Improving the Traditional Heat Pump System Control through Prediction of Daily Solar Radiation

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It's sunny outside: does your heat pump know?
Traditional control approaches for heat pump systems in residential buildings are based on the "heating curve" setting, where the supply temperature to the heating (or cooling) distribution system is defined as a function of the outdoor temperature. If the outdoor temperature is the only control input available, the heat pump system cannot take into account important additional inputs, like solar radiation, that can substantially vary on a daily basis throughout the year and negatively affect the indoor comfort and the energy-saving possibilities.

Heat pump systems represent a well-established technology that has been growing in the last decades, reaching a mature technical development. In parallel, a new perspective for improving the efficiency and flexibility of heating and cooling systems have been rising thanks to the availability of cost-effective and powerful controller units. The computational power of electronic devices has been increasing in the last decades, together with storage and connection capability [1], and there has been a growing interest in the possibility of introducing advanced features in the heat pump system controllers. With the decreased costs of data processing, storage and communication over recent years, the design and implementation of more complex control techniques have become accessible [2], and several studies have been dedicated to the development of advanced system control.

The EffSys Expand project P18, “Smart Control Strategies for Heat Pump systems” [3], is a research project co-founded by the Swedish Energy Agency and focused on the improvement of single-family house Heat Pump heating systems. The P18 project evaluated several methods that can be potentially implemented in the controller of heat pump systems in order to increase the overall energy efficiency while guaranteeing the indoor comfort conditions. The project focused on solutions that can effectively be adopted in both newly built and existing heat pump systems. The final goal of the project was the improvement of the annual system efficiency and the minimization of the annual operating cost of the system, exploiting predictive control strategies by analyzing the data available regarding people's behavior, weather forecast and environmental condition measurements. As a result, the maximization of the thermal comfort in single-family houses will be possible together with a reduction of the annual electricity consumption obtained through the minimization of the usage of electrical auxiliary heaters. This article presents a short description of one of the solutions proposed, considering the improvement of the traditional control approach for heat pump systems through the prediction of the daily solar radiation.

The traditional and basic control approach for heat pump systems in residential buildings is based on the calculation of the supply temperature to the heating (or cooling) distribution system based on the outdoor temperature. The function that expresses the supply temperature is called the “heating curve” and is typically defined as a piecewise function.

The heating curve is typically defined and set during the system installation phase depending on the building envelope characteristics, the heating distribution type (radiators or floor heating, for example) and the design temperature conditions for a given location. The approach is based on the idea that, for a given outdoor temperature, a supply temperature can be defined to balance the building heating demand in order to guarantee an indoor temperature that corresponds to the thermal comfort conditions. In Sweden, a large portion of the heat pump installations for residential buildings consider the heating curve as the only input for the system controller. The indoor temperature is in many cases monitored but not actively employed in the control logic implementation.

The indoor temperature is not univocally related to the outdoor temperature. The solar radiation and the occupant activities, for example, represent energy gains that can affect the indoor temperature stability and thermal comfort. The adjustment of the heating curve based on additional inputs has been considered in project P18, and the results of an improvement potential study have been presented [3]. Simulation models of single-family house heat pump installations have been developed in order to test advanced control strategies that could lead to minimize the Heat Pump energy consumption while maintaining the overall thermal comfort. The results show that an energy-saving greater than 10% could be potentially achieved by compensating for the free energy gain from the solar radiation in selected periods of the year, which for Sweden are typically from March to May and from September to October.

