BNXS05: The Heat Replacement Effect

Version 9.1

This Briefing Note and referenced information is a public consultation document and will be used to inform Government decisions. The information and analysis form part of the Evidence Base created by Defra's Market Transformation Programme.

1 Summary

This Briefing Note defines the Heat Replacement Effect and looks at how it affects the savings obtained from improved lighting and home appliances. Provisional factors are developed for use in calculations that estimate net savings in energy, carbon emissions, and costs.

The energy and carbon savings attributed to better home appliances and lighting are not fully achievable because less heat is given up to the building in which they are installed. In the winter, the heat from appliances and lighting is “useful”, and if it is reduced the deficit will be made up automatically by the thermostatically controlled heating system (usually a gas boiler and radiators). The effect is significant, and should be taken into account when estimating the benefits from energy saving measures in national energy efficiency policies and programmes.

2 Introduction

The energy consumed by interior lighting and most electrical appliances is converted to heat and warms the building. If that is reduced, by substituting more energy-efficient products, then in the cold months of the year the heating system will compensate for the reduction. This effect is called heat replacement, and takes place automatically if, as is usually the case, the heating system is controlled thermostatically.

Consequently, the apparent energy savings from improvements to lighting and appliances in heated living space are not fully achievable. The extent depends on a number of factors, but it is important to recognise the principle that energy from appliances heats the building and, in doing so, alleviates the load on the heating system.

This Briefing Note explains how the heat replacement effect influences the savings achieved in practice through improvements to lights and appliances. A distinction is drawn between gross and net savings, the former being the values normally quoted by considering the product alone, whereas the latter are those achieved after installation and allowance for heat replacement. Estimates are developed for the numerical factors to be applied when converting one to the other. The Briefing Note is intended as an aid to policy makers when assessing the impact of energy efficiency measures concerning lights and appliances, especially when comparing them with efficiency measures for improved heating and insulation – which may be in competition for funds. It sets out the rationale and factors for calculations that estimate net savings in energy, carbon emissions, and costs.

3 Background

This topic was introduced as a Market Transformation Programme (MTP) paper in December 1999, and in 2003 the initial version of this Briefing Note expanded the original explanation and added definitions, equations, and tables of factors, with an additional section on proposed treatment of domestic artificial lighting. In 2004, the factors were refined using results from thermal simulation modelling; quantified examples from the thermal simulation modelling are given in Appendix B. In September 2007 the factors were re-calculated using updated carbon emission figures obtained from Ref [7] and fuel prices from Ref [8].

4 Relevance to MTP areas

The heat replacement effect is significant, and affects the ranking of national benefits obtainable from more efficient appliances and energy efficiency measures. Claims for potential savings influence energy efficiency investment decisions, so it is essential to distinguish between gross savings (calculated for the product in isolation) and net savings (after allowing for heat replacement).

Models that estimate the whole energy consumption of buildings should already take account of heat gains from lighting and appliances, and a brief explanation of how this is done by the BRE Domestic Energy Model (BREDEM) (see Ref [5]) is given in Appendix C. However, historically, the heat replacement effect has not been taken into account in the energy models for specific products. To avoid distortion, it would be better if it were – otherwise the potential savings from lights and appliances are over-stated, and misleading conclusions may be drawn as to the benefits compared with other energy saving measures (especially from insulation). Furthermore, the overall picture will be false if it is derived from the combination of projected savings from a number of product areas.

Suitable heat replacement factors for domestic lighting and appliances have been derived from early work, and were revised after carrying out thermal simulation modelling studies in March and August 2004. They are shown in Table 3.

5 Definitions

The heat replacement factor, *R*

The heat replacement factor, ***R***, is defined as the proportion of energy consumed by lighting or appliances which contributes to the heating of the building, for which additional heat from the heating system will be substituted if no longer present. This is determined separately for lighting and particular appliances, taking account of their functional characteristics, how they are used, and where they are installed. For energy modelling of the national building stock, reasonable figures should be developed to reflect average conditions in the different building sectors (in this

Briefing Note, the housing sector only). ***R*** can be derived from a number of product factors, described below (see section 6).

The beneficial saving factor, *S*

When energy performance improvements are made to lights or appliances, an apparent (gross) saving in energy consumption is often quoted. The **beneficial saving factor**, ***S,*** is defined as the proportion of gross savings in delivered energy (or running cost, or carbon emitted) achieved after allowance is made for the heat replacement effect. This is a gross to net savings conversion factor, and depends on the type and efficiency of the heating system that is the source of replacement heat, together with fuel and power prices and carbon intensities.

