Client Report :

The Effect of clock changes on energy consumption in UK Buildings

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Executive Summary

The issue of clock changes has been raised as a potential way of reducing carbon emissions under the current review of the UK Climate Change Programme. An earlier study[1] concentrated on modelling the expected impact of the clock change on the likelihood of artificial lighting being switched off in response to daylight availability. The work presented here expands on this earlier work and looks at the impact of clock change on energy use for lighting, heating and cooling using dynamic simulation modelling to capture the interactions between the energy services.

To determine the effect of a change from the current GMT/BST clock regime to Central European Time (BST/DBST (Double British Summer Time)) and from GMT/BST to BST all through the year (BST/BST) on UK energy consumption in buildings some energy simulation runs were carried out. The simulations were used to determine the impact of a clock change on annual energy consumption for heating[A], and in the case of non-domestic buildings for lighting and cooling as well.

The modelling results were scaled to the UK level for 2010 and 2020 based the projected energy consumption for the reference scenarios developed for the domestic and non-domestic sectors.

The result of this study indicate that both clock change regimes would result in an increase in energy consumption in UK buildings, rather than realise any savings. Overall the changes result in only a small difference to energy for heating, lighting and cooling in UK buildings and were similar for 2010 and 2020. The switch to Central European Time (BBST/DBST) showing 2% increase in both delivered energy use and CO_2 emissions (around 40 PJ and 2.5 M Tonnes CO_2, respectively). Whilst a switch to BST all year round (BST/BST) would result in a smaller increase of just under 1% (around 20 PJ and 3 5 M Tonnes CO_2, respectively).

The only instances where savings are realised are for domestic lighting and non-domestic cooling for the switch to Central European Time. However, these savings are more than offset by the increases in non-domestic heating and lighting, as well as a small increase in domestic heating.

As these results are based on a limited number of simulations, there is uncertainty associated with the final figures. However, it is unlikely that the a switch to either Central European Time (BBST/DBST), or BST all year round (BST/BST) would lead to significant CO_2 savings.

[1] P Littlefair, “The Effects of clock change on lighting energy use”, BRE ref 285/89, prepared for publication in Energy World

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[A] Due to the way in which the domestic model had been constructed for the heat replacement work, the simulation only generated heating savings, and so lighting savings had to be calculated separately.

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1 Introduction

The work described in this report has been carried out for DEFRA's Global Atmosphere Division as part of a contract titled CO_2 and Energy Use in UK Buildings, contract reference EPG 1/1/152. This report describes the expected impact of changing the current clock change regime in the UK to British Summer Time (BST) in the winter and Double British Summer Time (DBST) in the summer on energy consumption in the UK building stock. It had been claimed previously[2,3] that such a change would result in significant energy savings. At first glance it would seem that switching from GMT/BST to BST/DBST would lead to a better match between waking hours and daylight hours for most people.

Figure 1 shows sunrise and sunset times in six widely spaced UK locations together with typical waking hours (rising at 7:15 and going to bed at 23:00) for the current UK time, whilst Figure 2 shows the same information for BST/DBST.

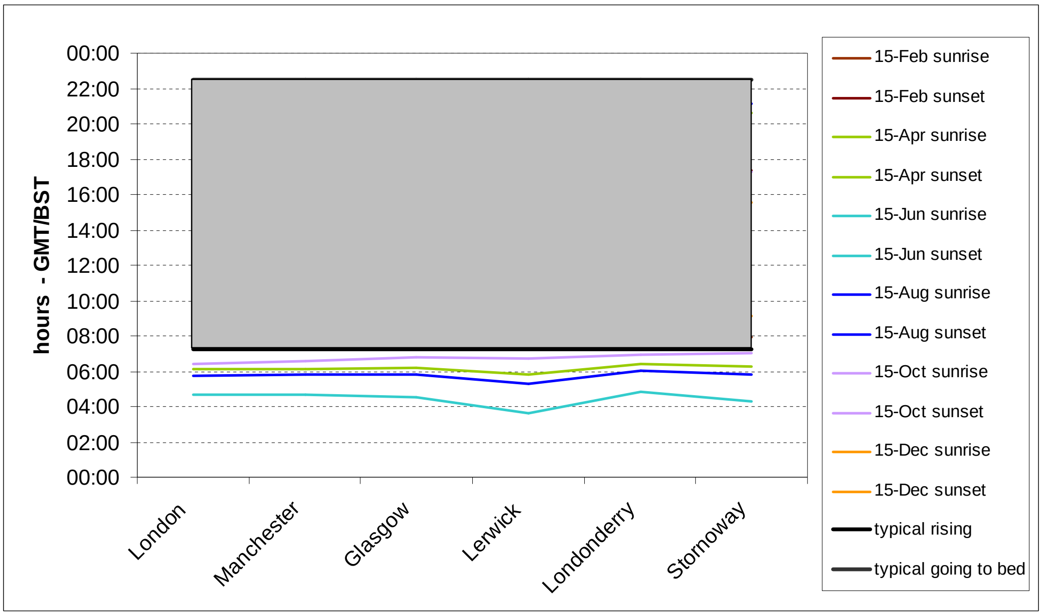

Figure 1: Coincidence of daylight and waking hours - current clock

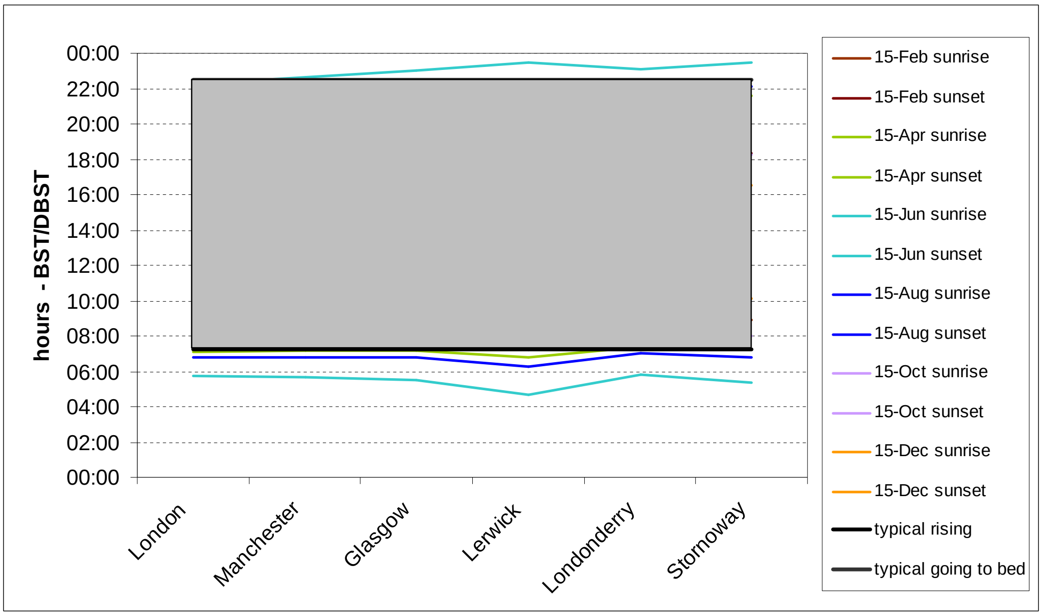

Figure 2: Coincidence of daylight and waking hours - alternative clock

In response to the earlier claims a study was undertaken by BRE which concluded that such a change would in fact lead to a small additional increase in lighting costs of around £10 M pa in 1989[4]. The issue of clock changes has been raised again more recently, this time as a potential way of reducing carbon emissions under the current review of the UK Climate Change Programme. The earlier study concentrated on modelling the expected impact of the clock change on the likelihood of artificial lighting being switched off in response to daylight availability in both domestic and non-domestic buildings. The work presented here expands on this earlier work and looks at the impact of clock change on energy use for lighting, heating and cooling using dynamic simulation modelling to capture the interactions between the energy services.

2 Description of the project

To determine the effect of a change from the current GMT/BST clock regime to Central European Time (BST/DBST (Double British Summer Time)) and from GMT/BST to BST all through the year (BST/BST) on UK energy consumption in buildings some energy simulation runs were carried out. The simulations were used to determine the impact of a clock change on annual energy consumption for heating, and in the case of non-domestic buildings for lighting and cooling as well.

2.1 Choice of Software

Clearly there are several commercially available software products that could have been used to carry out the dynamic simulations required here. For the non-domestic sector, EnergyPlus offered two significant advantages. Firstly, in the form of Design Builder[B] a simple to use interface is available that enables building details to be entered quickly. Secondly, EnergyPlus is already set up to work with the activity schedules[C] that have been generated for use National Calculation Tool being developed by ODPM for the asset rating of buildings under the Energy Performance of Buildings Directive. Whilst for the domestic sector IES <*Virtual Environment*> was used to conduct the dynamic thermal modelling using an existing building model which has been used to evaluate the Heat Replacement Effect (HRE) for domestic lighting.

2.2 Building Types Modelled

To generate results that are representative of the impact that is likely across the UK, simulations were run on two building shells for non-domestic buildings, a medium sized, highly glazed and well insulated building, and a building of the same shape and size with a more traditional shell with less glazing, less insulation and a greater level of air infiltration. To represent the range of uses in the non-domestic sector five different activity schedules were used. These five building types together comprise 70% of total non-domestic floor area

- Office
- Shop
- Hospital
- School

[B] DesignBuilder is developed by Andy Tindale of Energy Coding – The β test version is available from www.energycoding.co.uk

[C] These activity schedules contain information on typical occupied hours, service demand levels (e.g., temperature set points, required lighting and ventilation levels) and internal gains for various activity types found within non-domestic buildings.

- Warehouse[D]

For the domestic sector, simulation runs were made on a typical three bedroom semi-detached house using typical occupancy pattern for working household was used. Due to the way in which the domestic model had been constructed for the heat replacement work, the simulation only generated heating savings, and so lighting savings had to be calculated separately.

Figures 3 and 4 show the models used to represent the non-domestic building, and domestic buildings respectively.

