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Potential energy savings achievable by zoned control of individual rooms in UK housing compared to standard central heating controls

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A B S T R A C T

Energy is wasted in domestic buildings when rooms that are heated are not occupied. Allowing those rooms to cool reduces the inside – outside temperature difference and therefore rate of heat loss, resulting in an energy saving. This suggests a cost effective way to upgrade an existing modern heating system, especially in older properties where other energy saving possibilities are limited. Assessing the savings achievable requires an analysis of a range of influencing factors, such as house type and age, location and occupancy patterns. Door opening has a major influence due to the impact on air exchange between heated and unheated zones in a house, so this was also considered.

Annual simulations were carried out on dynamic models of the thermal and air flow interactions, for all combinations of influencing factors, to compare the potential energy savings of zoned versus non-zoned control.

Savings of between 12% and 31% were obtained in the case of a semi-detached house model, and between 8% and 37% for a single storey bungalow. The largest percentage savings occurred in older properties, with interconnecting doors kept closed, and for the more intermittent types of occupancy. The average saving obtained for both house types was around 20%.

1. Introduction

Reducing energy consumption in homes, largely driven by the need to meet carbon dioxide emission reduction targets, is being achieved in new build properties predominantly through higher insulation standards, increased air tightness and more efficient domestic lighting and appliances. However, at least 80% of the building stock that will exist in 2050 is already built [1], so increasing attention is being paid to finding energy saving solutions for existing properties. Relatively simple and cost effective measures such as loft insulation, cavity wall insulation, weather stripping, and boiler replacement are widely deployed. More costly and invasive demand reduction measures include replacement windows, and internal or external wall insulation. Further measures usually involve the deployment of renewable technologies, such as solar thermal and PV panels, biomass boilers and heat pumps. These solutions are heavily promoted by manufacturers, but are expensive, and significant uptake is driven by government aid programmes such as the Renewable Heat Incentive and the Energy Company Obligation [2,3].

Heating controls are a neglected technology in the home, and although there is now acceptance that time and temperature control can reduce energy use, mainly by avoiding unnecessary fuel use, there is a lack of knowledge or understanding as to what technologies and techniques could be applied to obtain the maximum benefit in particular instances. Only in recent years have even the simplest domestic heating controls become a standard for new heating systems in the UK, the minimum installation requiring a single time and temperature control zone for floor areas up to 150 m^2, and two independent time and temperature control zones for floor areas greater than 150 m^2. Thermostatic radiator valves (TRVs) are required on all radiators except in the room where the thermostats are located [4]. Even this basic standard level of control does not exist in 70% of UK homes [5]. More advanced thermostats, usually combining time and temperature programming, allow more complex profiles to be accommodated, and this can lead to some additional savings. Until recently, this level of control sophistication was all that could be achieved by automatic control, using standard components available to installers. Recent developments now offer a practical means of controlling the environment in individual rooms in a house.

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These technologies allow the thermostatic radiator valve head (the part that actuates the valve) to be replaced by a wirelessly controlled motorised actuator. By this means, every room can be controlled independently, so heating can be turned off in those rooms not in use during parts of the day, or temperatures may be increased in a room without affecting the heat supply to the rest of the property. A central control unit receives the demands from all radiators, and switches the boiler on or off as required to meet the current demand throughout the day. This is a relatively low cost retrofit option in many existing homes, no alterations to pipework and only minimal additional wiring being required. By this means, energy savings should be achievable, compared to single point time and temperature control of the entire heating system.

There remains a substantial proportion of the housing stock for which the more conventional solutions are difficult to apply, due to architectural, location and conservation constraints. In contrast, multi-zone heating system controls suffer no such constraints, and can often be installed as an upgrade to an existing heating system.

The premise under investigation is that a multi-zone control system could offer a means to save energy in many existing properties, as an alternative, or addition to the conventional solutions. The purpose of this paper is to demonstrate a range of potential energy savings achievable by deployment of multi-zone controls for a variety of occupancy patterns in various UK house types, locations, and ages. This will indicate what overall energy saving could be achieved by deploying multi-zone controls in existing housing on a national basis, and lend additional weight to the argument that such systems should receive more recognition and support by government agencies responsible for determining the scope of standard assessment procedures and incentive schemes.

