Climate Comfort and Energy

The Environmental Design of Buildings Msc

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Coursework Asignment 2019-2020

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For this report, I have reviewed a range of sources covering three key subjects:

Subject One: Climate, Region and The Site - The majority of the data used within the report has been obtained from The MET Office and the CIBSE Guide A. The chosen MET Office data falls between 1981-2010, from Heathrow Weather Station. Heathrow is located 10Km away from the report site, providing accurate data for the study. CIBSE Guide A data falls between 1996- 2005 from a weather station in a 'central London rooftop location'. The data used from the central London location will be less accurate due to influences of the urban environment and increased altitude of the station. Climate change and the increasing adverse effect this is having on temperatures is important for the dates of the two data sets. Data from the last 20 years would provide around a 1 degree Celsius temperature increase compared to the data taken from the start of the century and this rise is set to continue. (MET Office, 1981-2010; MET Office, 2018)

Subject Two: The Thermal Balance - The key literature for this section is from CIBSE guide A & F and Approved Documents A-R. The CIBSE guides offer comprehensive technical guidance on building services engineering. The latest publication of the guides is 2019, so it is an up-to date resource for relevant data. The Approved Documents A-R are published by The Ministry of Housing, Communities and Local Government, these provide guidance on the performance of materials and building work in order to comply with the building regulations. Approved Document L which provides the most relevant data for this study was updated in 2018. (Chartered Institution of Building Services Engineers, 2019; HM Government, 2018)

Subject Three: Current and Best Practice- I have used relevant publications including ArchiDaily and PassiveHouse Plus magazine. Both leading global Architectural publications provide up-to date resource of current research and designs. I combined these with scientific research through Science Direct with two physical and engineering science publications. The key publication used is 'Solar Energy', the official journal of the International Solar Energy Society, which is devoted exclusively to the science and technology of solar energy applications. (ArchiDaily, 2020; PassiveHouse Plus, 2020; Science Direct, 2019)

United Kingdom

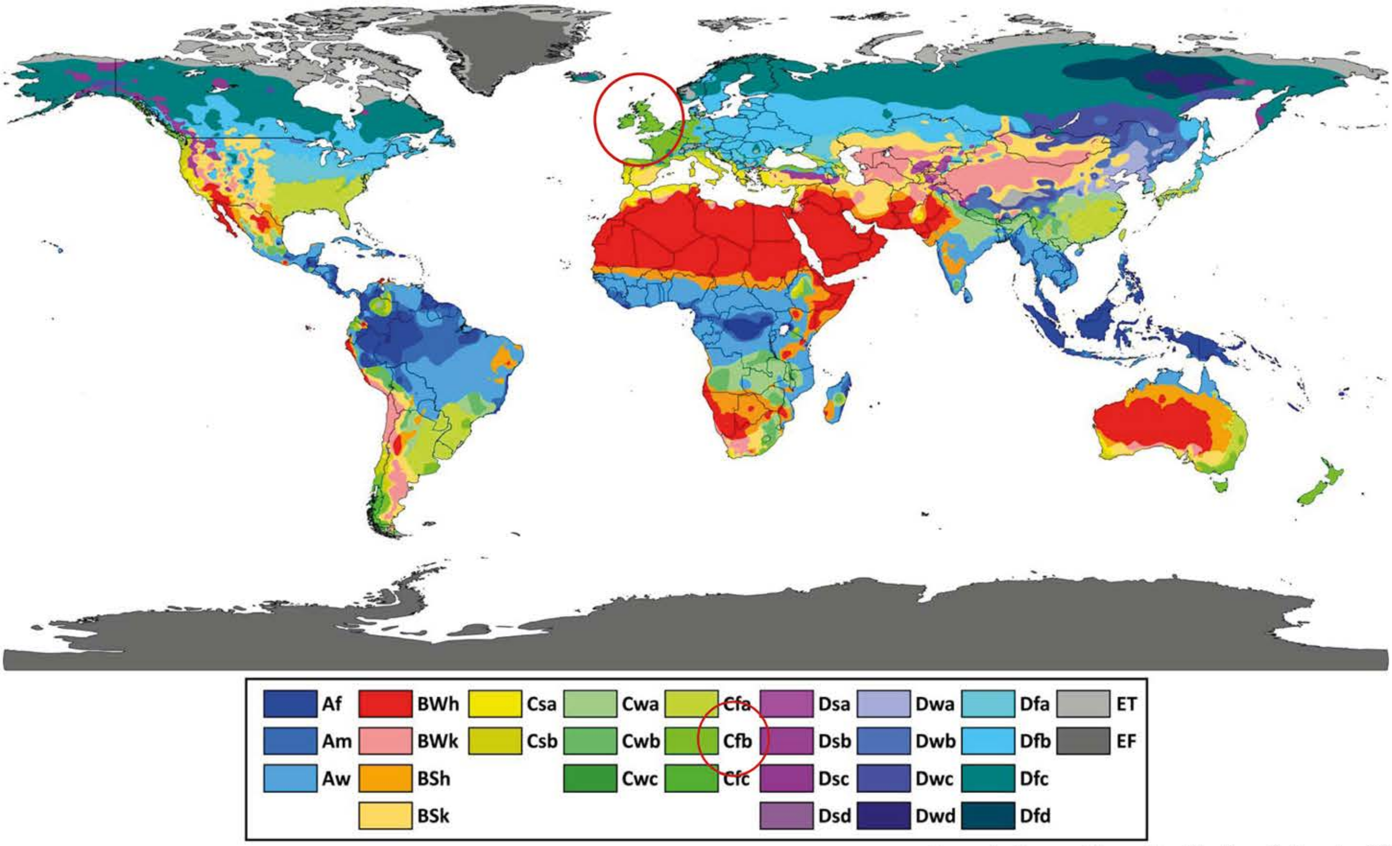


Image 1. Koppen Climae Classification, (Britannica, 2019)

The site is located in the United Kingdom in Europe. According to the Koppen-Geiger climate classification the UK falls under the category Cfb as per image 1:

C- 'Temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month less than 18 °C but greater than –3 °C'
f- 'precipitation more evenly distributed throughout year; criteria for neither s nor w satisfied'
b- 'temperature of each of four warmest months 10 °C or above but warmest month less than 22 °C' (Britannica, 2019)

The chosen site is in Cobham, Surrey, South-Eastern, UK. The nearest weather station to the site is located at Heathrow Airport, approximately 10km away as discussed previously. See image 3.

