A heat pump system control based on solar gain prediction

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The implementation of advanced system control strategies, able to achieve a considerable increase of the system efficiency, can represent a convenient solution to reduce the system operation costs while maintaining a desired level of comfort. A control algorithm developed within a Swedish national research project shows annual energy savings of 10%, through the prediction of the solar energy gains in single family house installations. In principle, the developed control algorithm does not require any hardware modification and can be implemented in both new and existing installations.

Introduction

The traditional and basic control approach for heat pumps in residential buildings adopted in Central and Northern European countries is based on the calculation of the supply temperature to the heating (or cooling) distribution system, which in turn is based on the outdoor temperature. The function that expresses the supply temperature is called "heating curve" and is typically defined as a piecewise function.

The heating curve has to be defined during the system installation phase. It depends 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. Considering the case of Sweden, the vast majority of the heat pump installations for residential buildings considers 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 project "Smart Control Strategies for Heat Pump systems" [1] was a research project co-funded by the Swedish Energy Agency, focused on the improvement of single-family house heat pump heating systems with traditional control based on the building heating curve. The project evaluated several possible adjustments to the building heating curve method that can be potentially implemented in both new and existing controllers of heat pump systems.

A thorough analysis has been performed to evaluate the impact that additional inputs to the heating curve control approach can have on energy saving and indoor comfort. More specifically, the prediction of user internal gains, ambient temperature, wind and solar radiation are among the inputs considered in the study for different types of single family buildings. A study on the potential control improvement based on perfect prediction of weather forecast and user occupancy was presented at the IEA Heat Pump Conference in 2017 [2].

In this article, the results regarding the development of a control algorithm based on the prediction of the solar energy gain are briefly summarized.

Heat pump predictive control

The traditional heat pump control approach is based on the building heating curve. The supply temperature to the heating (or cooling) distribution system is calculated as a function of the outdoor temperature.

The heating curve control algorithm is relatively easy to implement and setup, and is currently the most popular control approach in use for single family house installations. Despite this, a few well-known shortcomings of this approach are too often neglected.

First of all, the indoor temperature is not univocally related to the outdoor temperature. The solar radiation and the occupants' activities, for example, represent energy gains that can significantly affect the indoor temperature and thermal comfort.

Simulation models of single-family house heat pump installations have been developed using the software TRNSYS in order to test advanced control strategies that could lead to minimizing the Heat Pump energy consumption while maintaining the overall thermal comfort. The results obtained through building simulations reveal that a significant energy saving could be potentially achieved by systematically modifying the heating curve on a daily basis depending on the predicted energy gains from the solar radiation during selected periods of the year.

The inspection of a typical daily solar radiation profile can help explaining how the daily solar radiation energy gain can be predicted. As an example, Figure 1 shows the solar radiation profile in Stockholm, Sweden, during one day. The clear sky radiation profile has been calculated by considering the relative position of the sun. This

