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Programmable Thermostats as Means of Generating Energy Savings: Some Pros and Cons

André Plourde*
EPCOR Professor of Energy Policy
The University of Alberta School of Business
e-mail: andre.plourde@ualberta.ca

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Executive Summary

Programmable thermostats allow the selection of a target ambient temperature for a building that can be maintained for a set number of hours, and which can be allowed to be lower during the remainder of the day. Once the thermostat is programmed, no further intervention by the building occupant(s) is required.

Early work that examined the effectiveness of programmable thermostats, based on simulation models, and focusing almost entirely on oil- and gas-fired space conditioning in a residential setting, concluded that these devices had a significant potential to reduce energy use. A general rule of thumb that derived from this analysis was that for each degree Fahrenheit of nighttime temperature setback implemented for eight hours each day, energy savings of the order of 1% would be achieved.

However, more recent results, including survey evidence, suggest that for various reasons the extent of any energy savings resulting from programmable thermostats in a residential context is much less than this amount. A recent paper suggests that there may be untapped potential for energy savings from programmable thermostats in the commercial sector, although more extensive analysis to support this finding would be required. A systematic empirical investigation of the effectiveness of programmable thermostats in reducing energy requirements does not appear to have been conducted in Canada for either the residential or commercial sectors, and would appear to be warranted.

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1. Ambient Temperature and the Comfort Level of Households

Imagine a household facing the following two daily choices about the approaches to heating the space in which it lives:

1. choose an target ambient temperature, and maintain it throughout the day;
2. choose the same target ambient temperature, maintain it only for a set a number of hours, then allow the target ambient temperature to be lower during the remainder of the day.

To the extent that space heating is at all needed during that day, option 2 will deliver a lower *average* ambient temperature, which for a number of energy-using technologies will lead to reduced energy consumption and thus expenditures on space heating, all else held equal. Indeed, the longer the period with the lower ambient temperature (called "setback" or "offset" period in the literature) and the larger the setback or offset, the larger the potential savings in terms of energy use and expenditures.[1]

A "programmable thermostat" is an instrument that allows consumers to implement option 2 repeatedly without having to manipulate the space-heating system's thermostat on a daily basis. Once programmed, the thermostat will automatically vary the desired target ambient temperature according to a set pattern, thus delivering option 2 without any need for further intervention by the consumer.

A similar level of energy consumption reduction (and, by extension, of expenditure reduction) can also be delivered by a different space-heating choice, that of selecting an intermediate target ambient temperature to be maintained throughout the day; a target temperature that is lower than that incorporated in option 1, but higher than the one implied by option 2's setback. A key consideration, however, in assessing the implications of this "third option" relates to the fact that it most likely will generate larger reductions in the level of *comfort*

[1] Of course, the same argument can be made in terms of *space cooling*. In this case, the offset would entail a *higher* target ambient temperature for some part of the day. In turn, a higher average ambient temperature should deliver *lower* energy consumption (and thus lower expenditures) in situations where space cooling is required.

experienced by the members of the household than either of the other two options outlined above. Here, the notion that "not all hours are alike" in terms of household comfort levels is critical to this assessment. Quite simply put, the argument is that a lower ambient temperature at night or during periods when no individuals occupy the living space will result in a much smaller reduction in household comfort levels than in periods when household members are present and active. It is thus possible for the household to sustain a greater ambient temperature reduction in some parts of the day and still realize a higher comfort level than that associated with an intermediate ambient temperature sustained throughout the day.

There are obviously limits to this tradeoff – cases where the household would clearly prefer to have the constant, intermediate ambient temperature, such as would likely be the case were the temporary offset to be large enough to result in frozen water pipes, for example. However, over some range of ambient temperature differentials, an important potential advantage of programmable thermostats is that these can deliver reductions in energy consumption and expenditure with minimal effects on the level of comfort experienced by the households that use them. Indeed, this is the (typically unstated) underlying premise of almost all research into the usefulness of programmable thermostats in residential settings.