6 Estimating the Heat Replacement Effect

Lights and appliances are usually electric, whereas a variety of fuels are commonly used for heating, and so the heat replacement effect frequently involves fuel switching (ie, substitution of one fuel for another). In some cases the beneficial saving factor for delivered energy may be zero or even negative, but a cost and carbon emission benefit is still obtained because of the substitution of heating fuel (gas or oil) for electricity. It is possible, though less likely, for the reverse to occur; ie, there could be cost and carbon emission penalties if savings from more efficient gas appliances are replaced by heat from an electrical source.

Energy savings are quoted in terms of delivered energy, as that is the basis on which energy customers pay. However, the additional demand imposed on the heating system for replacement heat is useful energy, which is related to delivered energy by the efficiency of the heating system. Heat replacement leads to the substitution of heating fuel (or power) for appliance energy saved, and gives rise to additional heating energy, costs, and carbon emissions. These additional quantities can be calculated using the equations:

$$\textbf{replacement energy (useful)} = \text{gross energy saving} \times \mathbf{R} \times \eta e$$
$$\textbf{replacement energy (delivered)} = \text{gross energy saving} \times \mathbf{R} \times (\eta e / \eta g)$$
$$\textbf{replacement cost} = \text{gross cost saving} \times \mathbf{R} \times (\eta e / \eta g) \times (pg / pe)$$
$$\textbf{replacement carbon} = \text{gross carbon saving} \times \mathbf{R} \times (\eta e / \eta g) \times (Cg / Ce)$$

where ***R***, ηe, ηg, pe, pg, Ce, Cg are defined in Table 1 (it is assumed here that the appliance energy saved is electricity).

Net savings (ie, those actually achieved) are the gross savings less heat replacement, in the relationships:

$$\textbf{net delivered energy saving} = \boldsymbol{S}_{\text{energy}} \times \text{gross energy saving}$$
$$\textbf{net cost saving} = \boldsymbol{S}_{\text{cost}} \times \text{gross cost saving}$$
$$\textbf{net carbon saving} = \boldsymbol{S}_{\text{carbon}} \times \text{gross carbon saving}$$

where ***S*** is the beneficial saving factor calculated as:

$$\boldsymbol{S}_{\text{energy}} = 1 - \boldsymbol{R} \times (\eta e / \eta g)$$

$$\boldsymbol{S}_{cost} = 1 - \boldsymbol{R} \times (\eta e / \eta g) \times (pg / pe)$$
$$\boldsymbol{S}_{carbon} = 1 - \boldsymbol{R} \times (\eta e / \eta g) \times (Cg / Ce)$$

Table 1: Heat replacement - general terms	
R	Heat replacement factor
S	Beneficial saving factor
yrh	Heating season as a proportion of the year
ηe	Efficiency of electrical appliances (for heating purposes)
ηg	Seasonal efficiency of heating systems
pe	Price of electricity (GBP/GJ)
pg	Price of heating fuel (GBP/GJ)
Ce	CO_2 emission for electricity (kg/GJ)
Cg	CO_2 emission for heating fuel (kg/GJ)

When appliances that emit heat to the air within the building are installed wholly in heated living space, and are used at a uniform rate throughout the year, then the heat replacement factor ***R*** will be equal to the heating season as a proportion of the year; ie, ***R*** = yrh, where yrh is defined in Table 1. Clearly those conditions do not fully apply, and better estimates of ***R*** can be obtained after more detailed consideration of the characteristics of particular appliances, as explained below (see section 7).

7 Simple estimates for dwellings

The heat replacement principle applies only in buildings where the heating system is capable of providing heating to the level required by the occupant; ie, where under-heating (through incapacity of the system) does not occur. The most common type of heating in dwellings in the UK is a central heating system with gas boiler and radiators, and in Table 2 that is assumed to be the source of replaced heat. The values vary over time because of changes in fuel prices, carbon intensities, and boiler efficiencies.

