Thermal modelling of the heat replacement effect and its implications for energy saving programmes

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Abstract

'The heat replacement effect' was introduced at the EEDAL 2003 conference in Turin in a paper by Bruce Young. This term describes the process whereby energy savings from lower appliance consumption lead to additional space heating energy consumption, because of the lower level of heat gains from appliances. In cold countries, this partly offsets any appliance savings achieved. The opposite is true in climates where cooling is more important than heating, where additional savings will be made. The effect has sometimes been ignored when designing energy efficiency programmes, leading to incorrect estimates of likely carbon savings and potentially, therefore, to programme underachievement.

This paper reports on further analysis that has been undertaken since 2003, using thermal simulation software to refine previous estimates. The factors developed can be used with reasonable confidence to estimate the proportion of the expected savings from more efficient lights and appliances that are foregone due to the heat replacement effect. This should be useful for policy makers and analysts, as it offers a simple way to produce more realistic estimates of the carbon and cost savings from policies that encourage the uptake of efficient electrical goods.

The findings reinforce those from earlier work, and confirm that ignoring the heat replacement effect can have a significant negative impact on the accuracy of energy saving claims from national programmes. In the UK for example, failure to account for heat replacement would lead to the carbon saving from low energy lights and appliances being overestimated by more than 30%. That would severely reduce the credibility of reported results.

Introduction

A description of the heat replacement effect

In the process of performing their intended function, lights and appliances (L&A) convert the energy they use into heat. When used inside buildings, this has the effect of raising the internal temperature. If appliance use is coincident with the need for space heating, this contributes to maintaining the required internal temperature. If the temperature of the building is thermostatically controlled, the output of the heating system will automatically be reduced due to the presence of these heat gains[1].

If lights and appliances are replaced with more efficient models, the energy they use and the heat they produce will be reduced. A greater amount of heat will therefore be required from the heating system to maintain the same internal temperature. The energy apparently saved by using lower energy appliances is thus 'replaced' by that from the heating system. Hence, the process is known as the heat replacement effect (HRE).

When looked at over a day, month or year, it is likely that not all of the energy saved will be replaced, because not all of the heat produced by lights and appliances will be coincident with the need for heating. In many countries, heating is needed only during certain months of the year. For the remaining months there will be no heat replacement and savings from more efficient devices will be proportionate to their reduced consumption. And even during months when space heating is required, if heating is not on 24 hours a day, some of the heat from lights and appliances may occur outside the

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[1] Even in the absence of thermostatic control, it would be reasonable to assume that reduced gains will lead to some compensative response by the dwelling's occupants. For example, the heating device might be left on for slightly longer because the dwelling takes longer to reach the required temperature.

heated hours, again leading to less than full heat replacement. Thus, it is often not easy to estimate the magnitude of the HRE.

To consider the impact of the HRE on the energy, cost and carbon savings from using more efficient appliances, the level of coincidence of the heat output of L&A with the need for space heating must be considered. Of course, this varies with the location and characteristics of the building, as well as the preferences of its occupants and the efficiency of the heating system[2]. It will often involve the replacement of heat produced using one fuel (usually electricity) with that from another (the space heating fuel), complicating the calculation of the associated cost and carbon emissions savings.

HRE works in the opposite direction in buildings that are actively cooled. As for heating, this will occur automatically if the cooling system is thermostatically controlled (and probably manually if not). Where this is the case, for any heat produced by L&A (or any other internal source), additional energy has to be used to remove it from the building. Hence, reducing L&A energy use will yield additional reductions in cooling energy use.

Previous work

In a paper presented at EEDAL 2003 in Turin [1], Bruce Young introduced the concepts behind the HRE and used a simple procedure to estimate factors to calculate its affect on the energy, cost and carbon savings for lighting and certain appliances applicable to the UK. These were primarily based on the calculation of the coincidence between heating hours and the likely hours of use for the device being considered, taken over a whole year. This yielded a coincidence factor that was greatest for lighting. The key findings from that work are given in Table 1.

