Titre: Title:	Impact of Maestro thermostats on heating energy use
Auteurs: Authors:	Kun Zhang
Date:	2017
Type:	Rapport / Report
Référence: Citation:	Zhang, K. (2017). *Impact of Maestro thermostats on heating energy use* (Rapport d'étude - Cycles supérieurs). Tiré de https://publications.polymtl.ca/3114/

POLYTECHNIQUE MONTRÉAL

Impact of Maestro thermostats on heating energy use

NSERC Engage Partnership EGP 507668-16 – Final report

Kun Zhang, PhD Candidate

Michaël Kummert, Eng., M.Sc., Ph.D., Associate Professor

2017-11-10

Department of Mechanical Engineering
Pavillon Principal, Office C-318.10
t : +1-514-340-4711 x4507
f : +1-514-340-5917
e : michael.kummert@polymtl.ca

Mailing address
PO Box 6079 Stn. centre-ville
Montréal QC H3C 3A7

Physical address
Campus de l'Université de Montréal
2900 blvd. Édouard-Montpetit
2500 chemin de Polytechnique
Montréal QC H3T 1J4
Canada

1. Project objective

This research project is a collaboration between Polytechnique Montréal and our industrial partner Stelpro, funded by an Engage grant from the Natural Sciences and Engineering Research Council of Canada (NSERC).

Stelpro is a leading manufacturer of electric heating solutions in North America. Their products include baseboard heaters, convectors, radiant heaters, furnaces and in-duct heaters, as well as floor heating solutions. They are also manufacturing thermostats and have recently joined forces with "Internet of Things" partners to develop a new generation of connected thermostats.

Stelpro has a need to assess the potential benefits of their products through numerical simulation and experimental testing, in order to guide their R&D effort and to perform cost-benefit analyses for their potential customers. One of the tasks is to evaluate the energy performance of their newly designed connected thermostat Maestro. To this end, the objective of this Engage project is to assess the energy performance of Maestro through building performance simulation. Conventional thermostats such as mechanical and programmable electronic thermostats are also modeled for performance comparison with Maestro.

2. Methodology

2.1. Reference building – CCHT house

An important market for Stelpro is in the residential building section, thus the building archetype that we focus on in this project is residential buildings. The selected residential building in the study is the Canadian Centre for Housing Technologies (CCHT) house, which was built to represent the typical housing stock in Canada.

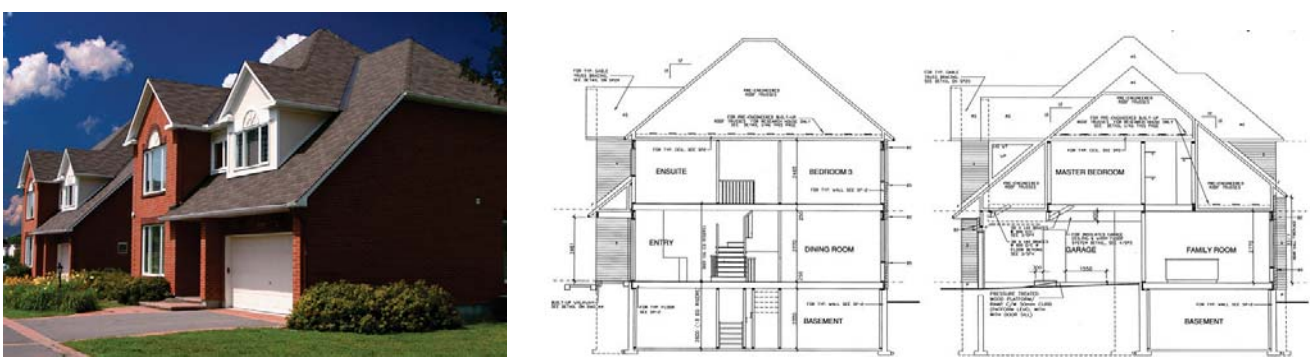

Figure 1 Photo and drawings of CCHT houses (CCHT, 2017)

The CCHT houses are twin houses located in Ottawa, Canada and jointly operated by National Research Council, Natural Resources Canada and the Canada Mortgage and Housing Corporation (see Figure 1). The mission of these two houses is to test new technologies for the housing market by conducting side-by-side comparison experiments. This neutral third-party evaluation can help to better integrate the new technologies and accelerate their market acceptance, especially for the Canadian context.

The houses were built in 1998 based on the Canadian R-2000 building standard. They are three-story houses with a basement, main floor and second floor. The physical parameters of the building envelope, heating, ventilation and air conditioning (HVAC) systems, lighting, domestic hot water etc. are well documented. Both houses are fully monitored with over 250 sensors and 23 energy meters. Table 1 gives a brief summary of CCHT house characteristics (Zhang, Quintana, Bradley, Kummert, & Riley, 2015).

