

BNXS05: The Heat Replacement Effect

Version 9.0

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

1 Summary

This Briefing Note describes the Heat Replacement Effect, provides the factors currently used on the Market Transformation Programme, describes why these were changed from previous values and how these were derived.

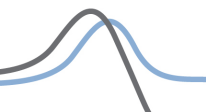
2 Introduction

The Heat Replacement Effect (HRE) has been defined as:
“the contribution to heating made by lighting and appliances in heated living space”.

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, in part, compensate for the reduction

In accordance with the first law of thermodynamics (the law of conservation of energy), which states that energy can be transformed but not created or destroyed, such an effect should exist. This compensation should take place automatically if, as is usually the case, the heating system is controlled thermostatically. Research on this topic is scarce. Moreover, the Market Transformation Programme (MTP) has not been able to find any in-situ measurements made of this effect.

Provisional factors estimating the effects in 1999 were based on building energy simulations models (BESM) designed to measure the far larger effects of heating system loads on building heat retention. On request from Defra, and because it was concerned that product energy efficiency may detract from the savings attributed to insulation, the Building's Research Establishment (BRE) used a BESM in an attempt to quantify the effects of HRE so as to be able to develop provisional factors to be used until improved factors were available (provisional 1999 factors). MTP has now re-evaluated these factors. Its experts, along with experts consulted at Lawrence Berkeley National Laboratory (LBNL, the national laboratory conducting the regulatory analysis for appliance standards in the USA), as well as documentation from LBNL, suggest that these provisional 1999 factors



significantly overstated the HRE. In light of these findings, MTP has revised the provisional 1999 factors.

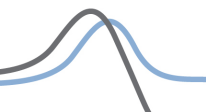
This briefing note sets out the revised HRE factors for product use in the domestic sector and then describes the rationale for revising the provisional 1999 factors and the methodology used for this.

There is insufficient data to estimate the heat replacement effect in non-domestic buildings. Available evidence, however, suggests that the heat replacement effect is cancelled out by an equally large cooling replacement effect, with the net effect being zero. (US DoE, 2000)

Nevertheless, given that electricity savings are part of the traded sector and gas and other fuel savings are not, Government has requested that an attempt be made to quantify the HRE in the non-domestic sector. The scarcity of evidence available on this subject makes this a difficult task. Results for this sector are opinions only and further evidence and investigation will be required in order to come up with evidence-based factors that can be relied upon with any degree of confidence. Like the previous provisional 1999 factors in the domestic sector, the factors presented here for the non-domestic sector should be treated as provisional and used with extreme caution.

This Briefing Note also explains how the heat replacement effect influences the savings achieved in practice by improvements to lighting and appliances. A distinction is drawn between gross and net energy 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 Note is intended as an aid to policy makers when assessing the impact of energy efficiency measures concerning lights and appliances. It sets out the rationale and factors for calculations that estimate net savings in energy, carbon emissions, and costs.

Section 2 sets out the newly revised HRE factors. **Section 3** provides the rationale for revising the provisional 1999 HRE factors. **Section 4** outlines the revised methodology used to develop the revised domestic HRE factors. Due to lack of evidence, non-domestic HRE factors are estimations only and, accordingly, a detailed description of these factors is not possible, they are described in Section 2 and must be used with extreme caution due to their speculative nature. How HRE factors are used in energy, carbon and cost calculations and how the beneficial saving factors are derived for different fuel types, is explained in **Section 5**.



3 Current HRE Factors

Current factors for the HRE for the **domestic sector** are as follows:

Table 1: Heat replacement factors for different appliances in DOMESTIC use¹

Factors:	Disposal to room f_{sur}	Contribution to heating in primary living area f_{in}	Coincidence with heating demand periods f_{hs}	New heat replacement factor R
Lighting	100%	52%	41%	21%
Refrigerators & freezers	100%	71%	35%	25%
Cooking (electric)	60%	75%	41%	18%
Cooking (gas)	60%	75%	41%	18%
Wet ^b (washing machines, etc)	20%	71%	33%	5%
Consumer electronics and ICT	100%	64%	34%	22%
Standby power	same as consumer electronics			22%
Added heating ⁶ (electric)	0%	45%	100%	0%
Added heating (gas)	0%	45%	100%	0%

3.1 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.

Other terms in the table are described in section 4

The three separate product factors, f_{sur} , f_{in} , f_{hs} , above can be combined to give the heat replacement factor, R , for different appliances as:

$$R = f_{sur} \times f_{in} \times f_{hs}$$

Provisional factors for the HRE for the **non-domestic sector** have been estimated as follows:

¹ These factors are applicable to the average type of housing stock projected to exist in the UK between 2009 and 2020.

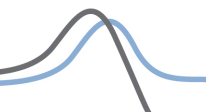


Table 2 Estimated provisional heat replacement factors for difference appliances NON-DOMESTIC use²

Factors:	Disposal to room	Contribution to heating in primary living area	Coincidence with heating demand periods	Calculated heat replacement factor	New heat replacement factor (used)
	f_{sur}	f_{in}	f_{hs}	R	
Motors	0%	0%	0%	0%	0%
Office equipment	100%	80%	34%	27%	30%
Lighting	100%	80%	41%	32%	30%
Refrigeration	10%	20%	35%	1%	0%
Air-conditioning	0%	0%	0%	0%	0%

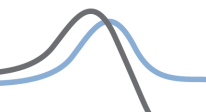
Due to lack of evidence, the non-domestic HRE factors should be treated with extreme caution. These HRE factors have been rounded to the nearest 5%, reflecting the lack of data for the calculation of the factors.

3.2 Rationale for revising the provisional 1999 HRE factors

The 1999 provisional factors were based on a building energy simulation model (BESM) designed to measure the far larger effects of heating system loads on building heat retention, as well as assumptions based on usage and heating systems data available in 1999. The approach taken (BESM) could not take into account transfer of heat between rooms and from the inside to the outside differentiated by room, in the way that the current approach does. The BESM treated the house like a "shell" without taking internal walls and spaces into consideration (BREDEM 1986). Moreover, no measurement of usage of appliances and heating systems was available (e.g. Swedish Energy Agency, 2008) at the time of developing the provisional 1999 factors; and projections for heating seasons were based on the average housing stock in the 1990s, which did not take into consideration the subsequent increase in insulation in the UK housing stock.

