BNXS29: The Heat Replacement Effect – thermal simulation of domestic lighting and appliances

Version 2.0

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 note describes work undertaken to improve our understanding of the heat replacement effect. Specifically, the degree to which the energy saved by efficient lights and appliances is offset by an increased need for space heating energy was investigated by the computer simulation of typical houses. The work undertaken is described in detail and the results are used to calculate heat replacement factors that can be applied to gross energy savings to convert them into savings net of the heat replacement effect.

2 Introduction

Savings from energy performance improvements to lighting and appliances are often quoted from measurements of these products in isolation. But when installed in heated buildings, the savings actually achieved will be significantly lower. The reason is that lighting and appliances contribute to the warmth of the building, and alleviate the load on the heating system: if their contribution is reduced then the heating system is called upon to supply more heat, and this is known as the Heat Replacement Effect. The principles are discussed in detail in the Market Transformation Programme Briefing Note BNXS05: The Heat Replacement Effect (Ref [1]).

In January 2004 a meeting was convened by DEFRA (see Ref [2]) to discuss how the Heat Replacement Effect should be calculated for domestic lighting. It was decided that thermal simulation modelling was the most promising method for refining the initial factors proposed for converting gross savings to net. (Gross savings are those from improvements to the energy performance of products considered in isolation, whereas net savings take account of their installation in buildings.)

Subsequently, a first batch of thermal simulation modelling was carried out to examine the interaction between domestic heating and lighting in a number of simple cases. The results were presented in an earlier version of this note, BNXS29, in June 2004. A second batch of modelling was carried out in August 2004 to re-run some of the earlier cases under more realistic conditions, and, in addition, examine the interaction between domestic heating and appliances that are used at a uniform rate throughout the year. This later version of Briefing Note BNXS29 replaces the earlier version, and reports the results from both batches of thermal simulation modelling, and develops new gross-to-net conversion factors from them. This version also corrects an error in the earlier version, in which the “with TRVs” and “without TRVs” cases were interchanged.

3 Thermal Simulation Modelling Method

3.1 Dwelling characteristics and modelling cases

A number of modelling cases for examination were specified, as set out in Appendix A. Detailed thermal simulation work to examine the interaction between heating and lighting, and heating and appliances, was then undertaken by IES using ‘ApacheSim’ modelling software. An outline description of ApacheSim is given in Appendix B.

All simulation cases were based on a semi-detached dwelling of average size, typical of the UK housing stock. Characteristics relevant to the heat replacement effect were systematically varied. Energy consumption for space heating, lighting, and appliance use was calculated by the simulation software for each case. A total of 17 cases were modelled, in two batches.

Heat replacement effect factors are derived by examining the results from pairs of cases. Such pairs are identical except for a single characteristic; eg, for lighting, the dwelling may be illuminated in one case by conventional tungsten lamps and in the other by compact fluorescent lamps (CFLs). For appliances, high (300W) and low (200W) power consumption were compared. From a number of comparisons such as these the heat replacement effect can be evaluated, and estimates made of the extent to which it is influenced by the different variables.

Key characteristics of the standard dwelling (SD) modelled were:

- Floor area of 88.8m^2, two storey semi-detached house, 3-bedrooms
- Brick/brick cavity walls (unfilled), 150mm loft insulation, single glazed
- Standard heating pattern assumed: weekdays 7am-9am, then 4pm-11pm, weekends 7am-11pm (this is the same as in SAP)
- Heating system: gas central heating system of average efficiency 70%, controlled by a programmer, room thermostat in the hall, and thermostatic radiator valves (TRVs) elsewhere.

Such a dwelling would achieve a SAP rating of about 51, which is equal to the stock average for England according to the English House Condition Survey (EHCS) 2001. To model artificial lighting levels, monthly profiles were developed from Electricity Association monitoring data. These profiles were then reconciled to give the average annual total using the Domestic Energy Fact File (Ref [3]).

