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The role of Programmable TRVs and the Smart Home Concept for Heating Energy Demand Reduction in UK Homes

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Abstract

This study aims to investigate the potential of advanced radiator controls to reduce space heating energy demand in dwellings. The study uses Dynamic Thermal Modelling (DTM) to compare the space heating energy consumption of dwellings with programmable Thermostatic Radiator Valves (TRVs) and dwellings with conventional TRVs. Conventional TRVs can often lead to overheating or heating rooms when not required. Programmable TRVs can overcome these limitations by using occupancy linked schedules and therefore can reduce space heating energy demands.

It is found that use of programmable TRVs can lead to great space heating energy savings which cannot be achieved using conventional radiator controls. Using programmable TRVs, fine control of room temperature can be achieved which would help to reduce space heating energy consumption while maintaining occupant's thermal comfort. Furthermore, heating time can be controlled in individual rooms using programmable TRVs which provide considerable space heating saving as shown by simulation results.

Keywords: Space Heating, Programmable TRV, Modelling, Occupancy, Thermal Comfort

1. Introduction

Heating and cooling for providing thermal comfort have required human intervention since the first fire was lit in a cave (Meier and Walker, 2008). The first oil crisis which occurred in 1973 urged the necessity for the first energy code (Building Energy Efficiency Standards). This code was established in 1978 in California and a part of it required the use of clock or set back thermostats for new homes. The main function of these thermostats was to save energy by automatically relaxing the temperature set points during night time when people were sleeping (Peffer et al., 2011). The oil price shock of 1970s raised the interest in energy saving potentials of automated systems, while mostly comfort criteria had been considered before (Kastner et al., 2005).

In UK, over 40% of energy is consumed in buildings. The Department of Energy and Climate Change (DECC) has published a breakdown of domestic energy consumption in UK domestic dwellings (DECC, 2011). According to this report, the majority of domestic energy consumption is related to space heating. Space heating was responsible for 61% of the total oil equivalent in 2009. The UK government plans to reduce the net UK carbon account for the year 2050 to at least 80% below the level of net UK emissions of targeted greenhouse gases in 1990 (Climate Change Act, 2008) and reducing space heating energy consumption in domestic section is expected to have great impact on UK emissions of targeted greenhouse gases.

New technologies in domestic sector are expected to have considerable energy saving potential. The main gap of the literature is that there is an ongoing debate about the effectiveness of new home technologies like programmable TRVs and more studies are required to investigate energy saving potential of these technologies.

The aim of this project is to explore the potential of advanced radiator controls for reducing day-to-day heating energy demand in UK homes. This study also aims to provide recommendations to occupants, house builders, government and manufacturers for the use of advanced radiator controls to maximise their heating energy saving potentials. To achieve the above aims, five objectives are listed below:

1. To review previous research in the area of thermal modelling, smart homes and energy demand reduction.
2. To construct a dynamic thermal model of homes with and without advanced radiator controls.
3. To estimate the impact of programmable radiator controls by analyzing space heating energy demand of dwellings before and after installation of programmable TRVs and comparing space heating energy consumption to base case model.
4. To investigate possible control approaches for reducing space heating energy demand of dwellings. This is performed by introducing various cases for space heating reduction based on programmable TRVs capacities.
5. To make recommendations to occupants, house builders, government and for the use of advanced radiator controls to maximise their energy saving potentials.

2. Methods

This study employs a DTM software package, DesignBuilder to estimate the heating energy consumption of a two storey; post World War II, semi-detached dwelling located in England. The heating system consists of a gas boiler which distributes hot water through hot water loops to radiators in each room. Based on programmable TRVs capacities, possible cases for saving space heating are introduced and simulations are run to quantify reductions in total heating energy consumption of the dwelling. These cases include reduction in heating set-points and turning off radiators.

In the building under study, living room, one of the bedrooms and kitchen are located on the ground floor while other two bedrooms, a box room, bathroom and toilet are located on the first floor. The building is connected to another semi-detached building which has same built type, construction details and floor plans. The front of building faces south-east and it has a pitched roof covered with concrete roof tiles. The building has wooden external and internal doors and windows are single glazed with painted wooden frame. External facade is covered with red brick mainly and a single chimney way is provided. The building also has an insulated loft space which has access from the first floor hall.

Building model is created in DesignBuilder software package and location is selected as East Midlands, UK but Birmingham weather data is used in simulations as it is the closest to the location of building. The model of building has total area of 92m^2, 13m^2 of which is unoccupied (loft space). Internal walls are 0.1m and external walls are 0.36m thick. The materials used in the model are selected in accordance with the common construction materials used in semi-detached dwellings of 1940s. Heating systems is assumed to be working from 06:00 to 10:00 and from 16:00 to 24:00 during work days and from 06:00 to 24:00 during weekends and holidays to heat the

building. Occupancy profiles and gain data are assigned in accordance with data from the Time Use Survey, 2000 (Office for National Statistics, 2003).

