Power Demand of Programmable Thermostats with a Built-in Pick-up Algorithm for Electric Baseboard Heaters

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Abstract: - The objective of this study is to determine the power demand impact on the electric grid when thermostat setbacks are applied in single-family dwellings. A pilot-project, consisting of 400 all-electric sites, was carried out in Chicoutimi (Quebec); 200 automated and 200 reference sites. The hourly energy demand was monitored for all sites; in addition, the space heating electricity consumption and the room temperature were also monitored for the automated sites. In the experimental sample, the wall-mounted thermostats were replaced by programmable ones equipped with a built-in pick-up algorithm intended to control the electric baseboard heaters' output. Results reveal that morning pick-up, often occurring during a peak period, increases the power demand on the utility's grid. It is shown that the implementation of an algorithm within the programmable thermostats reduce this impact by shifting the peak load before the grid's critical period.

Key-Words: - Programmable thermostats, baseboard heaters, night setback, pick-up algorithm, field test

1 Introduction

In Quebec's Nordic climate, the space heating load is responsible for a large part of the overall energy consumption in the residential market. In an effort to reduce the amount of energy dedicated to space heating, federal and provincial agencies are promoting the use of programmable electronic thermostats [1]. The promotion is based on energy savings that could be achieved through a precise temperature control and thermostat setbacks when occupants are asleep or away. A literature survey revealed that most studies done to date have focused on energy savings from the customer's viewpoint [3-6]. However, the effect on the grid if such a measure is widely implemented did not receive a lot of attention.

Hydro-Quebec[1] is concerned by the impact of thermostat setbacks on its grid for the following reasons:

- With today's prices, programmable thermostats are becoming more popular.
- Approximately 70% of Quebec residential customers are using electricity for space heating.
- Most of commercially available line-voltage programmable thermostats do not have a built-in algorithm that allows a gradual increase of the thermostat set point.

This study provides a look at the user's behaviour with respect to setback schedule as well as the impact of programmable thermostats on the power demand during peak hours from the utility's viewpoint. Remedies are proposed to reduce this impact.

2 Instrumentation and procedure

Programmable thermostats that have been used in this project were specially designed to monitor the duty cycle, the temperature set point and the room temperature via the thermostat's thermistor. The duty cycle is defined as the ratio of ON time to the total time per thermostat cycle. The communication between the centralized data collector and approximately 1450 thermostats is achieved at 5 minute intervals using power line carrier.

An algorithm has been implemented into the thermostats in order to smooth the power demand often occurring during the utility's peak periods. The algorithm controls the baseboard's output based on the room and set point temperatures and on the previous days' space heating load, using an auto-adaptive routine. The algorithm in question is well described in a pending patent [2]. The power output of each baseboard heater has been measured at full

[1] Hydro-Quebec is a major Canadian electric utility with a 38000 MW generation capacity mainly from hydroelectricity. It is a winter peaking utility.

load. The space heating energy consumption is deducted by multiplying the power output by the duty cycle.

The hourly energy demand was monitored for the 400 sites participating in the project. The monitoring campaign lasted for two years: a year before the replacement of the thermostats and a year after.

Although occupants have been instructed to maintain their initial schedule and thermostat set-points, they were free to adjust the thermostat settings as needed. but most of them did not alter the initial settings.

3 Results and discussion

3.1 Setback and pick-up schedules

The setback schedule and the pick-up hours programmed by the occupants are presented in figure 1 by the regular (negative values) and bold (positive values) curves respectively.

Figure 1 reveals that, even if a dual setback is sometimes used, most of the occupants apply a single night setback schedule. It appears that the morning pick up hour is concentrated around 6:30 am more or less half an hour. The increase of the thermostat set point in a tight time interval has a major impact on the increase of power demand especially if the pick-up hour coincides with the utility peak hours as it will be discussed later.

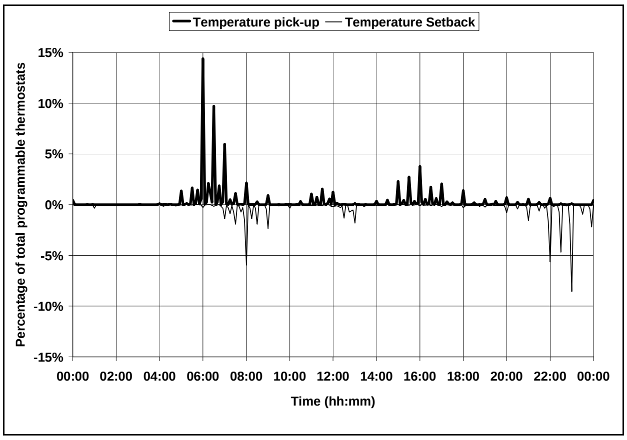

Fig. 1 Distribution of pick-up and setback hours

As mentioned before, occupants are responsible to program the set point temperature as well as the setback temperature accordingly to their priorities: comfort or energy savings. However, the adaptive built-in algorithm has the advantage to anticipate a gradual heating prior to the pick-up hour programmed on the thermostat. The algorithm acts smartly by energizing the baseboard such as the desired comfort temperature is reached at the wake-up hour. Usually, occupants set the pick-up hour thirty minutes before they wake up. It is important to mention that the adaptive algorithm changes the temperature pick-up duration period and power output accordingly to what happened the previous days to take into account the effect of outdoor conditions.