Characteristics of the 17 cases simulated were:

1. Standard dwelling (SD) with no lighting but heated normally
2. SD with GLS tungsten filament lamps
3. SD with CFLs of same illumination power as in case 2 (1/5th of power)

4. SD with CFLs using same electrical power as case 2 (the dwelling will be over-lit)
5. Tungsten lamps, no lampshades
6. CFLs, no lampshades
7. Poorly insulated variant of SD, with GLS tungsten filament lamps
8. Poorly insulated variant of SD, with CFLs of same illumination power
9. Better insulated variant of SD, with GLS tungsten filament lamps
10. Better insulated variant of SD, with CFLs of same illumination power
11. Tungsten lamps, all day heating pattern (on 7am to 11pm every day of the week)
12. CFLs, all day heating pattern (on 7am to 11pm)
13. Tungsten lamps, SD with no TRVs
14. CFLs, SD with no TRVs
15. SD with no appliance energy use
16. SD with 300W constant appliance load
17. SD with 200W constant appliance load

The above is tabulated in Appendix A, Table 4.

The first batch of thermal simulation modelling comprised cases 1-14, and the second batch comprised 7-10 and 15-17. Cases 7-10 were repeated because, in the first batch, the length of heating season was the same in every case: in the second batch an adjustment to length of heating season was made to allow for the different levels of insulation.

3.2 Notes on the modelling cases

The cases were designed to address specific points of interest, so not all of them represent realistic patterns of occupation.

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. The contribution to heating from lighting was debated at length at the DEFRA Workshop.

Cases 2 and 3 allow a direct comparison of the heating and lighting energy needs before and after the replacement of tungsten lamps with 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, but to examine the assertion that the differing proportions of radiant and convective heat from filament lamps and CFLs affects 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. At the DEFRA workshop it was claimed that lampshades convert some radiant to convective heat and so 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 loft insulation). Insulation level was expected to be a parameter that could affect the magnitude of heat replacement.

Cases 9 and 10 have the same characteristics as 2 and 3, except they are well-insulated versions of the standard dwelling, with insulated cavity walls, 250mm of loft 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 (7am-11pm).

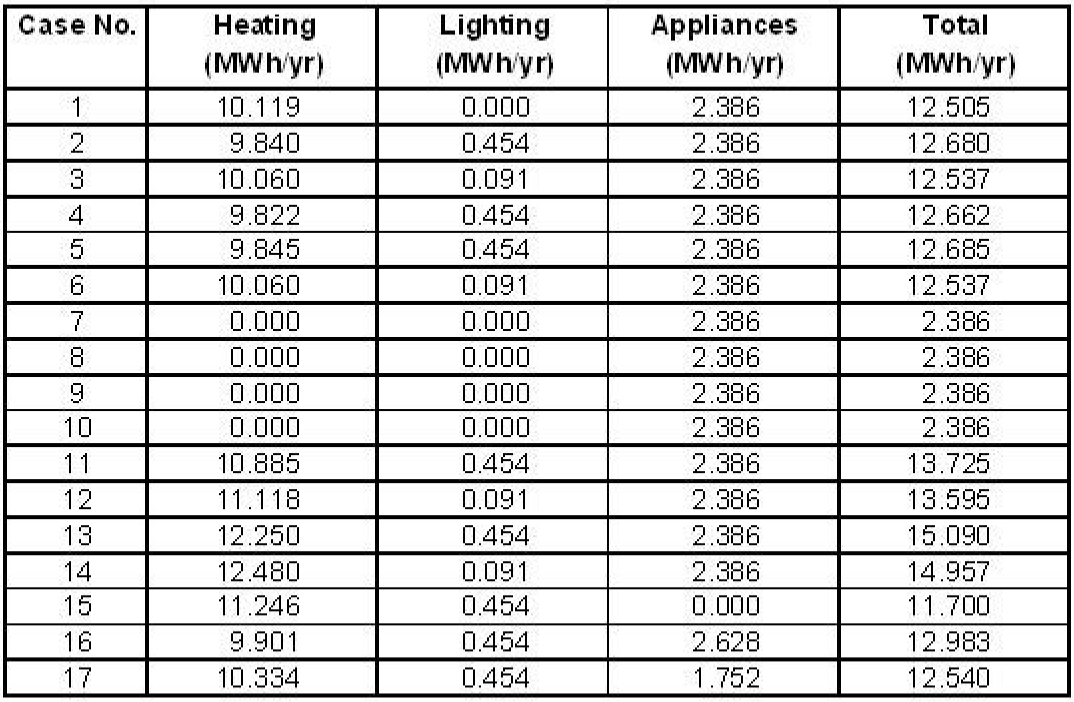
Cases 13 and 14 assume there are no TRVs present on radiators and that the temperature of the whole house is controlled by the room thermostat (assumed to be the hall).