The approach of this study was to use dynamic computer modelling and simulation, using the open source building performance simulation (BPS) package ESP-r [6], which has been developed over three decades by the Energy Systems Research Unit (ESRU) at the University of Strathclyde and a global community of users. ESP-r is used to carry out all aspects of building performance appraisal within a modelling environment that accounts for thermal energy flows, air flows and climate interactions. To ensure that the simulation results were credible, a validation check was carried out using published data from a monitored site.

2. Multi-zone control behaviour

Multi-zone control in a domestic property achieves energy savings, compared with single zone control, because radiators in rooms that would otherwise be heated can be turned off or adjusted to reduce heat output. The achievable energy saving will depend on the extent to which the temperatures in such rooms fall before heating is again required in those rooms. This in turn is dependent on room location, duration of the off (or reduced temperature set-point) period, thermal exchange with connected rooms or zones, the overall insulation level of the property, internal gains, solar gains and the external temperature. For example, a room in a semi-detached property with other heated rooms on all sides and below, will not cool down as rapidly as a corner room in a bungalow, and therefore will deliver a lower energy saving if turned off for short periods. Turning the heating off in a room for a longer period will increase the obtainable energy saving per unit time, because a lower average temperature, and therefore lower heat loss to the external environment, will be experienced. A room with an open door into a neighbouring zone will gain heat from that zone as long as the temperature is lower, and this will reduce the energy saving in that room, and increase the energy required to maintain temperature in the connected zone. The potential for energy saving will also be affected by the overall external fabric insulation levels. A well-insulated building will not lose heat very rapidly from a room with no heating, so the potential energy savings will be quite low compared with an older, unimproved property. A similar property in a cooler climatic location would also be expected to achieve greater energy savings (though not necessarily in proportion to its total energy consumption).

The study therefore included variations in parameters that would allow observation of these various effects on the savings due to multi-zone control.

3. Previous studies

Given the energy saving potential of multi-zone control, it has received surprisingly little attention in the published literature. On the other hand, there are several papers that demonstrate the benefit of simple controls (such as a single thermostat with timed control and TRVs) over poorly controlled systems (e.g. timed boiler on/off control). However, empirical studies are difficult to undertake at a scale that may lead to reliable estimates of savings, and both measurement and modelling studies that have been undertaken show a large range in potential savings. For example, Peffer et al. [7] undertook a review of thermostat studies in North America and found reported energy savings from the use of programmable thermostats varying from zero to 9%. 1Liao et al. [8] reviewed current practice regarding control of heating systems in residential buildings in the UK and Peeters et al. [9] undertook a similar study in Belgium. In both cases, they demonstrated the inefficiency of many installations, and concluded that overall efficiency is affected markedly by the boiler size, the choice of boiler control, whether weather compensation is applied, and the particular configuration of a control thermostat and TRVs.

Regarding multi-zone control, a detailed experiment was undertaken by Beizaee et al. [10] on a matched pair of semi-detached houses: in one house the space heating was controlled with a single thermostat with timed control and TRVs; in the other, zonal control was used to heat rooms only when they were occupied. More details of the experiment are given in the Model Validation section in this paper where the published data are used as a check on the modelling work. Extrapolating the results to the range of UK climates, it was concluded that zonal control could reduce space heating by around 12% for the un-refurbished 1930's houses that were tested.

Meyers et al. [11] undertook a high level scoping study of the potential energy savings in US residential buildings resulting from better control and increased appliance efficiency. Technologies they considered were programmable thermostats, smart meters and outlets, zone heating, automated sensors, and wireless communication infrastructures. They estimated that in the order of 4.2% of primary energy is wasted by heating and cooling unoccupied houses, 6.2% is wasted by heating or cooling living areas during the daytime, and 9.7% is wasted heating and cooling bedrooms when the house is occupied, but the bedrooms are not being used.

Leow et al. [12] undertook a modelling study on occupancy-moderated zonal temperature control. They developed algorithms that would control different house zones based on occupancy, including demand-response adjustments to heating and cooling based on the prevailing electricity price. They showed, for zoning control (without demand-response load shifting) over a range of climates in the USA, overall savings averaging around 23%, depending on the particular configuration. Potential cooling energy savings were found to be higher than heating energy savings. The reference for the calculated savings was the whole house heated or cooled to the chosen set-point temperatures of 23.9 °C for cooling and 21.1 °C for heating.