Table 1 Summary of CCHT house characteristics

Features	Details
Livable area	210 m^2 (2 stories)
Insulation	Attic: R=8.6 m².K/W; Walls: R=3.5 m².K/W; Rim joints: R=3.5 m².K/W
Basement	Poured concrete, full basement Floor: concrete slab, no insulation Walls: R=3.5 m².K/W in a framed wall
Windows	Low-e coated, argon filled windows Area: 35 m^2 total, 16.2 m^2 south facing
Exposed floor over garage	R=4.4 m².K/W with heated/cooled plenum air space between insulation and sub-floor
Airtightness	1.5 h^{-1} @ 50 Pa

2.2. Reference building model

The reference house is modeled in the TRNSYS energy performance simulation program, which is capable of a wide range of system simulations including buildings, HVAC systems, renewable energy systems and so on. The software is certified based on ASHRAE standard 140 and has been accepted for certifications such as LEED and ASHRAE standard 90. Figure 2 shows a section of the models representing different components in the building system for this project.

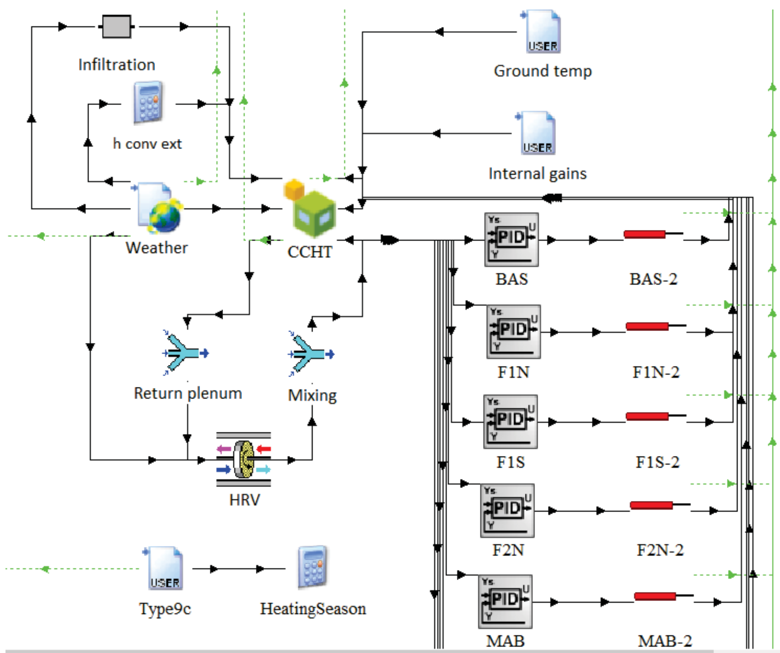

Figure 2 TNRSYS simulation studio

The reference house model used for this study has been validated with measured data from 2002 to 2003 (a measured reference year). The yearly energy use for heating, cooling and hot water is within 0.5% against the measurements and the hourly energy use is also within ASHRAE Guideline 14 *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs*. Figure 3 shows the monthly furnace gas and electricity use between simulation results and measured data.

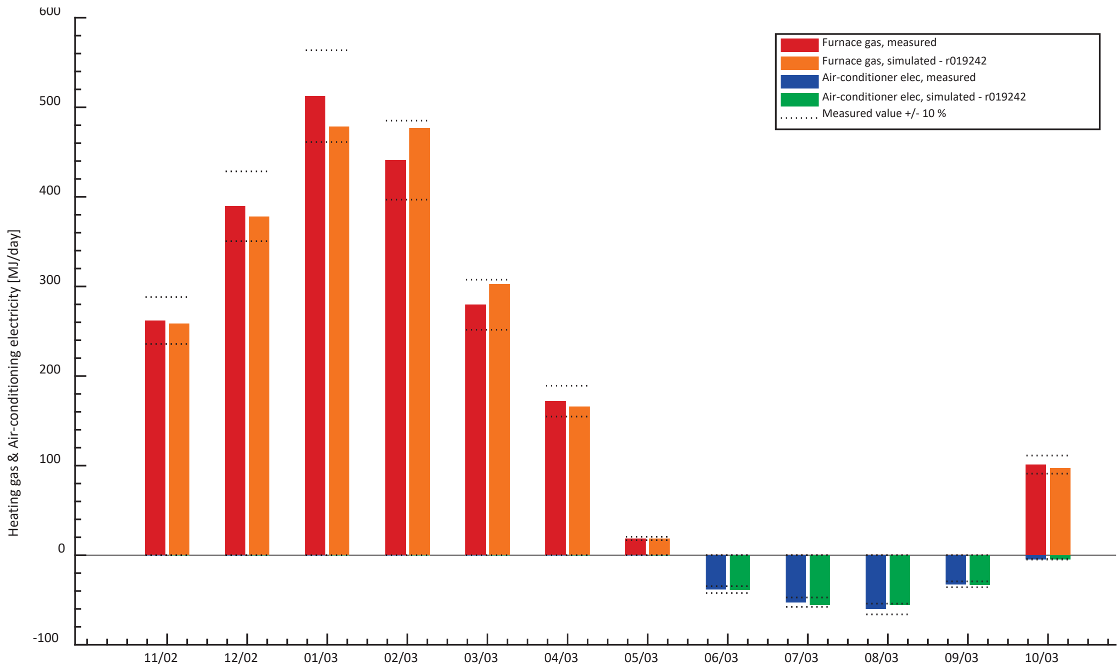

Figure 3 Monthly furnace gas and air-conditioner electricity use

The heating system adopted in the project was changed from furnace gas in the original CCHT house to electric baseboard heating to represent the most common system in the province of Quebec. The sizing equation for the baseboard power is suggested by the Stelpro project team as follows (Stelpro, 2017):

$$P(W) = A(sq.ft)\times 10$$

Where A is the area of the room in square feet and P is the baseboard power in Watts. It should be noted that this equation may result in an overestimated heating capacity for the CCHT house given that it is a well-insulated house. But this equation was used in the project because it represents a common practice when people select and install baseboards in Canada. The resulting installed power is summarized in Table 2.