Table 1 – Key factors estimated in previous HRE study

Device type	HRE factor, R	Energy saving factor, S_{energy}	Cost saving factor, S_{cost}	Carbon saving factor, S_{carbon}
Lighting	70.3%	-0.4%	81.9%	52.8%
Fridges & freezers	55.1%	21.3%	85.8%	63.0%
Electric cooking	58.0%	17.1%	85.1%	61.1%
Gas cooking	58.0%	42.0%	42.0%	42.0%
Wet appliances (washing machines, etc.)	2.8%	96.0%	99.3%	98.1%
Consumer electronics	58.0%	17.1%	85.1%	61.1%
Standby power	56.8%	18.9%	84.6%	61.9%
Added electric heating	100%	-43.0%	74.3%	32.9%
Added gas heating	100%	0.0%	0.0%	0.0%

Source: Domestic figures from table 3 of reference [1]

Full descriptions and derivations of the terms used in Table 1 are given in [1], but for convenience brief descriptions are given here.

- *R* is the proportion of the energy used by the appliance that offsets energy that would otherwise be provided by the heating system

- *S* is the proportion of the reduction in energy, cost or carbon used by the appliance that is still present when the additional space heating energy is taken into account. For example, if S_{carbon} is equal to 50%, for every unit of carbon saved in reduced appliance energy use an additional 0.5 units will be produced in providing the extra heat required to maintain the same internal temperature as before.

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[2] The figures reported in this paper therefore can more reliably be applied to schemes involving a large number of dwellings than to individual dwellings (although the same principles apply).

Purpose of this study

The purpose of the previous work on HRE was to describe the nature of the HRE, to consider which factors it depends most upon and to provide initial estimates of its magnitude. The purpose of the work undertaken since has been to provide more refined estimates of the values of the factors derived. Therefore, following a meeting on the subject where interested parties in the UK discussed the initial findings, it was decided to undertake a series of detailed simulations to consider the utilisation of gains in houses in more detail. The remainder of this paper describes the cases that were modelled, uses these results to derive HRE factors and considers the implications of the findings for energy/carbon saving programmes and policies.

Description of the work undertaken

Simulation modelling

Detailed thermal simulation modelling was carried out for a series of cases. These were all variations of a 'base case' dwelling, which had characteristics which were either average (where known) or typical (where the average was not known) of an existing UK house. By modifying features of the base case, 17 slightly different situations were devised, designed to show how a number of factors affect the utilisation of the gains from L&A. Detailed specifications for each case were prepared and sent to the team selected to perform the modelling. A full list of the cases modelled is given in Table 2.

Key characteristics of the base case dwelling were:

- Floor area of 88.8m^2, two storey semi-detached house, 3-bedrooms
- Brick/brick cavity walls (unfilled), 150mm roof insulation, single glazed
- Typical bi-modal UK heating pattern assumed: weekdays 7am-9am, then 4pm-11pm, weekends 7am-11pm
- Heating system: gas central heating system of average efficiency 70% (supplying hot water to radiators), controlled by a programmer (to control on/off periods), room thermostat (set to 21°C), and thermostatic radiator valves (TRVs) elsewhere set to 18°C
- Such a dwelling achieves an energy efficiency rating that is very close to the average for the UK's housing stock

Table 2 – Cases modelled

Case	LIGHTING				SHADES		DWELLING TYPE			HEATING				APPLIANCES			
number	None	GLS	CFL - same lux	CFL - same power	No lampshades	Lampshades	Poorly insulated	Average	Well insulated	Bi-modal	All day	No TRVs	TRVs	None	Average	200W const.	300W const.
1	X					X		X		X			X		X		
2		X				X		X		X			X		X		
3			X			X		X		X			X		X		
4				X		X		X		X			X		X		
5		X			X			X		X			X		X		
6			X		X			X		X			X		X		
7		X				X	X			X			X		X		
8			X			X	X			X			X		X		
9		X				X			X	X			X		X		
10			X			X			X	X			X		X		
11		X				X		X			X		X		X		
12			X			X		X			X		X		X		
13		X				X		X		X		X			X		
14			X			X		X		X		X			X		
15		X				X		X		X			X	X			
16		X				X		X		X			X				X
17		X				X		X		X			X			X	

Notes on the cases chosen

The cases were designed to address specific points of interest, so not all of them represent realistic scenarios of L&A use.

Case 1 assumes there is heating, but no lighting. Comparing the heating energy for this case with others where lights are present illustrates how much of the heat from lighting usefully offsets that which would otherwise come from the space heating system. This is fundamentally important in explaining and estimating the magnitude of the heat replacement effect.

Cases 2 and 3 allow a direct comparison of the heating and lighting energy needs before and after the replacement of tungsten lamps with compact fluorescent lamps (CFLs) to give the same level of illumination.