Cases 15, 16 and 17 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.

4 Results

Table 1 summarises the results from the simulation model, giving the annual heating and lighting energy requirements for cases 1 -14. For cases 15 -17, the heating and appliance energy load loads are given. More detailed monthly figures are given in Appendix C.

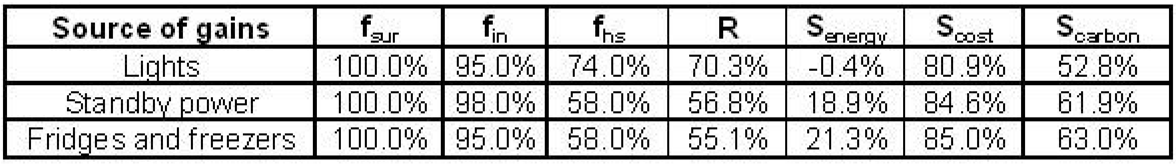
Table 1 – Thermal modelling simulation results



Case No.	Heating (MWh/yr)	Lighting (MWh/yr)	Appliances (MWh/yr)	Total (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	0.000	0.000	2.386	2.386
8	0.000	0.000	2.386	2.386
9	0.000	0.000	2.386	2.386
10	0.000	0.000	2.386	2.386
11	10.885	0.454	2.386	13.725
12	11.118	0.091	2.386	13.595
13	12.250	0.454	2.386	15.090
14	12.480	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

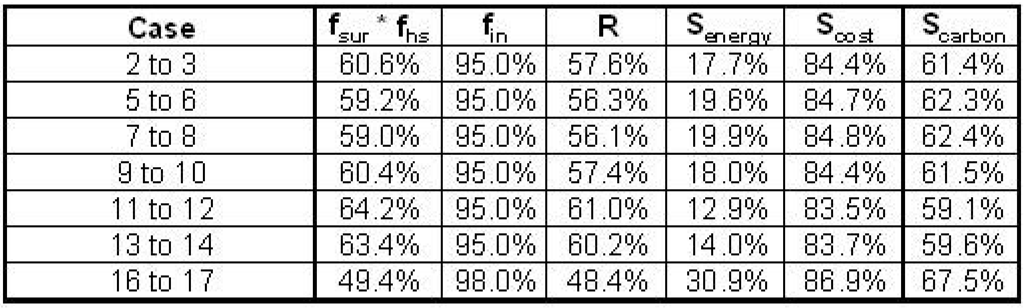
From this primary information, the values in Table 2b were derived, providing comparable figures to those given in an earlier version (Revision 1, January 2003) of Market Transformation Programme Briefing Note BNXS05 (Ref [1]). To aid comparison, the initial estimates in BNXS05 are repeated here in Table 2a:

Table 2a – Factors derived in BNXS05 (March 2003)



Source of gains	f_{sur}	f_{in}	f_{hs}	R	S_{energy}	S_{cost}	S_{carbon}
Lights	100.0%	95.0%	74.0%	70.3%	-0.4%	80.9%	52.8%
Standby power	100.0%	98.0%	58.0%	56.8%	18.9%	84.6%	61.9%
Fridges and freezers	100.0%	95.0%	58.0%	55.1%	21.3%	85.0%	63.0%

Table 2b – Factors derived from thermal simulation model



Case	$f_{sur} * f_{hs}$	f_{in}	R	S_{energy}	S_{cost}	S_{carbon}
2 to 3	60.6%	95.0%	57.6%	17.7%	84.4%	61.4%
5 to 6	59.2%	95.0%	56.3%	19.6%	84.7%	62.3%
7 to 8	59.0%	95.0%	56.1%	19.9%	84.8%	62.4%
9 to 10	60.4%	95.0%	57.4%	18.0%	84.4%	61.5%
11 to 12	64.2%	95.0%	61.0%	12.9%	83.5%	59.1%
13 to 14	63.4%	95.0%	60.2%	14.0%	83.7%	59.6%
16 to 17	49.4%	98.0%	48.4%	30.9%	86.9%	67.5%

Table 2a 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 2a, but are not separable in Table 2b. The thermal simulation model 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).