Month	Temperature and relative humidity					
	London (Heathrow)		Manchester (Ringway)		Edinburgh) (Turnhouse)	
	Temp. /°C	RH /%	Temp. /°C	RH /%	Temp. /°C	RH /%
January	4.9	84	4.2	83	3.5	83
February	4.7	82	4.1	80	3.7	81
March	6.9	77	5.8	76	5.3	78
April	8.8	71	7.8	71	7.0	75
May	12.6	69	11.3	68	9.9	75
June	15.7	69	14.1	71	12.8	75
July	17.9	68	16.1	72	14.7	76
August	17.6	70	15.8	74	14.4	78
September	14.9	75	13.3	77	12.1	80
October	11.2	81	10.3	81	9.2	82
November	7.6	84	6.7	82	5.8	83
December	5.9	86	5.2	84	4.3	84

* National Climatic Data Center (NCDC) (http://www.ncdc.noaa.gov)

Image 2. Table 7.10 Monthly Mean Temperature and Relative Humidity for Interstitial Condensation Calculations (Chartered Institution of Building Services Engineers, 2019)

02 Climate and Weather

South-East United Kingdom

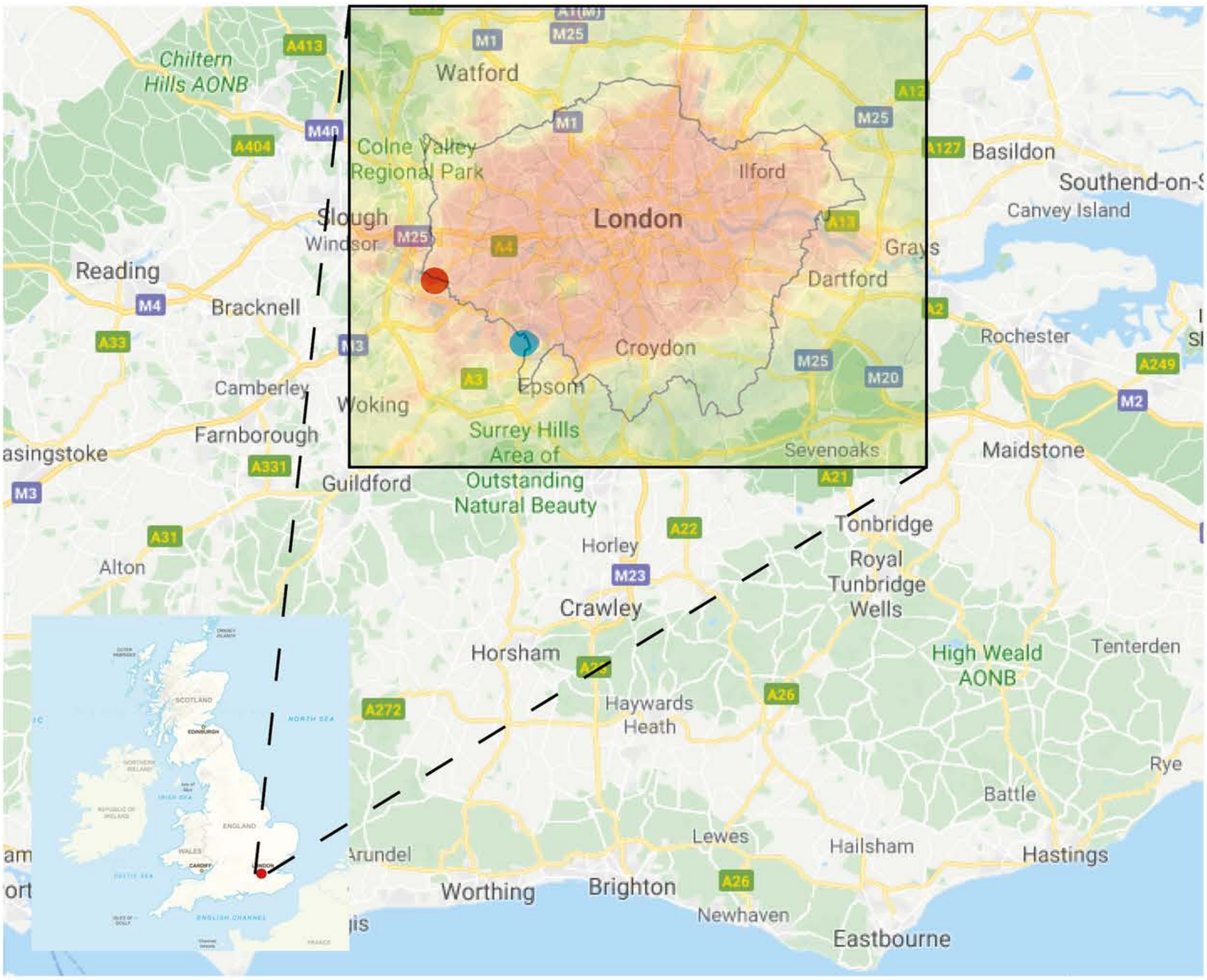


Image 3. (Diigimap, 2020)

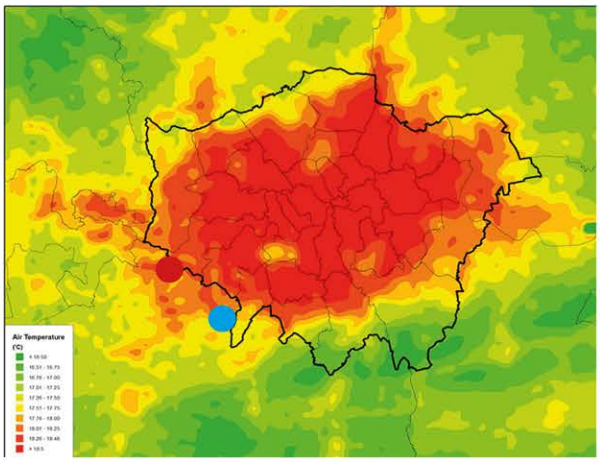
● Heathrow Weather Station ● Cobham, Surrey

Due to it;s proximity London, Cobham will be effected by the urban heat island of the city. According to Oke the intensity of the urban heat island can be correlated to population:

Maximum UHI intensity (Europe) = $2.01\log_{10}P - 4.06$
Maximum UHI intensity London = 9.79 °C (Cardiff University,2019)

As per the urban heat island map (Image 4), both Cobham and Heathrow are effected equally, therefor experiencing an equal increase in temperature for both sites. There will be a variance from data within CIBSE guide A, which uses data from a Central London Weather Centre which will be more greatly effected by the urban heat island.