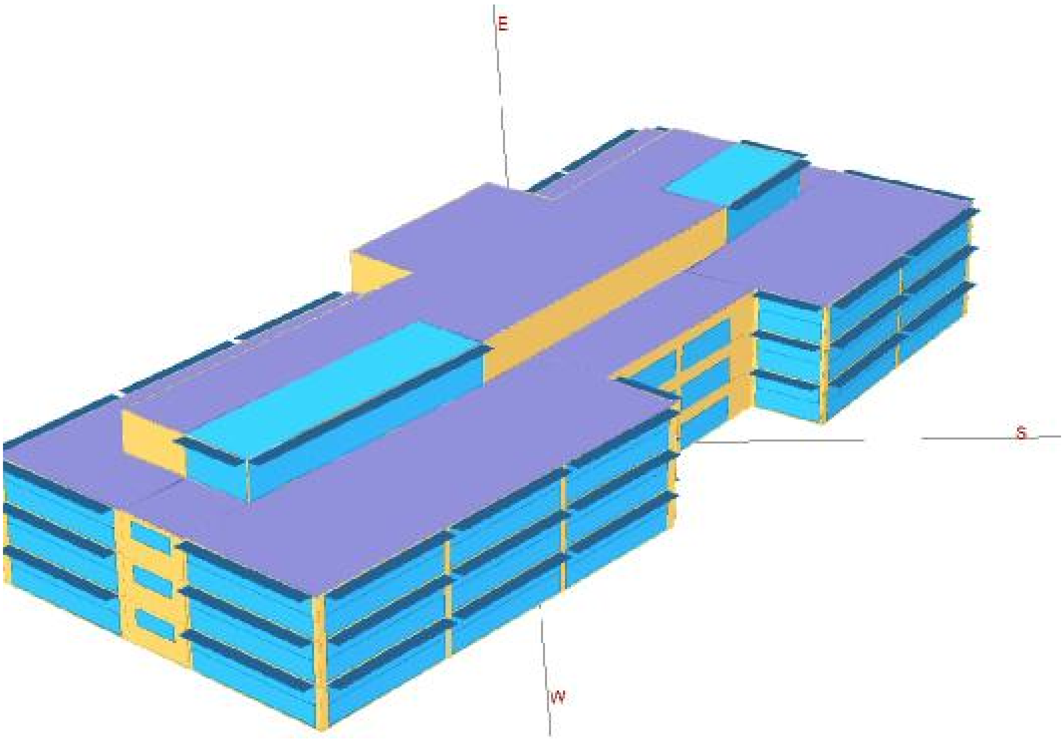

Figure 3: Model of Non-Domestic Building

[D] Energy use in industrial buildings has not been included in this study. However, it would be expected that the impact of clock time changes on industrial heating and lighting demands will be small in comparison to those for domestic, commercial and public buildings.

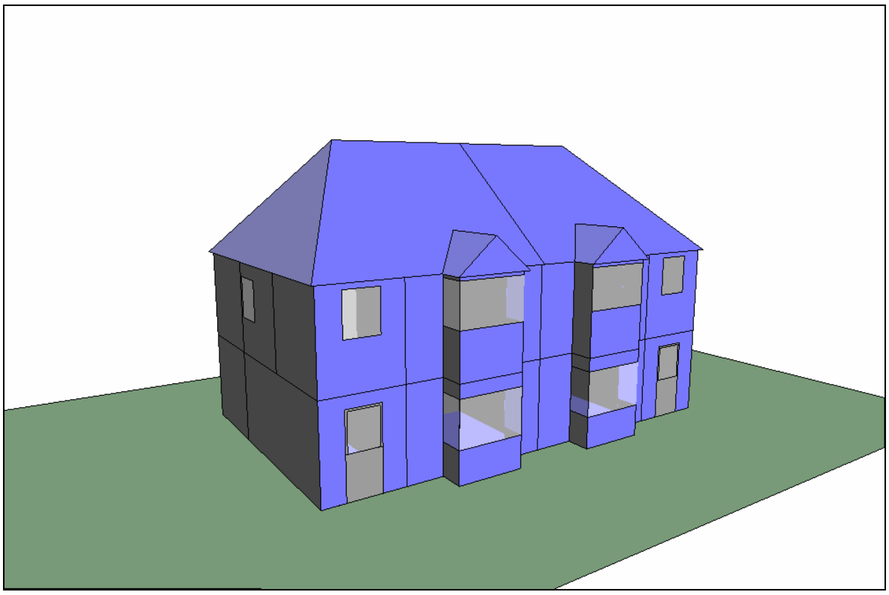

Figure 4: Model of Domestic Building

Details of the models are included in Appendix A and B for the domestic and non-domestic models, respectively.

2.3 Location

All the simulations were run using Manchester weather data which approximates to the centre of the UK when weighted for population density, and provides a reasonable representation of the average UK Climate.

Once the simulation runs were completed the resultant delivered energy savings were scaled to the UK level to produce national savings estimates.

Clearly it would be desirable to run simulations of more building types at more locations in the UK. However, it was only possible to carry out a limited number of simulations and subsequent analyses. Nevertheless, the results should provide a good indication of the actual effect of clock change regimes across the UK.

2.4 Limitations

The modelling results for lighting in non-domestic buildings captured the theoretical effect of clock change on lighting use but did not explicitly capture the observed behavioural responses to the availability of lighting. This issue is particularly applicable to non-domestic buildings where there are no automatic lighting controls, as studies show that once switched on, a percentage of artificial lighting tends to be left on even when sufficient daylight becomes available[5].

2.5 Scaling modelling results

The modelling results were scaled to projected annual delivered energy emissions previously reported for the domestic and service sectors[6,7] for 2010 and 2020, taking the reference case values in each case. For the non-domestic sector the expected mix of building types in 2010 and 2020 were derived from floor area estimates that were developed for some revised scenarios of carbon emissions from public and commercial buildings[8]. Because the 5 main building types that were modelled explicitly in this study account for only 70% of the total floor area we have assumed that the net change in energy consumption for the remaining 30% of buildings types are due to be published shortly. The increasing proportion of new (highly insulated, highly glazed and air tight) premises in the non-domestic building stock in future years was modelled by combining the results from modelling the new and existing premises as 10% new, 90% existing for 2010, and 20% and 80% for 2020, approximating to a 2% new build rate.

The impact of domestic lighting had already been assessed in an earlier BRE paper[3] which was used as the basis for this study. This earlier work was based on the probability (over a whole year) of manual switching on of lighting, as a function of daylight factor and time of day[9]. The model assumed that a fresh switching decision (on or off) is made every half hour during occupancy. To update the results of this earlier study the percentage savings were simply applied to the expected consumption in 2010 and 2020. As the earlier study had only looked at the impact of switch to BST/DBST, the ratio of overlap between daylight hours and waking hours between the three respective regimes was used to estimate the likely impact of a switch to BST throughout the year.

The following carbon dioxide emission factors were used to calculate the change in emissions that the two clock change regimes brought about.

$kgCO_2/GJ$	Solid	Gas	Oil	LPG	Biomass	electricity
2010	80.4	54.0	74.3	61.1	7.0	121.0
2020	80.4	54.0	74.3	61.1	7.0	81.4

Where emission factors for electricity were taken from the updated DTI projections[10].

3 Findings

The impact of the two changes in clock regime (GMT/BST to BST/DBST and GMT/BST to BST/BST) in terms of delivered energy and the associated CO_2 emissions for they years 2010 and 2020 is summarised in charts and tables presented in this section.

3.1 Effect of clock change regimes on 2010 energy and CO_2 emissions from heating, lighting and cooling in buildings

Delivered Energy (PJ)	Sector	Domestic	Domestic	Non-Domestic	Non-Domestic	Non-Domestic	**All**
	End Use	heating	lighting	heating	lighting	cooling	**All**
Total Energy Use pa	GMT/BST	1,281	72	634	137	48	**2,172**
	BST/DBST	1,282	68	665	147	47	**2,210**
	BST/BST	1,283	74	642	142	48	**2,189**
Change in Energy Use pa	BST/DBST	1	- 4	31	10	- 1	**37**
	BST/BST	2	1	8	5	0	**16**
% Difference	BST/DBST	0.1%	-5%	5%	7%	-1%	**2%**
	BST/BST	0.2%	1.8%	1.2%	3.6%	0.0%	**0.8%**

Table 1: Impact on delivered energy consumption in 2010 resulting from a change from GMT/BST to BST/DBST.