Case 4 models CFLs of the same electrical power as the tungsten lamps they replace. This is not intended to be a realistic scenario (because it implies 5 times more illumination than is normal), but to examine how the differing proportions of radiant and convective heat from filament lamps and CFLs affect their contribution to heating.

Cases 5 and 6 are the same as 2 and 3, except that there are assumed to be no lampshades present. This is relevant because lampshades convert some radiant to convective heat and so could have an effect on the proportion of the output from the lights that usefully heats the dwelling.

Cases 7 and 8 have the same characteristics as 2 and 3, except for inferior insulation (solid brick walls and no roof insulation). Insulation level was expected to be a parameter which affects the magnitude of the HRE.

Cases 9 and 10 have the same characteristics as 2 and 3, except they are better-insulated versions of the standard dwelling, with insulated walls, 250mm of roof insulation and low-emissivity double glazing.

Cases 11 and 12 are the same as 2 and 3, except an all-day heating pattern was used for the whole week (7am-11pm). This is a common heating pattern in homes where an occupant is usually at home during the day.

Cases 13 and 14 assume there are no TRVs present on radiators and that the temperature of the whole house is controlled by the room thermostat.

Cases 15, 16 and 17, which look at appliance gains rather than lighting gains, assume typical insulation levels and that TRVs are present. Case 15 assumes no appliance gains (for the same reason that case 1 assumed no lighting). A constant level of appliance gains is assumed 24 hours per day for 16 and 17, with the magnitude reduced in the latter case to see the effect this has on the space heating energy.

The results (in the form of annual energy consumption figures for space heating and appliance use) were then analysed as described below to derive HRE factors, R. From those, the beneficial savings factors S_{energy}, S_{cost}, and S_{carbon} were calculated.

Results

The energy consumption figures resulting from the modelling are shown in Table 3. Note that the space heating figures refer to the amount of heat energy usefully delivered to the dwelling, rather than the amount of fuel energy the heating appliance would require (the difference being due to the inefficiency of the heating device). Energy required for hot water is not considered because it is not affected by the HRE and would be identical in each case.

Table 3 – Energy consumption data from modelling

Case number	Space heating energy requirement (MWh/yr)	Lighting energy consumption (MWh/yr)	Appliance energy consumption (MWh/yr)	Total energy consumption (MWh/yr)
1	10.119	0.000	2.386	12.505
2	9.840	0.454	2.386	12.680
3	10.060	0.091	2.386	12.537
4	9.822	0.454	2.386	12.662
5	9.845	0.454	2.386	12.685
6	10.060	0.091	2.386	12.537
7	15.507	0.454	2.386	18.347
8	15.721	0.091	2.386	18.198
9	4.136	0.454	2.386	6.976
10	4.355	0.091	2.386	6.832
11	10.885	0.454	2.386	13.725
12	11.118	0.091	2.386	13.595
13	12.25	0.454	2.386	15.090
14	12.48	0.091	2.386	14.957
15	11.246	0.454	0.000	11.700
16	9.901	0.454	2.628	12.983
17	10.334	0.454	1.752	12.540

From this primary information, the values in Table 5 were derived using the equations described in [1], providing comparable figures to those given in the earlier work on HRE. To aid comparison, the initial estimates from [1] are repeated here in Table 4.

Table 4 – HRE factors from earlier work for comparison with new values

Source of gains	f_{sur}	f_{in}	f_{hs}	R	S_{energy}	S_{cost}	S_{carbon}
Lights	100%	95%	74%	70.3%	-0.4%	80.9%	52.8%
Standby power	100%	98%	58%	56.8%	18.9%	84.6%	61.9%
Fridges and freezers	100%	95%	58%	55.1%	21.3%	85%	63%

Table 5 – Factor derived from thermal simulations

Case	f_{sur} x f_{hs}	f_{in}	R	S_{energy}	S_{cost}	S_{carbon}
2 to 3	60.6%	95%	57.6%	17.7%	84.4%	61.4%
5 to 6	59.2%	95%	56.3%	19.6%	84.7%	62.3%
7 to 8	59.0%	95%	56.1%	19.9%	84.8%	62.4%
9 to 10	60.4%	95%	57.4%	18.0%	84.4%	61.5%
11 to 12	64.2%	95%	61.0%	12.9%	83.5%	59.1%
13 to 14	63.4%	95%	60.2%	14.0%	83.7%	59.6%
16 to 17	49.4%	98%	48.4%	30.9%	86.9%	67.5%

Table 4 gives figures for both standby power and fridges and freezers as examples of ‘always on’ appliances, whose daily energy consumption is not expected to vary much throughout the year. They can reasonably be compared with the findings for appliances in the thermal simulation modelling work.