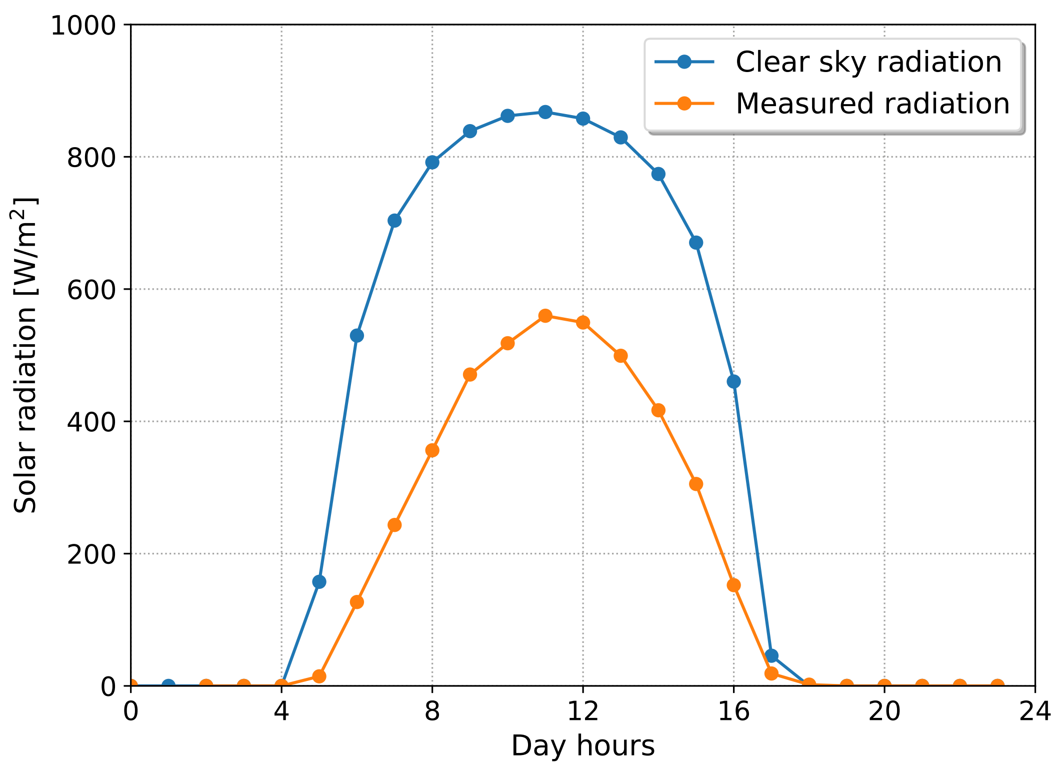

Fig. 1 Example of the solar radiation profile ratio of one day in March. The theoretical clear sky radiation profile is compared to the measured data.

calculation can be easily performed for any time at a given location and can be considered the same every year. In the same chart, the actual measured solar radiation is also plotted, showing what we call the solar radiation ratio. It is worth noticing that the area under the "clear sky radiation" curve represents the maximum energy provided by solar radiation during the selected day of the year at a given location. On the other hand, the area under the "measured radiation" curve represents the actual energy provided by solar radiation during the same day. Among the reasons that cause the solar radiation attenuation that is shown in Figure 1, the sky cloudiness is one of the most important factors. Intuitively, the more the sky is covered with clouds during the daytime, the more the actual solar radiation is reduced compared to the theoretical (clear sky) one.

Typically, over one year, there are months where the average ambient temperature is quite similar while the solar radiation is significantly different. In the case of Stockholm, for example, this can be shown considering November and April. A heat pump controller merely based on the heating curve would control the heating system in the same way both in April and November, since the ambient temperature are relatively similar. On the other hand, the effect of the solar radiation (significantly different between November and April) would lead to a possible overheating of the building, a waste of energy and a higher electricity consumption than needed.

For these reasons, a prediction model has been developed to allow the prediction of the daily solar radiation using the average cloudiness value provided by the weather forecast. For each day, in particular, the predicted energy gain due to the solar radiation is calculated considering the theoretical solar radiation profile (easy to calculate and available for any location) and the average cloud coverage that is forecasted. This prediction model has been tuned and tested in the simulation models developed by our group.

It should be noted that the control described in the article is valid also for other types of heating (for instance district heating) and cooling systems.

Figure 2 shows the results obtained by the daily solar radiation prediction model in terms of energy consumption and energy savings for a single family house building of 125 m^2 located in Stockholm.

In Figure 2, the energy consumption of the heat pump system based on the traditional heating curve approach is labelled "basic control". The energy consumption of the same system controlled considering the prediction of the daily solar radiation gain is labelled "proposed control". The same figure shows the monthly energy saving obtained by the solar radiation predictive model over the traditional control approach.

The monthly energy saving profile is clearly not uniform since, as mentioned above, the highest energy saving potential occurs for relatively low ambient temperature and relatively high solar radiation gains. These conditions typically corresponding to the period between the end of winter and the spring months.