In most cases, the US Department of Energy does not take the heat replacement effect into consideration. This is at least in part due to the fact that heating and cooling effects are considered to balance each other out. Only in exceptional circumstances does Lawrence Berkeley National Laboratory (LBNL) take a similar effect into consideration – on domestic cooling (air conditioning) (US DoE, 2009). LBNL has, however, considered a similar topic in a commercial context (nonetheless finding the net effect to be equivalent to zero). In this context, LBNL considered the effects of lighting on heating systems in small hotels, which of the available data are the closest proxy available to domestic situations (US DoE, 2000). The US heating effect figures revealed marked differences from the UK provisional 1999 factors but are closely aligned with the revised UK factors, suggesting that the latter are more accurate.

² Factors in this table have been rounded to the nearest 5% due to their highly speculative nature.



This section describes the reason that BESMs are not ideal tools for measuring HRE factors and set out in brief the US findings on lighting in small hotels, comparing them to the old and new UK factors.

3.3 BESMs not the ideal tool for measuring HRE

Building's energy simulations models (BESM) are intended to provide a calculation of a building's energy demand under standardised conditions taking into account a number of factors including:

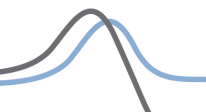
- Size
- Orientation
- Level of insulation
- Thermal mass
- Heating system
- Ventilation system
- Internal heat gains (from people and appliances)

BESM calculate heating and cooling energy demand of a building using high-level approximations for various inputs often based on generic assumptions instead of in-situ measurements.

Evidence concerning the internal heat gains from appliances is scarce. Evidence about the impact of internal heat gains from appliances on building energy demand is virtually non-existent and this aspect is usually modelled based on the assumed impact of appliance usage on a building's heating and cooling energy demand.

BESM are used to project the heating and cooling energy demand of a whole building and not of each input factor individually. As variations in building energy demand are several orders of magnitude larger than variations in appliance energy use, these models lack the granularity required to work backwards and analyse the interaction of small changes in appliance energy use with a much larger heating energy demand in sufficient detail.

The lack of accuracy at the level of inputs can be demonstrated for example by the fact that BESM often consider a whole house or at least a whole floor as a single unit. This does not account for the dynamics of internal heat transfers such as barriers or time lags in internal heat transfers (internal walls) and local heat losses (e.g. kitchen ventilation). Although these may not be relevant in the context of a high level assessment of a building's energy demand, they are essential factors in determining the different impacts of small variations in appliance energy use on a building's heating or cooling system.



3.4 LBNL research compared

LBNL has developed factors for heating and cooling effects in a commercial lighting context (US Department of Energy, 2000). The US factors developed which are most comparable to domestic HRE would be those for small hotels. Although these buildings are not directly comparable to the UK housing stock, they provide an indication of the order of magnitude of the effects estimated by LBNL. These factors differ greatly from the provisional HRE factors developed in 1999 (provisional 1999 factors), in the UK domestic context. However, the US change in heating factors for lighting are similar to the revised UK factors currently developed, validating the revised factors. The table below compares the US findings for small hotels with the UK provisional 1999 factors and revised factors for lighting.

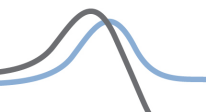
Table 3 US small hotels compared to UK domestic lighting HRE factors

	Change in Heat demand due to more EE lighting	Change in Cooling demand due to more EE lighting	Change in overall HVAC demand due to more EE lighting
US 1989 building stock	22%	-21%	1%
US 1990- 1995 building stock	21%	-20%	1%
UK provisional 1999 factors for lighting	60%	not estimated	60%
UK revised factors	21%	not estimated	21%

4 Current Methodology

The following factors were calculated or estimated in order to estimate the heat replacement effect:

- **Percentage disposal to room f_{sur} :** proportion of energy consumed by the product which ends up as heat delivered to the room in which the product is located
- **Contribution to heating in primary living area f_{in} :** the proportion of heat generated by the product/appliance which is likely to contribute to the primary living area – generally the living room
- **Coincidence with heating demand f_{hs} :** proportion of heat generated by the product/appliance that will contribute to diminishing the heating load required by the building (where bimodal operation is in use, the heat generated by appliances/products will begin to contribute to diminishing the heating load required both before the time the heating is turned on and during part of the period of operation of heating system)
- **Product usage per time of day:** the average proportion energy used by a product each hour of the day. This is used to calculate the coincidence with heating demand.
- **Beneficial heating per time of day:** the average proportion of energy generated during each hour of the day which will contribute to diminishing the heating load required by the building. This is used to calculate the coincidence with heating demand.
- **Heating season:** the proportion of the year during which heating is required.



- **Heating demand per time of day:** the average amount of heating required during each hour of the day. Separate factors have been developed for Spring/Autumn and Winter (assumed no heating in summer).

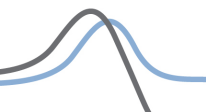
The methodology and assumptions used to obtain each input is described below along with the results found. The last two factors (heating season and heating demand per time of day) were used to analyse the average heating demand per time of day, on average over a typical year. The methodology used to determine the beneficial heating per time of day is based on this and is described in the next section below. The following subsections set out in more detail the factors described above.

4.1 Percentage disposal to room

The percentage disposal to room represents the proportion of energy generated by the product that ends up as heat delivered to the room in which the product is located. Factors are provided in the table below along with the relevant rationale.

Table 4 Disposal to room factors and rationales

Product area	Factor	Rationale
Domestic		
Lighting	100%	Virtually all energy from lighting is dissipated to the surrounding, as ambient heat.
Refrigerators & freezers	100%	All energy is dissipated to the surroundings, as ambient heat.
Cooking (electric)	60%	All energy is dissipated to the surroundings, as ambient heat, but a share of that is 'ventilated away', primarily through extractor hoods / fans and other ventilation. Expert opinion suggests the remaining share to be 60%.
Cooking (gas)	60%	All energy is dissipated to the surroundings, as ambient heat, but a share of that is 'ventilated away', primarily through extractor hoods / fans and other ventilation. Expert opinion suggests the remaining share to be 60%.
Wet (washing machines, etc)	20%	Most energy is lost to waste water, but a share of the energy is dissipated to the surroundings, as ambient heat. Expert opinion suggests this to be 20%.
Consumer electronics and ICT	100%	All energy is dissipated to the surroundings, as ambient heat.
Standby power	same as consumer electronics	
Additional electric or gas heating	100%	All energy is dissipated to the surroundings, as ambient heat.
Non-domestic		
Motors	0%	Motors are typically used in unheated space, even when used for building systems.