Figure 1 shows the monthly ambient temperature distribution in Stockholm over the period 2014-2017. Figure 2 shows the Monthly values of the daily solar radiation distribution in Stockholm over the same period. In the violin plots and box plots shown in the Figures, the white dots and the middle lines represent, respectively, the median values. It is interesting to notice, for instance, that the median temperatures in April and November are quite

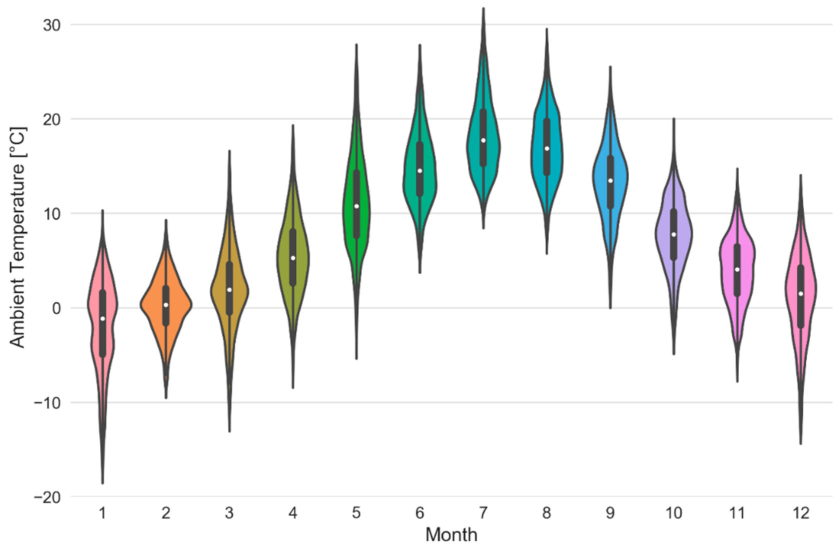

Figure 1. Monthly ambient temperature distribution in Stockholm over the period 2014-2017. Source: SLB-analys [5].

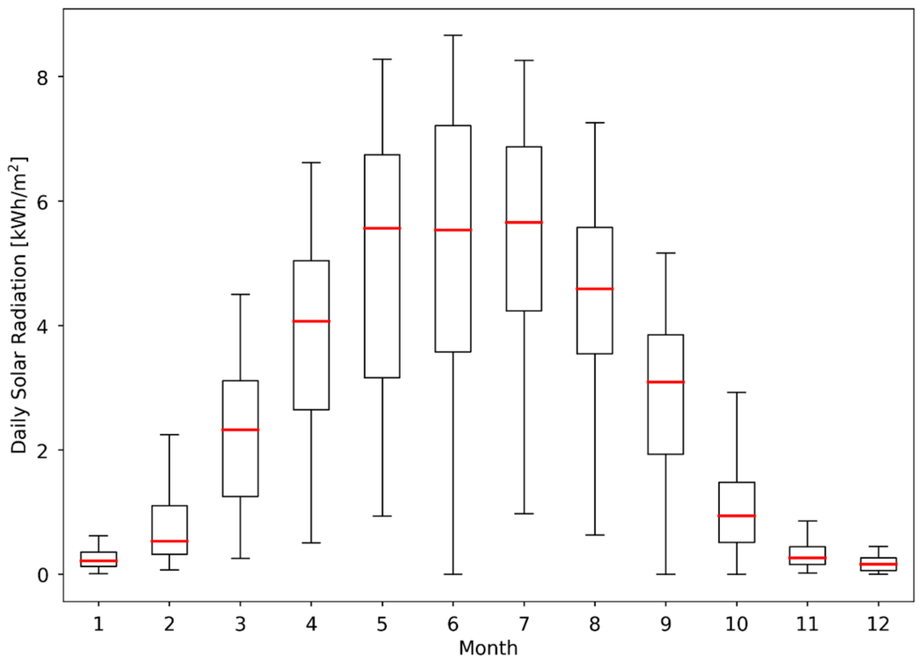

Figure 2. Monthly values of the daily solar radiation distribution in Stockholm over the period 2014-2017 Source: SLB-analys [5].

similar; the difference is, in fact, below 1.5ºC, and the temperature distribution is also comparable. On the other hand, the median value of the daily solar radiation in April is about 4 kWh/m², while in November is close to zero. The heating curve control clearly cannot distinguish between outdoor temperatures with or without of solar radiation. In principle, the prediction of the daily solar radiation would allow the heating curve to be adjusted to avoid, for example, the overheating of the indoor environment and, at the same time, reduce the energy consumption of the heating system.