Image 4. Satellite Images Reveal Londons Heat Island Effect, (Matt Ball, 2013)



02 Climate and Weather

Cobham, Surrey, United Kingdom

Heathrow and London Weather Station Data

Image 5: UK Average, Maximum and Mean Temperatures, (MET Office, 1981-2010; MET Office, 2018; Chartered Institution of Building Services Engineers, 2019)

Temperature Data	oC	1981 - 2010 Av Temperature*		2018 Av Temperature**		Adaptive Comfort (oC)****	
	Av Temperature ***	max oC	min oC	max oC	min oC	free running	Mechanical
January	4.9	8.1	2.3	9.7	2	13.1282	19.96529
February	4.7	8.4	2.1	6.4	3.3	13.0214	19.970305
March	6.9	11.3	3.9	9.8	5.8	13.9826	20.24731
April	8.8	14.2	5.5	15.5	5.7	19.4828	20.55116
May	12.6	17.9	8.7	20.8	8.4	21.4586	21.34884
June	15.7	21	11.7	24.2	11.9	23.114	22.11584
July	17.9	23.5	13.9	28.3	14.9	24.449	22.71469
August	17.6	23.2	13.7	21.5	14.1	24.2888	22.62796
September	14.9	19.9	11.4	20.9	11.8	22.5266	21.910225
October	11.2	15.5	8.4	16.5	8.6	16.3856	21.0326
November	7.6	11.1	4.9	12.2	4.3	14.5166	20.33168
December	5.9	8.3	2.7	10.1	4	13.3418	20.1004

*** Data from MET Office Monthly minimum and maximum Averages Heathrow weather station between 1981-2010**

**** Based MET Office Historical 2018 data for Heathrow Weather stations, average minimum and maximum monthly values**

***** Monthly mean temperatures for London CIBSE Guide A - National Climatic Data Center (NCDC) (1996-2005) (http://www.ncdc.noaa.gov)**

****** Based on worst case scenerios of average max and min temps for winter and summer months**

******* Based on monthly mean relative humidity for London CIBSA Guide A - National Climatic Data Center (NCDC) (http://www.ncdc.noaa.gov)**

Data for Image 5 has been collated from CIBSE Guide A and The MET Office. The thermal balance equation requires **average** monthly temperatures only available from CIBSE Guide A (the MET office only provides minimum and maximum values). I expect to see different temperatures from the two data sets as CIBSE Guide A uses 1996-2005 data and The MET Office uses 1981-2010 data.

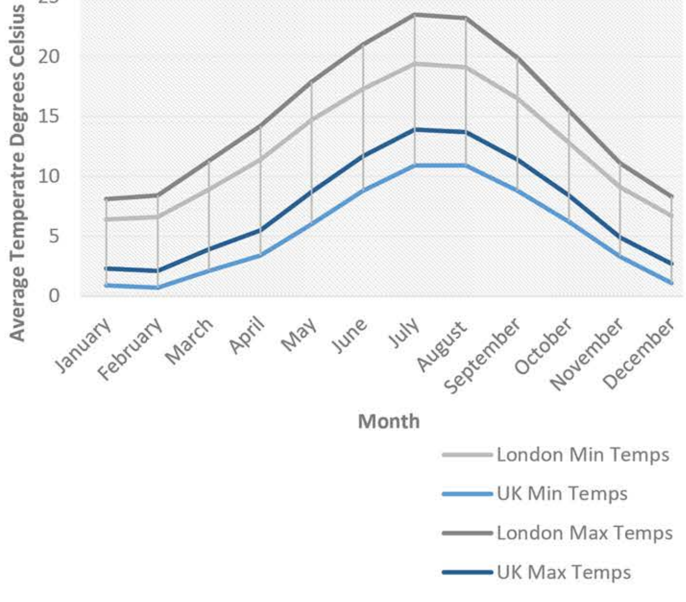
The MET office 2017 UK Climate Report states that since their 1961 records, the UK 2017 average temperatures have increased by 1°C. This warming is unlikely to be effectively represented in the average temperature data sets and as warming is predicted to carry on increasing at an exponential rate. This could cause these data sets to become redundant. (MET Office, 2018)

To calculate internal temperatures, I will use the adaptive comfort for a mechanically heated and cooled building:

$Tc=23.9+0.295\ (To-22)e^{-\{(To-22)/33.941\}2}$ (Cardiff University,2019)

Image 6 shows UK average temperatures from the MET Office monthly average minimum and maximum data tables (1981-2010). The south east UK experiences considerably higher than UK average temperatures. The highest recorded London Weather Station temperature was in Summer 2018 at 28.3°C, the lowest was in 1963 at-4.3°C. (MET Office, 1981-2010)

Image 6 - London and UK Min and Max Temperatures, (Megan Hill, 2019; Chartered Institution of Building Services Engineers, 2019; MET Office, 1981-2010)



02 Climate and Weather

Cobham, Surrey, United Kingdom

Heathrow Weather Station Data

Image 6: UK Solar Radiation Data, (MET Office, 1981-2010; MET Office, 2018; Chartered Institution of Building Services Engineers, 2019)

Solar Radiation Data	I (W/m2)* N	I (W/m2)* NE	I (W/m2)* E	I (W/m2)* SE	I (W/m2)* SW	I (W/m2)* W	I (W/m2)* NW	hours** sunshine
January	0	0	22	88	87	21	0	61.5
February	0	2	38	106	110	42	2	77.9
March	0	12	67	129	142	79	16	114.6
April	1	29	86	126	129	90	32	168.7
May	13	57	107	115	113	103	54	198.5
June	13	56	105	111	110	103	55	204.3
July	7	49	99	114	92	70	82	212
August	1	1	81	118	121	85	30	204.7
September	0	0	77	132	125	70	15	149.3
October	0	0	48	118	123	51	3	116.5
November	0	0	24	93	94	25	0	72.6
December	0	0	23	87	83	20	0	52