Product area	Factor	Rationale
Office equipment	100%	Office equipment is typically used in heated areas. Virtually all energy is dissipated to the surrounding, as ambient heat
Commercial Lighting (excludes street and traffic lighting)	100%	Lighting is typically used in heated areas. Virtually all energy is dissipated to the surrounding, as ambient heat
Commercial Refrigeration	10%	Commercial refrigeration is typically used in unheated space, though there may be a small impact on heating in restaurants, shops etc.
Air-conditioning	0%	Air conditioning typically dissipates waste heat to outside areas

4.2 Contribution to heating in primary living area

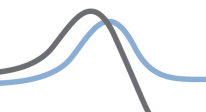
The contribution to heating in primary living area represents the proportion of heat generated by the product/appliance which is likely to contribute to the primary living area – generally the living room. The living room generally determines whether people need heating and thermostats are predominantly located in the living room or the hallway. Thermostats tend to be set in order to maintain a suitable temperature in the living room. The factors set out in the table below have been developed based on expert opinion and the most common locations of the products/appliances.

Contributational factors have been developed for transfers of heat to the living area from different locations (living area, kitchen, bedroom area, and outside heated space). These are based on the typical layout of houses, and distances and internal heat barriers between rooms.

Table 5 Contribution to domestic heating in primary living area factors

Product area	Factor	Main use of product			
		Living room	Kitchen	Bedroom area	Outside heated space
Lighting	52% ³	40%	20%	35%	5%
Refrigerators & freezers	71%	0%	95%	0%	5%
Cooking (electric)	75%	0%	100%	0%	0%
Cooking (gas)	75%	0%	100%	0%	0%

³ NB A correction is needed for lighting, as most lighting is installed close to or built into ceilings, and will only partially contribute to heating of the living area - the remainder contributing to the heating of the upstairs area. The estimated ratio is 70%-30% (living room/upstairs area). The same applies to lighting in kitchens. Contributational factors for lighting are corrected to reflect this.



Product area	Factor	Main use of product			
		Living room	Kitchen	Bedroom area	Outside heated space
Wet ⁵ (washing machines, etc)	71%	0%	95%	0%	5%
Consumer electronics and ICT	64%	50%	5%	40%	5%
Standby power	same as consumer electronics				
<i>Contributonal factor</i>		100%	75%	25%	0%
	Living room	100%			
	Kitchen		75%		
	Bedroom area			25%	
	Outside				0%

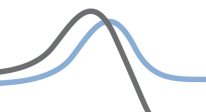
For non-domestic use the assumptions are more simple, reflecting the lack of evidence.

Table 6 Contribution to non-domestic heating

Product area	Factor	Rationale
Motors	0%	Not applicable, as it is assumed that motors are not used in or near heated space
Office equipment	80%	Office / IT equipment is typically used in heated areas, although some products (e.g. servers) are more likely to be found in unheated areas
Lighting (excludes street and traffic lighting)	80%	Commercial lighting is typically used in heated areas
Commercial Refrigeration	20%	Commercial refrigeration is typically used in unheated space, though there may be a small impact on heating in restaurants, shops etc.
Air-conditioning	0%	Air conditioning typically dissipates waste heat to the environment, not inside heated areas

4.3 Coincidence with heating demand

Coincidence with heating demand represents the proportion of heat generated by the product/appliance that will contribute to diminishing the heating load required by the building. For example, if bimodal operation is in use the heat generated by appliances/products will begin to contribute to diminishing the heating load required both



before the time the heating is turned on and during part of the period of operation of heating system – but not after and when there is no heat demand for a longer period of time.

The table below sets out the coincidence with heating demand. It is based on measurement of usage of appliances and heating systems (Swedish Energy Agency, 2008). Relevant factors used are set out in Appendix 1.

Table 7 Coincidence with heating demand

Product area	Lighting	Cold (fridges & freezers)	Cooking (electric)	Cooking (gas)	Wet (washing machines, etc)	Consumer electronics and ICT	Standby power	Added heating (electric)	Added heating (gas)
Factor	41%	35%	40%	40%	33%	34%	Same as consumer electronics	100%	100%

In the absence of evidence the same factors have been assumed the same for non-domestic product areas , ie the coincidence is assumed to be:

- 34% for ICT
- 41% for lighting
- 35% for refrigeration.

4.3.1 Product usage per time of day

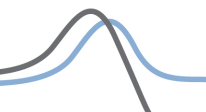
The product usage per time of day represents the average proportion of energy used by a product each hour of the day. This is used to calculate the coincidence with heating demand. The product usage per time of day is based on actual measurements of usage (Swedish Energy Agency, 2008). Figures used are set out in Appendix 1 to this document.

4.3.2 Beneficial heating per time of day:

The beneficial heating per time of day represents the average proportion of energy generated during each hour of the day, which will contribute to diminishing the heating load required by the building. This factor is based on the heat demand per time of day, typical heat retention characteristics of buildings, and the average product usage time of day. Heat demand and product usage are based on actual measurements (Swedish Energy Agency, 2008); heat retention characteristics are based on expert assumption. Heat retention characteristics assumptions are used to determine to what extent heat (energy) generated hours before heat is needed is beneficial to the heat demand of the house at a later hour. Figures used are set out in Appendix 1 to this document.

4.3.3 Heating season:

The heating season represents the proportion of the year during which heating is required. Results for heating season are set out in Appendix 2. This factor was used in the analysis of heating demand per time of day described below.



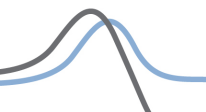
4.3.4 Heating demand per time of day:

The heating demand per time of day represents the average amount of heating required during each hour of the day. Separate factors have been developed for Spring/Autumn and Winter. Results for heating demand per time of day are set out in Appendix 2. This factor was used in the analysis of heating demand per time of day described below.