The factor f_{in} (proportion of energy consumed in heated living space) in Table 2a for lighting assumes that 95% of the lighting energy is consumed in heated living space, the remaining 5% being mainly for external lighting that does not contribute to the heating of the building. For the thermal simulation model, 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 2a).

The heat replacement factor ***R*** represents the proportion of the energy used by lights or appliances that provides useful heat to the dwelling, offsetting heat requirements from the heating system. From this, the beneficial saving factors ***S*** are calculated for energy, cost and carbon emissions ($\boldsymbol{S}_{energy}$, $\boldsymbol{S}_{cost}$, $\boldsymbol{S}_{carbon}$). (These are the gross-to-net saving factors, needed to take account of the heat replacement effect, defined fully in BNXS05.)

5 Discussion of Results

5.1 Lighting

Lighting is treated differently from appliances as a greater proportion of it is required at the same time as heating. 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 previously developed in BNXS05: The Heat Replacement Effect, (Revision 1, January 2003), and is repeated here, for information, in Appendix D – Lighting and heating coincidence in dwellings.

However, the thermal simulation modelling results now make the application of this coincidence factor 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 below, referring to raw data figures from Table 1.

(i) 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, the heat from lighting in this case reduces gas consumption by 0.3986 MWh/yr.

(ii) 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 70% efficiency of the heating system, an extra 0.0843 MWh /yr of gas would be needed to heat the dwelling without the heat obtained from the lights.

(iii) 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 less useful than convective heat for space heating.

(iv) 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 the incident radiation and converts it to convective heat, which is more useful for space heating.

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

(i) 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%.

(ii) 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 in BNXS05 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.

(iii) Similarly, 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 much more expensive than gas, 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.

(iv) Similarly, in terms of carbon savings, because electricity is significantly more carbon intensive than gas, 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.

5.3 Sensitivity of HRE (lighting) to dwelling characteristics

(i) 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.

(ii) 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 there by the start of the next heating period.

(iii) 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, more of which is wasted when the heating period is broken between morning and evening.

(iv) 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 2b into a single set of factors for practical use. Common cases for heating the housing stock 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 3.

Table 3 – Overall factors for domestic lighting derived from thermal simulation model

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%**

5.4 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 lower 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 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.

6 Conclusions

6.1 Lighting

A substantial proportion of the energy used for lighting ends up as useful heat, offsetting the need for space heating. About 60% of the energy used for lighting is useful, whether from tungsten lamps or CFLs.

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(ii) Lamps that have higher convective/radiant fractions contribute a slightly higher proportion of their energy to useful space heating. Thus, CFLs provide more heating per Watt of input power than tungsten lamps, though the difference is small.

(iii) The test cases show that the presence or absence of lampshades, and changes to building insulation from poor to good, have little effect upon the heat replacement factor, ***R***. Variations between these cases were less than 1.5 percentage points.

(iv) The test cases show that a change from intermittent heating to all day heating raises ***R*** by 3.4 percentage points, and that a change from all TRVs to no TRVs raises ***R*** by 2.6 percentage points. These characteristics have a greater influence on the heat replacement factor than the others examined.

(v) The study shows that the magnitude of the heat replacement effect is not strongly affected by any of the variables examined. In view of that and other uncertainties, it is suggested that a reasonable approach is to combine the most common cases into a single set of factors. Using that approach:

- the **heat replacement factor**	is 60%
- the net **delivered energy** saving	is 14% of the gross saving
- the net **cost** saving	is 84% of the gross saving
- the net **carbon** saving	is 60% of the gross saving.

6.2 Appliances

(i) Though less than lighting, a substantial proportion of the energy used by appliances produces useful heat, offsetting the need for space heating. About 48% of the energy used in appliances that are used uniformly throughout the year (such as standby power and TV and audio equipment) provides useful space heating. Note that this does not apply to appliances that dispose of most of their heat outside their house (eg, washing machines) – see discussion in Ref. [1].