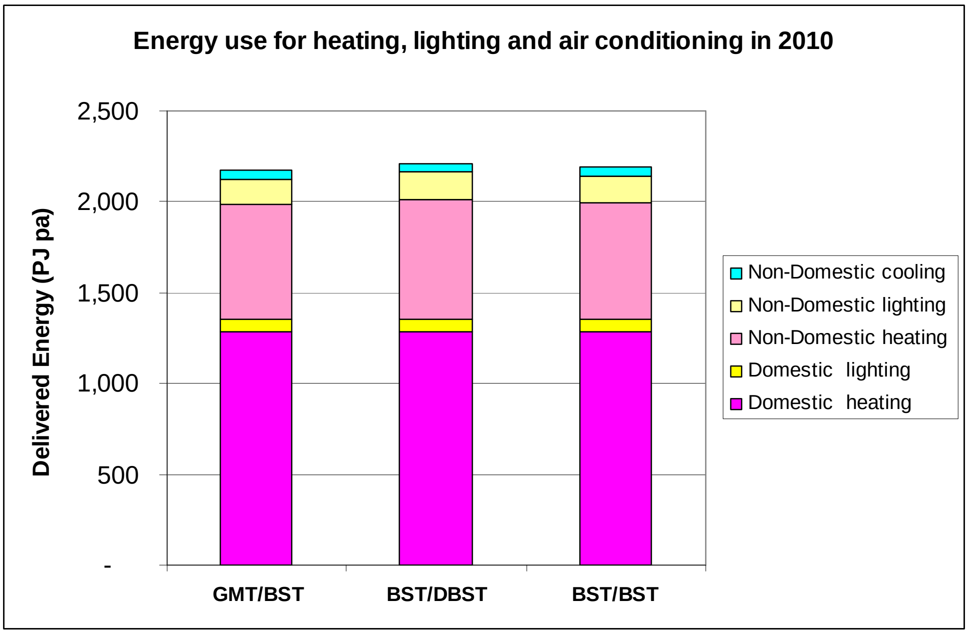

Figure 5: Delivered energy consumption in 2010 for heating, lighting and cooling under 3 different time regimes

Emissions (M Tonnes CO_2)	Sector	Domestic	Domestic	Non-Domestic	Non-Domestic	Non-Domestic	**All**
	End Use	heating	lighting	heating	lighting	cooling	**All**
Total Emissions pa	GMT/BST	74	9	37	17	6	**142**
	BST/DBST	74	8	38	18	6	**144**
	BST/BST	74	9	37	17	6	**143**
Change in Emissions pa	BST/DBST	0.1	- 0.5	1.8	1.2	- 0.1	**2.5**
	BST/BST	0.1	0.2	0.5	0.6	0.0	**1.3**
% Difference	BST/DBST	0.1%	-5%	5%	7%	-1%	**2%**
	BST/BST	0.2%	1.8%	1.2%	3.6%	0.0%	**0.9%**

Table 2: Impact on CO_2 emissions from energy use in 2010 resulting from a change from GMT/BST to BST/DBST.

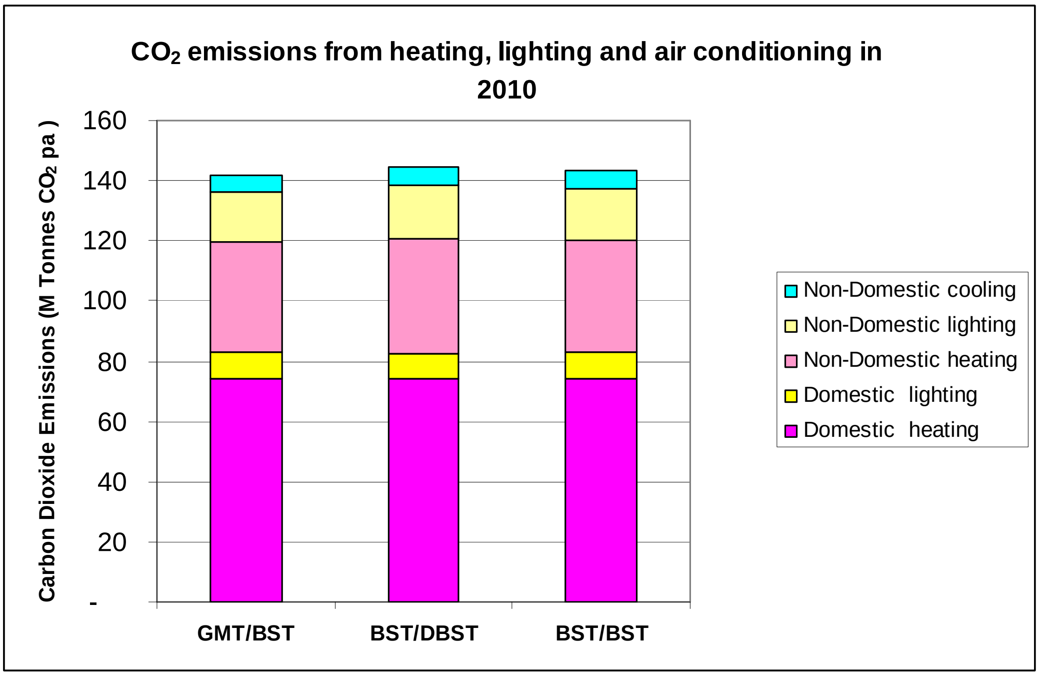

Figure 6: CO_2 emissions from energy use in 2010 for heating, lighting and cooling under 3 different time regimes

It is clear from the results of this analysis that overall changes in time regime will not lead to energy savings in buildings. Overall the changes will make only a small difference to energy consumption in UK buildings. A switch to Central European Time (BBST/DBST) is likely to result in a 2% increase in delivered energy use and the associated CO_2 emissions, whilst a switch to BST all year round (BST/BST) would result in a smaller increase of just under 1%.

The only instances where savings are realised are for domestic lighting and non-domestic cooling for the switch to Central European Time. However, these savings are more than offset by the increases in non-domestic heating and lighting, as well as a small increase in domestic heating.

On the face of it the changes realised for heating are much smaller relative to the lighting. Clearly there will be a much greater impact for lighting than heating and the diurnal variation that exists for lighting is much greater than that for heating. Furthermore the thermal mass of the building envelope will moderate the effect of the diurnal temperature changes effectively blurring out much of the impact of changes in clock change regimes on heating.

3.2 Effect of clock change regimes on 2020 energy and CO2 emissions from heating, lighting and cooling in buildings

Delivered Energy (PJ)	Sector	Domestic	Domestic	Non-Domestic	Non-Domestic	Non-Domestic	**All**
	End Use	heating	lighting	heating	lighting	cooling	**All**
Total Energy Use pa	GMT/BST	1,401	75	692	149	65	**2,382**
	BST/DBST	1,402	71	726	160	63	**2,422**
	BST/BST	1,403	77	701	154	65	**2,400**
Change in Energy Use pa	BST/DBST	1	- 4	34	11	- 2	**40**
	BST/BST	2	1	9	5	0	**18**
% Difference	BST/DBST	0.1%	-5%	5%	7%	-3%	**2%**
	BST/BST	0.2%	1.8%	1.2%	3.6%	0.1%	**0.7%**

Table 3: Impact on delivered energy consumption in 2020 resulting from a change from GMT/BST to BST/DBST.

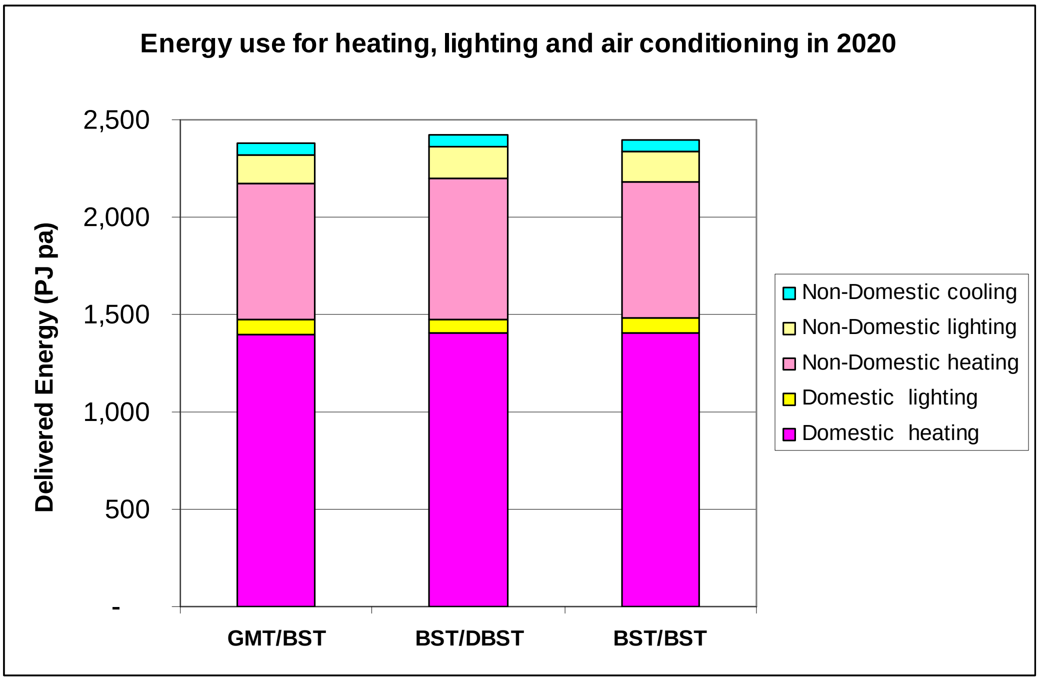

Figure 7: Delivered energy consumption in 2020 for heating, lighting and cooling under 3 different time regimes

Emissions (M Tonnes CO2)	Sector	Domestic	Domestic	Non-Domestic	Non-Domestic	Non-Domestic	**All**
	End Use	heating	lighting	heating	lighting	cooling	**All**
Total Emissions pa	GMT/BST	79	6	39	12	5	**141**
	BST/DBST	79	6	41	13	5	**144**
	BST/BST	79	6	39	13	5	**142**
Change in Emissions pa	BST/DBST	0.1	- 0.3	1.9	0.9	- 0.1	**2.4**
	BST/BST	0.1	0.1	0.5	0.4	0.0	**1.2**
% Difference	BST/DBST	0.1%	-5%	5%	7%	-3%	**2%**
	BST/BST	0.2%	1.8%	1.2%	3.6%	0.1%	**0.8%**

Table 4: Impact on CO_2 emissions from energy use in 2020 resulting from a change from GMT/BST to BST/DBST.