Note that the two factors f_{sur} (proportion of heat disposed to surroundings) and f_{hs} (proportion of heat disposed that is coincident with space heating need) are given separately in Table 4, but are not separable in Table 5. The thermal simulation modelling gives a single figure equal to the product of f_{sur} and f_{hs}. However, the value of f_{sur} is likely to be close to 100%, since only a small proportion of the energy is able to leave the building without heating it (eg, light passing through a window). An exception to this is wet appliances, where much of the energy may be lost from the dwelling in the form of hot water down the drain, or in the case of non-condensing tumble dryers, the deliberate external venting of warm air.

The factor f_{in} (proportion of energy consumed in heated living space) in Table 4 for lighting assumes that 95% of the lighting energy is consumed in the heated living space, the remaining 5% being for external lighting that does not contribute to the heating of the building. For the thermal simulation modelling, it was assumed that all lights were in the dwelling, so it was necessary to apply the same factor to the simulation results to obtain comparable figures. For appliance gains, it was assumed that 98% is emitted within the heated space (in line with the 'standby' figure from Table 4).

Discussion of results

Lighting

Lighting is treated differently from appliances as a greater proportion of it is required at the same time as heating. Especially in more northerly climates, there are lengthy periods when it is both dark and cold, during which human habitation calls for artificial light and heat simultaneously. An estimate of the coincidence factor f_{hs} for lighting was developed in the previous study.

However, the thermal simulation modelling results now make the application of this coincidence factor, which was a source of uncertainty, unnecessary. Simulation over a full year shows the proportion of the annual lighting energy that ends up as useful heat. Simulation results relevant to this are discussed in the remainder of this section, referring to raw data figures from Table 3.

A comparison of the results from case 1 (no lighting) with case 2 (tungsten lamps) reveals that the 0.454 MWh/yr of electrical energy supplied for lighting reduces the heat required from the heating system by 0.279 MWh/yr. Thus, 61.4% of the energy used by the lights during the whole year has been converted to useful heat - heat that would otherwise be required from the space heating system. Assuming the space heating is supplied from a gas central heating system of 70% efficiency (a typical heating system in the UK), the heat from lighting in this case reduces gas consumption by 0.3986 MWh/yr.

Comparing case 1 (no lights) with case 3 (CFLs) shows that the 0.091 MWh/yr supplied to the lights reduces the energy required from the heating system by 0.059 MWh/yr (so 64.8% of lighting energy is converted to useful heat). For a 70% efficient heating system, an extra 0.0843 MWh/yr of gas would be needed to heat the dwelling without the heat obtained from the lights.

Comparing cases 4 (where light is provided by CFLs of the same electrical power as tungsten lamps) and 2 with case 1 shows that the useful space heating from CFLs is slightly higher than that from tungsten lamps of the equivalent power (65.4% is useful compared to 61.4%). A higher proportion of the heat output from CFLs is in the form of convective heat rather than radiation, so this demonstrates that radiation from lights is slightly less useful than convective heat for space heating.

Comparing case 5 (where no lampshades are present) with case 2 shows that a lampshade slightly increases the useful heat output of lights. 61.4% is useful where lampshades are present, compared to 60.3% where they are not. This is because a lampshade absorbs incident radiation and converts it to convective heat, which is slightly more useful for space heating.

The magnitude of the heat replacement effect for lights in a typical UK dwelling

Comparing cases 2 and 3 shows that for the dwelling simulated in this study, 0.363 MWh/yr of electricity is saved by replacing tungsten lamps with CFLs. Because of this, the annual heat requirement increases by 0.220 MWh/yr. This implies a heat replacement factor of 60.6%. However, an allowance should be made for lighting energy used in external lighting. The factor f_{in} (95%) is therefore applied, leading to a heat replacement factor R of 57.6%.

In terms of delivered energy savings, assuming a 70% efficient gas heating system provides the extra heat, 100% / 70% = 1.429 times the quantity of missing heat from lights will be required to heat the dwelling to the same level. Using the formula from [1] the delivered energy saving factor S_{energy} is thus 17.7%. In other words, only 17.7% of the gross delivered energy saving will be achieved in practice.