Figure 3 shows the evolution of the solar radiation during one day of March, arbitrarily selected. The Figure shows both the clear sky radiation and the measured radiation. The clear sky radiation represents the maximum radiation that can be available at a given time and can be calculated considering the relative position of the sun to a given location. Worth noticing that the position of the sun is available for any time through astronomy calculations. The second curve in the Figure includes the actual measurements of the solar radiation recorded on the same day. The measured radiation is always lower than the clear sky radiation, and the ratio between the corresponding daily energy (in kWh/m²) can be calculated. In the project P18, a method to predict the daily solar radiation based on the prediction of the attenuation of the clear sky radiation was developed and implemented in simulation models of single-family house heat pump systems. The complete explanation of the method is available online in the project P18 report [4].

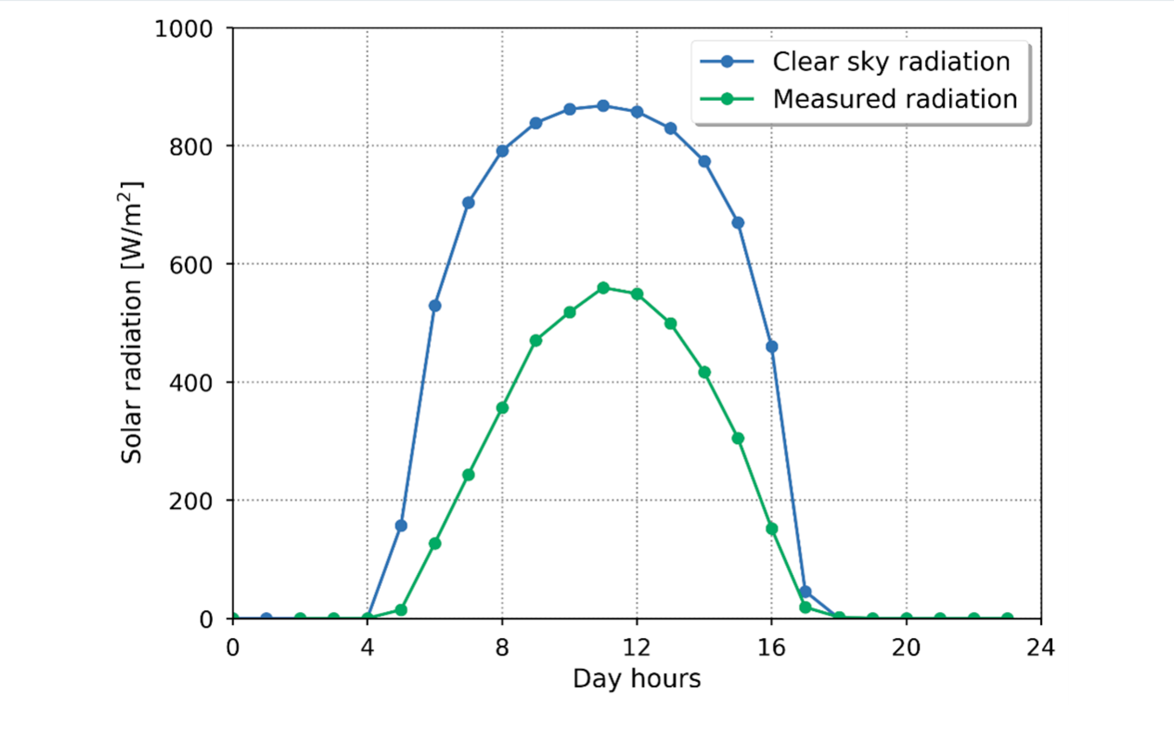

Figure 3. Example of the solar radiation profile ratio of one day in March. The theoretical clear sky radiation profile is compared to the measured data.

Figure 4 shows the results obtained through simulations performed in TRNSYS considering real weather data for Stockholm over the period 2014-2017. The results show that the modulation of the heating curve through predicting the daily solar radiation allows monthly energy-saving higher than 10% in some cases. The highest reduction of energy use occurs during the spring period while, as expected, no energy can be saved with this method during autumn and winter periods with the lowest daily solar radiation.