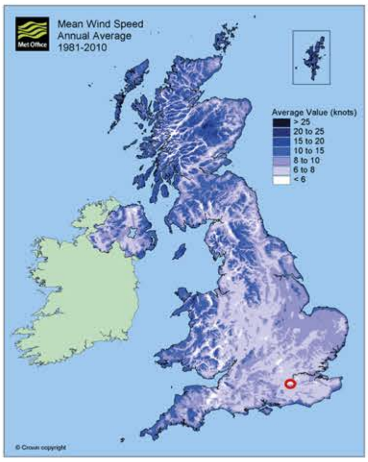
* (Daily mean) London CIBSE Guide A - National Climatic Data Center (NCDC) (1996-2005) (http://www.ncdc.noaa.gov)

** Data from MET Office Monthly Averages Heathrow weather station between 1981-2010

Data for image 6 for London is taken from CIBSE Guide A. The data relevant to the site will be irradiance for the North East, South East and South West in relation to the glazing of the building.

Image 9 shows other relevant climate data for the site and images 7 & 8 put these into context of the UK.

Image 7 & 8: Mean Wind Speed and Rainfall Annual Average, (MET Office, 1981-2010)



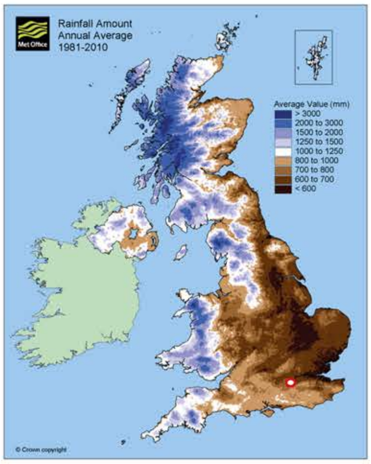


Image 9: Rainfall and Wind Speed UK, (Chartered Institution of Building Services Engineers, 2019)

	mm Rainfall*	days > 1mm Rainfall*	m/s Wind speed*	% RH*****
January	55.2	11.1	7.6	84
February	40.9	8.5	7.2	82
March	41.6	9.3	7.4	77
April	43.7	9.1	6.8	71
May	49.4	8.8	6.7	69
June	45.1	8.2	6.4	69
July	44.5	7.7	6.6	68
August	49.5	7.5	6.2	70
Septembe	49.1	8.1	6.1	75
October	68.5	10.8	6.5	81
Novembe	59	10.3	6.9	84
December	55.2	10.2	6.7	86

******* Based on monthly mean relative humidity for London CIBSA Guide A - National Climatic Data Center (NCD**

The site experiences some of the lowest mean annual wind speeds and rainfall compared to the rest of the UK (MET Office, 1981-2010). Lower levels of rainfall means less heat loss externally from a building due to lower rates of required evaporation. On a regional scale we can expect low mean wind speeds (MET Office, 1981-2010), which could limit useful wind potential in passive cooling of a building during the Summer.