In terms of fuel costs, replacing tungsten lamps with CFLs reduced electricity consumption by 0.363 MWh/yr and increased space heating consumption by 0.220 MWh/yr. However, since electricity is more expensive than gas (by a factor of about 4 in the UK), the gross cost saving will not be so heavily reduced when including the effect of heat replacement. In this case, 84.4% (S_{cost}) of the gross cost saving will be achieved.

Similarly, in terms of carbon savings, because electricity is significantly more carbon intensive than gas in the UK (by a factor of 2.2), the gross carbon saving is not as heavily reduced when converting to a saving net of heat replacement. Simulation cases 2 and 3 suggest 61.4% (S_{carbon}) of the gross carbon saving will be achieved.

Sensitivity of HRE (lighting) to dwelling characteristics

Cases 5 and 6 show that the heat replacement factor is slightly lower in a dwelling with no lampshades. This is explained by the fact that with no lampshades a slightly larger proportion of the heat is radiant, providing a smaller useful input to the dwelling's space heating need. Thus when the heat input from lights is reduced by installing CFLs, less heat needs replacing, so a lower heat replacement factor is found.

Cases 7, 8, 9 and 10, with their different insulation levels, suggest that the heat released from lights in well insulated dwellings provides slightly more useful space heating than in poorly insulated ones (hence giving a higher value of R). This may be because any heat released outside heating times is stored for longer within the dwelling, so more of it will still be present by the start of the next heating period.

Cases 11 and 12 show that homes heated all day, rather than morning and evening, have a slightly greater heat replacement factor. This may be caused by better use of heat from lighting during winter mornings, less of which is utilised when the heating period is broken between morning and evening.

Cases 13 and 14 show that the heat replacement factor for lights in dwellings with no TRVs is slightly higher than where TRVs are present. This may be because the lighting gains in the room containing the thermostat have a disproportionately large effect, as the thermostat controls all the heating in the house.

The study shows that the magnitude of the heat replacement factor R for lighting is not strongly affected by any of the variables examined (with the range of R for all cases looked at being between 56.1 and 61.0%). It is therefore suggested that a reasonable approach is to combine the most common cases from Table 5 into a single set of factors for practical use. Common cases for heating in the UK are:

- intermittent heating, with TRVs

- all day heating, with TRVs

- intermittent heating, without TRVs

- all day heating, without TRVs.

and the values of R for three of them are shown in Table 3. The fourth case ("all day heating, without TRVs") has not been modelled, but as the "intermittent heating, without TRVs" case was 2.6 percentage points higher than "intermittent heating, with TRVs", it is likely that "all day heating, without TRVs" would have a value for R somewhat above 61%.

An overall factor for domestic lighting of R = 60% is therefore proposed, and is shown as the final line in Table 6.

Table 6 – Overall factors for domestic lighting derived from thermal simulation

Cases		**Description**	**Heat replacement factor**	**Beneficial savings factors**		
GLS	CFL		R	S_{energy}	S_{cost}	S_{carbon}
2	3	Intermittent heating, TRVs	57.6%	17.7%	84.4%	61.4%
11	12	All day heating, TRVs	61.0%	12.9%	83.5%	59.1%
13	14	Intermittent heating, no TRVs	60.2%	14.0%	83.7%	59.6%
Overall factors for domestic lighting			**60%**	**14%**	**84%**	**60%**

Space heating by appliances

Unlike lighting, appliances here are assumed to consume energy at roughly the same daily rate throughout the year. Comparing cases 15 and 16 shows that of the 2.628 MWh of appliance energy 48.8% provides useful space heating over the course of a year. This is a lower proportion than lighting because of the reduced coincidence with heating. Note that it does not apply to appliances that dispose of most of their heat outside their house (eg, washing machines) – see discussion in Ref. [1].

Using a value for f_{in} of 98% and the value for $f_{sur} \times f_{hs}$ from the modelling (48.8%) gives a value for R of 47.8%.

Using the same method applied to the lighting figures, the net energy savings from better appliances are about 31% of the gross energy savings. Similarly, only about 87% of gross cost savings and 67.5% of gross carbon savings will be achieved. In other words S_{energy} = 31%, S_{cost} = 87% and S_{carbon} = 67.5%.