Table 2: Estimated values of parameters used to derive the heat replacement factor and beneficial saving factors in UK dwellings with gas central heating *(values updated in August 2007)*		
yrh	Heating season as proportion of year (about 7 months)	58%
ηe	Efficiency of electrical appliances (for heating purposes)	100%
ηg	Typical seasonal efficiency[2] of heating systems	75.1%
pe	Price of electricity (p/kWh)	10.0
pg	Price of gas (p/kWh)	2.9
Ce	CO_2 emission for electricity (kgC/kWh)	0.146
Cg	CO_2 emission for gas (kgC/kWh)	0.052

Substituting the values of ηe, ηg, pe, pg, Ce, Cg from Table 2 in the general equations gives:

replacement energy (useful) = gross energy saving x ***R***

replacement energy (delivered) = gross energy saving x ***R*** x 133%

replacement cost = gross cost saving x ***R*** x 39%

replacement carbon = gross carbon saving x ***R*** x 47%

The beneficial saving factors are then:

$\boldsymbol{S}_{energy}$ = 1 – ***R*** x 133%
$\boldsymbol{S}_{cost}$ = 1 – ***R*** x 39%
$\boldsymbol{S}_{carbon}$ = 1 – ***R*** x 47%

Consequently,

net delivered energy saving = 23% x gross energy saving
net cost saving = 77% x gross cost saving
net carbon saving = 73% x gross carbon saving

These figures are a simple approximation for use in dwellings where electricity consumed by lights and appliances displaces gas for central heating systems of typical seasonal efficiency. Separate figures have been developed by the same method for other heating fuels, and are given in Appendix A.

8 Thermal simulation of dwellings

An improvement on the simple estimates above can be achieved by thermal simulation modelling, in which the characteristics of buildings and climates can be specified in much greater detail. Modelling can account more precisely for the interaction between heating, lighting, and appliances over short periods, and the results accumulated to represent the effect over a whole year.

Two such modelling studies were carried out for the MTP in March and August 2004, and the results are presented in detail in Briefing Note BNXS29: – "The Heat Replacement Effect – thermal simulation of domestic lighting and appliances" (Ref [6]). They have also been used to calculate the factors shown in Table 3.

9 Heat replacement in non-domestic buildings

Additional work, beyond the scope of this Briefing Note, is necessary to develop heat replacement factors for other building sectors. Nevertheless, some initial values are included later in Table 3 to serve as an illustration of likely values. The factors will require further modification for use in buildings where cooling systems are installed, as the heat output from lights and appliances adds to the cooling load during the cooling season.

10 Heat replacement factors

In section 6 above, it was explained that the heat replacement factor, R, was equal to yrh only under limited circumstances. Better estimates are obtainable by taking account of the characteristics of particular products, the main factors being:

(a) Type: this affects disposal of the energy consumed. For a few appliances, such as washing machines, dishwashers, and tumble driers, hot water or hot air is evacuated from the building and most of the heat is wasted; for others, including interior lighting, the energy consumed heats the building. A 'Disposal to surroundings' factor, 'fsur', should be estimated for the proportion of heat not evacuated – see Table 3 for estimated values.

(b) Position: whether or not customarily installed in heated living space. The proportion installed in heating living space should be estimated as a 'Present in heated living space' factor, 'fin', (see Table 3 for estimated values).

(c) Usage pattern: extent to which annual usage patterns coincide with heating periods, estimated as a 'Heating coincidence' factor, 'fhs'. For most appliances there is little seasonal variation in usage, and, unless better information is available, coincidence with heating can be presumed to be the same as the heating season as a proportion of the year, so fhs = yrh. A notable exception is artificial lighting, where a much higher coincidence factor applies as less of it is wanted in the longer days of summer that lie outside the heating season.

The three separate product factors (a) to (c) above can be combined to give the heat replacement factor, ***R***, for different appliances as:

$$\boldsymbol{R} = \mathbf{f}_{sur} \times \mathbf{f}_{in} \times \mathbf{f}_{hs}$$

Simple initial estimates for product factors and ***R***, using these three product factors, are given in Table 3 for commercial buildings. For dwellings, improved estimates are available from the thermal simulation modelling work described earlier, and these are also shown in Table 3 with fhs determined by the thermal simulation modelling results.

11 Beneficial savings factors

The beneficial saving factors, ***S***, in specific circumstances can be determined only with knowledge of the system supplying replacement heat. Heating system performance depends on the type and carbon intensity of heating fuel, efficiency of the heat generator, controls, building occupancy, and climate. The performance of installed heating systems in different types of building also varies widely in different countries, so that specific national or regional treatment is necessary. But for UK dwellings with gas central heating, ***S*** can be calculated for known typical conditions, and the results have been applied in Table 3 to domestic and commercial product sectors. Alternative values for ***S*** in dwellings using other fuels for central heating are presented in Appendix A.