4.3.5 Analysis of heating demand per time of day

An analysis of heating demand per time of day was performed based on the beneficial heating per time of day, the heating season, the heating demand per time of day and the following assumptions:

- Heating demand varies in different months: heating is required for more hours during periods of low outdoor temperatures (winter months) than during spring and autumn months;
- Heating demand is dependent on the type and degree of insulation of housing: well-insulated houses have reduced heat losses and shorter heating seasons;
- Insulation levels are increasing and are expected to continue to do so. New housing stock is much better insulated and retrofitting of insulation in existing housing increasing. Over time, this will reduce the heating season;
- Levels of insulation were estimated based on age and type of housing stock (BRE, 2008)
- The heating season currently lasts around 7 months for existing housing stock, comprising of 4 months of spring/autumn type usage, and 3 months of winter-type usage;
- The heating season currently lasts around 5 months for new housing stock, comprising of 3 months of spring/autumn type usage, and 2 months of winter-type usage;
- By 2020, due to retrofitting and increases in insulation requirements, the heating season will have shortened to 6 months for existing houses (4 months autumn / spring-type, 2 months winter-type) and 4 months for new houses (2 months autumn/spring-type, 2 months winter-type);
- As the analysis is intended for forward-looking projections, a 50-50% mix of current and 2020 heating periods is used;
- There are three dominant types of heating control in use in the UK:
 - bi-modal operation (time-driven), used in existing housing only
 - programmable thermostat operation (thermostat-controlled during some hours; off during other hours), used in all types of houses and the most common type for new heating systems
 - continuous operation (thermostat-controlled all hours during the heating season), used only in new low-energy housing
- For each type of heating control, and matching housing type, useful heat typical retention times were estimated based on the typical insulation and thermal mass characteristics of the buildings. These useful heat retention times take into account that energy released into a building while there is a heat demand will contribute towards meeting that energy demand. They also factor in that energy released some hours prior to a heat demand period will partially contribute towards meeting the heat demand, as the building's fabric stores some of that heat and releases it later. This effect is broadly



proportional to the time lapse between the energy being released and the heat demand, as the energy is released regardless of a heat demand being present and this energy will dissipate from the building due to transmission and ventilation losses. These losses are larger in older, less insulated building, leading to shorter useful heat retention times. Useful heat retention times are estimated in three stages:

- 100%, indicating that most of the energy released during a period will be beneficial
- 50%, indicating that around half of the energy released during a period will be beneficial
- 0%, indicating that only a small share of the energy released during a period will be beneficial.
- Heat retention times have been estimated to be:
 - For bi-modal heating systems (typically in older, existing housing): heat generated up to 4 hours in advance contributes to heating, 100% for 0-2 hours in advance, 50% for 2-4 hours in advance
 - For programmable thermostat (used across all house ages and types): heat generated up to 6 hours in advance contributes to heating, 100% for 0-3 hours in advance, 50% for 3-6 hours in advance
 - For continuous operation (typical in new, low-energy housing): heat generated up to 12 hours in advance contributes to heating, 100% for 0-6 hours in advance, 50% for 6-12 hours in advance
- A sensitivity analysis was conducted to assess the impacts of longer and shorter heat retention periods. Minimum and maximum heat retention times resulted in around a 7%-point decrease and increase, respectively, in the overall heat replacement factors.

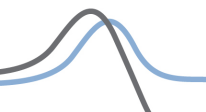
5 Using HRE Factors: The Beneficial Saving factors

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 (i.e., 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 (MTP, BNXS26) and carbon emission benefit (MTP, BNXS01) is still obtained owing to the substitution of heating fuel (gas or oil) for electricity. It is possible, though less likely, for the reverse to occur; i.e., 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 for customer payment. But the additional demand on the heating system for replacement heat arises as 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 following equations:

replacement energy (useful)	= gross energy saving x R x η_e
replacement energy (delivered)	= gross energy saving x R x (η_e / η_g)
replacement cost	= gross cost saving x R x (η_e / η_g) x (p_g / p_e)
replacement carbon	= gross carbon saving x R x (η_e / η_g) x (C_g / C_e)

where **R**, η_e , η_g , p_e , p_g , C_e , C_g are defined in Table 6(it is assumed here that appliance



energy saved is electricity).

5.1 The beneficial saving factors

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[s] 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.

There are 3 types of beneficial savings factors:

1. **Energy (S_{energy})**: based on heating system efficiency
2. **Carbon (S_{carbon})**: based on heating systems efficiency and CO2 factors for fuel
3. **Cost (S_{cost})**: based on heating systems efficiency and energy price differences.

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

$$\begin{aligned} \text{net delivered energy saving} &= S_{\text{energy}} \times \text{gross energy saving} \\ \text{net cost saving} &= S_{\text{cost}} \times \text{gross cost saving} \\ \text{net carbon saving} &= S_{\text{carbon}} \times \text{gross carbon saving} \end{aligned}$$

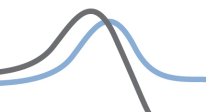
where S is the beneficial saving factor calculated as:

$$\begin{aligned} S_{\text{energy}} &= 1 - R \times (\eta_e / \eta_g) \\ S_{\text{cost}} &= 1 - R \times (\eta_e / \eta_g) \times (p_g / p_e) \\ S_{\text{carbon}} &= 1 - R \times (\eta_e / \eta_g) \times (C_g / C_e) \end{aligned}$$

Table 6 Heat replacement – general terms

R	heat replacement factor
S	beneficial saving factor
yrh	heating season as a proportion of the year
η_e	efficiency of electrical appliances (for heating purposes)
η_g	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 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, $R = \text{yrh}$, where yrh is defined in Table 6. But 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 later.



Beneficial saving factors for different appliances in UK dwellings with various heating fuels are set out in Appendix 4.

6 Principle References:

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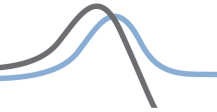
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Appendix 1 - Figures supporting coincidence with heating demand factors

The figures supporting heating coincidence with heating demand are based on figures measuring usage of appliances and heating systems (Swedish Energy Agency, 2008)

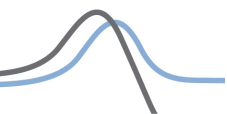
Table A1 Coincidence with heating demand per hour

These factors indicate to what extent the waste heat resulting from energy demand (average energy demand per hour, see also table A2) contributes to the heating demand of the building. Indicated percentages are a multiplication of the factors in tables A2 and A3, which, added up, result in the beneficial heating factor R.