(ii) This study concludes that for such appliances:

- the **heat replacement factor**	is 48%
- the net **delivered energy** saving	is 31% of the gross saving
- the net **cost** saving	is 87% of the gross saving
- the net **carbon** saving	is 68% of the gross saving.

(iii) The heat replacement factor for appliances has been estimated only for a single heating regime; ie, intermittent heating with TRVs. If it had been estimated also for the three other common heating regimes (all day heating with TRVs; intermittent heating without TRVs; all day heating without TRVs) it is likely that, as for lighting, the average value would be 2 to 3 percentage points higher.

6.3 Further work

No further work is proposed. If, however, further refinement of the heat replacement factors is required the following lines of investigation are suggested:

(1) seek better information, from other sources, on the proportion of energy consumed by lights and appliances outside heated living space;

(2) use thermal simulation model to examine all four of the common heating regimes for lighting and appliances (to date we have examined 3 for lighting and 1 for appliances);

(3) from other sources, obtain weighting factors for the four common heating regimes, and use them to calculate weighted average heat replacement factors for both lighting and appliances;

(4) examine behaviour of appliances with known non-uniform annual and/or daily pattern of energy consumption;

(5) look at more extreme poorly insulated and well insulated houses, to investigate relationship with heat replacement factors.

7 References

[1] MTP Briefing Note BNXS05 (formerly BNDH05) *Revision 2, September 2003*

[2] DEFRA workshop: notes of meeting *January 2004*

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

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

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

Related MTP information

- BNXS05 discusses the basis for the HRE in more detail

Appendix A – Modelling specification

Purpose

To establish, by thermal modelling based on simulation techniques, the magnitude of the heat replacement effect for domestic lighting. The results from each modelling case will provide the electrical energy needed for lighting, and fuel energy needed for heating, taken over a whole year.

Effects to be considered

The model will examine the variation in the heating effect of lighting caused by differences in lamp technology (proportions of radiant v. convective heat emissions), lampshades, building insulation, heating pattern and controls.

Modelling cases

Simple modelling cases for the initial work are set out in Table 4, with detailed comments on the various conditions given below.

Lighting

Cases have been devised to determine how much of the building's heating demand is being provided by the lighting. An initial case with no lighting, while unrealistic for occupied premises, will show the heating requirement when no lighting is provided. The results will be compared with cases where the building is illuminated by GLS tungsten filament lamps, CFLs of wattage to give the same light output as GLS, and with CFLs of the same wattage as the GLS lamps. The latter case is an unrealistically high level of lighting, but is included to show how the differing radiant and convective proportions of the heat given out by GLS lamps and CFLs affect the useful space heating they provide.

The lighting demand pattern will be matched to Electricity Association field data and reconciled to the national average given in Ref. [3].

Appliances

Three cases have been devised to help consider the heating effect of appliance gains. This first assumes no appliance gains, while the second and third assume a high (300W) and low (200W) level of gains for comparison.

Building

In each case, the dwelling modelled will be the BRE standard semi-detached dwelling of typical size. It has a heat loss equivalent to the average of the UK housing stock, as given in Ref. [3]. It has been used previously in a number of major pieces of work, such as to provide the energy savings for the Energy Efficiency Commitment. Poorly insulated and well insulated variants of the same size building will be used to examine the sensitivity of the heat replacement effect to the standard of insulation.

Heating

The heating regime assumed in SAP will be used for each of the cases, meaning morning and evening heating on week days and all day heating at the weekends. Sensitivity to this assumption will be examined by simulating an all day heating pattern (matching the weekend heating times assumed for SAP).

In all cases a room thermostat will be assumed to control the heating system and provide boiler interlock. In most cases it will be assumed TRVs are fitted in rooms other than the room containing the room thermostat, but sensitivity to absence of TRVs will also be examined. Thermostat settings will be based on those assumed in SAP.

Climate

Manchester weather data will be used because it is the closest to the national average of the recent CIBSE Test Reference Year data sets. These are based entirely on real weather data, arranged to give something very close to an average weather year for the region.