Conclusions

The method briefly described in this article allows energy saving that on a monthly basis can be greater than 10% compared to a basic heating curve controller and can be implemented in both new and existing heating system installations.

It is very important to mention that no additional sensors are required for the implementation of this control

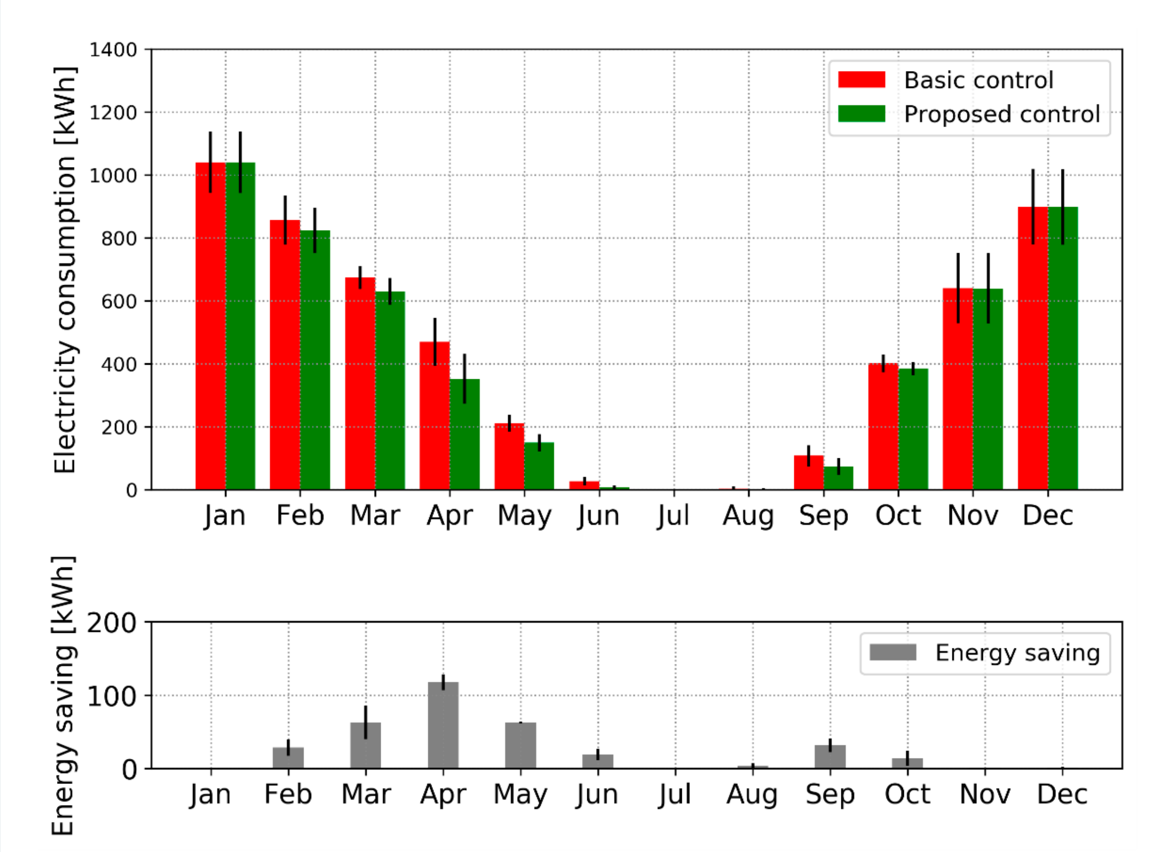

Figure 4. Summary of energy consumption and energy saving profiles resulting from the simulations with weather data considering the period 2014-2017.

strategy. In particular, no direct measurement of solar radiation is required, and no hardware modifications of the system are needed.

The proposed control strategy was developed with the clear intention of maintaining the simplicity of the traditional heating curve approach and could be implemented through a software modification of the controller.

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