Table 2 Heating capacities for each room

Room	Short name	Area [m²]	Heating capacity [kW]
Basement	BAS	89	9.6
Dining room, Kitchen, Family room	F1N	61	6.6
Living room	F1S	30	3.1
Bathroom 1 on main floor	BATH1	46	4.4
Guest room	F2N	40	3.4
Master bedroom	MAB	16	1.7
Children bedroom	CHB	1.7	0.5
Bathroom 2	BATH2	5.5	0.6
Bathroom 3	BATH3	8.4	0.9
Total		282	30.8

Note that in Table 2, the heating capacity for Bathroom 1 on the main floor was increased from 0.3 kW (according to the sizing equation) to 0.5 kW because the lower capacity was shown to result in under heating in the bathroom, which shares a wall with the unheated garage.

2.3. Thermostats

As explained in Section 1, the purpose of the project is to assess the energy performance of the new generation Maestro thermostat by Stelpro. To compare the performance, two other thermostats were also modelled: a mechanical (bimetallic) thermostat and a programmable electronic thermostat. The control strategies for each type of thermostat are briefly summarized below.

2.3.1. Mechanical (bimetallic) thermostat

The mechanical thermostat is also called line voltage bimetallic thermostat as a strip of two different metals works as the electric contact breaker. It can only work in the On/Off fashion. The dead band of the mechanical thermostat was assumed to be ± 2 °C based on existing Stelpro mechanical thermostats. This dead band means the temperature can go up to 2 °C above or below the setpoint in its controlled room.

The mechanical thermostat can only have one setpoint for each room, unless users change it. The setpoint temperature for this type of thermostat was assumed to be constant for each room, which is a common practice according to Stelpro market research. The basement setpoint is 19 °C and the rooms on the main floor and second floor were kept 23 °C. This assumption signifies that the lowest temperature for the two living floors was 21 °C, and for basement it was 17 °C. Figure 4 visualizes the setpoint temperature distribution in different rooms on each floor.

Figure 4 Heating zones for mechanical thermostat

2.3.2. Single programming electronic thermostat

Single programming electronic thermostat represents a big share of thermostat market in Canada. Unlike mechanical thermostat, this type of thermostat is controlled electronically. Its control algorithm is more sophisticated and can track the setpoint with a better accuracy than mechanical thermostats.

The algorithm for the single programming electronic thermostat simulated in the project adopted a Proportional-Integral (PI) algorithm and the parameters of the PI strategy were obtained from Stelpro. Since it is a programmable thermostat, two cases were considered in the work. The first case adopted a constant setpoint, and the second case used a setback setpoint profile. The constant setpoint case for the electronic thermostat is 2 °C lower than that of the mechanical thermostat so that the lowest room temperatures in the house for these two types of thermostats are similar. Table 3 summarizes the setpoint temperatures on each floor for the mechanical and single programming electronic thermostat.

The setback case differs from the constant case in that during some unoccupied and sleeping hours, the setpoint temperature would be set back from 21 °C to 17 °C. The setback periods and temperature ranges were proposed by the Stelpro project team based on common practice. Figure 5 shows the setback temperature profile separately for weekdays and weekends.

Table 3 Setpoint temperatures for mechanical and single programming electronic thermostat

Floor	Mechanical thermostat	Single programming electronic thermostat
Basement	19 °C	17 °C
Main floor	23 °C	21 °C
Second floor	23 °C	21 °C