Site Plan

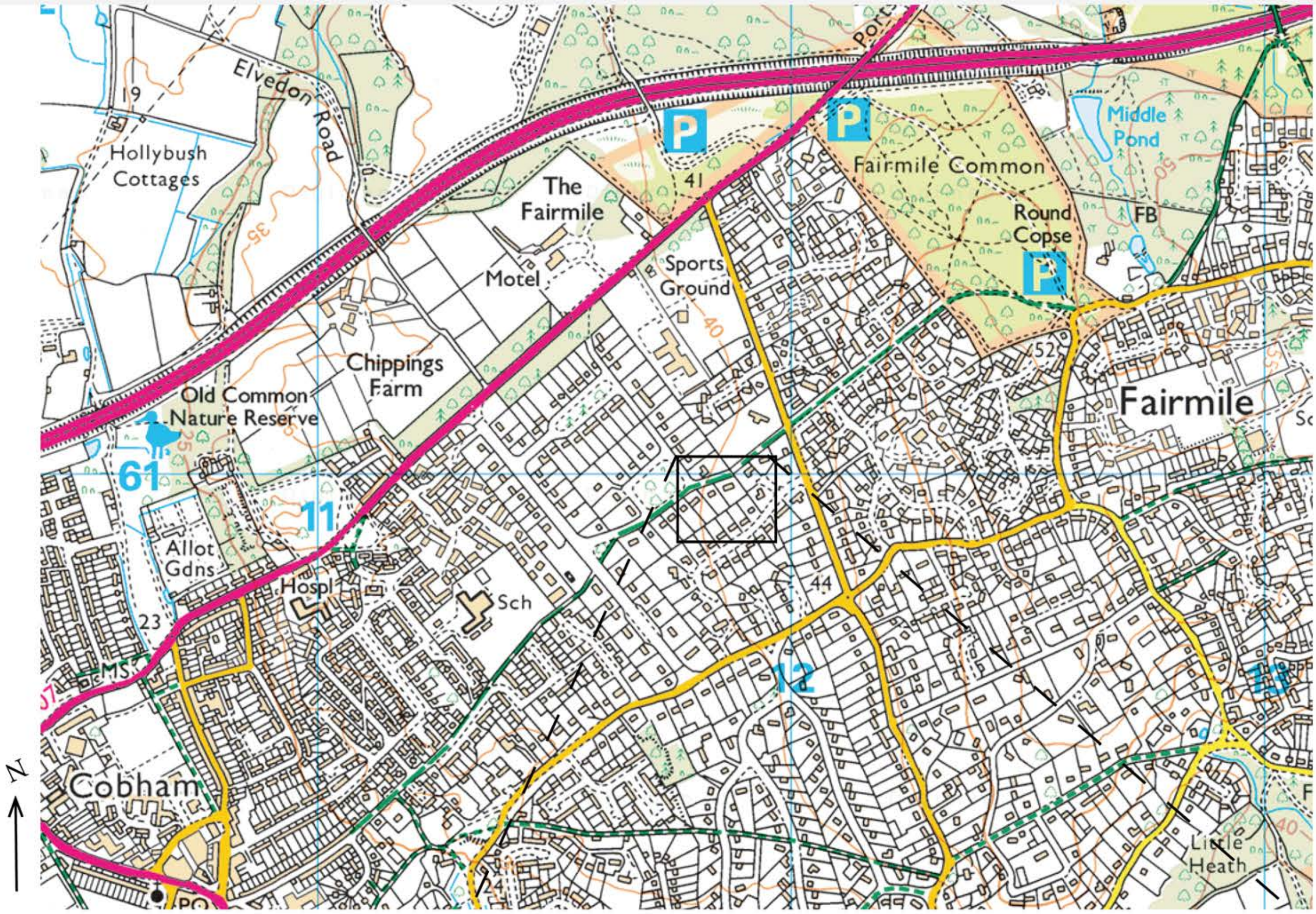


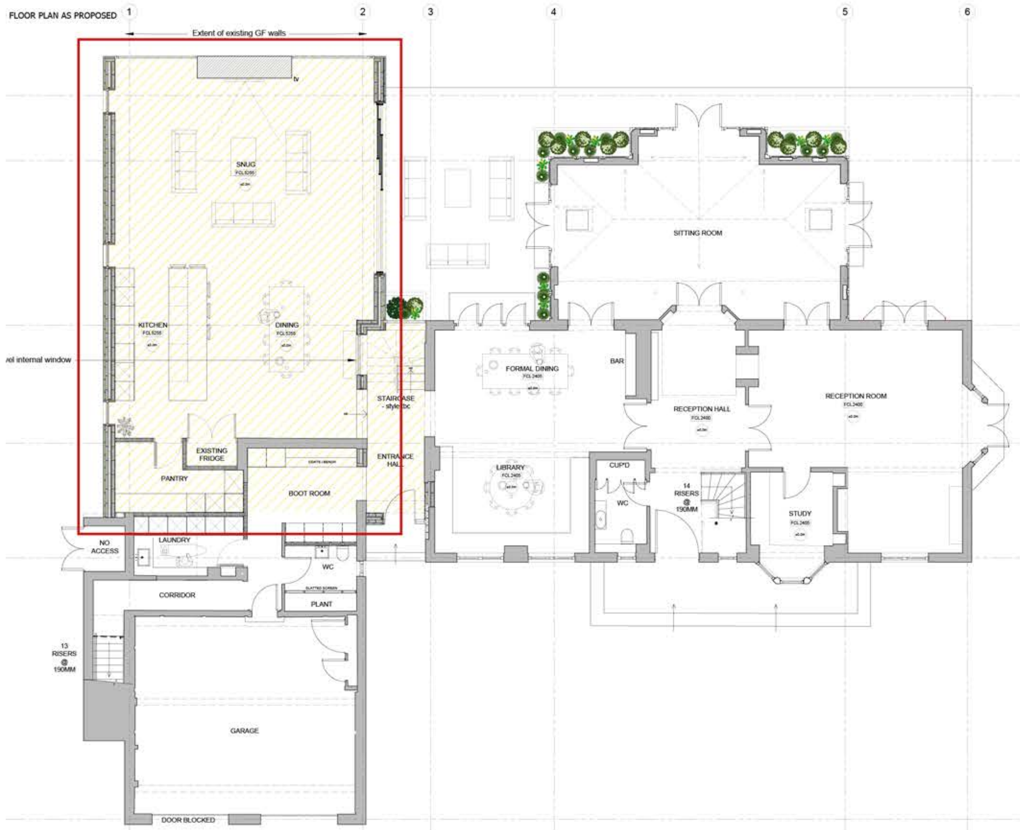
Image 10: Cobham Map, (Diigimap, 2020)

The site is a private house in Cobham, Surrey. The building consists of an existing detached 1960's house of which the construction fabric is unknown. I am the Project Arhcitect for the new 'wing' of accommodation currently under construction.

Maps not to scale

Image 11: Location Plan, (Diigimap, 2020; Concept Eight Architects, 2019)

Internal Accommodation and Use



Floor Area = 94m2

N

Image 12- Ground Floor Plan (Concept Eight Architects, 2019) Map not to scale

The ground floor consists of an open plan kitchen, dining and living space. The area of focus for the study is highlighted in the red box in image 12.

This space is occupied by a family of 6, all of whom are at home for a few hours in the morning and evening, but for most of the day the space would house the maximum of one occupant. This is important for the thermal heat balance as demonstrated in image 13. The equation uses averages for a each given month; the average occupancy level of the room is likely to be 1 person, the worst case scenario for high gains would be the full 6 members of the family. This value is effected by annual routine, for example during school holidays we can assume the average occupancy of the room will increase compared to other months. This is reflected within the monthly occupancy gains for the equation.

Image 13: Adaptive Temperature and Occupant Gains, (Chartered Institution of Building Services Engineers, 2019)