	<i>Time (hours)</i>	Beneficial energy use (%) per product area per hour											
		<i>0,1</i>	<i>1,2</i>	<i>2,3</i>	<i>3,4</i>	<i>4,5</i>	<i>5,6</i>	<i>6,7</i>	<i>7,8</i>	<i>8,9</i>	<i>9,10</i>	<i>10,11</i>	<i>11,12</i>
Lighting**		0.29	0.52	0.53	0.46	0.53	0.79	1.78	2.54	1.32	0.43	0.42	0.99
Refrigerators and freezers		0.49	1.35	1.82	1.94	1.93	1.95	1.96	1.99	1.19	0.44	0.44	1.08
Cooking (electric)		0.05	0.11	0.16	0.17	0.17	0.84	1.47	1.47	0.63	0.19	0.35	0.90
Cooking (gas)		0.05	0.11	0.16	0.17	0.17	0.84	1.47	1.47	0.63	0.19	0.35	0.90
Wet (washing machines)		0.33	0.62	0.44	0.24	0.24	0.22	0.67	1.74	1.26	0.52	0.45	0.96
Consumer Electronics		0.35	0.83	1.06	1.01	1.00	1.04	1.31	1.48	0.92	0.35	0.36	0.94
	<i>Time (hours)</i>	<i>12,13</i>	<i>13,14</i>	<i>14,15</i>	<i>15,16</i>	<i>16,17</i>	<i>17,18</i>	<i>18,19</i>	<i>19,20</i>	<i>20,21</i>	<i>21,22</i>	<i>22,23</i>	<i>23,24</i>
Lighting**		1.45	1.74	1.86	2.15	2.88	3.75	4.74	4.33	2.72	2.45	1.73	0.14
Refrigerators and freezers		1.60	1.94	2.06	2.09	2.09	2.14	2.18	1.74	1.03	0.97	0.86	0.11
Cooking (electric)		1.48	1.39	1.39	2.28	5.27	8.01	7.58	4.04	1.31	0.77	0.40	0.05
Cooking (gas)		1.48	1.39	1.39	2.28	5.27	8.01	7.58	4.04	1.31	0.77	0.40	0.05
Wet (washing machines)		1.42	2.25	2.31	2.24	2.45	3.22	3.43	3.04	2.16	1.61	1.26	0.12
Consumer Electronics		1.40	1.73	1.93	2.13	2.46	2.71	3.26	2.29	1.98	1.80	1.24	0.11

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Coincidence with heating demand per hour figures set out in the table above are based on Product Usage Per Time of Day as a factor of Beneficial Heating per Time of Day, set out in the tables below. A seasonal correction factor has been applied to lighting, to correct for lighting (hence the **) being used more often in winter than in summer. It is assumed that lighting use in winter is 1.2 x the yearly average, and in summer 0.8 x the yearly average (only the winter value was used in this calculation).

Table A2 Product Usage per Time of Day

These factors indicate which share of daily energy demand, per product area, occurs within a given hour.

	<i>Time (hours)</i>	Average energy demand (%) per hour											
		0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12
Lighting		2	2	1	1	1	2	4	5	4	4	4	4
Refrigerators and freezers		4	4	4	4	4	4	4	4	4	4	4	4
Cooking (electric)		0	0	0	0	0	2	3	3	2	2	3	3
Cooking (gas)		0	0	0	0	0	2	3	3	2	2	3	3
Wet (washing machines)		3	2	1	0	0	0	1	4	4	5	4	4
Consumer Electronics		3	2	2	2	2	2	3	3	3	3	3	4
	<i>Time (hours)</i>	12,13	13,14	14,15	15,16	16,17	17,18	18,19	19,20	20,21	21,22	22,23	23,24
Lighting		4	4	4	4	6	8	10	11	12	11	9	5
Refrigerators and freezers		4	4	4	4	4	4	4	4	4	4	4	4
Cooking (electric)		4	3	3	5	11	16	15	10	6	3	2	2
Cooking (gas)		4	3	3	5	11	16	15	10	6	3	2	2
Wet (washing machines)		4	5	5	5	5	7	7	8	9	7	6	4
Consumer Electronics		4	4	4	4	5	6	7	7	8	8	6	4

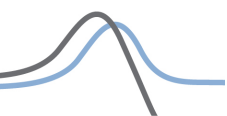
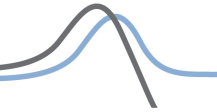


Table A3 [Beneficial Heating per Time of Day]

These figures indicate the share of heating that is beneficial to the heating demand of the building, per hour, for the three main types of heating system operation.

	Proportion of heating stock	Time (hours)	Beneficial share of waste heat (%) to heating demand											
			0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12
Average			12	33	46	49	49	49	49	49	29	11	11	26
Bi-modal operation	20%		0	0	15	29	29	29	29	29	29	0	0	0
Programmable thermostat	79%		15	42	54	54	54	54	54	54	29	13	13	33
Continuous operation	1%		42	42	42	42	42	42	42	42	42	42	42	42
		Time (hours)	12,13	13,14	14,15	15,16	16,17	17,18	18,19	19,20	20,21	21,22	22,23	23,24
Average			38	46	49	49	49	49	49	39	24	22	20	3
Bi-modal operation	as above		0	15	29	29	29	29	29	29	29	29	29	0
Programmable thermostat	as above		48	54	54	54	54	54	54	42	22	20	19	3
Continuous operation	as above		42	42	42	42	42	42	42	42	42	42	42	42



Appendix 2 – Main factors used in heating demand per time of day analysis (heating season and heating demand per time of day)

Table A4 Heating season (in months)

	Average		Current		2020	
	Winter	Spring/Autumn	Winter	Spring/Autumn	Winter	Spring/Autumn
Bi-modal operation	3.5	3	3	4	2	4
Programmable thermostat	3.5	3	3	4	2	4
Continuous operation	2.5	2.5	2	3	2	2

Table A5 Heating demand per time of day – Spring/Autumn months

	Time (hours)	% Heating demand per time of day - Spring/Autumn months											
		0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12
Bi-modal operation		0	0	0	0	0	0	100	100	0	0	0	0
Programmable thermostat		0	0	0	0	0	0	100	100	0	0	0	0
Continuous operation		5	5	5	5	50	100	100	100	100	10	10	10
	Time (hours)	12,13	13,14	14,15	15,16	16,17	17,18	18,19	19,20	20,21	21,22	22,23	23,24
Bi-modal operation		0	0	0	0	50	100	100	50	0	0	0	0
Programmable thermostat		0	0	0	0	50	100	100	50	0	0	0	0
Continuous operation		10	10	50	50	100	100	100	100	10	10	10	10

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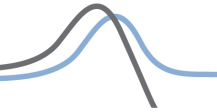
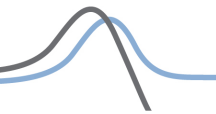