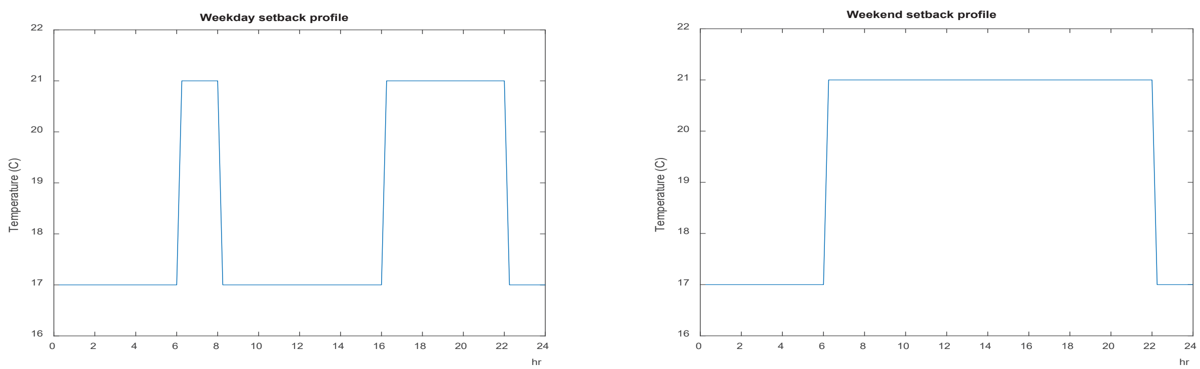

Figure 5 Setback profile for single programming electronic thermostat

2.3.3. Maestro

Maestro is a new generation electronic thermostat designed by Stelpro. It is connected to the internet through different protocols. Therefore, it can be controlled remotely by smart phones, laptops, tablets and so on. It has the capability of zone grouping, through which different rooms or zones can be controlled in a group. Its geo-fencing function automatically detects the presence or absence of occupants in the rooms and adjusts the setpoint temperatures in different rooms accordingly. It is also capable of anticipating schedule events: it can for example bring the setpoint back up to the "day" value earlier than the scheduled time if it anticipates that it will take a long time to warm-up the room from the "night" to the "day" setpoints.

The local feedback control algorithm for Maestro is the same as the single programming electronic thermostat (PI algorithm to maintain the setpoint). The differences come from many different scenarios of setpoint profiles due to the advanced functions of Maestro. In this project, we mainly investigated four types of scenarios: a typical weekday, a typical weekend, weekend outings and a week-long vacation (spring break). Table 4 Maestro eventssummarizes the events considered in the study. Note that the simulation uses a 15-min time step, so randomly occurring events can only take place every 15 minutes.

Table 4 Maestro events

Event	Typical weekday	Typical weekend
Wake-up	6:00 (anticipated)	8:00 (anticipated)
Leave home	07:15 ~ 08:30 (random in between)	--
Return home	16:15 ~ 17:45 (random in between)	--
Bedtime	22:00 ~ 23:30 (random in between)	22:00 ~ 23:30 (random in between)
Ski Saturdays	--	8:00 ~ 16:00, one weekend out of two randomly between January and March
Family outings	--	8:00 ~ 16:00, one weekend out of two, randomly
Vacation	one week in March (spring break)	

For each event, different zones have different setpoint temperatures. To simplify the comparison with setback case of single programming electronic thermostat, only two temperatures were considered in the 7 zones excluding basement which stays 17 °C constantly. In other words, when people actively occupy the zones (not sleeping), the room setpoint temperatures for the occupied zones are 21 °C; when the rooms are not actively occupied, their setpoint temperatures are 17 °C. When people leave for the spring break, the whole house is set back to 13°C. The zone distribution for Maestro on each floor are shown in Figure 6.

Figure 6 Zoning for Maestro

Figure 7 presents a random weekday setpoint temperature profile by Maestro. We can see that on that specific day, people get up at 5:45, setpoint temperatures for F1N (Dining room, Kitchen, Family room), Master bedroom, Children's bedroom and three bathrooms are 21 °C, all the other rooms stay at 17 °C. When people leave home at 8:15, the setpoint temperatures for all the rooms change to 17 °C. In the afternoon, when people get back home at 17:45, the main floor and Master bedroom, Children's bedroom and Bathroom 2 and 3 are setup to 21 °C until 22:15 at bedtime.