This study investigates the possible cases for space heating energy saving which can be achieved using programmable TRVs. These cases consider reduction in heating set-points and turning off individual radiators. The main parts of this study are:

1. Study of base case model and
2. Impact of radiator controls on space heating energy demand including the change in heating set-points and turning individual radiators off.

First part of the study looks into the base case model and validates the simulation results. Base case model doesn't consider any programmable TRVs and assumes a conventional dwelling. Second part of the study investigates impact of radiator controls on space heating energy consumption and thermal comfort of occupants. In this part it is assumed that dwelling uses programmable TRVs and heating set-points can be altered when needed with fine precision.

3. Results and Discussions

Results are presented in two parts. First part presents overall, annual, monthly and daily results of base case model and validates these results. Table 1 presents the floor area, annual electricity consumption, heating set-point, annual sensible heating load in each room and total annual electricity and gas consumption of the dwelling. The energy consumption break down shows 14,615 kWh of natural gas and 4,149 kWh of electricity is annually consumed in the building. Zone sensible heating is the amount of heat transferred from radiator to the room. Sensible heating in halls and staircases are zero because there is no radiator in these spaces.

Table 1 Floor area, heating set-point and base case simulation results (annual electricity and sensible heating energy demand and annual heat loss in each room)

	Room Type	Area	Electricity[1] Demand	Sensible Heating Energy Demand	Gas[2] Demand	Set-point	Heat Loss
		m^2	kWh/yr	kWh/yr	kWh/yr	°C	kWh/yr
Ground Floor	Bedroom	13.3	455	2,415	–	23	2,923
	Living room	15.5	882	2,626	–	23	2,961
	Kitchen	5.7	547	612	–	21	2982
First Floor	Bedroom1	13.3	455	1,713	_	23	3,032
	Bedroom2	15.5	530	2,141	–	23	3,106
	Bathroom	4.8	297	758	_	22	1114
	Toilet	1.0	191	114	_	21	307
	Box room	4.4	293	453	_	21	1386
	Other (Halls)	5.5	499	0	_	_	2,085
	Total	79.0	4,149	10,831	14,615	_	19,896

[1] Electricity consumption includes lighting, appliances and cooking only, it is assumed that boiler consumes no electricity

[2] Gas demand is the amount of gas consumed by boiler and the ratio of Sensible heating energy demand to gas demand shows the heating system efficiency (74%)

Simulation results show that dwelling gas consumption has great agreement with DECC statistics by floor area while electricity consumption of dwelling shows a good agreement with DECC statistics by age. Results of other studies in the area of domestic energy consumption would also help to justify the simulation results of base case model of the dwelling. Table 2 summarizes the comparison of base case model energy consumption to national statistics and previous studies.

Table 2 Comparison of dwelling energy consumption to national statistics

Source		Gas Consumption	Electricity Consumption
		kWh/year	kWh/year
Base case model	Annual consumption	14,615	4,149
Sub-national energy consumption statistics by age (DECC, 2013)[1]	Annual Consumption	16,484	4,123
	Difference[3]	11.3%	-0.6%
Sub-national energy consumption statistics by floor area (DECC, 2013)	Annual Consumption	14,651	3,949
	Difference[3]	0.2%	-5.1%
NEED[2] (DECC, 2013)	Annual Consumption	16,971	3,474
	Difference[3]	13.9%	-19.4%
Semi-detached dwellings (Firth et al., 2010)	Annual Consumption	17,727	4,439
	Difference[3]	17.6%	16.2%
All dwellings (Firth et al., 2010)	Annual Consumption	17,449	4,574
	Difference[3]	16.2%	9.3%

[1] The UK Government's Department for Energy and Climate Change (DECC) publishes energy consumption statistics on the gove.uk website. These include domestic gas and electricity consumption data at the regional output areas.

[2] National Energy Efficiency Data framework (NEED) covers both domestic and non-domestic buildings. NEED provides the largest data source currently available for analysis of energy consumption at the building level.

[3] This is the percentage difference of source annual consumption compared to the base case annual consumption

3.1. Impact of Radiator Controls

Two cases are studied here; first one investigates the impact of reducing heating set-points in dwelling on space heating energy consumption. Second case, quantifies the energy saving and percentage reduction in space heating energy resulted from turning off radiators in different rooms one by one. In first case, heating set-point in all rooms reduced with 1°C steps up to 5°C at the same time and the reduction in total gas consumption of dwelling is quantified. According to simulation results, 1°C reduction in heating set-point of whole house can lead to gas consumption saving of 16% annually. Another 1°C reduction in heating set-point would result in a further 16% and a total of 30% reduction in gas consumption of dwelling. Total gas consumption in a dwelling can be reduced up to 64% with 5°C reduction in heating set-point. Decreasing heating set-point of whole dwelling beyond 2°C doesn't seem to be practical during cold winter days as this would result in reduced thermal comfort of

occupants which is not desired. Hence, it would be helpful to look into impact of reducing heating set-points on internal air temperatures of mainly occupied rooms.