For commercial buildings, Table 3 should be regarded as a set of unrefined estimates only, and further work is necessary to deal more realistically with other building sectors. The mix of heating fuels and levels of usage in dwellings in Britain are set out in Ref [2].

Table 3: Product factors for different appliances for homes with gas central heating *(for other fuels, and the average fuel mix, see Tables 4a to 4c)*

	Disposal to surroundings f_{sur}	In heated living space f_{in}	Simulation / Coincidence with heating periods f_{hs}	Heat replacement factor R	Beneficial saving factor[3] S_{energy}	Beneficial saving factor[3] S_{cost}	Beneficial saving factor[3] S_{carbon}
Domestic[4]							
Lighting	100%	95%	63.2%	60.00%	20.08%	76.82%	71.54%
Refrigerators & freezers	100%	95%	49.4%	46.90%	37.53%	81.88%	77.75%
Cooking (electric)	100%	100%	49.4%	49.40%	34.20%	80.92%	76.56%
Cooking (gas)	100%	100%	49.4%	49.40%	34.20%	80.92%	76.56%
Wet[5] (washing machines, etc)	5%	95%	49.4%	2.30%	96.94%	99.11%	98.91%
Consumer electronics	100%	100%	49.4%	49.40%	34.20%	80.92%	76.56%
Standby power	100%	98%	49.4%	48.40%	35.53%	81.30%	77.04%
Added heating[6] (electric)	100%	100%	100.0%	100.00%	-33.20%	61.37%	52.56%
Added heating (gas)	100%	100%	100.0%	100.00%	0.00%	0.00%	0.00%
Commercial[7]							
Motors	100%	50%	58%	29%	58.57%	88.80%	86.24%
Office equipment	100%	100%	58%	58%	17.14%	77.60%	72.48%
Lighting	100%	90%	70%	63%	10.00%	75.66%	70.11%
Refrigeration	100%	60%	58%	35%	50.29%	86.56%	83.49%
Air-conditioning	100%	100%	0%	0%	100.00%	100.00%	100.00%

12 Conclusions

The factors developed can be regarded as one way of correcting for the over-simplification inherent in estimating the savings potential of improvements to products in isolation. They take into account the interaction between energy-using products and the heated environment in which they are mostly installed. The factors in this Briefing Note are a first-level approximation, based on assumptions about typical housing in Britain, but the principles can be extended to a more accurate analysis where information about individual buildings is available.

The factors are significant, and may be further refined to take account of the behaviour of particular appliances in greater detail. Their effect is too large to be ignored. In particular, the following actions are recommended:

(1) Energy modelling studies of consumption in heated buildings should make clear how, and where, the heat replacement effect has been incorporated. If not so incorporated, the conclusions should be suitably qualified.

(2) Similar recognition is necessary in comparative studies of the costs and benefits of energy efficiency measures and programmes for heating, lighting, and appliances.

(3) The present Briefing Note contains factors derived from thermal simulation modelling, which improve the simple estimates given in the initial version. They

should be quoted in the corresponding MTP Policy Briefs for individual product sectors.

13 References

[1] Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2001 Edition

[2] Domestic Energy Fact File 2003, L D Shorrock and J I Utley, BRE Report BR 457, 2003

[3] End use demand profile data (1996-97) from Electricity Association, UK

[4] The Domestic Heating Boiler Energy Model: Methods and Assumptions, MTP Briefing Note BNDH11

[5] BREDEM-12, BRE Report BR 315, 1996

[6] The Heat Replacement Effect – thermal simulation of domestic lighting and appliances, MTP Briefing Note BNXS29

[7] MTP Briefing Note BNXS01 Carbon Emission Factors for UK Energy Use

[8] MTP Briefing Note BNXS44 Fuel prices

[1] Further information and briefing on related issues are available at **www.mtprog.com** or follow the links if viewing on-line.
[2] Seasonal efficiency is calculated using gross calorific value, as that is the basis of payment for gas in UK. The average for the UK housing stock is estimated in the Market Transformation Programme Boiler Energy Model (see Ref [4]).
[3] The saving factors depend on fuel used for the heating system, and in Table 3 the fuel is assumed to be natural gas. See Appendix A for savings factors for other fuels.
[4] For lighting and appliances in dwellings, the product factor $\mathbf{f}_{hs}$ has been determined from thermal simulation modelling (see Ref. 6).
[5] Condensing tumble driers do not evacuate most of the heat from the building and should be treated separately.
[6] This includes electrical equipment switched on when the heating system is operating; eg, pumps, fans, motorised valves.
[7] These are simple initial estimates. Additional work is necessary to allow for differences in building sectors and cooling systems (where fitted).