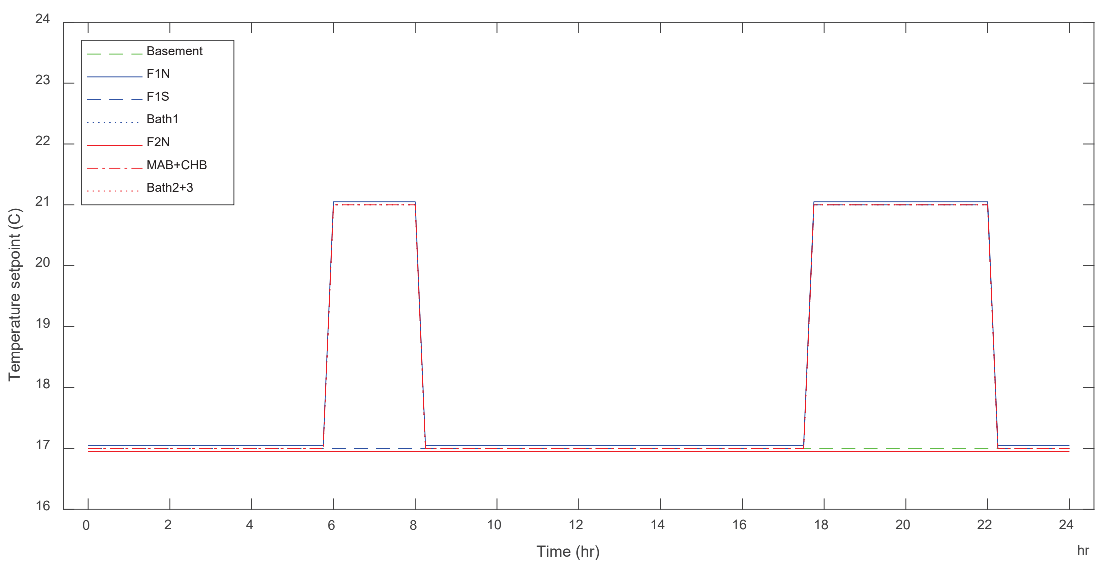

Figure 7 A random weekday setpoint temperature profiles by Maestro

3. Results and discussions

3.1. Reference scenario

All the simulations in the project were run in a year with a 15-minute time step. The reported heating season is from October 15 to April 30. Figure 8 depicts the temperature profiles of different zones on a winter day for the case of the mechanical thermostat. We can see that the room temperature oscillates up or down 2 °C along the setpoint in each zone. This result reflects the assumptions that we made about the mechanical thermostat.

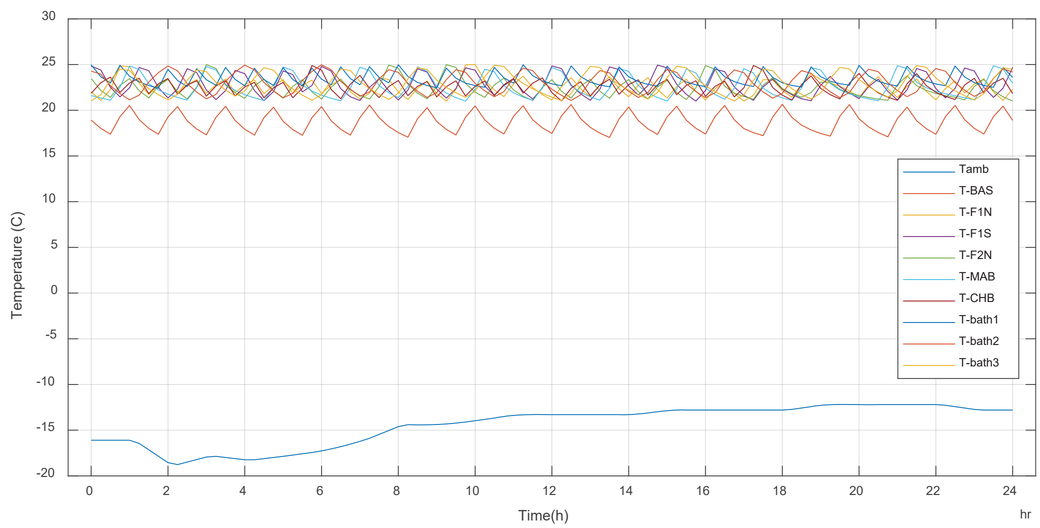

Figure 8 Room temperatures on a winter day with the mechanical thermostat

Figure 9 shows the room temperatures for the electronic thermostat with constant setpoint case. We can clearly see that the electronic thermostat can follow the setpoint temperature very closely in each zone. The overshoots occurred in the morning and afternoon for the zone F1N (Dining room, Kitchen) are due to the internal gains (mostly cooking) and the tiny overshoot for the zone F2N (Living room) in the evening is due to the internal gains (occupants and lighting) as well.

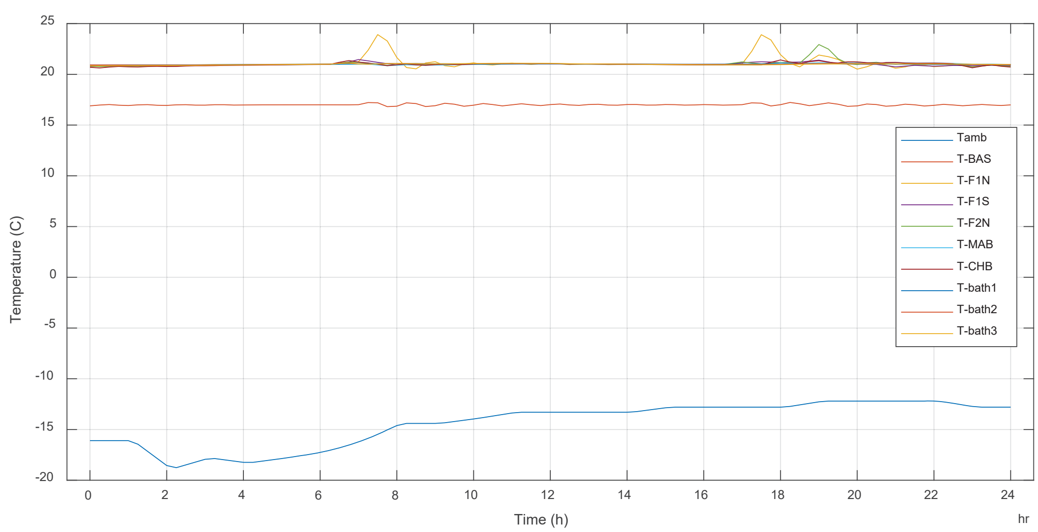

Figure 9 Room temperatures on a winter day with the electronic thermostat

The temperature results validate the PI algorithm in our assumption. It is also a showcase that the electronic thermostat can maintain the room temperature very precisely following the setpoint temperature, unlike the oscillation phenomenon of the mechanical thermostat. The setback case for the single programming electronic thermostat and Maestro also track the setpoint temperature very well.