2. Programmable Thermostats in Residential (and Commercial) Use: Key Research Findings

The paper by Nelson and MacArthur (1978) is quite similar in terms of both its methodological approach and conclusions about effectiveness to much of the research on programmable thermostats published in the 1970s. The authors first construct detailed models of energy flows through a dwelling of specific characteristics, and then use these models in simulation analyses of the potential energy savings associated with programmable thermostats in cases where space heating is assured by natural gas-using equipment. This assessment involves repeated comparisons of the results of two simulation runs, similar to options 1 and 2 outlined above. A base case is specified (including average ambient temperatures – both indoors and out, and the extent and duration of setbacks), and then the model is used to simulate the implications of options 1 and 2 in separate runs. Other factors thought to affect household energy consumption are allowed to vary in subsequent runs, and each time the consequences of options 1 and 2 are simulated.

The key results obtained are follows. First, the model suggests that on average a daily eight-hour *nighttime* setback can bring about close to a 1% reduction in natural gas consumption for each degree Fahrenheit offset (or about a 1.8% reduction for each degree Celsius offset). Proportionally smaller savings should be expected in situations where the indoor temperature does not reach the lower setback temperature as frequently. The simulation results also suggest that *daytime* setbacks typically yield lower energy savings, for identical setbacks and periods of equal length. Second, the volume of energy savings tended to be directly related to the severity of climate conditions: the colder the weather, the greater the energy savings from using a programmable thermostat, especially if the offset (or setback) period was assumed to be at night. However, savings as a proportion of energy use tended to be higher in milder climates. Third, the volume of energy savings tended to be inversely related to the quantity of insulation used in the structure: greater energy savings were recorded for structures with lower assumed quantities of insulation. When expressed as a proportion of energy use, however, simulated savings were generally not related to insulation thickness.[2]

As indicated earlier, these results were obtained from simulations incorporating natural gas space-heating systems. Given the similarities across technologies, the same kinds of

[2] Note that Nelson and MacArthur (1978) did not vary the assumed dwelling size in any of their simulation runs.

simulated energy savings should be expected in the case of oil-based space-heating equipment. Indeed, this broad characterization of a "1% energy saving for each 1°F of nighttime offset sustained for eight hours daily" became and remains the rule of thumb that guides much of the discussion on the effectiveness of programmable thermostats in situations involving gas- and oil-fired heating systems.[3]

However, in the case of electricity – and specifically in situations involving heat pumps – Nelson and MacArthur (1978, p. 325) warn us to expect lower energy savings resulting from the use of programmable thermostats. Bullock (1978) also used a detailed computer simulation model to show that potential energy savings were much lower with heat pump systems. In some cases, energy use was higher while average (indoor) ambient temperature was lower when the operation of heat pumps was simulated jointly with that of programmable thermostats. A recent paper by Bouchelle *et al.* (2000) uses a sample of 200 heat-pumps users in Florida to obtain results that are broadly consistent with the views expressed in Bullock (1978): the joint operation of heat pumps and standard programmable thermostats yields, at best, modest reductions in energy use, even when temperature setbacks are significant.

A technical feature of heat-pump systems turns out to be the key factor explaining this lower potential for energy savings. According to Bouchelle *et al.* (2000, p. 11), a standard heat pump is equipped with auxiliary (or strip) heating capabilities that are triggered into operation when the thermostat setting is at least 2°F higher than the ambient temperature. While this reduces the time needed for the heat pump to increase the ambient temperature, it does so at a

[3] See, for example, Alberta Environment (undated) and United States Department of Energy (1997).

cost: the heat-producing efficiency of the auxiliary system is much lower than that of the heat pump's.[4]

For standard nighttime setbacks of 5°F or 10°F, it is clear that the operation of a programmable thermostat would often lead to situations where the heat pump's auxiliary heating capability would be activated in the morning, as the setback period came to an end. This situation would simply be avoided were a constant target temperature selected: under normal operations, strip heating would not prove necessary since the thermostat would not allow a 2°F gap to emerge between target and actual indoor temperatures. The use of a programmable thermostat thus leads to additional electricity requirements at the end of the setback period – the additional electricity used by the strip heating equipment acts to offset (to some degree) the reductions in electricity use during the setback period. On average, in the sample studied by Bouchelle *et al.* (2000), this offset is not complete, but the net electricity savings are significantly reduced. Again, this is consistent with the results obtained earlier by Bullock (1978) using a detailed simulation model.[5] There are indications that manufacturers of heat pumps and programmable thermostats have recognized this problem and begun to address it (Brautigam 1997; US DOE 1997; US EPA 2000). However, the costs of the more sophisticated temperature control equipment required can be significant, thus reducing the attractiveness of acquiring and using such equipment. In addition, if the heat pump were to include an "advanced recovery" feature, then the period of adjustment to the removal of the temperature offset would be longer. While this would reduce the call on the unit's strip heating equipment, it would also result in reduced comfort levels during the extended adjustment period, or shorter setback periods, or some