Related MTP information

- Briefing Note BNXS24: Overview of the heat replacement effect
  http://www.mtprog.com/ApprovedBriefingNotes/pdf.aspx?intBriefingNoteID=324
- Briefing Note BNXS29: The heat replacement effect – thermal simulation of domestic lighting and appliances
  http://www.mtprog.com/ApprovedBriefingNotes/pdf.aspx?intBriefingNoteID=343
- Briefing Note BNXS01: Carbon Emission Factors for UK Energy Use
  http://www.mtprog.com/ApprovedBriefingNotes/pdf.aspx?intBriefingNoteID=150
- Briefing Note BNXS44: Fuel prices

Changes from version 8.2

Carbon factors revised in accordance with changes to BNXS01 and fuel prices from BNXS44

Consultation and further information

Stakeholders are encouraged to review this document and provide suggestions that may improve the quality of information provided, email **info@mtprog.com** quoting the document reference, or call the MTP enquiry line on +44 (0) 845 600 8951.

For further information on related issues visit **www.mtprog.com**

Appendix A

Beneficial saving factors for different appliances in UK dwellings with various heating fuels

The beneficial saving factors, ***S***, in specific circumstances can be determined only with knowledge of the system supplying replacement heat. Table 3 (see section 11) gave saving factors for dwellings which have typical central heating systems with gas boilers (the most common form of domestic heating in UK). Tables 4a, 4b and 4c below also give saving factors for domestic heating systems using other fuels. The columns headed 'mix' are averages for the UK housing stock as a whole, weighted in proportion to the heating fuel used. The mix of heating fuels and levels of usage in dwellings in Britain are set out in Ref [2].

Table 4a: Gross to net energy savings conversion factors (S_{energy}) for different heating fuels in UK dwellings

	Heat replacement factor ***R***	Fuel used by heating system					
		Gas	LPG	Oil	Electricity (off-peak)	Solid fuel	Mix
Domestic							
Lighting	60.0%	20.1%	20.1%	27.3%	40.0%	0.0%	21.6%
Fridges & freezers	46.9%	37.5%	37.5%	43.2%	53.1%	21.8%	38.7%
Cooking (electric)	49.4%	34.2%	34.2%	40.1%	50.6%	17.7%	35.5%
Cooking (gas)	49.4%	34.2%	34.2%	40.1%	50.6%	17.7%	35.5%
Wet (washing machines, etc)	2.3%	96.9%	96.9%	97.2%	97.7%	96.2%	97.0%
Consumer electronics	49.4%	34.2%	34.2%	40.1%	50.6%	17.7%	35.5%
Standby power	48.4%	35.6%	35.6%	41.3%	51.6%	19.3%	36.8%
Added heating (electric)	100.0%	-33.2%	-33.2%	-21.2%	0.0%	-66.7%	-30.6%
Added heating (gas)	100.0%	0.0%					

Table 4b: Gross to net cost savings conversion factors (S_{cost}) for different heating fuels in UK dwellings							
	Heat replacement factor ***R***	Fuel used by heating system					
		Gas	LPG	Oil	Electricity (off-peak)	Solid fuel	Mix
Domestic							
Lighting	60.0%	76.8%	76.8%	78.9%	82.6%	71.0%	77.3%
Fridges & freezers	46.9%	81.9%	81.9%	83.5%	86.4%	77.3%	82.2%
Cooking (electric)	49.4%	80.9%	80.9%	82.6%	85.7%	76.1%	81.3%
Cooking (gas)	49.4%	80.9%	80.9%	82.6%	85.7%	76.1%	81.3%
Wet (washing machines, etc)	2.3%	99.1%	99.1%	99.2%	99.3%	98.9%	99.1%
Consumer electronics	49.4%	80.9%	80.9%	82.6%	85.7%	76.1%	81.3%
Standby power	48.4%	81.3%	81.3%	83.0%	86.0%	76.6%	81.7%
Added heating (electric)	100.0%	61.4%	61.4%	64.8%	71.0%	51.7%	62.1%
Added heating (gas)	100.0%	0.0%					