Figure 10 shows the total yearly heating energy use with different thermostats and scenarios, and Table 5 shows the yearly energy use of each room for space heating. We can see that Maestro saves 30% of heating energy in overall compared with the mechanical thermostat. If compared with the single programming thermostat with constant setpoint scenario, Maestro saves 16%.

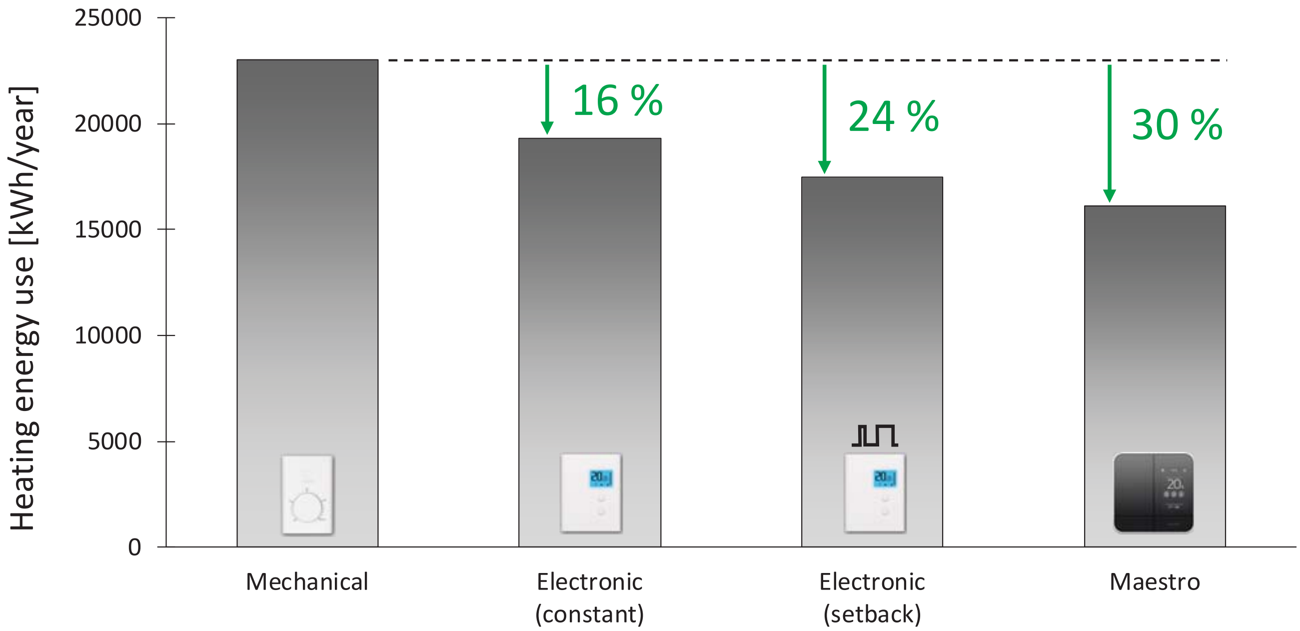

Figure 10 Total heating energy use of CCHT house

If we look at the energy use for each room, we can see that the energy use of the second floor and garage for all the cases give very similar results. The largest energy savings for the electronic thermostat and Maestro come from the basement. Maestro has more savings against the mechanical thermostat for Living room (F1S) and Bathroom 1 than single programming thermostat (both cases) because these two rooms have less "active use" time in the Maestro scenarios due to its flexible control ability of groups of zones.

Table 5 Heating energy use of CCHT house (MWh/year)

Room	Mechanical	Single programming (constant)	Single programming (setback)	Maestro
BAS	6.8	4.1	4.8	4.7
F1N	4.9	4.6	3.5	3.5
F1S	2.7	2.5	2.0	1.4
BATH1	2.4	2.4	2.2	1.0
F2N	1.9	1.7	1.6	1.7
MAB	1.1	1.1	0.9	1.0
CHB	1.0	1.0	0.8	0.8
BATH2	0.8	0.7	0.6	0.7
BATH3	0.8	0.7	0.6	0.7
GAR*	0.3	0.3	0.3	0.3
Total	22.7	18.9	17.2	15.9

* GAR represents the zone Garage, which maintains at 5 °C constantly for the heating season for all the scenarios.

Figure 11 presents peak power demand for different thermostats. The mechanical thermostat has the highest peak power demand, while the single programming thermostat with constant setpoint case shows the lowest peak demand. Maestro has also very high peak demand due to the instant setpoint temperature increase from 13 °C to 21 °C from vacation in various zones (shown by the dotted line above the bar for Maestro). However, this event is only a one-time event, therefore a smart control strategy proposed in Maestro to curtail this peak, where a linear setpoint temperature increase during two hours before arriving home is implemented. After adopting this “smart” recovery strategy, Maestro only shows moderate peak power demand, lower than the electronic thermostat with setback temperature case.