Table A5 Heating demand per time of day – Winter months

		% Heating demand per time of day - Winter months											
	<i>Time (hours)</i>	<i>0,1</i>	<i>1,2</i>	<i>2,3</i>	<i>3,4</i>	<i>4,5</i>	<i>5,6</i>	<i>6,7</i>	<i>7,8</i>	<i>8,9</i>	<i>9,10</i>	<i>10,11</i>	<i>11,12</i>
Bi-modal operation		0	0	0	0	0	100	100	100	100	0	0	0
Programmable thermostat		0	0	0	0	0	100	100	100	100	10	10	10
Continuous operation		25	25	25	25	25	100	100	100	100	25	25	25
	<i>Time (hours)</i>	<i>12,13</i>	<i>13,14</i>	<i>14,15</i>	<i>15,16</i>	<i>16,17</i>	<i>17,18</i>	<i>18,19</i>	<i>19,20</i>	<i>20,21</i>	<i>21,22</i>	<i>22,23</i>	<i>23,24</i>
Bi-modal operation		0	0	0	0	100	100	100	100	100	100	100	0
Programmable thermostat		10	10	10	10	100	100	100	100	10	10	50	10
Continuous operation		25	25	25	25	100	100	100	100	10	10	50	10



Appendix 3 – Typical heating demand pattern

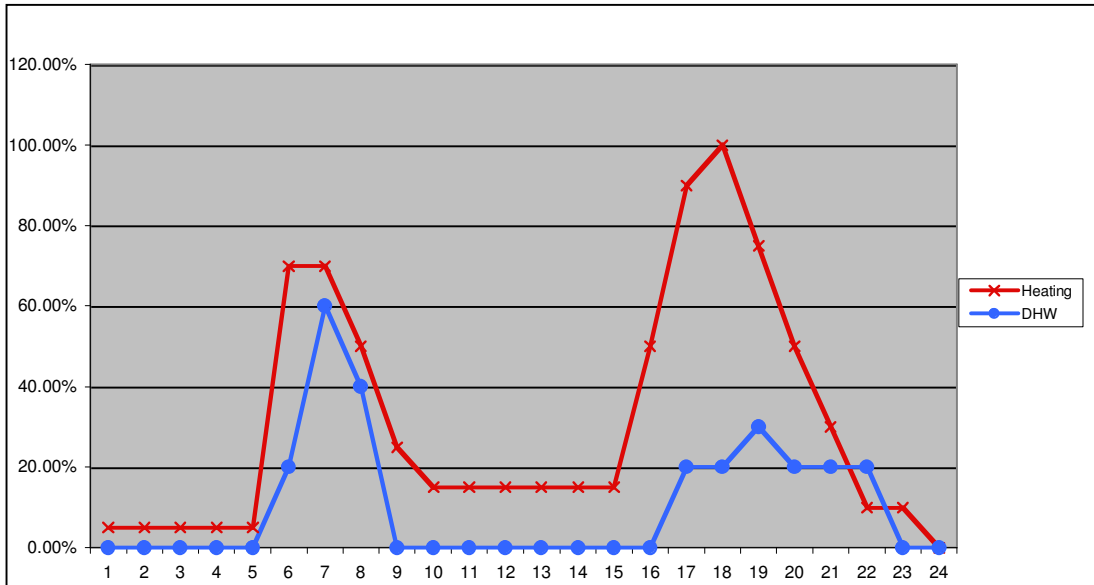
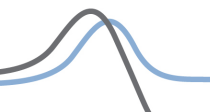


Figure A1 Indicative heating and hot water hourly demand profile for a typical UK dwelling (WSP, 2009)

Figure A1 shows indicative values for average heating and hot water demand. This is validated to some extent, by the measured data shown for two days in figures A2 and A3.



The graphs below (Figures 1 and 2) illustrate the transient space heating, DHW and electrical demand, resultant internal air temperature and external air temperature on the overcast winter day and shoulder day respectively.

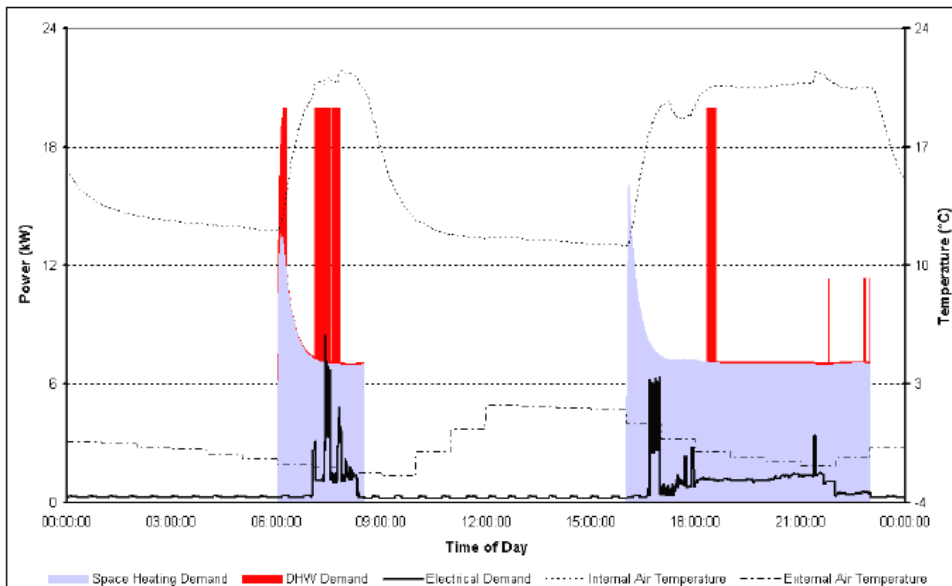


Figure 1: Transient Demand and Internal & External Air Temperatures for Overcast Winter Day

Figure A2 Hourly energy demand profile with internal and external air temperatures for an overcast day⁴ (Kane D, 2006)

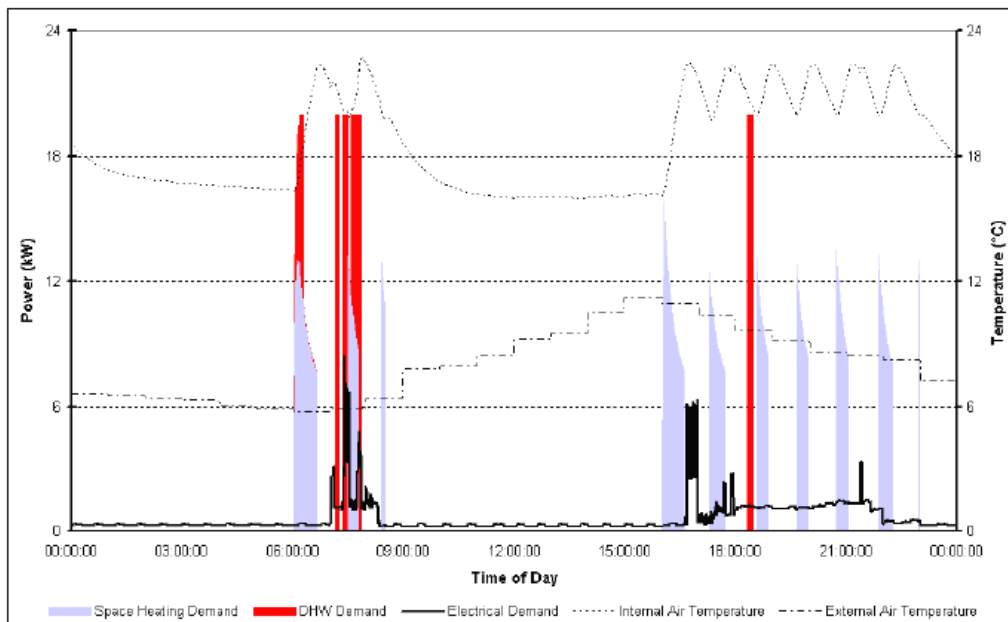
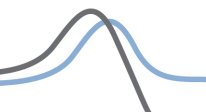