Table 4c: Gross to net carbon savings conversion factors (S_{carbon}) for different heating fuels in UK dwellings							
	Heat replacement factor ***R***	Fuel used by heating system					
		Gas	LPG	Oil	Electricity (off-peak)	Solid fuel	Mix
Domestic							
Lighting	60.0%	71.5%	65.1%	64.0%	40.0%	45.6%	67.1%
Fridges & freezers	46.9%	77.8%	72.7%	71.9%	53.1%	57.5%	74.3%
Cooking (electric)	49.4%	76.6%	71.2%	70.4%	50.6%	55.2%	72.9%
Cooking (gas)	49.4%	76.6%	71.2%	70.4%	50.6%	55.2%	72.9%
Wet (washing machines, etc)	2.3%	98.9%	98.7%	98.6%	97.7%	97.9%	98.7%
Consumer electronics	49.4%	76.6%	71.2%	70.4%	50.6%	55.2%	72.9%
Standby power	48.4%	77.0%	71.8%	71.0%	51.6%	56.2%	73.5%
Added heating (electric)	100.0%	52.6%	41.8%	40.0%	0.0%	9.4%	45.2%
Added heating (gas)	100.0%	0.0%					

Appendix B: Example of the heat replacement effect

Examples are given below of energy consumption in a house. Case 1 (the reference case) is a typical 3-bedroom semi-detached house in the UK with cavity walls (unfilled), gas central heating with a boiler of average efficiency, general lighting service (GLS) filament lamps throughout, and normal (not low-energy) appliances. The estimated energy usage covers all end uses including heating, hot water, lights, appliances and cooking (by gas).

The examples were calculated using earlier cost and carbon emission factors, and have not been updated in line with other tables given in this Briefing Note: they are retained for historic interest only. The examples show savings in electricity that may be expected as a result of introducing simple energy efficiency improvements to lighting and appliances. The corresponding change in gas consumed for heating, when the heat replacement effect is taken into account, is also shown, together with the totals for both fuels. Table 5a shows the delivered energy, fuel costs, and carbon emissions for seven cases, and Table 5b shows the savings in comparison with the reference case.

Table 5a: Annual energy consumption, costs, and emissions, in typical house in UK

		Delivered Energy (kWh/yr)			Cost (GBP /yr)			Carbon Emission (CO_2 tonne/yr)		
		Electricity	Gas	Both	Electricity	Gas	Both	Electricity	Gas	Both
1	Typical 3-bed semi-detached house (reference case)	3,086	24,471	27,557	219	329	548	1.28	4.76	6.03
2	As reference case, but with 2 CFLs in high-use fittings	2,897	24,633	27,530	205	332	537	1.20	4.79	5.99
3	As reference case, but with 6 CFLs	2,745	24,763	27,508	195	333	528	1.14	4.81	5.96
4	As reference case, but with A-rated fridge-freezer	2,952	24,561	27,513	209	331	540	1.22	4.77	6.00
5	As reference case, but with 6 CFLs and A-rated fridge freezer	2,611	24,853	27,464	185	335	520	1.08	4.83	5.93
6	As reference case, but with cavity wall insulation	3,086	17,426	20,512	219	235	454	1.28	3.39	4.67
7	As reference case, but with cavity wall insulation and A-rated fridge freezer	2,952	17,516	20,468	209	236	445	1.22	3.41	4.63

Table 5b: Comparisons with reference case										
		Saving of delivered energy (kWh/yr)			Saving of cost (GBP /yr)			Saving of carbon emission (CO_2 tonne/yr)		
		Electricity	Gas	Both	Electricity	Gas	Both	Electricity	Gas	Both
1-1	Reference case (no change)	0	0	0	0	0	0	0	0	0
1-2	Saving with 2 CFLs in high-use fittings	189	-162	27	13	-2	11	0.08	-0.03	0.04
1-3	Saving with 6 CFLs	341	-292	49	24	-4	20	0.14	-0.06	0.07
1-4	Saving with A-rated fridge-freezer	134	-90	44	9	-1	8	0.06	-0.02	0.03
1-5	Saving with 6 CFLs and A-rated fridge freezer	475	-382	93	34	-5	28	0.20	-0.07	0.11
1-6	Saving with cavity wall insulation	0	7,045	7,045	0	95	95	0.00	1.37	1.37
1-7	Saving with cavity wall insulation and A-rated fridge freezer	134	6,955	7,089	9	94	103	0.06	1.35	1.40

Notes to Tables 5a and 5b:

Energy costs do not include standing charges, and the unit prices are taken from Table 12 of SAP 2001 (Ref [1]). Carbon emissions for electricity and gas are taken from Table 15 of SAP 2001.