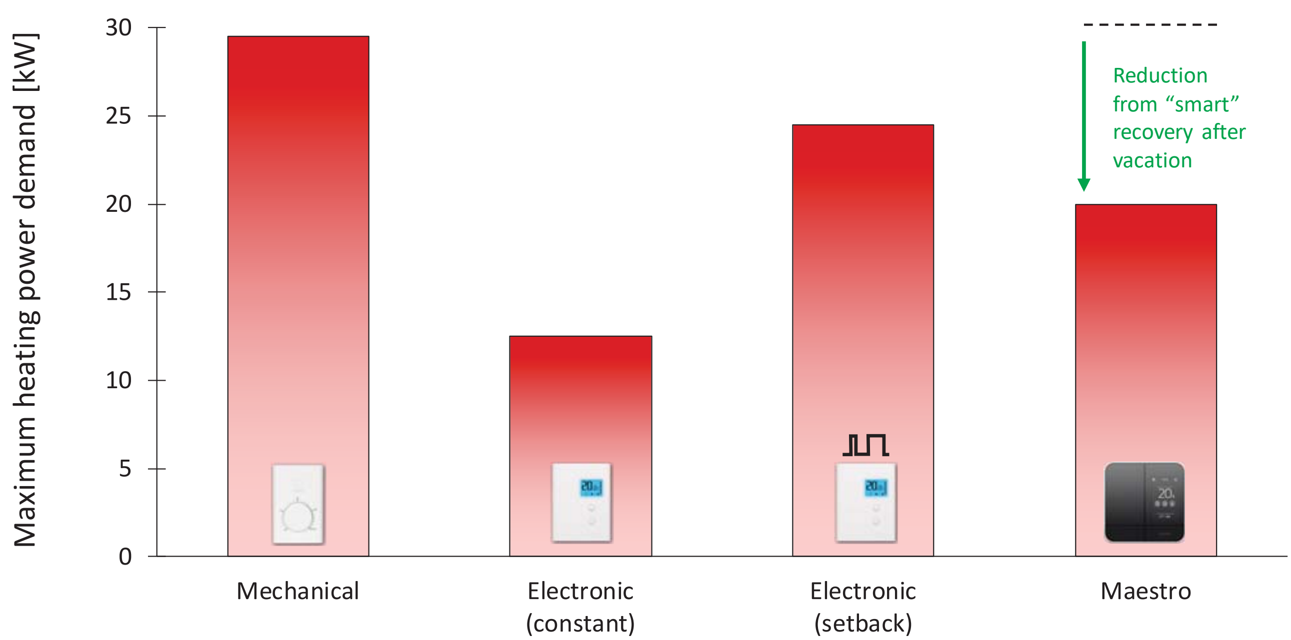

Figure 11 Peak power demand with different thermostats and scenarios

3.2. Less insulated house

The CCHT house is well insulated, even by today's standards, and it does not necessarily represent older dwellings in the housing stock. A quick modification of the CCHT model was conducted to investigate the energy use for the less insulated houses, where air infiltration and solar shadings for windows were artificially increased.