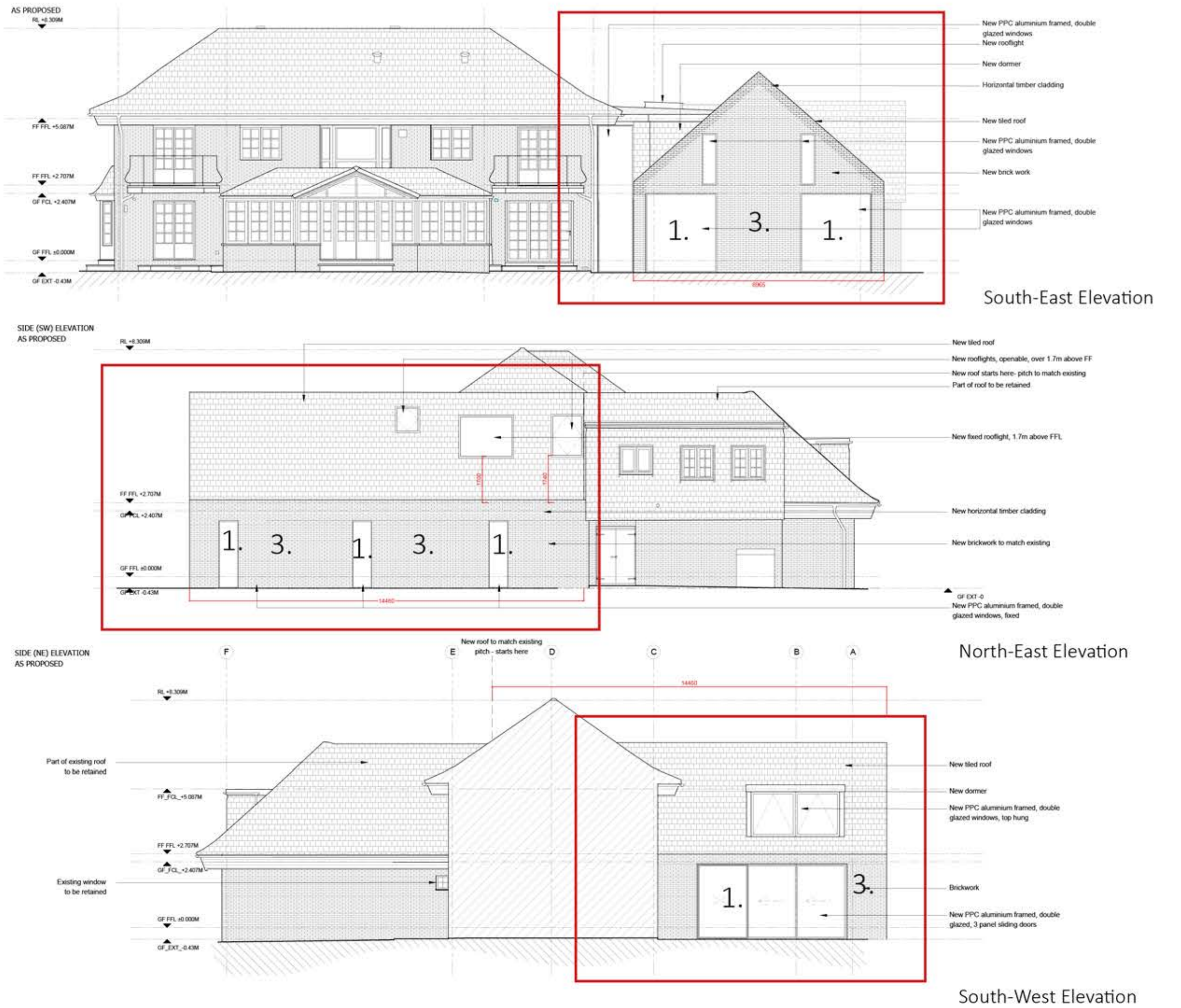
	Adaptive Comfort Temp		Qo based on occupants			Watts	Watts
	oC	Qo* (Watts)	1 male	1 female**	4 children***	Qo Max	Qo Av
January	19.96529	110	110	93.5	330	533.5	93.5
February	19.97031	110	110	93.5	330	533.5	93.5
March	20.24731	110	110	93.5	330	533.5	93.5
April	20.55116	110	110	93.5	330	533.5	93.5
May	21.34884	110	110	93.5	330	533.5	93.5
June	22.11584	100	100	85	300	485	85
July	22.71469	100	100	85	300	485	235
August	22.62796	100	100	85	300	485	235
September	21.91023	100	100	85	300	485	85
October	21.0326	110	110	93.5	330	533.5	93.5
November	20.33168	110	110	93.5	330	533.5	93.5
December	20.1004	110	110	93.5	330	533.5	258.5

* Based on Table 6.3 from CIBSE Guide A for 'Standing, light work, walking' sensible heat gain (W)

** Heat gain for women at 85% of given CIBSE data based on an adult male

*** Heat gain for children at 75% of given CIBSE data based on an adult male

Internal Accommodation and Use



Map not to scale

Image 14: Elevations, (Concept Eight Architects, 2019)

The kitchen houses an oven, fridge and dishwasher; there is also a TV and a total 26 low energy LED bulbs. I will assume the kitchen is in 'full use' for 3 hours of the day. For the rest of the time the equipment will still be on, but in a standby position. We must make some assumptions on how the room is used by the occupants at different times of the year

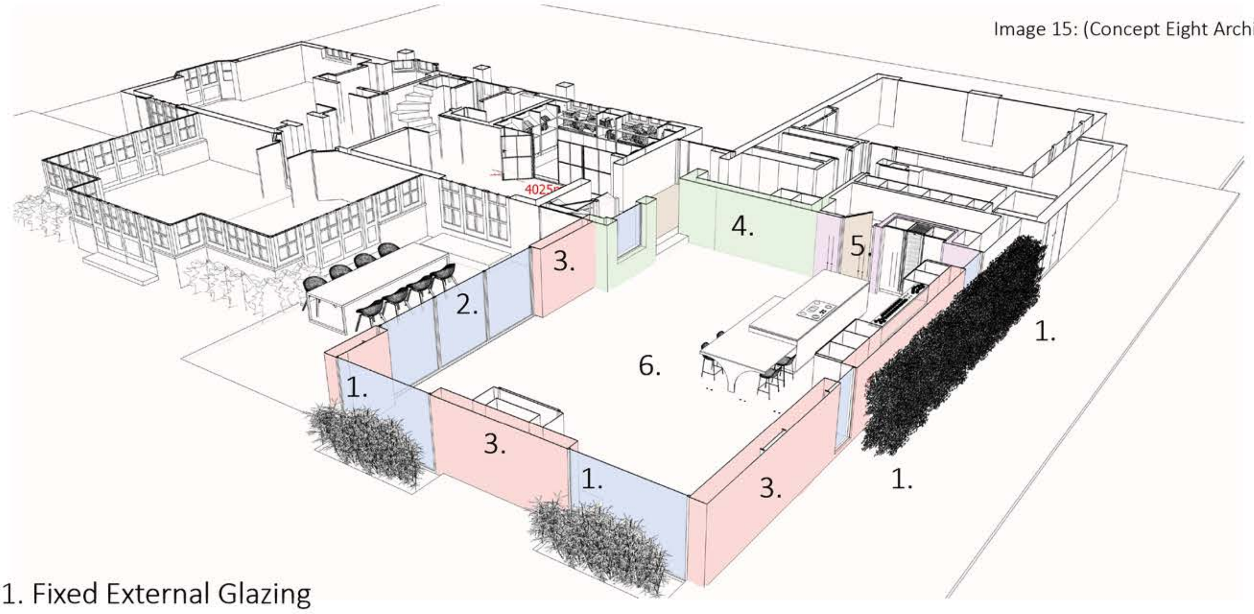
As we are looking at an average scenario we should make assumptions on the usage and heat loading of this equipment. It would be sensible to assume that the lights aren't on during the brightest hours of the day, which will vary between winter and summer months. This can be suitably reflected in the heat balance equation breakdown which I will go into more detail in the following section.