Figure 2: Transient Demand and Internal & External Air Temperatures for Shoulder Day

Figure A3 Hourly energy demand profile with internal and external air temperatures for a shoulder day⁵(Kane D, 2006)

⁴ Dwelling comprised of a detached, 180m² dwelling constructed between 1988-1994. It is modelled to have a timber frame with a 25% glazing/gross external wall ratio and ventilation rate 0.76 and is located in Oban, Scotland. Occupants are a wealthy, four person family during a typical working day (Kane D, 2006).



Appendix 4 – Beneficial saving factors for different appliances with typical heating fuel mix

The beneficial saving factors, **S**, in specific circumstances can be determined only with knowledge of the system supplying replacement heat. Tables A7a to A7f, below, give saving factors for dwellings and non-domestic premises that have typical central heating systems (the most common form of domestic heating in UK) , with a mix of typical fuels used.. (**NB** data on the efficiency and fuel type for non-domestic buildings was not available. Therefore as an approximation the domestic data was used.) These are averages for the UK housing stock and non-domestic buildings as a whole, weighted in proportion to heating fuel used. The mix of heating fuels and levels of usage in dwellings in Britain are derived using 2007 data provided by BRE.

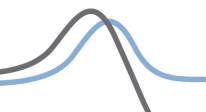
The energy price data for domestic and non-domestic sectors used is stated in BNXS26. The different fuel emission factors used are stated in BNXS01.

Non-domestic factors must be treated with great caution due to their highly speculative nature.

Table A7a

Gross to net energy savings conversion factors (S_{energy}) for mixed fuels in UK dwellings									
Year	Lighting	Fridges & freezers	Cooking (electric)	Cooking (gas)	Wet Appliances	Consumer electronics	Standby power	Added heating (electric)	Added heating (gas)
2008	74%	68%	77%	77%	94%	73%	73%	100%	100%
2009	74%	69%	77%	77%	94%	73%	73%	100%	100%
2010	74%	69%	78%	78%	94%	73%	73%	100%	100%
2011	75%	69%	78%	78%	94%	74%	74%	100%	100%
2012	75%	70%	78%	78%	94%	74%	74%	100%	100%
2013	75%	70%	78%	78%	94%	74%	74%	100%	100%
2014	75%	70%	79%	79%	94%	74%	74%	100%	100%
2015	76%	71%	79%	79%	95%	74%	74%	100%	100%
2016	76%	71%	79%	79%	95%	75%	75%	100%	100%
2017	76%	71%	79%	79%	95%	75%	75%	100%	100%
2018	76%	71%	79%	79%	95%	75%	75%	100%	100%
2019	76%	71%	79%	79%	95%	75%	75%	100%	100%
2020	76%	71%	79%	79%	95%	75%	75%	100%	100%
2021	76%	71%	79%	79%	95%	75%	75%	100%	100%
2022	76%	71%	79%	79%	95%	75%	75%	100%	100%
2023	76%	71%	79%	79%	95%	75%	75%	100%	100%
2024	76%	71%	79%	79%	95%	75%	75%	100%	100%
2025	76%	71%	79%	79%	95%	75%	75%	100%	100%
2026	76%	71%	79%	79%	95%	75%	75%	100%	100%
2027	76%	71%	79%	79%	95%	75%	75%	100%	100%
2028	76%	71%	79%	79%	95%	75%	75%	100%	100%
2029	76%	71%	79%	79%	95%	75%	75%	100%	100%

⁵ Dwelling comprised of a detached, 180m² dwelling constructed between 1988-1994. It is modelled to have a timber frame with a 25% glazing/gross external wall ratio and ventilation rate 0.76 and is located in Oban, Scotland. Occupants are a wealthy, four person family during a typical working day (Kane D, 2006). Shoulder days take place between autumn/winter and winter/spring when outside temperatures are generally warmer than winter days.



2030	76%	71%	79%	79%	95%	75%	75%	100%	100%
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Table A7b

Gross to net energy savings conversion factors (S_{energy}) for mixed fuels in UK non-domestic premises					
Year	Motors	Office equipment	Lighting	Refrigeration	Air-conditioning
2008	100%	62%	62%	100%	100%
2009	100%	63%	63%	100%	100%
2010	100%	63%	63%	100%	100%
2011	100%	64%	64%	100%	100%
2012	100%	64%	64%	100%	100%
2013	100%	64%	64%	100%	100%
2014	100%	65%	65%	100%	100%
2015	100%	65%	65%	100%	100%
2016	100%	65%	65%	100%	100%
2017	100%	65%	65%	100%	100%
2018	100%	66%	66%	100%	100%
2019	100%	66%	66%	100%	100%
2020	100%	66%	66%	100%	100%
2021	100%	66%	66%	100%	100%
2022	100%	66%	66%	100%	100%
2023	100%	66%	66%	100%	100%
2024	100%	66%	66%	100%	100%
2025	100%	66%	66%	100%	100%
2026	100%	66%	66%	100%	100%
2027	100%	66%	66%	100%	100%
2028	100%	66%	66%	100%	100%
2029	100%	66%	66%	100%	100%
2030	100%	66%	66%	100%	100%