[4] In contrast to oil- and gas-using systems, the heat pump thus "works more intensively" (in the sense of using more electricity to produce each unit of heat) when the setback period comes to an end.
[5] Note that in some of the simulation runs reported by Bullock (1978), the net effect of these two opposing forces was to *increase* electricity use, when compared to constant target temperature operation.

combination of the two. It is also important to remember that recent technological developments could well have improved the effectiveness of the joint operation of "new" heat pumps and "new" programmable thermostats. However, these new technologies are of much less relevance to the existing stock of heat pumps.

The combined use of programmable thermostats and electricity-based space-conditioning systems in general (not only heat pumps, but also electric baseboards, furnaces, and air conditioners, for example) gives rise to issues not encountered when oil- and gas-fired systems are used. To the extent that such users of programmable thermostats in a given area select setback periods of similar length at the usual times, then as these setbacks end a sharp increase in electricity use will be recorded within the morning or early evening period of peak demand. In some cases, this will lead to load-management problems for electricity service providers, and may create pressures on these providers to invest in additional generation capacity to meet the higher peak demand.

A recent paper (Nevius and Pigg 2000) has raised questions about the effectiveness of programmable thermostats, even when used in conjunction with gas-using space-heating systems. This study, based on a survey of 299 Wisconsin households, revealed that households with programmable thermostats used about the same amount of energy for space-heating purposes as did those with only manual thermostats. One of the key factors explaining this result is the fact that both options 1 and 2 outlined above (and typically used in simulation-based studies of programmable-thermostat effectiveness) can be implemented *without the use of a programmable thermostat*. This is indeed what a number of households in the Wisconsin survey chose to do: set back their thermostats manually, and reap the energy savings that the simulation studies had assumed could only be obtained with the use a programmable thermostat.

At the other end of the spectrum is the fact that a number of households owned a programmable thermostat, but did not use it effectively. Reasons typically invoked by survey participants for behaving in this manner include, among others, the argument that programming the thermostat was too complicated, concerns about the comfort levels of children leading to the decision to forego nighttime setbacks, and the choice of not having a daytime setback period as a result of concerns about the comfort levels of individuals and pets occupying the dwelling during the day.

Finally, Nevius and Pigg (2000) also uncover evidence of the existence of a self-selection bias within their sample. They find that households who own a programmable thermostat are more likely to favour energy conservation than households who do not own this equipment. The authors argue that individuals who favour energy conservation would be much more likely than average to implement setback periods even if they owned a manual thermostat. Therefore, the total net energy savings realized by such households due to the use of a programmable thermostat would be quite small, since many of them would have implemented setback periods manually.[6]

In contrast, another recent study (Maheshwari *et al.* 2001) highlights the potential for programmable thermostats to yield energy savings in the commercial sector. Options 1 and 2 above are implemented in alternating weeks in three Kuwaiti commercial buildings, and the differences in actual energy use for space-cooling purposes are tracked. Energy savings of between 25% and 45% of the consumption levels without temperature offsets were recorded, with minimal effects on the comfort levels of those using the buildings. Basically, the

[6] Of course, it could be argued that the use of a programmable thermostat can yield higher comfort levels by allowing households to "warm up" (or cool down, as appropriate) the dwelling prior to individuals getting up in the morning, or returning home in the late afternoon – outcomes that manual thermostats cannot deliver. While this is true, note that the higher comfort levels come at the cost of effectively shorter setback periods, and thus of lower energy savings.

thermostats were programmed to implement offsets in periods where the facilities were not in use (weekends for a kindergarten, for example), so that the higher ambient temperatures did not lead to additional discomfort for individuals since the buildings were empty at the time. The results of this paper suggest that by choosing the offset periods appropriately, it is possible to use programmable thermostats to reduce energy consumption for space-conditioning purposes in some commercial buildings without reducing the comfort levels of those using the space.

Further, the coordination problems associated with attempting to rely on manual thermostat adjustments are likely to be greater in commercial-sector settings than in individual households. As a result, the kinds of energy savings documented in this paper are much more likely to require the use of programmable thermostats than would be the case in the residential sector. To date, almost all studies of the effectiveness of programmable thermostats have involved situations in the residential sector. The work by Maheshwari *et al.* (2001) reminds us that the potential for energy savings from the use of programmable thermostats in the commercial sector is a neglected area of study.

