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Using machine learning methods to save energy in a smart home

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Abstract

Despite global energy challenges and the continued increase in household electricity bills, it is increasingly urgent that people look for ways to reduce costs. This article delves into the use of data generated by smart home systems to forecast the behavior of their inhabitants, drawing insights from historical household data. Through training an LSTM neural network on this dataset, including details such as the presence of the occupants, their GPS coordinates, and weather conditions, we aim to predict hot water consumption patterns. The introduction of selective heating strategies in advance of anticipated use leads to a significant reduction in water heating energy costs of almost 30%, while maintaining comfort levels. This solution is made accessible as an add-on to the Home Assistant platform, ensuring a straightforward installation for households equipped with boilers.

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1. Introduction

In the face of rising energy prices, any solution that helps individuals reduce their expenses is highly valued. Furthermore, modern homes possess a wealth of data that can be used not only to cut costs, but also to contribute to environmental sustainability.

In households where hot water boilers maintain water at an average temperature of 60 °C, the yearly energy loss amount is around 3800 Kč. However, a simple adjustment, reducing the average temperature by 20 °C, has the potential to produce significant yearly savings, reaching approximately 2000 Kč.

2. Existing solutions

In my Bachelor's thesis [1], I addressed a similar issue, focusing on the prediction of water consumption using a long-term average approach. This method resulted in a 30% reduction in energy consumption, although with a slight impact on user comfort, when actual state of the home or its inhabitants was not taken into account. Furthermore, the diploma thesis [2] employed a different approach, utilizing selected characteristics to train an LSTM network to predict the temperature of the water in the output, resulting in a notable cost reduction of maximum 24%. The article [3] delves into the application of LSTM neural networks to predict the energy consumption of household appliances in smart homes. Using data from sensors that track temperature, humidity, and electricity usage, the results demonstrate the superior performance of LSTM models over traditional methods, showcasing their potential to optimize energy management in smart home systems and promote sustainable energy practices. The solution from DZ Dražice claims minimal 15% savings resulting from their smart heating algorithm, which is part of their OKHE SMART boilers [4]. Unfortunately, this or any other commercial solutions do not offer the possibility of smart heating based on current information on the state of the smart home, and the integration of this solution into any smart home system is almost impossible.

3. Solution

To control the heating of the boiler and measure the amount of electricity consumed, the power input of the boiler was connected to the Shelly 1PM smart relay, which was together with all sensors integrated into the Home Assistant running on the Raspberry Pi 4 with 8 GB of RAM. For this solution, data of water consumption and its temperature were collected, from which was derived the amount of heat consumed per hour. Additionally were collected data about the presence of occupants by monitoring connected devices to the local Wi-Fi router and also GPS position of the smartphones, along with information on current outdoor weather conditions. This time series data was stored in the InfluxDB database running as an add-on for the Home Assistant.

From historical smart home data, a datased was created, which was used for training a sequential model with an LSTM layer containing 100 hidden neurons and a fully connected Dense layer with one output neuron. This network is then used to predict consumption for the next six hours taking in account an actual information about the smart home and its inhabitants. The comparison between real and predicted consumption with RMSE of 0.17 is shown in Chart 1. Subsequently, this prediction is used in a heating algorithm, ensuring that the anticipated amount of heat is delivered to the boiler just before consumption. Outside of predicted consumption intervals, the temperature can remain at a lower stand-by temperature, resulting in a reduction in heat loss through the imperfect insulation of the tank shell. The system schema can be seen in Figure 1, where a high-level description of the whole solution of smart heating in a smart home is shown.

In addition to the function of the prediction of the consumption, other features were integrated into the system. The first is a vacation mode function that allows users to stop heating when they are away and not using the boiler, thus optimizing energy usage. This is achieved by creating an event on their Google Calendar, and during this event, the water in the boiler will remain at a minimal temperature.

The second is an antilegionella function, which heats the water in the boiler once every three weeks to prevent the spread of Legionella bacteria, which can cause serious health problems.

The third is an anti-freeze function, which ensures that the temperature of the water in the boiler does not drop below 5 °C which would cause serious damage to the heating system.

For households equipped with photovoltaic systems having a SOLAX API[1] was implemented function monitoring the status of battery charge, current solar production, and household power consumption. When the battery is fully charged and household consumption is lower than production, instead of selling surplus electricity at a low price, the algorithm redirects the energy to heat the boiler above its normal temperature, effectively storing excess energy for later use.

4. Results and outcome

During the testing phase of this solution in two households, a significant reduction in consumption was achieved by enhancing ratio between consumed and added energy to boiler, as depicted in Chart Chart 2. This resulted in a 27% decrease in consumption for the first household. In the second household with dynamic behavior of its members, where the prediction is less accurate, the decrease was around 20%. The trend of decreasing weekly electricity consumption for the first household can be seen in the Chart 3.

According to the feedback of residents of the two monitored households, they did not notice any significant change in comfort compared to the state before smart heating.

Furthermore, the solution offers pre-trained models to new users based on data from the testing households. This means that new users do not need a long-term of collecting the consumption data to train the model. However, users can decide whether they want to fine-tune these models with data from their own homes or opt to train their models from scratch.

This solution of the smart heating of the water based on consumption prediction and other additional functions has been published as an add-on[2] for simple integration into platform for smart homes – Home Assistant.

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