Table 4 – Thermal modelling cases

Case number	LIGHTING				SHADES		DWELLING TYPE			HEATING				APPLIANCES			
	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	

Appendix B – ApacheSim Features

Overview

- Dynamic thermal simulation of buildings and their energy systems
- Application areas:
  - Thermal performance analysis
  - Building fabric design
  - Comfort statistics
  - Natural ventilation studies
  - Façade analysis
  - Energy consumption prediction
  - Plant design and sizing
  - Mixed-mode design
  - Building Regulations
  - CFD boundary conditions
- Based on first-principles models of heat transfer processes and driven by real weather data
- Incorporates advanced solar features:
  - shading and internal solar tracking using data generated by SunCast
  - direct and diffuse radiation transfer through unlimited numbers of internal openings
  - direct and diffuse external shading
  - effects of blinds and curtains
  - angle-dependent glazing transmission analysis based on Fresnel equations
  - anisotropic sky model
- Performs carbon emissions calculations for Building Regulations Part L and Part J
- Supported by validation studies and full documentation on methodology
- Undergoing continuous development supported by current academic research

Interoperability

- Runs within the Apache View of the Virtual Environment Integrated Data Model
- Uses geometry data entered in ModelIT
- Shares thermal input data with Apache Calc (Heat Loss & Heat Gain)
- Links to SunCast or SunCast Lite to account for external shading and internal solar tracking
- Links to Apache HVAC for fully integrated HVAC simulation
- Links to MacroFlo for bulk air flow and natural ventilation modelling
- Links simultaneously to APhvac and MacroFlo to model interactions between natural and mechanical ventilation air flows

Analysis Options

- Time-steps down to 1 minute under user control
- SunCast and MacroFlo Links
- Idealised or detailed HVAC plant modelling
- Options on natural and mechanical ventilation: specify flows in advance or calculate using MacroFlo and Apache HVAC.
- Choice of models for internal and external convection

Input Data

- Building geometry passed automatically from ModelIT
- Location and weather data
- Construction data
- Gains from lights, equipment and occupants
- Natural ventilation, mechanical ventilation and infiltration
- Plant operation profiles
- Plant efficiency and fuel characteristics
- Data entry is supported by powerful facilities for assigning and editing time-varying room data such as plant, gains and air exchanges, and databases of constructions, time-series profiles, location and weather data

Outputs and Deliverables

- ApacheSim's output dataset can be browsed to interrogate every aspect of building thermal performance, from individual surface temperatures to annual energy consumption
- The results are displayed by the Virtual Environment program Vista, along with the weather data used to drive the simulation
- Results are accessed via graphical views of the building, allowing interrogation of data at a hierarchy of levels: building, room, surface, opening
- Vista generates graphs, tables, monthly summaries, ranges or user-specified synopses
- Room performance indicators include:
  - Room temperatures: air, mean radiant, dry resultant
  - Comfort indices: PMV, PPD
  - Room loads: heating, cooling, humidification, dehumidification
  - Load breakdowns: casual & solar gains, conduction and ventilation losses, plant inputs
  - MacroFlo-generated air flows for rooms or individual openings
  - Surface temperatures
- Building and system performance indicators include:
  - Totals of room and ventilation loads: heating, cooling, humidification, dehumidification
  - HVAC loads
  - System energy from HVAC simulation or idealised plant characteristics
  - Building energy consumption: lights and small power
  - Carbon emissions for system and building, optionally broken down by fuel
- Multiple results can be displayed simultaneously or aggregated
- Metric and imperial units are available
- Graphical and numerical data can be exported to Excel, Word and other applications

Appendix C – Monthly data from simulations

Case No.	Month	Room Heating Load (MWh)	Lighting Load (MWh)
1	January	1.875	0.000
	February	1.602	0.000
	March	1.308	0.000
	April	0.821	0.000
	May	0.150	0.000
	June	0.000	0.000
	July	0.000	0.000
	August	0.000	0.000
	September	0.214	0.000
	October	0.825	0.000
	November	1.522	0.000
	December	1.801	0.000

Case No.	Month	Room Heating Load (MWh)	Lighting Load (MWh)
2	January	1.830	0.058
	February	1.566	0.046
	March	1.278	0.039
	April	0.802	0.030
	May	0.142	0.024
	June	0.000	0.019
	July	0.000	0.020
	August	0.000	0.025
	September	0.200	0.031
	October	0.792	0.045
	November	1.480	0.053
	December	1.751	0.063