Implications of results

Implications for estimates of energy, cost and carbon savings

The findings from this study confirm the earlier conclusions that the HRE is a significant factor and therefore one that needs to be taken into account to obtain realistic predictions of the savings from reducing energy consumption by lights and appliances within buildings.

In a typical UK house, the cost saving from installing low energy lighting, if the HRE is ignored, will be overestimated by about 19% and the carbon saving by about 67%. It would be reasonable to expect a similar level of overestimation when looking at the potential savings for a large group of dwellings, rather than an individual typical house. Failure to recognise this when performing calculations could lead to wrong conclusions being drawn and, potentially, to wrong decisions being made.

Implications for policies and programmes

When designing an energy or carbon saving programme it is usual to produce an estimate of its expected benefits, i.e. how much energy or carbon it is expected to save. Often this will be an important part of the decision on whether the programme offers good value for money, or if that money could be better spent elsewhere. If the programme incorporates measures aimed reducing the energy consumed by L&A, the expected saving will be incorrect in most circumstances unless the HRE is taken into account properly. This may result in resources being misdirected and an overall reduction in the amount of energy or carbon saved by the programme. It is therefore vital that the implications of HRE are understood and calculated at the programme design stage, not just during the post-programme evaluation.

The work undertaken for this study and in [1] together clearly define and describe the HRE and show how its affects can be evaluated for a given situation. They also show how it is possible to derive factors that can simplify the process for those designing or analysing programmes, allowing them to take account of the HRE more easily in their calculations. The factors derived in this paper are applicable to programmes based on the UK housing stock, but the method could be repeated to derive suitable factors for many other situations, for example those involving other climates, other housing stocks, or non-domestic energy users. Indeed, in situations where electricity is the main heating fuel, it may be a more simple process to derive these factors, since fuel switching (typically from electricity to gas in the case of UK dwellings) will not complicate matters.

An example of the use HRE factors in a national programme

In the UK, one of the government's main tools to help reduce carbon emissions from housing is the Energy Efficiency Commitment (EEC) [2]. This effectively places a legal requirement on energy supply companies to deliver carbon savings by encouraging the installation of energy efficiency measures in homes. For each measure installed, they are credited with an appropriate carbon saving. The sum of their total carbon savings over the course of the programme must meet or exceed their target. The current phase of EEC started in 2005 and is due to run for three years.

In order to justify the expense of EEC (which is funded through customer fuel bills), estimates of programme costs and carbon savings were made by the UK government before it began. And since energy suppliers are given credit for measures installed on the basis of how much carbon each is estimated to save, it is very important to the success of the scheme that the estimates of savings are reliable. Under previous phases of EEC a significant proportion of the savings have been achieved by offering incentives to encourage the purchase of low energy lights and appliances. Hence, following the publication of work on HRE, appropriate factors were used to estimating the likely carbon savings taking HRE into account and in setting the appropriate level of credit for each L&A measure that might be installed. In previous EEC phases (which were designed before this work on HRE), this had not been taken account of and is thought to have lead to overestimation of the likely savings achieved by L&A efficiency measures.

Conclusions

The HRE is a significant factor affecting the magnitude of energy, cost and carbon savings from lights and appliances. Ignoring it will lead in most situations to an incorrect estimate of savings. HRE tends to reduce the gross saving one might expect from more efficient lights and appliances in situations where space heating is more important than cooling, whilst taking into account HRE in warmer climates, where space cooling is the dominant load, will increase their savings.

For the UK housing stock, figures have been derived to make it easier to take into account the effect of HRE on savings. They show that, typically, only around 60% of the expected carbon savings from reducing lighting consumption, and only about 68% of the saving expected from lower appliance consumption will be achieved in practice. This is because about 60% and 48% respectively of the energy they consume usefully heats the building they are in, so heating needs increase accordingly when that is reduced.

It would be quite possible to use the same methodology described here to derive similar factors that are suitable for use in other countries and situations.

Policy makers and programme designers should take account of HRE when considering the likely energy and carbon savings of their schemes. Failure to do so can lead to over-prediction (or even under-prediction) of the benefits, potentially causing incorrect decisions to be taken and misallocation of resources.

References

[1] Young B. *The Heat Replacement Effect*. Proc. of EEDAL 2003 (Turin, Italy, 1 – 3 October 2003) paper number 15.

[2] See http://www.defra.gov.uk/environment/energy/eec/