Energy consumption:

An analysis of the reference case by the BRE Domestic Energy Model (BREDEM) (see Ref [5]) indicates annual electricity consumption is 11.109 GJ/yr and annual gas consumption is 88.096 GJ/yr.

Of the annual electricity consumption, 0.459 GJ/yr is used by the circulating pump for the heating system. The remaining electricity is 11.109 - 0.459 = 10.650 GJ/yr, and is used by lights and appliances. It is assumed that 16% x 10.650 = 1.704 GJ/yr is used for lighting, and 84% x 10.650 GJ/yr for appliances.

Lighting:

It is assumed that:

- Compact fluorescent lamps (CFLs) use 20% as much energy as GLS lamps for equivalent light output, whence the potential saving in electricity if all GLS lamps were replaced by CFLs is 80% x 1.704 = 1.3632 GJ/yr.
- Replacing two high usage GLS lamps by CFLs (case 2) saves 50% of this; ie 50% x 1.3632 = 0.6816 GJ/yr. It is assumed that replacing six GLS lamps by CFLs (case 3) saves 90% of the potential; ie 90% x 1.3632 = 1.2269 GJ/yr.
- The heat replacement factor ***R*** for lighting is 60%, from Table 3, and the UK housing stock average gas central heating boiler system efficiency is 70%. So the

replacement heat required (gas) is 60% / 70%x 0.6816 = 0.5842 GJ/yr for case 2, and 60% / 70% x 1.2269 = 1.0516 GJ/yr for case 3.

Figures in GJ/yr have been converted to kWh/yr in Tables 5a and 5b.

Appliances:

It is assumed that a typical (not low-energy) fridge freezer uses 284 kWh/yr and that an A-rated fridge freezer uses 134 kWh/yr. The annual electricity saving for an A-rated fridge freezer (case 4) is then 284 - 134 = 150 kWh/yr = 0.482 GJ/yr. The heat replacement factor (R) for refrigerators and freezers is 46.9%, from Table 3, and the UK housing stock average gas central heating boiler system efficiency is 70%. So the replacement heat required (gas) is 46.9% / 70% x 0.482 = 0.323 GJ/yr for case 4.

Figures in GJ/yr have been converted to kWh/yr in Tables 5a and 5b.

Appendix C

Consistency with BREDEM

The most widely used model of domestic energy consumption in the UK is the BRE Domestic Energy Model (BREDEM) (see Ref [5]). It applies to individual buildings whose dimensions, construction, insulation, and other relevant characteristics are known. SAP (Ref [1]) and other energy rating systems used in the UK are based on BREDEM.

BREDEM takes into account adventitious heat gains from lighting and appliances, and adjusts the estimates of energy required for heating accordingly. The general approach is that adventitious heat gains are considered to be potentially useful, and during the heating season reduce the amount of heat required from the heating system. Near the beginning and end of the heating season such heat gains alone may be sufficient to heat the building to the level required.

Because BREDEM makes use of individual building data, the effect on heating energy demand can be assessed more accurately than by using the general values for typical conditions that have been quoted in Table 2. For example, the heating benefit will be different in poorly-insulated and well-insulated buildings. However, the treatment of lighting and appliances in BREDEM has not been reviewed recently, and it does not take into account the characteristics of specific appliance types, such as disposal of heat to surroundings and coincidence with heating periods.

Some preliminary work has been undertaken to investigate how BREDEM treats changes in electricity consumption as a result of energy efficiency improvements to lighting and appliances, and their effect upon heating energy demand. Beneficial saving factors for energy, cost, and carbon emissions have been developed for comparison with those from the heat replacement effect work, and early results reveal wide variations according to insulation and level of solar gains. However, it can be seen that the relevant beneficial saving factors from the heat replacement effect are approximately in the centre of the range of those from BREDEM in each case (energy, cost, and carbon emissions). Further work is necessary before the results can be presented for comparison.