Figure 2 represents the effective pick-up hour as modified by the algorithm. It is shown that the morning pick-up hour has been shifted down by approximately an hour and an half to minimise the impact on the grid.

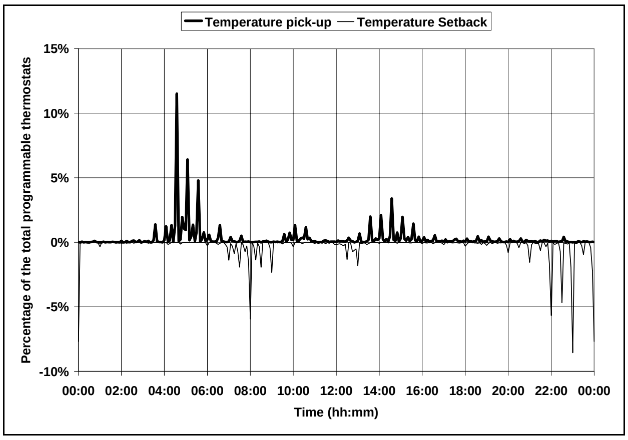

Fig. 2 Automatic shifting of pick-up hour using adaptive algorithm

The magnitude of the thermostat setbacks are represented by the distribution displayed in figure 3.

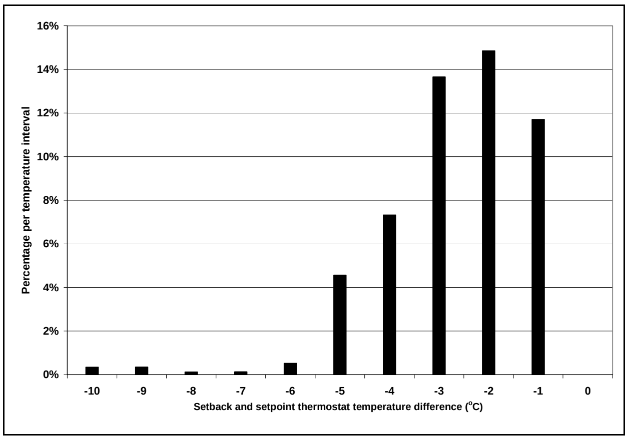

Fig. 3 Distribution of temperature differences between setback and set point.

In general, occupants decrease the thermostat set point 2 or 3°C below the comfort temperature. It is usually not advantageous to reduce the set point temperature by more than 3°C because both comfort and energy savings are compromised unless the setback is applied for a long period of time when occupants are away. Indeed, it requires more time to reach the desired temperature if the setback is important in term of temperature difference namely when the outdoor temperature is very cold. Equation 1 is used to calculate the required time as follows:

$$t = \frac{C\,\Delta T}{P_{tot} - UA\left(T_{set} - T_{out}\right)} \qquad (1)$$

where

C mass constant (kWh/ ^oC)
ΔT temperature difference in settings before and after the pick-up T_i - T_{i-1} (^oC)
P_{tot} total installed heating capacity (kW)
UA overall loss coefficient (kW/ ^oC)
T_{set} pick-up set point temperature T_i (^oC)
T_{out} outdoor temperature (^oC)

For a typical residential site in Quebec, the mean value of the mass constant equals 5 kWh/^{o}C while its overall heat loss coefficient is approximately 0.13 kW/^{o}C. The total installed space heating capacity is 15 kW and the comfort set point temperature is fixed at 20 ^{o}C. These values have been substituted in equation 1 and results obtained are represented graphically in figure 4. The required time to reach the set point temperature during the pick-up is displayed as a function of the temperature differences in the thermostat settings. One can notice that a setback of 4 ^{o}C requires more than two hours to reach the desired set point when the outdoor temperature is below -20 ^{o}C. Hence, the energy savings could be compromised if a long period of heating is required as mentioned before.