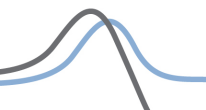


Table A7c

Gross to net cost savings conversion factors (S_{cost}) for mixed fuels in UK dwellings									
Year	Lighting	Fridges & freezers	Cooking (electric)	Cooking (gas)	Wet Appliances	Consumer electronics	Standby power	Added heating (electric)	Added heating (gas)
2008	93%	92%	94%	94%	99%	93%	93%	100%	100%
2009	93%	92%	94%	94%	98%	93%	93%	100%	100%
2010	92%	90%	93%	93%	98%	92%	92%	100%	100%
2011	92%	90%	93%	93%	98%	92%	92%	100%	100%
2012	92%	91%	93%	93%	98%	92%	92%	100%	100%
2013	92%	90%	93%	93%	98%	92%	92%	100%	100%
2014	92%	91%	93%	93%	98%	92%	92%	100%	100%
2015	92%	91%	93%	93%	98%	92%	92%	100%	100%
2016	92%	91%	93%	93%	98%	92%	92%	100%	100%
2017	92%	91%	93%	93%	98%	92%	92%	100%	100%
2018	92%	91%	93%	93%	98%	92%	92%	100%	100%
2019	92%	91%	93%	93%	98%	92%	92%	100%	100%
2020	92%	91%	93%	93%	98%	92%	92%	100%	100%
2021	92%	91%	93%	93%	98%	92%	92%	100%	100%
2022	92%	91%	93%	93%	98%	92%	92%	100%	100%
2023	92%	91%	93%	93%	98%	92%	92%	100%	100%
2024	92%	91%	93%	93%	98%	92%	92%	100%	100%
2025	92%	91%	93%	93%	98%	92%	92%	100%	100%
2026	92%	91%	93%	93%	98%	92%	92%	100%	100%
2027	92%	91%	93%	93%	98%	92%	92%	100%	100%
2028	92%	90%	93%	93%	98%	92%	92%	100%	100%
2029	92%	91%	93%	93%	98%	92%	92%	100%	100%
2030	93%	91%	94%	94%	98%	92%	92%	100%	100%

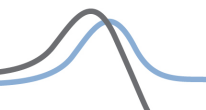


Table A7d

Gross to net cost savings conversion factors (S_{cost}) for mixed fuels in UK non-domestic premises					
Year	Motors	Office equipment	Lighting	Refrigeration	Air- conditioning
2008	100%	90%	90%	100%	100%
2009	100%	90%	90%	100%	100%
2010	100%	88%	88%	100%	100%
2011	100%	88%	88%	100%	100%
2012	100%	88%	88%	100%	100%
2013	100%	89%	89%	100%	100%
2014	100%	88%	88%	100%	100%
2015	100%	88%	88%	100%	100%
2016	100%	89%	89%	100%	100%
2017	100%	89%	89%	100%	100%
2018	100%	89%	89%	100%	100%
2019	100%	89%	89%	100%	100%
2020	100%	89%	89%	100%	100%
2021	100%	88%	88%	100%	100%
2022	100%	88%	88%	100%	100%
2023	100%	88%	88%	100%	100%
2024	100%	89%	89%	100%	100%
2025	100%	88%	88%	100%	100%
2026	100%	88%	88%	100%	100%
2027	100%	88%	88%	100%	100%
2028	100%	88%	88%	100%	100%
2029	100%	88%	88%	100%	100%
2030	100%	89%	89%	100%	100%

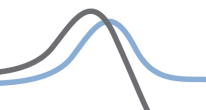


Table A7e

Gross to net energy savings conversion factors (S_{carbon}) for mixed fuels in UK dwellings									
Year	Lighting	Fridges & freezers	Cooking (electric)	Cooking (gas)	Wet Appliances	Consumer electronics	Standby power	Added heating (electric)	Added heating (gas)
2008	87%	84%	89%	89%	97%	86%	86%	100%	100%
2009	87%	85%	89%	89%	97%	87%	87%	100%	100%
2010	87%	85%	89%	89%	97%	87%	87%	100%	100%
2011	87%	85%	89%	89%	97%	87%	87%	100%	100%
2012	88%	85%	89%	89%	97%	87%	87%	100%	100%
2013	88%	85%	89%	89%	97%	87%	87%	100%	100%
2014	88%	85%	89%	89%	97%	87%	87%	100%	100%
2015	88%	85%	90%	90%	97%	87%	87%	100%	100%
2016	88%	86%	90%	90%	97%	87%	87%	100%	100%
2017	88%	86%	90%	90%	97%	88%	88%	100%	100%
2018	88%	86%	90%	90%	97%	88%	88%	100%	100%
2019	88%	86%	90%	90%	97%	88%	88%	100%	100%
2020	88%	86%	90%	90%	97%	88%	88%	100%	100%
2021	88%	86%	90%	90%	97%	88%	88%	100%	100%
2022	88%	86%	90%	90%	97%	88%	88%	100%	100%
2023	88%	86%	90%	90%	97%	88%	88%	100%	100%
2024	88%	86%	90%	90%	97%	88%	88%	100%	100%
2025	88%	86%	90%	90%	97%	88%	88%	100%	100%
2026	88%	86%	90%	90%	97%	88%	88%	100%	100%
2027	88%	86%	90%	90%	97%	88%	88%	100%	100%
2028	88%	86%	90%	90%	97%	88%	88%	100%	100%
2029	88%	86%	90%	90%	97%	88%	88%	100%	100%
2030	88%	86%	90%	90%	97%	88%	88%	100%	100%

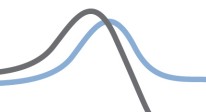


Table A7f

Gross to net energy savings conversion factors (S_{carbon}) for mixed fuels in UK non-domestic premises					
Year	Motors	Office equipment	Lighting	Refrigeration	Air-conditioning
2008	100%	81%	81%	100%	100%
2009	100%	82%	82%	100%	100%
2010	100%	82%	82%	100%	100%
2011	100%	82%	82%	100%	100%
2012	100%	82%	82%	100%	100%
2013	100%	82%	82%	100%	100%
2014	100%	83%	83%	100%	100%
2015	100%	83%	83%	100%	100%
2016	100%	83%	83%	100%	100%
2017	100%	83%	83%	100%	100%
2018	100%	83%	83%	100%	100%
2019	100%	83%	83%	100%	100%
2020	100%	83%	83%	100%	100%
2021	100%	83%	83%	100%	100%
2022	100%	83%	83%	100%	100%
2023	100%	83%	83%	100%	100%
2024	100%	83%	83%	100%	100%
2025	100%	83%	83%	100%	100%
2026	100%	83%	83%	100%	100%
2027	100%	83%	83%	100%	100%
2028	100%	83%	83%	100%	100%
2029	100%	83%	83%	100%	100%
2030	100%	83%	83%	100%	100%

Changes from version 8.2

- All factors changed
- Text describing derivation of current factors added

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