3. Conclusions and Avenues for Future Research

Early work on the issue of the effectiveness of programmable thermostats was based on simulation models, and concluded that the potential effect of these thermostats on residential energy use was significant. Expected energy savings for oil- and gas-fired space conditioning systems were on the order of 1% for each degree Fahrenheit of nighttime temperature setback implemented for eight hours each day. It was also shown that the potential for savings was influenced by other factors, such as weather and insulation levels. Nonetheless, more than twenty years later, the above remains a rule of thumb used to describe the potential energy savings that could result from the use of programmable thermostats in some residential-sector settings.

It was also soon realized that characteristics of the technology and operations of heat pumps reduced the effectiveness of standard programmable thermostats. Progress has been made to address this issue from a technological perspective, but the higher cost of the necessary equipment reduces the attractiveness of acquiring and using a programmable thermostat with a heat pump.

More recently, questions have been raised about the potential for programmable thermostats to deliver any additional energy savings, even in situations where natural gas is the energy source used for space-heating purposes. Survey evidence suggests that the net changes in temperature-setback behavior resulting from the ownership of a programmable thermostat are much smaller than assumed in the earlier, simulation-based studies.

As a recent paper reminds us, there has been very little research on the potential consequences of the use of programmable thermostats in the commercial sector. While the evidence provided in this paper is limited to three specific buildings, the energy savings documented are large enough to warrant further study in a broader context. In particular, if the kinds of savings documented in this paper are indicative of the potential effectiveness of programmable thermostats in the commercial sector, this would suggest that well designed policy initiatives aimed at increasing the penetration of programmable thermostats in this sector might lead to much larger energy savings than would be obtained if similar measures were directed at the residential sector. Additional research is needed to shed more light on this issue.

Finally, there appears to have been no systematic analysis of the consequences of programmable thermostat use in Canada. It should be possible to use the *Survey of Household*

Energy Use (SHEU) data to address this gap and to undertake a detailed analysis of the energy savings actually realized by Canadian households as a result of the presence of programmable thermostats in places of residence. In the spirit of early contributions to this literature, it would be possible to exploit the richness of the SHEU data to explore the effects of weather, dwelling size, insulation levels, etc. on the energy savings associated with programmable thermostats.

4. *References*

Alberta Environment (undated) "Energy Efficiency Information Kit", mimeo.

Bouchelle, Matthew P., Danny S. Parker, and Michael T. Anello (2000) "Factors Influencing Space Heat and Heat Pump Efficiency from a Large-Scale Residential Monitoring Study", *Proceedings of the 2000 Summer Study on Energy Efficiency in Buildings*, 15 pages. Washington: American Council for an Energy-Efficient Economy (ACEEE).

Brautigam, Jack (1997) "Energy-Saving Thermostats", EB 1835e, Washington State University Energy Program. Olympia, WA.

Bullock, Charles E. (1978) "Energy Savings through Thermostat Setback with Residential Heat Pumps", *ASHRAE Transactions*, Volume 83, AL-78-1 (3): 352-361.

Maheshwari, Gopal P., Hanay Al-Taqi, Raba'a Al-Murad, and Rajinder K. Suri (2001) "Programmable Thermostat for Energy Saving", *Energy and Buildings* 33: 667-672.

Nelson, Lorne W. and J. Ward MacArthur (1978) "Energy Savings through Thermostat Setbacks", *ASHRAE Transactions*, Volume 83, AL-78-1 (1): 319-333.

Nevius, Monica J. and Scott Pigg (2000) "Programmable Thermostats that Go Berserk? Taking a Social Perspective on Space Heating in Wisconsin", Energy Center of Wisconsin & University of Wisconsin. Paper prepared for the 2000 ACEEE Summer Study in Energy Efficiency in Buildings.

United States Department of Energy – US DOE (1997) "Automatic and Programmable Thermostats", DOE/GO-10097-375, FS 215. Washington, DC.

United States Environmental Protection Agency – US EPA (2000) "Energy Star® Labeled Programmable Thermostats", EPA 430-F-97-028, Merrifield, VA.

CBEEDAC
Department of Economics
University of Alberta
8-14 Tory Building
Edmonton, Alberta
Canada
T6G 2H4
cbeedac@ualberta.ca