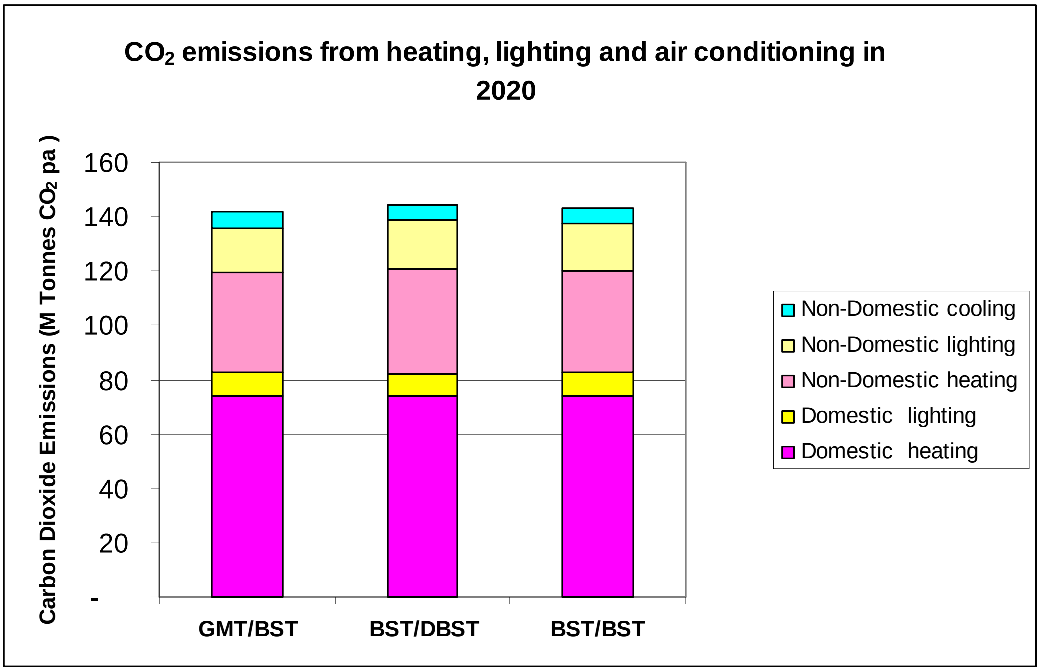

Figure 8: CO_2 emissions from energy use in 2020 for heating, lighting and cooling under 3 different time regimes

Overall the picture for 2020 is very similar to that for 2010. The actual changes are very slightly larger in 2020 for delivered energy. This is due to growth in the demand for energy services in both the domestic and non-domestic sectors. Whilst for CO_2 the opposite is true.

Conclusion and recommendations

A study has been carried out to determine the likely impact of two changes of clock regime; to Central European Time (GMT/BST to BST/DST). and to British Summer Time all through the year (GMT/BST to BST/DST).

Building simulations were carried out on a limited number of buildings to determine the effect of the two clock change regimes on heating, lighting and cooling energy use. Unfortunately, it was not possible to generate simulation results for domestic lighting for this study, so instead the effect on lighting was estimated based on earlier studies based on the probability of switching on lights in response to daylight factor. Whilst this means that the effect of the interaction between heating and lighting has not been capture for the domestic sector, as the impact of clock change regime on domestic heating is very small the impact of any interactions are likely to be very small indeed.

The modelling results were scaled to the UK level for 2010 and 2020 based the projected energy consumption for the reference scenarios developed for the domestic and non-domestic sectors.

The results indicate that both clock change regimes would result in an increase in energy consumption in UK buildings, rather than realise any savings. Overall the changes result in only a small difference to energy for heating, lighting and cooling in UK buildings and were similar for 2010 and 2020. The switch to Central European Time (BBST/DBST) showing 2% increase in both delivered energy use and CO_2 emissions (40 PJ and 2.5 M Tonnes CO_2, respectively). Whilst a switch to BST all year round (BST/BST) would result in a smaller increase of just under 1% (20 PJ and 3 5 M Tonnes CO_2, respectively).

The only instances where savings are realised are for domestic lighting and non-domestic cooling for the switch to Central European Time. However, these savings are more than offset by the increases in non-domestic heating and lighting, as well as a small increase in domestic heating.

As these results are based on a limited number of simulations, there is uncertainty associated with the final figures. However, it is unlikely that the a switch to either Central European Time (BBST/DBST), or BST all year round (BST/BST) would lead to significant CO_2 savings. Although it would be desirable to carry out more simulation runs to capture the interactions between heating and lighting in the domestic sector and to cover a more diverse range of building types and occupancy patterns to confirm the findings presented here. It would also be valuable to carry out some more detailed modelling for lighting in non-domestic buildings to capture the observed behavioural responses to the availability of lighting.

It is worth noting that there was some considerable variation in increase or decrease in energy use between different buildings types. In particular for the highly glazed, highly insulated air tight buildings significant reductions in cooling energy use were observed for some occupancy patterns. In a fully air conditioned buildings this could lead to significant savings in the summer months. It would be valuable to carry out some additional research to investigate the savings that might be achieved by changing working hours in the summer months and/or particularly hot periods for particular types of building. It may also be worth exploring how non-domestic building design could be “tuned” to meet intended occupancy hours.

References

[2] ‘Summer Time: A Consultation Document’ HMSO, London 1989.

[3] M Hillman, “Making the most of daylight hours’, Policy Studies Institute, London, 1988.

[4] P Littlefair, “The Effects of clock change on lighting energy use”, BRE ref 285/89, prepared for publication in Energy World.

[5] “Lighting controls and daylighting use” BRE Digest 272, 1982.

[6] J Utley “Possible scenarios for future domestic energy use and carbon emissions to 2050”, BRE Report 220 – 611, 2005 for DEFRA.

[7] C Pout, F MacKenzie and R Bettle, “Carbon dioxide emissions from non-domestic buildings: 2000 and beyond, BRE Report 442, CRC London, 2001.

[8] BRE Report to DEFRA on service sector scenarios to 2050, CR 210 -964, to be published sortly.

[9] “Estimating daylight in buildings”, BRE Digests 309 and 310, 1986.

[10] DTI Updated Energy Projections - http://www.dti.gov.uk/energy/sepn/euets.shtml#uep

Appendix A – Data for Domestic Model

Summary of Room Data

Zone	Area (m2)	Volume (m3)
L0 - Dining Room	14.04	33.7
L0 - Hall	10.08	24.19
L0 - Kitchen	5.04	12.1
L0 - Living Room	15.21	36.5
L1 - Bathroom	5.04	12.1
L1 - Bedroom 1	15.21	36.5
L1 - Bedroom 2	14.04	33.7
L1 - Bedroom 3	5.04	12.1
L1 - Hall	5.04	12.1

Summary of constructions used

Average Ext. Wall
Reference ID: WALL4

Layer	Thickness (m)	Resistance (m^2K/W)	Conductivity (W/m K)	Capacity (J/kg K)	Density (kg/m^3)
BRICKWORK (OUTER LEAF)	0.1050	0.125	0.840	800.0	1700.0
Air Gap	0.0650	0.180	0.000	0.0	0.0
BRICKWORK (INNER LEAF)	0.1050	0.169	0.620	800.0	1700.0
PLASTER (LIGHTWEIGHT)	0.0120	0.075	0.160	1000.0	600.0
Inside Surface		0.11709			
Outside Surface		0.05999			
Total Resistance		0.726			

CIBSE net U-value (W/m^2K)	1.3766
EN ISO net U-value (W/m^2K)	1.3901
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Poorly Insulated Ext. Wall
Reference ID: WALL5

Layer	Thickness	Resistance	Conductivity	Capacity	Density
	(m)	(m²K/W)	(W/m K)	(J/kg K)	(kg/m³)
BRICKWORK (OUTER LEAF)	0.2200	0.262	0.840	800.0	1700.0
PLASTER (LIGHTWEIGHT)	0.0120	0.075	0.160	1000.0	600.0
Inside Surface		0.11709			
Outside Surface		0.05999			
Total Resistance		0.514			

CIBSE net U-value (W/m²K)	1.9456
EN ISO net U-value (W/m²K)	1.9728
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Well Insulated Ext. Wall
Reference ID: WALL6

Layer	Thickness (m)	Resistance (m²K/W)	Conductivity (W/m K)	Capacity (J/kg K)	Density (kg/m³)
BRICKWORK (OUTER LEAF)	0.1050	0.125	0.840	800.0	1700.0
MINERAL FIBRE SLAB	0.0650	1.857	0.035	1000.0	30.0
BRICKWORK (INNER LEAF)	0.1050	0.169	0.620	800.0	1700.0
PLASTER (LIGHTWEIGHT)	0.0120	0.075	0.160	1000.0	600.0
Inside Surface		0.11709			
Outside Surface		0.05999			
Total Resistance		2.403			

CIBSE net U-value (W/m²K)	0.4160
EN ISO net U-value (W/m²K)	0.4173
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Ground Floor
Reference ID: FLOOR2

Layer	Thickness (m)	Resistance (m²K/W)	Conductivity (W/m K)	Capacity (J/kg K)	Density (kg/m³)
GLASS-FIBRE QUILT	0.0210	0.525	0.040	840.0	12.0
LONDON CLAY	0.5000	0.355	1.410	1000.0	1900.0
CAST CONCRETE	0.0500	0.044	1.130	1000.0	2000.0
SYNTHETIC CARPET	0.0100	0.167	0.060	2500.0	160.0
Inside Surface		0.11709			
Outside Surface		0.00951			
Total Resistance		1.218			

CIBSE net U-value (W/m²K)	0.8015
EN ISO net U-value (W/m²K)	0.7689
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Eaves Floor
Reference ID: FLOOR3

Layer	Thickness (m)	Resistance (m^{2}K/W)	Conductivity (W/m K)	Capacity (J/kg K)	Density (kg/m^3)
PLYWOOD (LIGHTWEIGHT)	0.0300	2.000	0.150	2500.0	560.0
GLASSWOOL	0.1500	3.750	0.040	670.0	200.0
Inside Surface		0.11709			
Outside Surface		0.00951			
Total Resistance		5.877			

CIBSE net U-value (W/m^{2}K)	0.1693
EN ISO net U-value (W/m^{2}K)	0.1678
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Roof
Reference ID: ROOF2

Layer	Thickness (m)	Resistance (m^{2}K/W)	Conductivity (W/m K)	Capacity (J/kg K)	Density (kg/m^3)
CLAY TILE	0.0150	0.018	0.840	800.0	1900.0
Inside Surface		0.11709			
Outside Surface		0.04000			
Total Resistance		0.175			

CIBSE net U-value (W/m^{2}K)	5.7160
EN ISO net U-value (W/m^{2}K)	6.3348
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

