)_i}, \tag{2}$$

where

P_{ci} the average electrical power consumed hourly by the heat pump, kW;
$P_b(t)_i$ the heating load of the building, kW;
$P_c(t)_i$ the average electrical power consumed by the heat pump at a given outdoor temperature, kW;
$P_h(t)_i$ is heat pump heating capacity at a given outdoor temperature, kW.

The average electrical power consumed during the hour by the heat pump from the grid (P_{Gi}, kW):

$$\begin{aligned} &P_{Gi} = P_{Ci} - P_{Ri} \; if \;\; P_{Ci} > P_{Ri} \\ &P_{Gi} = 0 \; if \;\; P_{Ri} \geq P_{Ci} \end{aligned}, \tag{3}$$

where P_{Ri} is hourly available renewable electrical power, kW.

This means that the daily consumed electrical energy from the grid (E_D, kW) for the heat pump can be calculated by the following equation:

$$E_D = \sum_{i=1}^{24} P_{Gi} \ . \tag{4}$$

The yearly energy consumption from the grid (E_Y, kW) is calculated by adding the daily energy amounts:

$$E_y = \sum_{j=1}^{365} E_{Dj} \ . \tag{5}$$

2) The second approach is to optimize the schedule of the heat pump by *RCOP*.

RCOP is defined as follows:

$$RCOP = \frac{P_r - P_c(t)}{P_h(t)} , \tag{6}$$

where

RCOP Renewable Energy Coefficient of Performance;

P_r available renewable electrical power, kW;

$P_c(t)$ power consumed by the heat pump at a given outdoor temperature, kW;

$P_h(t)$ heat pump heating capacity at a given outdoor temperature, kW.

In the absence of renewable energy, *RCOP* is related to *COP* according to the formula:

$$RCOP = -\frac{1}{COP} , \tag{7}$$

where *COP* is the Coefficient of Performance of the heat pump.

Based on the weather forecast, the *RCOP*, the heating demand of the building, and the available renewable energy per hour are calculated for the next 24 hours. All hours are then sorted by *RCOP* in descending order. Depending on the daily heating demand of the building, the number of first hours out of the pre-arranged hours must be calculated.

This means that the daily consumed electrical energy from the grid (E_{DG}, kWh) for the heat pump can be calculated by the following equation:

$$E_{DG} = \sum_{i=1}^{n} P_{Gi} , \tag{8}$$

where P_{Gi} the average electrical power consumed hourly by the heat pump from the grid, kW; n is the serial number of the last hour from the hours the heat pump was running, sorted by *RCOP*.

The yearly energy consumption from the grid (E_{YG}, kWh) is calculated by adding the daily energy amounts:

$$E_{YG} = \sum_{j=1}^{365} E_{DGj} \ . \tag{9}$$

3. RESULTS AND DISCUSSION

The optimized and non-optimized use of grid electricity by the air-to-water heat pump for each month is shown in Fig. 4.

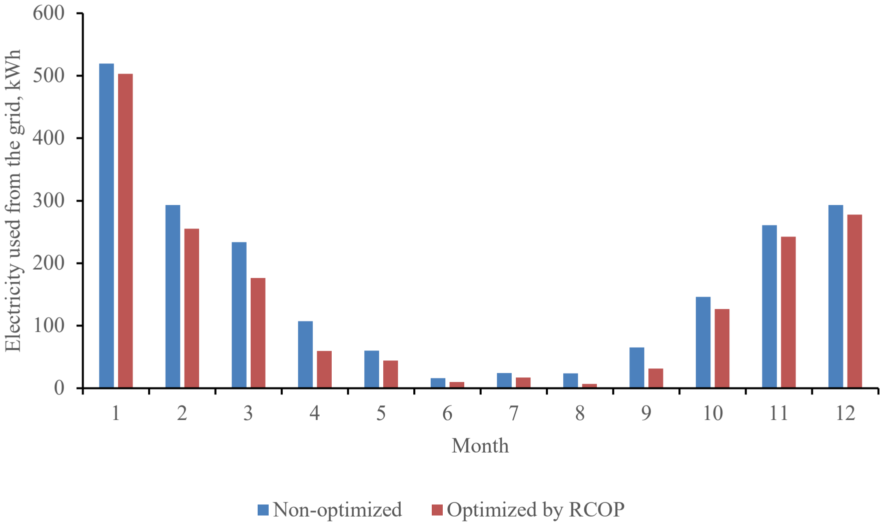

Fig. 4. The optimized and non-optimized use of grid electricity by the air-to-water heat pump for each month in 2019.

It can be seen from the figure that *RCOP* optimization reduces grid electricity consumption every month. Despite this, it has to be noted, that some months of the year have very low renewable energy production. The percentage of grid electricity use decreases more in those months when the availability of renewable energy is higher.

The reduction of grid electricity use by optimizing according to *RCOP* is shown in Fig. 5.

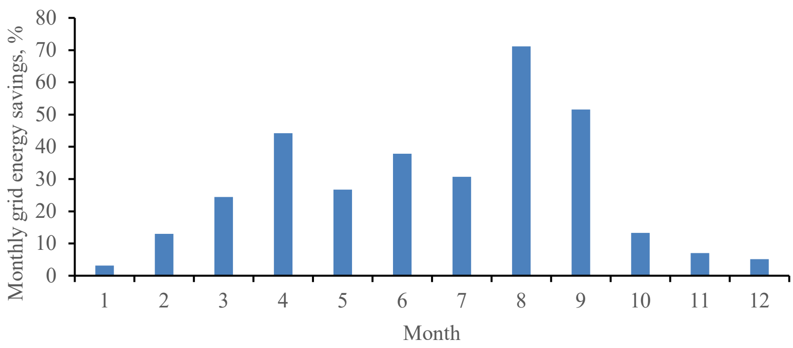

Fig. 5. Grid electricity savings with *RCOP* optimization in proportion to the unoptimized grid consumption of each month.

In 2019, the heat pump in the sample case used a total of 2526 kWh of electricity, of which 2044 kWh was taken from the grid. By using the *RCOP* optimization, 1751 kWh would have been taken from the grid and yearly grid electricity savings would have been 14.3 %.

3. CONCLUSION

Heat pumps and renewable energy generators are more and more installed on buildings and used for heating, but they do not operate in an optimal regime. The majority of the produced renewable energy is not used directly to operate the heat pump. An energy management concept was developed, with its main new parameter – *RCOP*, which enables to create an optimal working schedule that considers the renewable energy availability and heat pump coefficient of performance in relation to the outdoor temperature. The achieved yearly grid-electricity savings were 14.3 %. In months with the best renewable energy availability, the grid-electricity savings can reach up to 70 %.

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