04 Thermal Balance - Fabric

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

Qf = ∑ UA (Tei - Teo)

Image 15: (Concept Eight Architects, 2019)



1. Fixed External Glazing
2. Open-able External Glazing
3. New External Walls
4. Internal Existing Wall (block)
5. Internal New Wall (Stud)
6. Ground Floor
7. Ceiling (Not in diagram)

Image 16: Table 2Standards for New Thermal Elements, (HM Government, 2018)

Table 2 Standards for new thermal elements

Element[1]	Standard W/(m².K)[2]
Wall	0.28
Pitched roof – insulation at ceiling level	0.16
Pitched roof – insulation at rafter level	0.18
Flat roof or roof with integral insulation	0.18
Floors[3]	0.22[4]
Swimming pool basin	0.25

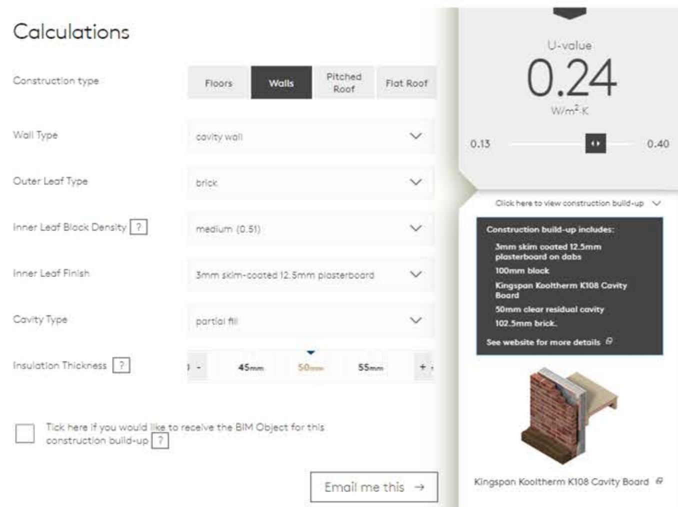
U-Values:

1. Fixed external glazing - 1.3W/m²K
Quote from Maxlight Glazing for 2 panel double glazed sliding door system with solar control: *See Appendix Item 1*

2. Open-able external glazing - 1.1 W/m²K
Quote from Bespoke Glazing for fixed double glazed Schueco AWS 70.HI with solar control: *See Appendix Item 2*

3. New external walls - 0.24 W/m²K
Partial fill cavity wall - 103mm facing brick, 50 mm clear cavity, 50mm Kingspan Kingspan Kooltherm K108 insulation fixed to 100mm standard block, 12.5mm plasterboard on dabs with a 3mm plaster skim. (Kingspan, 2019) *See Image 17*

Image 17: U-Value Calculations, (Kingspan, 2019)



04 Thermal Balance - Fabric

$Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0$

$Qf = \sum UA (Tei - Teo)$

4. Internal Existing Block Wall - 1.06 W/m²K (British Gypsum, 2019)

Cavity block wall - 12.5mm Gyproc WallBoard on dabs with a 3mm plaster skim, 100mm standard block, 100mm cavity, 100mm standard blockwork, 12.5mm Gyproc WallBoard on dabs with a 3mm plaster skim

Image 18, 19, 20: Internal Existing Block Wall, (Cardiff University, 2019; Kingspan, 2019; British Gypsum, 2019; HM Government, 2018)

Internal Existing Block Wall	x (m)	k (W/mK)	r (mK/W)	R (m2K/W)
air restistance internal 1				0.13
plaster	0.003	0.40	2.50	0.01
Gyproc WallBoard	0.013	0.19	5.26	0.07
Medium block	0.100	0.56	1.79	0.18
cavity	0.100			0.18
Medium block	0.100	0.56	1.79	0.18
Gyproc WallBoard	0.013	0.19	5.26	0.07
plaster	0.003	0.40	2.50	0.01
air restistance internal 2				0.13
Total				0.94
U-value				1.0596343

5. New Internal Stud Wall - 1.70 W/m²K (HM Government, 2018)

Timber GypWall classic C stud wall - 12.5mm Gyproc WallBoard with a 3mm plaster skim, 92mm Gypframe C stud (600mm centres), 12.5mm Gyproc WallBoard with a 3mm plaster skim (British Gypsum, 2019)

Image 19

Internal Stud Wall	x (m)	k (W/mK)	r (mK/W)	R (m2K/W)
air restistance internal 1				0.13
plaster	0.003	0.40	2.50	0.01
Gyproc WallBoard	0.013	0.19	5.26	0.07
cavity	0.720			0.18
Gyproc WallBoard	0.013	0.19	5.26	0.07
plaster	0.003	0.40	2.50	0.01
air restistance internal 2				0.13
Total				0.59
U-value				1.7048004

6. Internal Ceiling/Floors - 0.24 W/m²K (HM Government, 2018)

7. Internal Ground Floor - 0.22 W/m²K (HM Government, 2018)

Image 20

Lower Ground Floor	x (m)	k (W/mK)	r (mK/W)	R (m2K/W)
air restistance internal 1				0.17
Hardcore with sand blinding	0.150			0.01
Polythene layer	0.001			0.001
Concrete slab (mesh reinforcement)	0.150	2.30	0.43	0.07
Kingspan Kooltherm K103	0.070	0.02	55.56	3.89
Screed	0.065	1.40	0.71	0.05
DPM	0.001			0.001
Timber	0.020	0.15	6.67	0.13
				0.13
Total				4.45
U-value				0.2249279

Image 21: U-Value Calculations, (Kingspan, 2019)

CERTIFICATE CS/1004-1
U Value Competency Scheme

Kingspan Insulation

Project ID : Online
Structure element : Solid Ground floor
Description : Solid ground floor (insulation beneath screed / concrete slab)
File reference : 1E11A94A2A.FCF

Calculated 'U' value = 0.11W/m²K (Calculated in accordance with BS EN ISO 13370:2007)

Condensation risk has been assessed up to and including Level 4 Humidity Class (dwellings with high occupancy) within UK worst case environmental conditions.