1st floor ceiling
Reference ID: CEIL3

Layer	Thickness (m)	Resistance (m^{2}K/W)	Conductivity (W/m K)	Capacity (J/kg K)	Density (kg/m^3)
SYNTHETIC CARPET	0.0100	0.167	0.060	2500.0	160.0
PLYWOOD (LIGHTWEIGHT)	0.0180	0.120	0.150	2500.0	560.0
Air Gap	0.1700	0.180	0.000	0.0	0.0
GYPSUM PLASTERBOARD	0.0125	0.078	0.160	840.0	950.0
Inside Surface		0.11709			
Outside Surface		0.11709			
Total Resistance		0.779			

CIBSE net U-value (W/m^{2}K)	1.2837
EN ISO net U-value (W/m^{2}K)	1.3427
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Average - 2nd floor ceiling
Reference ID: CEIL2

Layer	Thickness (m)	Resistance (m^{2}K/W)	Conductivity (W/m K)	Capacity (J/kg K)	Density (kg/m^3)
GLASSWOOL	0.1500	3.750	0.040	670.0	200.0
GYPSUM PLASTERBOARD	0.0125	0.078	0.160	840.0	950.0
Inside Surface		0.11709			
Outside Surface		0.11709			
Total Resistance		4.062			

CIBSE net U-value (W/m^{2}K)	0.2462
EN ISO net U-value (W/m^{2}K)	0.2483
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Poorly Insulated - 2nd floor ceiling
Reference ID: CEIL4

Layer	Thickness	Resistance	Conductivity	Capacity	Density
	(m)	(m^{2}K/W)	(W/m K)	(J/kg K)	(kg/m^3)
GYPSUM PLASTERBOARD	0.0125	0.078	0.160	840.0	950.0
Inside Surface		0.11709			
Outside Surface		0.11709			
Total Resistance		0.312			

CIBSE net U-value (W/m^{2}K)	3.2020
EN ISO net U-value (W/m^{2}K)	3.5955
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Well Insulated - 2nd floor ceiling
Reference ID: CEIL5

Layer	Thickness	Resistance	Conductivity	Capacity	Density
	(m)	(m^{2}K/W)	(W/m K)	(J/kg K)	(kg/m^3)
GLASSWOOL	0.2500	6.250	0.040	670.0	200.0
GYPSUM PLASTERBOARD	0.0125	0.078	0.160	840.0	950.0
Inside Surface		0.11709			
Outside Surface		0.11709			
Total Resistance		6.562			

CIBSE net U-value (W/m^{2}K)	0.1524
EN ISO net U-value (W/m^{2}K)	0.1532
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Internal Partition
Reference ID: PART2

Layer	Thickness	Resistance	Conductivity	Capacity	Density
	(m)	(m^{2}K/W)	(W/m K)	(J/kg K)	(kg/m^3)
PLASTER (LIGHTWEIGHT)	0.0120	0.075	0.160	1000.0	600.0
BRICKWORK (INNER LEAF)	0.1050	0.169	0.620	800.0	1700.0
PLASTER (LIGHTWEIGHT)	0.0120	0.075	0.160	1000.0	600.0
Inside Surface		0.11709			
Outside Surface		0.11709			
Total Resistance		0.553			

CIBSE net U-value (W/m^{2}K)	1.8066
EN ISO net U-value (W/m^{2}K)	1.7261
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

wooden door
Reference ID: DOOR

Layer	Thickness	Resistance	Conductivity	Capacity	Density
	(m)	(m^{2}K/W)	(W/m K)	(J/kg K)	(kg/m^3)
Oak (Radial)	0.0300	0.158	0.190	2390.0	700.0
Inside Surface		0.11709			
Outside Surface		0.11709			
Total Resistance		0.392			

CIBSE net U-value (W/m^{2}K)	2.5505
EN ISO net U-value (W/m^{2}K)	3.0498
Absorptivity	0.70
Inside Emissivity	0.90
Outside Emissivity	0.90

Single Glazed
Reference ID: EXTW2

Layer Description	Resistance (m²K/W)	Reflectance	Absorptance	Transmittance	Refractive Index
CLEAR Single	-	0.070	0.070	0.860	1.526

Frame occupies 10.00% of area	
Outside Surface Resistance	0.05999
Inside Surface Resistance	0.15220
Inside Emissivity	0.58
Outside Emissivity	0.90000
CIBSE U-value (glass only)	5.6472
CIBSE net U-value	4.6970
EN ISO U-value (glass only)	5.8824
EN ISO net U-value (W/m²K)	5.8823

Low-E PVC U-value=2.0
Reference ID: EXTW3

Layer Description	Resistance (m²K/W)	Reflectance	Absorptance	Transmittance	Refractive Index
PILKINGTON K 6MM	-	0.150	0.150	0.700	1.526
Air Gap	0.323	0.000	0.000	0.000	0.000
CLEAR FLOAT 6MM	-	0.150	0.150	0.700	1.526

Frame occupies 10.00% of area	
Outside Surface Resistance	0.05999
Inside Surface Resistance	0.11709
Inside Emissivity	0.90
Outside Emissivity	0.90000
CIBSE U-value (glass only)	1.9997
CIBSE net U-value	1.9997
EN ISO U-value (glass only)	2.0284
EN ISO net U-value (W/m²K)	2.0284