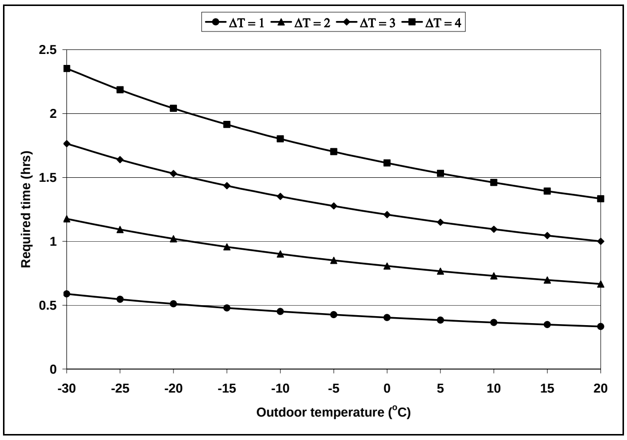

Fig.4 Time required for heating during pick-up

3.2 Power demand profiles

Figure 5 displays the relative power demand variations during an average weekday (Mon-Fri) for the coldest month say, January. The Y axis represents the duty cycle which can also be interpreted as the ratio of the baseboard power capacity being used to satisfy the space heating load. It is observed that the baseboard powers on one and an half hour before the schedule that has been entered into the thermostat by the occupants. This explains the relatively low duty cycle around the wake-up hours. The maximum value does not exceed 40% due to the natural diversity of space heating loads in residential sites which allows to reduce the thermostat impact during pick-up hours. In addition, the duty cycle is less important during the afternoon which is consistent with the fact that the majority of the occupants use only night setbacks as presented in figure 1.

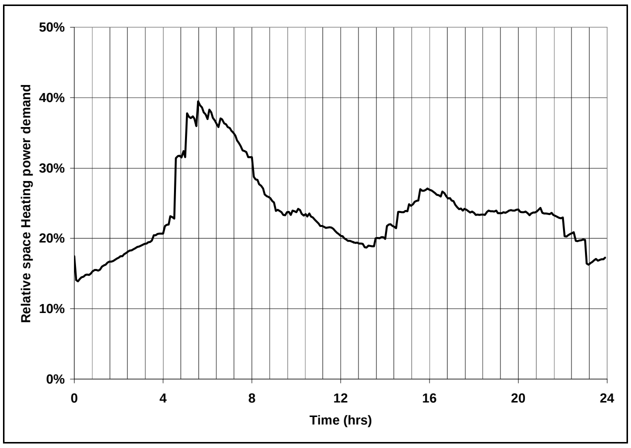

Fig. 5 Average space heating power demand with programmable thermostats

Figure 6 shows the average hourly demand profile for the automated and reference sites as for the electric utility. A fraction of the energy used by the reference sites has been erased for the automated sites, thus procuring some energy savings (~4%) and the peak demand due to the temperature pick-up in the morning has been shifted a couple of hours earlier than the peak originating from the reference sites. The latter would also present a peak demand in the morning, though less than the one from the automated sites, because some people do manual setback of their thermostats at night and because the demand increases in the morning due to the increased activity level in most sites.

Figure 6 shows that the pick-up algorithm imposed to the thermostats has succeeded in shifting most of the morning demand before the utility's peak period. There is still work to be done to refine the morning profile of the automated sites. In view of the results presented here, the recommendation would be to increase the room temperature by using a 2 hour non-linear ramp; the ramp should be a second order filter on the set up temperature. A non-linear ramp, as recommended, would reach two goals: it would increase the power output of the baseboards at the beginning of the pick-up period, thus decreasing the power demand coincidence with the utility's peak, and it would increase the comfort level of the users right at the beginning of the wake-up period. Another recommendation would be to add a random start-up delay to the algorithm; figure 1 showed that there is a low level of diversification in setback schedules. By adding a random pick-up delay between 0 and 30 minutes, it would definitely improve the diversification of the pick-up demand. The same random delay could be used at setback time to avoid sharp decreases in the power demand as shown on figure 5.

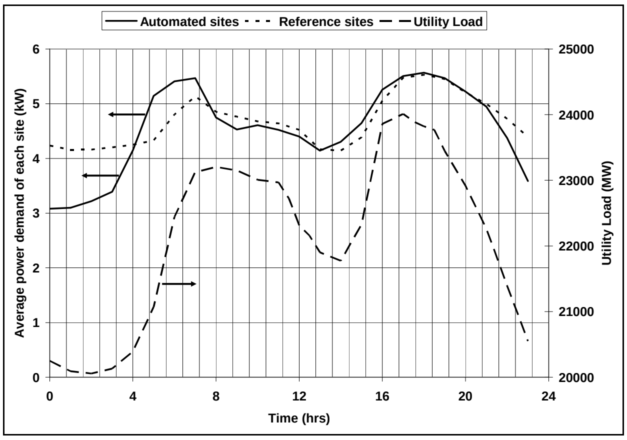

Fig. 6 Hourly demand profiles of the sites and of the electric utility

4 Conclusion

A pilot-project consisting of 200 automated sites and 200 reference sites showed the impact of programmable thermostats on the utility's power demand when a pick-up algorithm is implemented into the thermostats. The algorithm was supposed to shift the power demand, due to the temperature pick-up, from the utility's peak period to a off-peak period. It was successful in part; the power demand was shifted earlier but part of it was still coincident with the utility's peak. It was recommended to modify the pick-up algorithm to address this issue. It was also recommended to add a start-up random delay, between 0 and 30 minutes, to diversify the demand profiles of the automated sites; results showed a very low level of diversification in setback schedules.

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