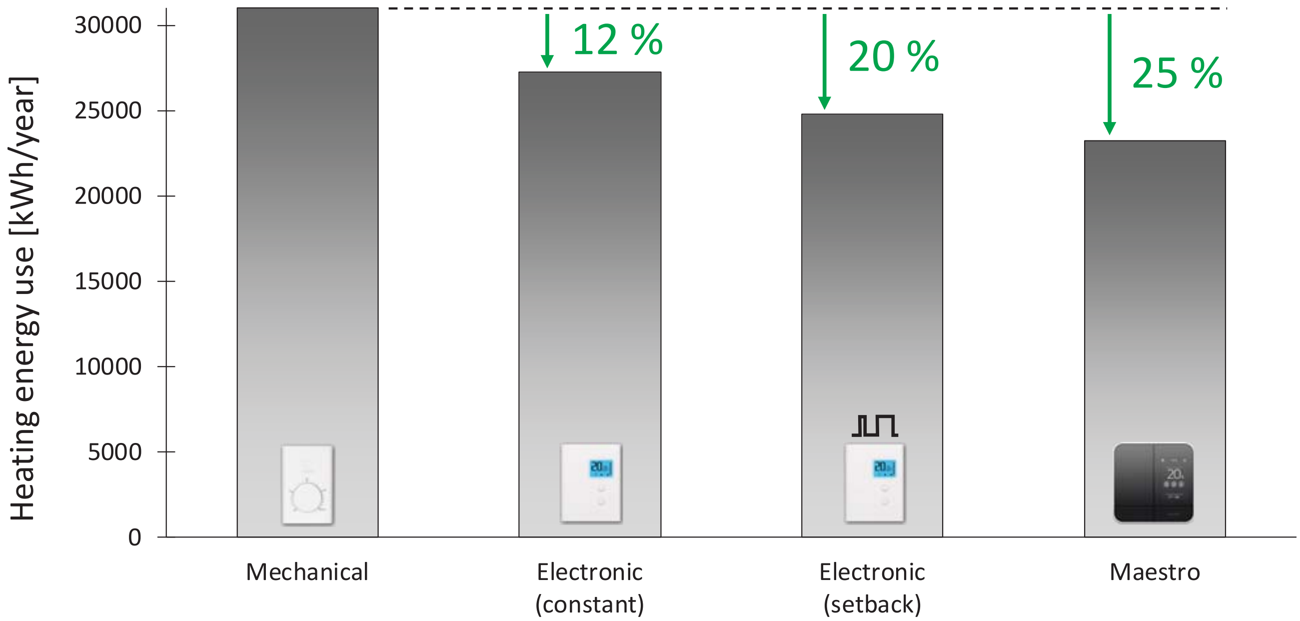

Figure 12 Total heating energy use of less insulated house

Figure 12 presents the yearly heating energy use for the less insulated house. Table 6 summarizes the energy use for each room. We can see that Maestro saves 25% against the mechanical thermostat for the less insulated house, 5% lower than for CCHT house. However, this lower savings in percentage amount to larger absolute values, saving 7700 kWh per year versus 6600 kWh for the CCHT house.

Table 6 Heating energy use of less insulated house (MWh/year)

Room	Mechanical	Single programming (constant)	Single programming (setback)	Maestro
BAS	8.8	5.9	6.7	6.7
F1N	6.5	6.3	4.9	5.0
F1S	3.7	3.5	2.8	2.1
BATH1	3.6	3.5	3.2	1.8
F2N	2.9	2.7	2.5	2.6
MAB	1.5	1.5	1.3	1.3
CHB	1.0	1.0	0.8	0.8
BATH2	1.0	0.9	0.7	0.9
BATH3	1.0	0.9	0.8	0.9
GAR	0.4	0.4	0.4	0.5
Total	30.3	26.6	24.2	22.6

4. Discussion, conclusion and future work

This collaboration between Polytechnique Montréal and Stelpro was made possible thanks to an NSERC-funded Engage Partnership. Its objective was to assess the energy performance of different types of thermostats in a residential building through a simulation study. The Canadian Centre for Housing Technologies (CCHT) house was selected and a building model was built and validated in the TRNSYS program. The evaluated thermostats are mechanical, electronic and a connected thermostat named Maestro. Setpoint scenarios were developed for these 3 thermostats based on common practice and assumptions on the occupants' behaviour.

Simulation results show that the Maestro thermostat delivers 30 % heating energy savings against the mechanical (bimetallic) thermostat over the heating season, and 16 % when compared to an electronic thermostat with constant setpoint. For a house with a higher heating demand (i.e. less insulated), results show that the savings from the Maestro thermostat are slightly lower in percentage (25 %) but higher in absolute energy (7700 kWh vs. 6600 kWh for the original CCHT house). The Maestro thermostat results in a higher peak demand than the electronic thermostat with constant setpoint, but a lower peak demand than the mechanical thermostat.

The energy savings of electronic thermostats (conventional programmable or Maestro) compared to mechanical thermostats result from their better ability to track the setpoint accurately, under the assumption that users will adjust the thermostats so that the minimum temperature reached in the room is the same.

The energy savings of the Maestro thermostat compared to the programmable thermostat depend on the assumptions made to characterize the occupants' behaviour. The constant setpoint profile represents passive occupants and results in the highest achievable savings for the Maestro thermostat. The setback strategy represents a pre-programmed fixed schedule, and the Maestro energy savings result from differences between the pre-programmed schedule and the actual schedule. It is assumed that the user-friendliness of the Maestro interface and the capability to program the thermostats from any internet device (including remotely) results in pre-programmed or on-demand events that match the actual use of the house more closely. Furthermore, the geo-fencing capability of the Maestro thermostat allows to detect unscheduled absence/presence events. This will result in energy savings if the "active use" of the house is reduced, under the assumption that occupants will neglect or forget to adjust conventional thermostats in similar events (e.g. leaving earlier for work, or leaving the house for errands or family outings).

Further work could aim at refining some of the assumptions that were made to represent the occupants' behaviour and to add different scenarios representing different family structures and lifestyles. It would also be interesting to compare the energy savings of different thermostats in different types of housing units representing the existing and future building stock. Thermal comfort could also be assessed in a more accurate way to replace the simple indicator in this study (dry bulb temperature in each room) and include the impacts of long-wave radiation and humidity (e.g. using ASHRAE standard 55).

5. Bibliography

CCHT. (2017). Retrieved October 31, 2017, from http://www.ccht-cctr.gc.ca/eng/

Stelpro. (2017). *Stelpro*. Retrieved October 31, 2017, from http://www.stelpro.com/en-CA/calculating-right-wattage-room

Zhang, K., Quintana, H., Bradley, D., Kummert, M., & Riley, M. (2015). Air-source integrated heat pumps (AS-IHPs) with smart zoning for residential space and water heating in cold climate. *Proceedings of Building Simulation 2015:14th Conference of International Building Performance Simulation Association, Hyderabad, India, Dec. 7-9*, (pp. 1623-1630).