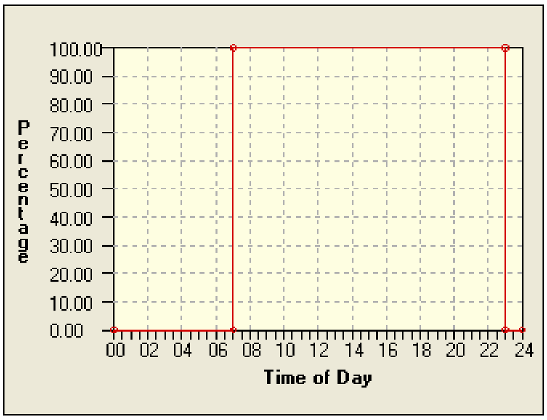

Figure 8: Weekday heating profile

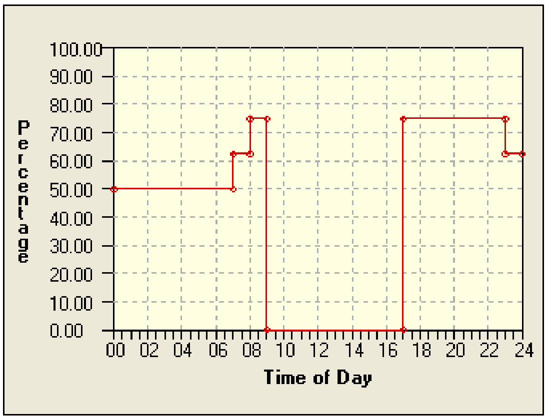

Figure 9: Weekend heating profile

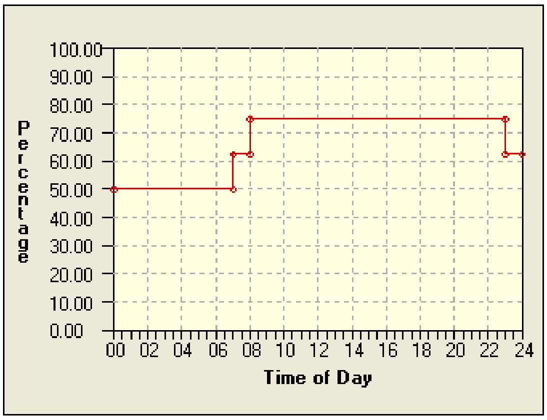

Figure 10: Weekday occupancy profile

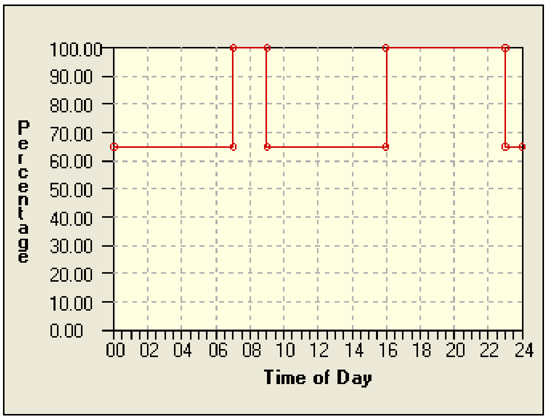

Figure 11: Weekend occupancy profile

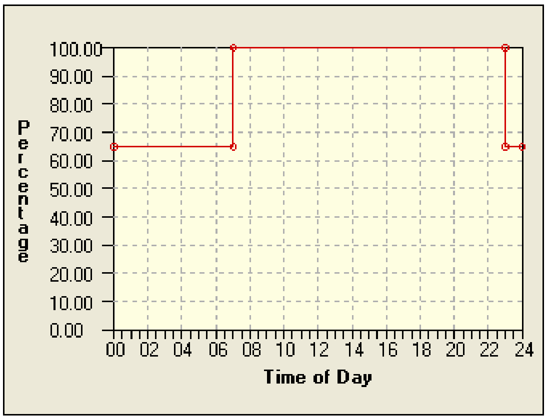

Figure 12: Weekday hot water profile

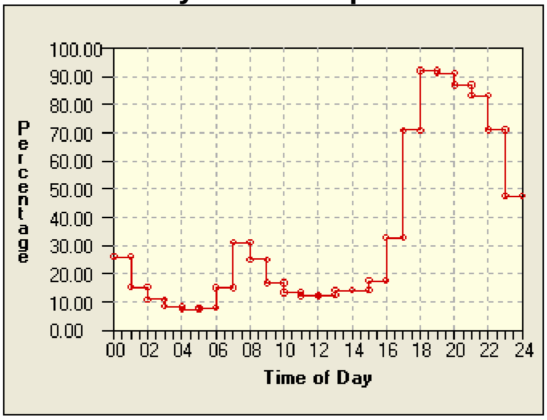

Figure 14: January lighting profile

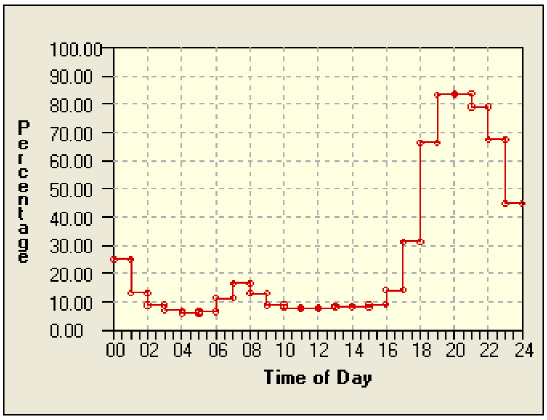

Figure 15: February lighting profile

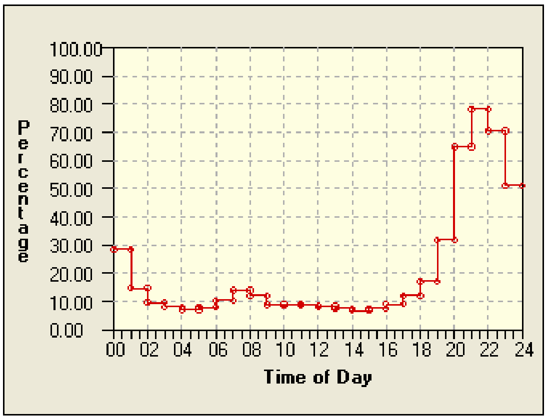

Figure 16: March lighting profile

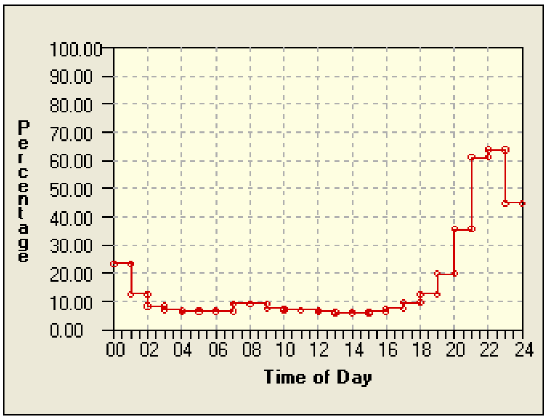

Figure 17: April lighting profile

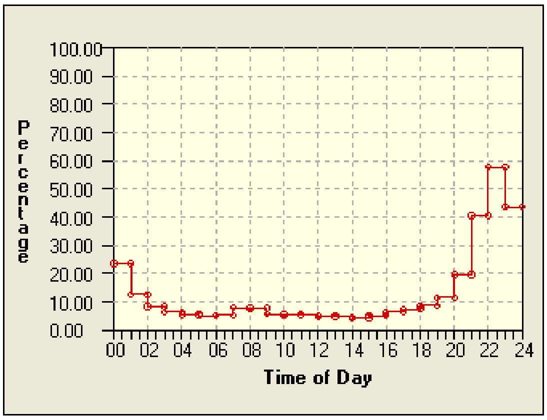

Figure 18: May lighting profile

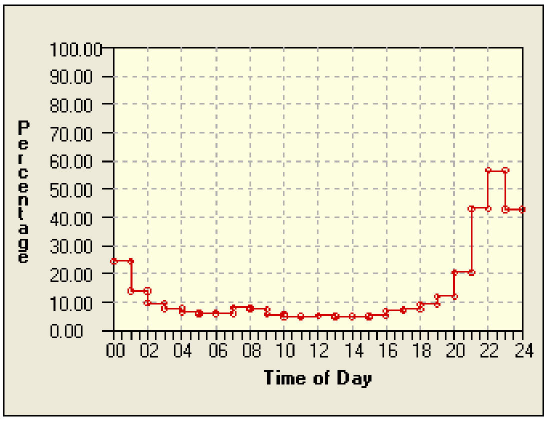

Figure 19: June lighting profile

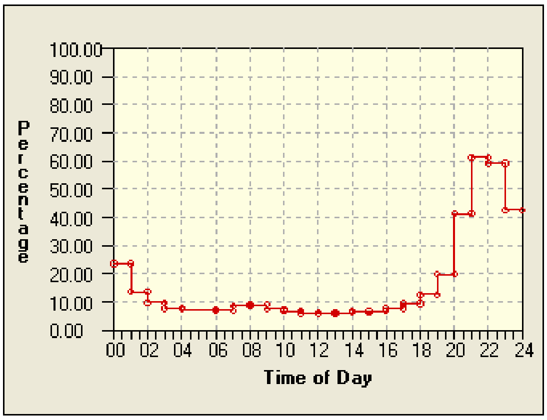

Figure 20: July lighting profile

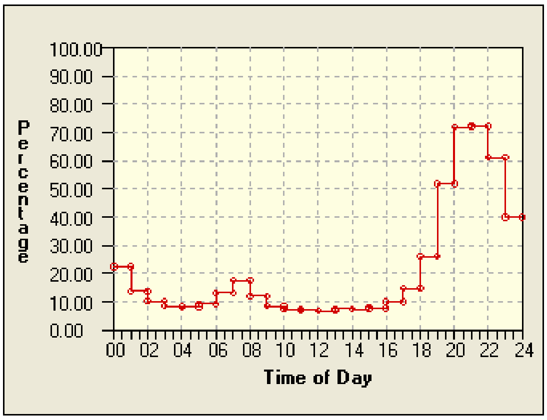

Figure 21: August lighting profile

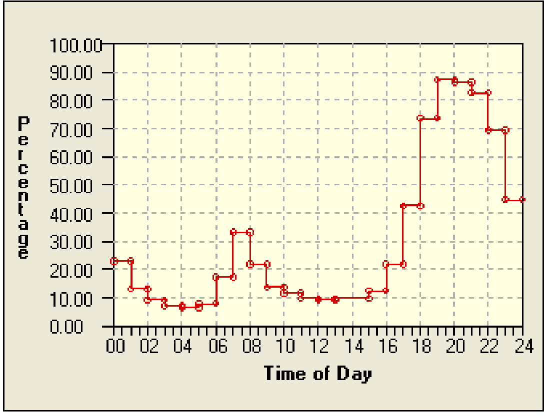

Figure 22: September lighting profile

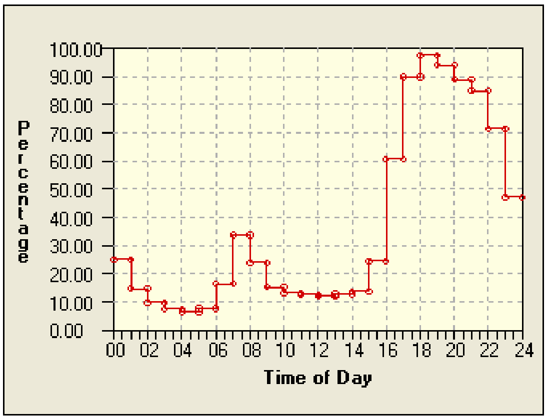

Figure 23: October lighting profile

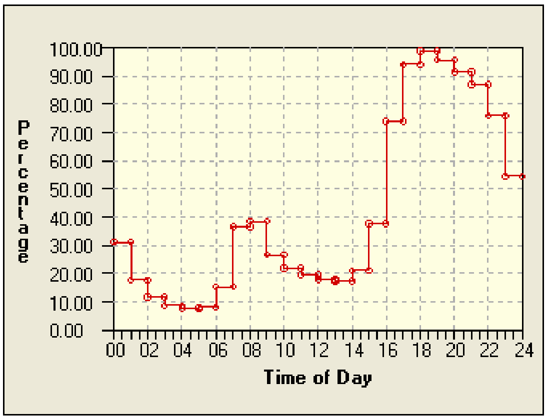

Figure 24: November lighting profile

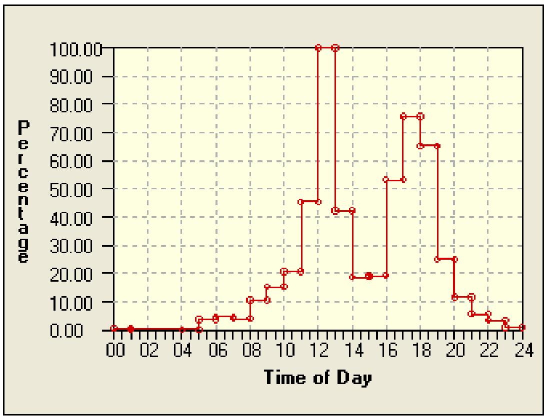

Figure 25: December lighting profile

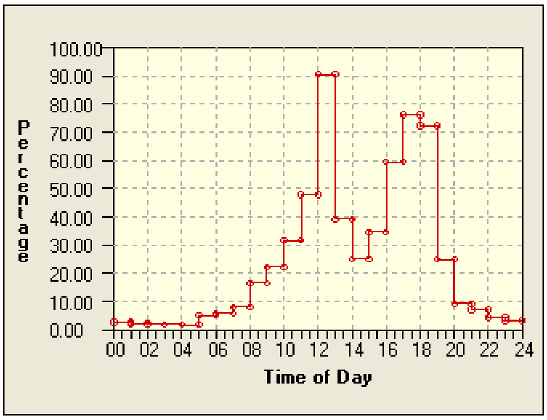

Figure 14: January cooking profile

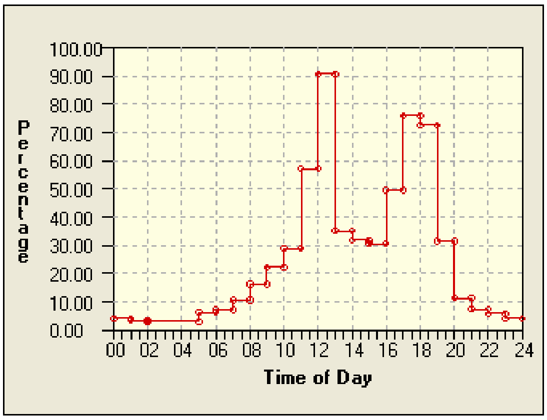

Figure 15: February cooking profile

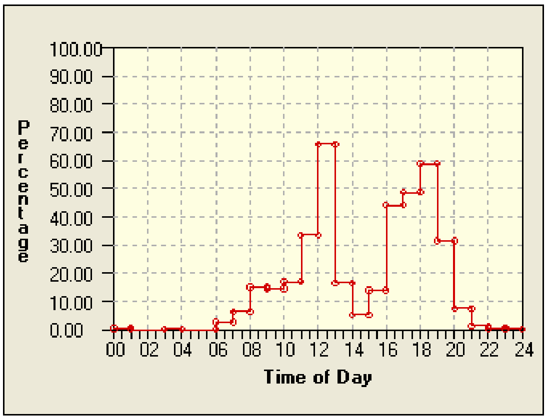

Figure 16: March cooking profile

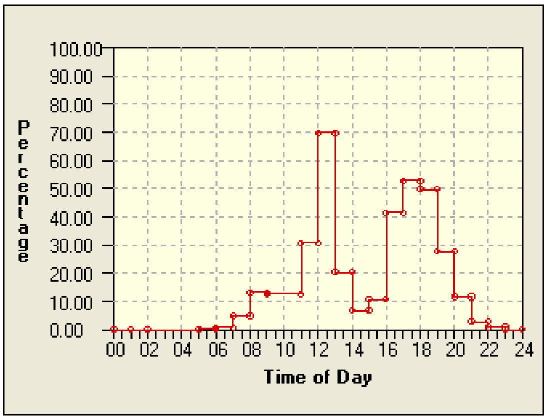

Figure 17: April cooking profile

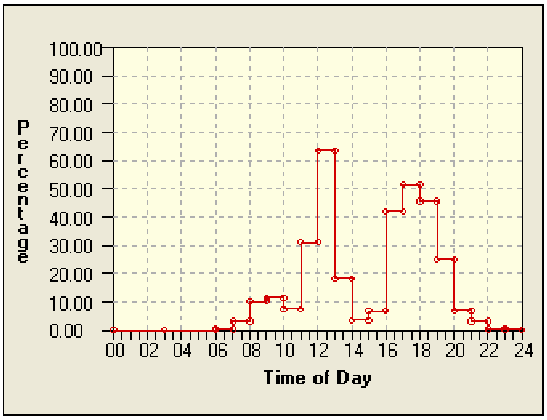

Figure 18: May cooking profile

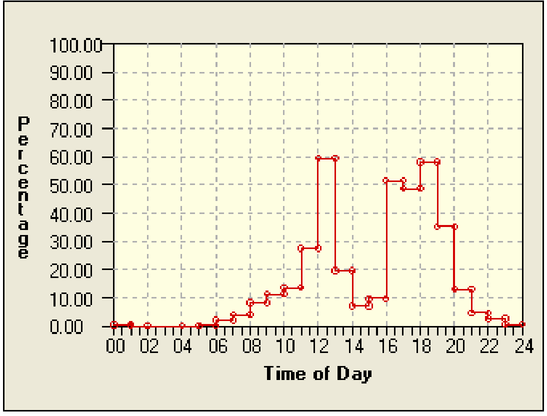

Figure 19: June cooking profile