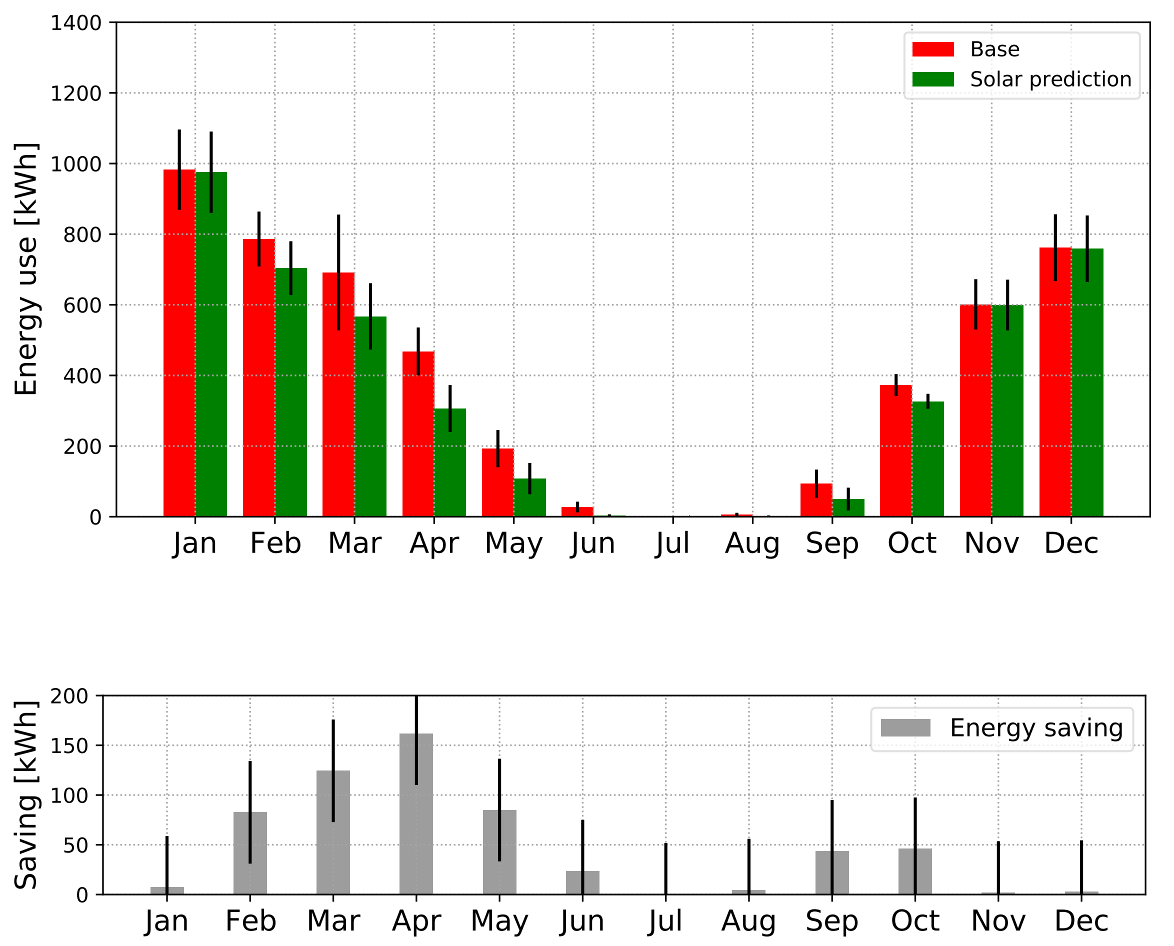

Fig. 2 Summary of energy consumption and energy saving profiles resulting from the simulations with weather data considering the period 2014-2017

The results have been obtained considering the weather data for Stockholm over the period 2014-2017 (sources: http://slb.nu and https://openweathermap.org/). For Stockholm, the monthly energy saving peak over this period always occurs over the month of April and can be up to 25%.

Conclusions

In this study, starting from the common control approach adopted in the vast majority of the Swedish heat pump systems, the heating curve, additional input variables based on human behavior and weather information have been considered in order to investigate the energy saving potential of modified control algorithms. The results shown in this article focus on the significant energy savings that can be made by considering the prediction of the daily solar radiation gains.

Through building system simulations performed by means of the software TRNSYS, the study of a new control method has been developed to allow the prediction of daily solar radiation without requiring additional sensors to be installed in the system. The simulations have been performed to compare the developed control method versus the traditional control method.

The results obtained show that the annual energy saving that can be achieved is about 9% and monthly energy saving greater than 25% is possible. The highest energy saving for the modelled system will be typically obtained over the spring period.

It is worth noticing that the control strategies here presented can be implemented in both new and existing heating system installations. No direct measurement of solar radiation is required and no major modifications of the system are needed. The control algorithm can in fact be implemented by a controller software upgrade; no additional sensors or invasive hardware are required. Also, it should be noted that the control described in the article is valid also for other types of heating (for instance district heating) and cooling systems.

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