Case No.	Month	Room Heating Load (MWh)	Lighting Load (MWh)
3	January	1.865	0.012
	February	1.594	0.009
	March	1.302	0.008
	April	0.817	0.006
	May	0.148	0.005
	June	0.000	0.004
	July	0.000	0.004
	August	0.000	0.005
	September	0.211	0.006
	October	0.818	0.009
	November	1.513	0.011
	December	1.790	0.013

Case No.	Month	Room Heating Load (MWh)	Lighting Load (MWh)
4	January	1.827	0.058
	February	1.563	0.046
	March	1.276	0.039
	April	0.801	0.030
	May	0.141	0.024
	June	0.000	0.019
	July	0.000	0.020
	August	0.000	0.025
	September	0.199	0.031
	October	0.790	0.045
	November	1.477	0.053
	December	1.748	0.063

Appendix D – Lighting and heating coincidence in dwellings

(previously published in BNXS05: The Heat Replacement Effect, (Revision 1, January 2003))

Domestic heating coincides with lighting to a greater extent than with household appliances, as both heating and lighting are used predominantly in winter when outside temperatures are lowest and hours of daylight least. It is therefore worthwhile to try to develop a better estimate of the coincidence factor f_{hs} explained [in BNXS05] above.

The variation of energy consumed for lighting with time of year can be estimated using a simple sinusoidal approximation for daylight hours, as shown in the line “Lighting L1” in Figure 1. The estimate can be improved by taking field data (see Ref [5]), which produces the line “Lighting L2” in Figure 1. The line “Heating” is superposed to represent the heating season, showing coincidence of usage, and f_{hs} is the proportion of the area under the lighting curve which also lies under the heating curve. The proportion is 71% for L1, and 74% for L2. It is believed that L2 is the more realistic curve, and so f_{hs} has been taken as 74% and inserted in Table 3 [in initial version of BNXS05].

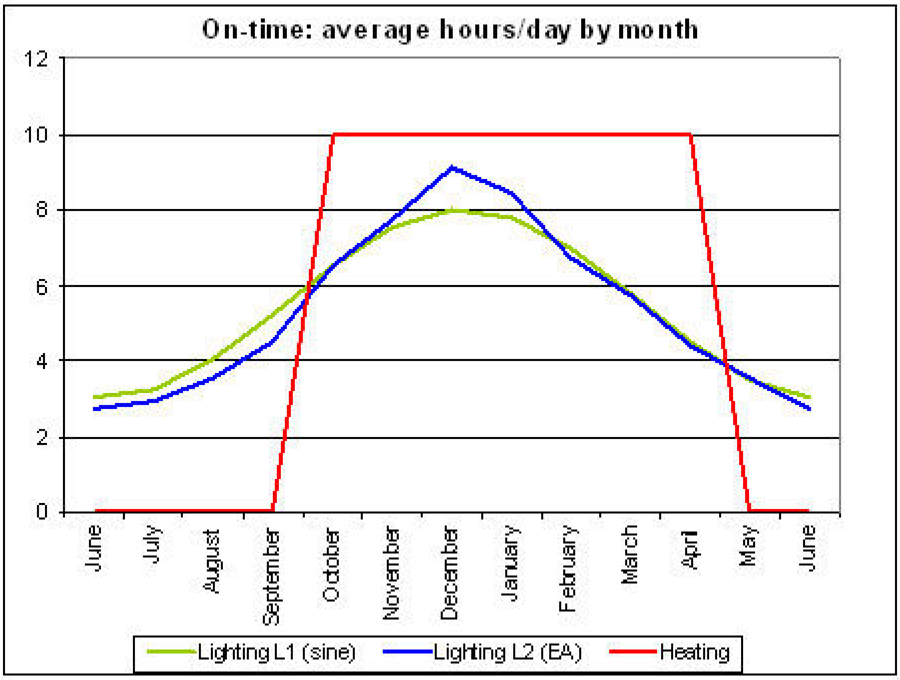

Figure 1 : Coincidence of domestic heating and lighting

Changes from version 1.0

- Summary 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**