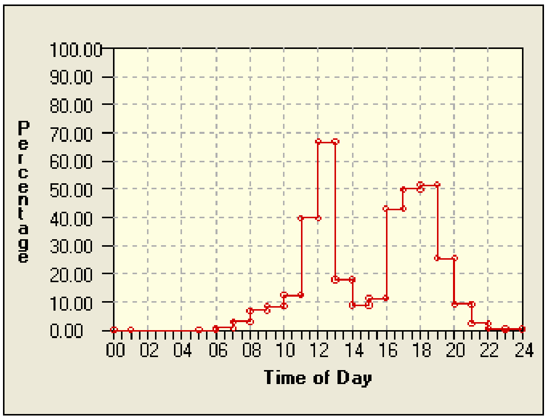

Figure 20: July cooking profile

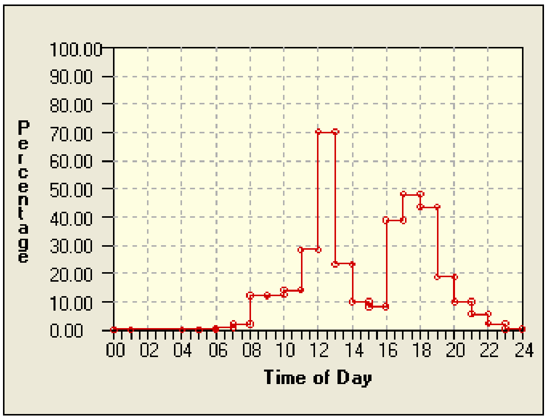

Figure 21: August cooking profile

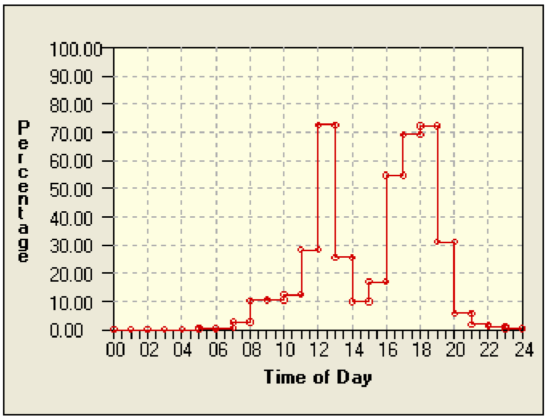

Figure 22: September cooking profile

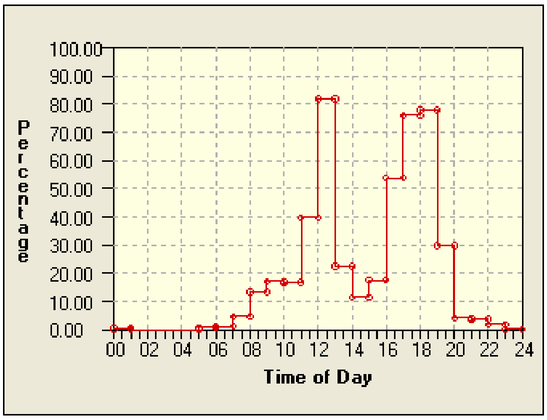

Figure 23: October cooking profile

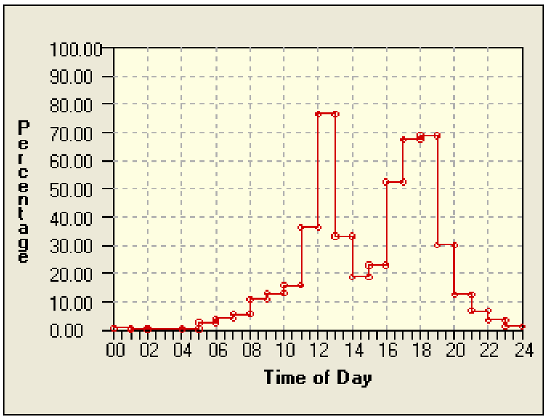

Figure 24: November cooking profile

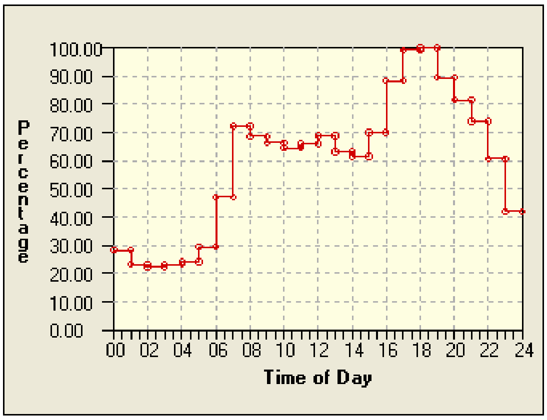

Figure 23: January, February and December appliances profile

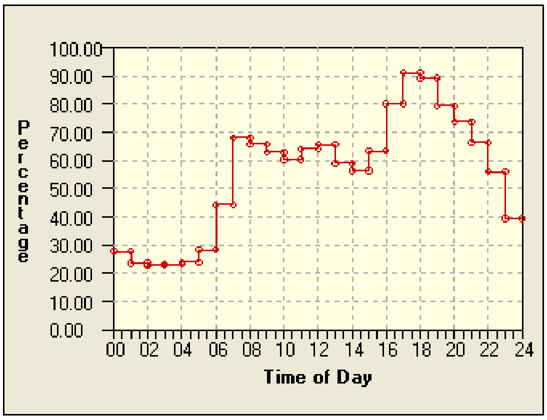

Figure 24: March, April, May, September, October and November appliances profile

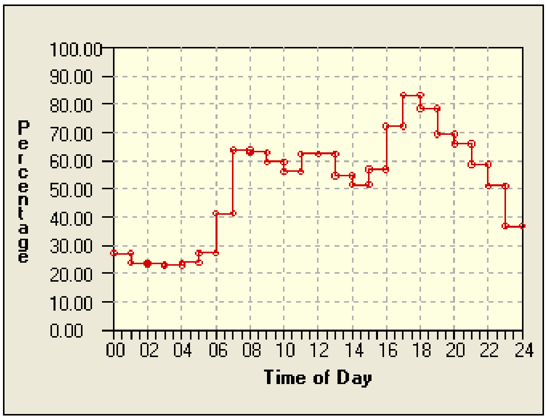

Figure 25: June, July and August appliances profile

The set-points to be achieved by heating through TRVs are as follows:

Zone Template	Heating Set-Point (^{o}C)
Living Room	21
All Other Zones	18

Casual gains

The casual gains assumed for the house can be summarised as follows:

Gain Type	Max Sensible	Max Latent	Radiant Fraction	Occupant Density (m2/person)
Family – Living Room	13.15	0	-	Zone dependent
Family – All Other Zones	2.72	0	-	Zone dependent
Hot Water – Bedroom2	7.12 W/m2	0	0.2	-
Hot Water – All Other Zones	1.34 W/m2	0	0.2	-
Appliances – Living Room	16.07 W/m2	0	0.2	-
Appliances – All Other Zones	3.33 W/m2	0	0.2	-
Cooking	56.35 W/m2	0	0.2	-
Filament – no lampshade	2.25 W/m2	0	0.93	-
Filament – lampshade	2.25 W/m2	0	0.85	-
Stick CFLs – no lampshade	0.45 W/m2	0	0.6	-
Stick CFLs – lampshade	0.45 W/m2	0	0.55	-
Look-alike CFLs	0.563 W/m2	0	0.7	-

– no lampshade				
Look-alike CFLs – lampshade	0.563 W/m2	0	0.64	-

Note these are the max W/m2 and the gains will be adjusted relating to the time percentage profiles for the months of the year. Appendix 4 shows the profiles for the gain types in more detail.