Comparing room internal air temperatures to thermal comfort criteria, it is realized that in bedrooms heating set-point can be reduced up to 2°C with no thermal discomfort and in kitchen up to 3°C with only a slight (0.5°C) difference with comfort temperatures. In living room, however, even a 1°C reduction in heating set-point results in decreased thermal comfort and further reduction in heating set-point may result in undesired thermal conditions.

In second case, radiators in different rooms are turned off one by one and the reduction in total gas consumption of dwelling is quantified. Impact of turning off radiators on internal temperatures of mainly occupied rooms is also studied. Table 3 shows the total gas consumption of base case model and the resultant gas consumption of dwelling when turning off different radiators. According to table 3 turning off the radiators in living room, ground floor bedroom and first floor bedroom 2 have the greatest effect on total gas consumption of the dwelling. This is in accordance with high sensible heating needed in these spaces as presented in Table 1.

Table 3 Simulation Results for whole house total gas consumption and percentage reductions corresponding to each stage of turning off radiators

Turning off radiator		Floor Area	Total Gas consumption	Reduction of Total Gas Consumption
		m^2	kWh/year	_
	base case	_	14,615	–
Ground Floor	Bedroom	13.3	11,883	18.7%
	Living room	15.5	11,781	19.4%
	Kitchen	5.7	13,928	4.7%
First Floor	Bedroom 1	13.3	13,135	10.1%
	Bedroom 2	13.3	12,812	12.3%
	box room	4.4	14,157	3.1%
	Bathroom	4.8	14,011	4.1%

4. Conclusions

This study investigated the potential of programmable TRVs in reducing space heating energy consumption in a semi-detached dwelling located in Loughborough, UK. Wide range of simulation results was obtained using Dynamic Thermal Modelling (DTM) software package DesignBuilder. Simulation results helped to study the possible heating control strategies that can be achieved using programmable TRVs. It was found that use of programmable TRVs can lead to great space heating energy savings which cannot be achieved using conventional radiator controls. Using programmable TRVs, fine control of room temperature can be achieved which would help to reduce space heating energy consumption while maintaining occupant's thermal comfort. These four main conclusions were achieved:

1. Reducing heating set-point in a house across all radiators at the same time from 1°C to 5°C is shown to result in 16% to 64% reduction in annual gas consumption for space heating. Study of occupant's thermal comfort showed that it is impossible to decrease heating set-point in whole house up to 5°C without having negative impact on thermal comfort of occupants. However, households that can tolerate lower room temperatures can achieve gas saving of up to 64%.
2. Turning individual radiators off, one at a time, is shown to result in a 3.1% to 19.4% reduction in annual gas consumption for space heating. The amount of gas saving is dependent on room type and sensible heating required to maintain thermal comfort in the room.
3. It is found that independent temperature control of individual rooms, which is achieved by using programmable TRVs, reduces the negative impact of changes in heating set-point of one room on thermal comfort of occupants in neighbouring rooms.
4. Simulation results showed that bedrooms and kitchen have highest potential to reduce space heating energy consumption. When in bed, occupants tend to tolerate lower temperatures in bedrooms. Kitchens, on the other hand, are not frequently occupied and usually cooking stove is on when occupants are in kitchen. Hence, further reduction in heating set-point of bedrooms and kitchen is possible.

5. References

Climate Change Act, 2008. Carbon Targeting and Budgeting, Chapter 27, Part 1. The Target for 2050. Her Majesty's Stationery Office Limited, London, UK.

DECC, 2011. Energy statistics publications. London, Department of Energy and Climate Change. Available at: www.decc.gov.uk/en/ content/cms/statistics/publications/publications. aspx.

DECC, 2013. Sub-national energy consumption statistics, Department of Energy and Climate Change, (https:/www.gov.uk/government/statistical-data-sets/ sub-national-energy-consumption-statistics).

Firth, S., Lomas, K., Wright, A., 2010. Targeting house hold energy efficiency measures using sensitivity analysis. *Building Research & Information* 38(1), 25–41.

Kastner, W., Neugschwandtner, G., Soucek, S., & Newman, H. M., 2005. Communication Systems. *Building Automation and Control*, 93(6), 1178–1203.

Meier A.K., Walker I., 2008. Residential thermostats: comfort controls in California homes. Berkeley: Lawrence Berkeley National Laboratory. LBNL938E.

Office for National Statistics 2003. United Kingdom Time Use Survey, 2000. Online: Available to registered users from: www.esds.ac.uk/findingData/snDescription.asp?sn=4504 Last accessed 25th June, 2013.

Peffer, T., Pritoni, M., Meier, A., Aragon, C., & Perry, D., 2011. How people use thermostats in homes: A review. Building and Environment, 46(12), 2529–2541. doi:10.1016/j.buildenv.2011.06.002