Air exchange

An infiltration level of 0.63 ACH has been set for all zones.

For the roof space, a small opening (25mm width) has been added into the eaves on the east and west sides. These openings have a MacroFlo opening type assigned to them and this will allow for dynamic airflow through the roof. This has been added due to the uncertainty on a fixed air-change rate for the roof space.

Appendix B: Non-Domestic Model Details

Constructions for a sample case

The materials used in the construction of the building were selected to comply with building regulations. The physical properties of each material are described as follows for completeness.

External walls: **U = 0.35 W/m^{2}K**

Materials	Width (m)	Conductivity (W/mK)	Density (kg/m^3)	Specific heat (J/kgK)	Resistance (m^{2}K/W)
Outside air film					0.06
Aluminium panel					0.001
Polyurethane board	0.061	0.025	30	1400	
Concrete block (medium-weight)	0.100	0.510	1400	1000	
Medium-weight plaster	0.012	0.259	900	837	
Cream paint					0.011
Inside air film					0.110

Concrete floor with plant room: **U = 3.2 W/m^{2}K**

Materials	Width (m)	Conductivity (W/mK)	Density (kg/m^3)	Specific heat (J/kgK)	Resistance (m^{2}K/W)
Outside air film					0.050
Cast concrete	0.200	1.130	2000	1000	
Inside air film					0.090

Flat roof metal: **U = 0.25 W/m^{2}K**

Materials	Width (m)	Conductivity (W/mK)	Density (kg/m^3)	Specific heat (J/kgK)	Resistance (m^{2}K/W)
Outside air film					0.09
Steel Siding (HF-A3)	0.002	44.970	7689	418	
Vapour barrier					0.160
Polyurethane board	0.090	0.025	30.000	1400.000	
Felt 3/8in (HF-E3)	0.009	0.190	1121	1674	
Asph Roll Roof (AR01)					0.026
Plywd 1/4in (PW01)	0.006	0.115	545	1213	
Inside air film					0.09

Floors: **U = 0.25 W/m^{2}K**

Materials	Width (m)	Conductivity (W/mK)	Density (kg/m3)	Specific heat (J/kgK)	Resistance (m2K/W)
Outside air film					0.09
Chip board	0.018	0.110	480	1590	
Polyurethane board	0.086	0.025	30.000	1400.000	
Cast concrete	0.200	1.130	2000	1000	
carpet					0.048
Inside air film					0.110

Double glazing Clear – 6mm Air 6mm-

Materials	Shading coefficient	Glass conductance W/m^{2}K	Visible transmittance	Outside emissivity
Clear double glazing (windows)	0.81	2.724	0.79	0.84

Internal Loads and infiltration for a sample case

The internal load in occupancy, lighting and equipment are based on standard assumptions and presented in next table. Infiltration is also showed as the number of air changes per hour considered.

SPACE	CONDITIONED	ORIENTATION	AREA (M2)	VOLUMEN (M3)	AREA/PERSON	Number of People	PEOPLE GAINS	W/M2 OCCUPPANCY	W/M2 LIGHTING	W/M2 EQUIPMENT	AIR-CHANGES/HR
			m2	m2	m2/p	p	W/p	W/m2	W/m2	W/m2	ach
ESP_0+01	Y	SW	314	862	10	31	110	11.0	15	20.0	0.5
ESP_0+02	Y	S	214	586	10	21	110	11.0	15	20.0	0.5
ESP_0+03	Y	NE	310	850	10	31	110	11.0	15	20.0	0.5
ESP_0+04	Y	NE	209	573	10	21	110	11.0	15	20.0	0.5
ESP_0+05	Y	SW	222	610	20	11	110	5.5	10	5.0	1.0
ESP_0+06	N	NE	147	402	10	15	110	11.0	20	5.0	1.0
ESP_0+07	N	NW	25	69	20	1	110	5.5	10	5.0	1.0
ESP_0+08	N	SE	26	72	20	1	110	5.5	10	5.0	1.0
ESP_1+01	Y	SW	314	862	10	31	110	11.0	15	20.0	0.5
ESP_1+02	Y	S	214	586	10	21	110	11.0	15	20.0	0.5
ESP_1+03	Y	NE	310	850	10	31	110	11.0	15	20.0	0.5
ESP_1+04	Y	NE	209	573	10	21	110	11.0	15	20.0	0.5
ESP_1+05	Y	SW	222	610	20	11	110	5.5	10	5.0	1.0
ESP_1+06	N	NE	147	402	10	15	110	11.0	20	5.0	1.0
ESP_1+07	N	NW	25	69	20	1	110	5.5	10	5.0	1.0
ESP_1+08	N	SE	26	72	20	1	110	5.5	10	5.0	1.0
ESP_1+09	N	INT	100	275	100	1	110	1.1	0	0.0	2.0
ESP_1+10	N	INT	52	142	100	1	110	1.1	0	0.0	2.0
ESP_2+01	Y	SW	314	862	10	31	110	11.0	15	20.0	0.5
ESP_2+02	Y	S	214	586	10	21	110	11.0	15	20.0	0.5
ESP_2+03	Y	NE	310	850	10	31	110	11.0	15	20.0	0.5
ESP_2+04	Y	NE	209	573	10	21	110	11.0	15	20.0	0.5
ESP_2+05	Y	SW	222	610	20	11	110	5.5	10	5.0	1.0
ESP_2+06	N	NE	147	402	10	15	110	11.0	20	5.0	1.0
ESP_2+07	N	NW	25	69	20	1	110	5.5	10	5.0	1.0
ESP_2+08	N	SE	26	72	20	1	110	5.5	10	5.0	1.0
ESP_2+09	N	INT	100	275	100	1	110	1.1	0	0.0	2.0
ESP_2+10	N	INT	52	142	100	1	110	1.1	0	0.0	2.0
ESP_3+01	N	ALL	223	610	50	4	110	2.2	5	30.0	2.0

Schedules for a sample case

Nombre	h00	h01	h02	h03	h04	h05	h06	h07	h08	h09	h10	h11	h12	h13	h14	h15	h16	h17	h18	h19	h20	h21	h22	h23
H_REC_D_1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H_REC_D_0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H_REP_D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H_FUN_D	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
H_FUN_D_0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H_D_0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H_CON_D_22	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
H_CON_D_WIN	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2	66.2
H_CON_D_SUM	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
H_COR_D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H_OCU_D_cell_wk	0	0	0	0	0	0	0	0.25	0.5	1	1	1	0.75	0.75	1	1	1	0.5	0.25	0	0	0	0	0
H_OCU_D_open_wk	0	0	0	0	0	0	0	0.25	0.5	1	1	1	0.75	0.75	1	1	1	0.5	0.25	0	0	0	0	0
H_OCU_D_recep_wk	0	0	0	0	0	0	0	0.25	0.5	1	1	1	0.75	0.75	1	1	1	0	0	0	0	0	0	0
H_OCU_D_meet_wk	0	0	0	0	0	0	0	0	0	0.25	0.5	0.5	0.25	0.25	0.5	0.5	0.5	0	0	0	0	0	0	0
H_OCU_D_toi_wk	0	0	0	0	0	0	0	0.1	0.1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.1	0	0	0	0	0	0
H_OCU_D_tea_wk	0	0	0	0	0	0	0	0.1	0.25	0.25	0.25	0.25	0.5	0.5	0.25	0.25	0.25	0.1	0.1	0	0	0	0	0
H_OCU_D_stoream_wk	0	0	0	0	0	0	0	0	0.15	0.15	0.15	0.15	0.05	0.05	0.15	0.15	0.15	0.15	0	0	0	0	0	0
H_OCU_D_plant_wk	0	0	0	0	0	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0
H_EQU_D_cell_wk	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	1	1	1	1	1	1	1	1	1	1	1	0.1	0.1	0.1	0.1	0.1
H_EQU_D_open_wk	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	1	1	1	1	1	1	1	1	1	1	1	0.1	0.1	0.1	0.1	0.1
H_EQU_D_recep_wk	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	1	1	1	1	1	1	1	1	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
H_EQU_D_meet_wk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H_EQU_D_toi_wk	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
H_EQU_D_tea_wk	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.05	0.05	0.05	0.05
H_EQU_D_stoream_wk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H_EQU_D_plant_wk	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0

H_INF_D_wk	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
H_INF_D_wkn	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
H_ILU_D_cell_wk	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
H_ILU_D_open_wk	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
H_ILU_D_recep_wk	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
H_ILU_D_meet_wk	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
H_ILU_D_toi_wk	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
H_ILU_D_tea_wk	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
H_ILU_D_stoream_wk	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
H_ILU_D_plant_wk	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
H_CON_D_WIN_cell_wk	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
H_CON_D_WIN_open_wk	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
H_CON_D_WIN_recep_wk	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
H_CON_D_WIN_meet_wk	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
H_CON_D_SUM_cell_wk	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77
H_CON_D_SUM_open_wk	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77
H_CON_D_SUM_recep_wk	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77
H_CON_D_SUM_meet_wk	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77	77