Element Description	Element Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m²K/W)	Mean T (K)	Delta T (K)
Inside surface	-	-	0.170	93.00	0.30
SAND CEMENT SCREED	65.0	1.400	0.046	92.80	0.08
CONCRETE 1:2:4 2000 kg/m³	150.0	1.400	0.107	92.67	0.19
POLYTHENE SEPARATION LAYER	0.5	-	0.001	92.57	0.00
KOOLTHERM K3	80.0	0.020	4.000	89.00	7.14
KOOLTHERM K3	80.0	0.020	4.000	81.85	7.14
DAMP PROOF MEMBRANE	0.9	-	0.001	78.28	0.00
Ground	-	-	0.040	78.24	0.07

Image 22: U-Value Calculations, (Kingspan, 2019)

Kooltherm K103 Floorboard

Thermal conductivity	0.018 W/m·K across all thicknesses

Image 23: Gyproc Wallboard, (British Gypsum, 2019)

Gyproc WallBoard

	12.5mm board	900 x 1800 / 2400mm TE or SE 1200 x 2400 / 2500 / 2700 / 3000 TE or SE 1200 x 3600mm TE
Thermal conductivity	λ 0.19W/mK	

Image 24: Typical Values for Thermal Conductivity, (Cardiff University, 2019)

Typical values for thermal conductivity:

Material	*Density Kg/m3*	*Conductivity W/mK*
medium block	1400	0.56
plaster		0.4
gypsum plasterboard	medium	0.65
	low (dry)	0.35

Surface and cavity resistances:

Surface Resistances, m²K/W	*Internal, R_{si}*	*External, R_{so}*
walls	0.13	0.04
floors or ceilings upward heat flow downward heat flow	 0.10 0.17	
roofs	0.10	0.04

Resistances of high emissivity sealed# cavities			
Width of cavity, mm*	Resistance, m²K/W, for each direction of heat flow		
	horizontal~	upward	downward
100	0.18	0.16	0.22

04 Thermal Balance - Fabric

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

Qf = ∑ UA (Tei - Teo)

Image 25 & Image 26, (HM Government, 2018; Chartered Institution of Building Services Engineers, 2019; Cardiff University, 2019)

Qf = ∑ UA	U ((W/m2K))	A (m2)
Glazing fixed	1.3	18.232
Glazing openable	1.1	15.37
New external wall	0.24	45.3945
Existing internal block wall	1.06	10.865
New internal stud wall	1.7	12.19
Ground Floor	0.22	94
Ceiling	0.24	94
Sum	**126.98318 (W/K)**	

∑ UA = 126.98 W/K

Teo will depend on each element of the building

Image 27: Volumetric Heat Capacity of Air, (Cardiff University, 2019)

Heat transfer due to ventilation and infiltration

The volumetric heat capacity of air is approximately 1200 J/(m3K)

04 Thermal Balance - Ventilation

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

Image 28: Table 5.1a Extract Ventilation Rates, (HM Government, 2018)

Table 5.1a **Extract ventilation rates**

Room	Intermittent extract	Continuous extract	
	Minimum rate	Minimum high rate	Minimum low rate
Kitchen	30 l/s adjacent to hob; or 60 l/s elsewhere	13 l/s	Total extract rate should be at least the ***whole dwelling ventilation*** rate given in Table 5.1b
Utility room	30 l/s	8 l/s	
Bathroom	15 l/s	8 l/s	
Sanitary accommodation	6 l/s	6 l/s	

Qv = Cv q (Teo – Tei)

Qv = nV/3 (Teo – Tei) (Ventilation + infiltration)

Required ventilation rate around kitchen area = 60l/s (HM Government, 2018)

Cvq = 1200 * 0.06 = 72 W/K

	Cv	q (l/s)	q (m3/s)
	1200	60	0.06
Sum	72 (W/K)		

Image 26

Image 29: Table 4.24 Ventilation and Air Infiltration, (Chartered Institution of Building Services Engineers, 2019)

Table 4.24 Empirical values for air infiltration rate due to air infiltration for rooms in buildings on normally exposed site partial exposure

Air permeability / ($m^3 \cdot h^{-1}/m^2$ at 50 Pa)	Infiltration rate (ACH) for given building size / h^{-1}					
	1 storey (10 m × 8 m × 2.75 m)* (Height to roof: 5.5 m)		2 storeys (10 m × 8 m × 2.75 m)* (Height to roof: 8.0 m)		Apartmts (storeys 1–5) (10 m × 8 m × 2.75 m)* (Floor spacing: 3.0 m)	
	Peak	Average	Peak	Average	Peak	Average
20.0 (leaky)	1.60	1.15	1.50	1.00	1.95	1.40
10.0 (Part L (2002))	0.80	0.60	0.75	0.50	1.00	0.70
7.0 (Part L (2005))	0.55	0.40	0.55	0.35	0.70	0.50

Expected infiltration rate = 0.35 ach/hour

nV/3 = (0.35*94*2.65 / 3) = 29.06W/K

Cvq + nV/3 = 101W/K

Image 30: Table 6.3 Internal Gains, (Chartered Institution of Building Services Engineers, 2019)

Table 6.3 Heat emission (W) from an adult male body (of surface area 2 m^2) and average heat emission per person for a mixture of men, women and children typical of the stated application

Activity	Typical application	Occupancy density		Total, sensible and latent heat emission (W) for stated application and dry bulb temperature (C) for adult male and (average for mixture of men, women and children)			
				20		22	
				Sensible	Latent	Sensible	Latent
Seated, inactive	Theatre, cinema (matinee)	0.75–1.0(2,3)	115 (100)	90 (78)	25 (22)	80 (70)	35 (30)
Seated, inactive	Theatre, cinema (evening)	0.75–1.0(2,3)	115 (105)	90 (82)	25 (23)	80 (73)	35 (32)
Seated, light work	Restaurant	1.0–2.0(2,3)	140 (126)	100 (90)	40 (36)	90 (81)	50 (45)
Seated, moderate work	Office	8–39(4–6), 14(4,7)*	140 (130)	100 (93)	40 (37)	90 (84)	50 (46)
Standing, light work, walking	Department store	1.7–4.3(2,3)	160 (141)	110 (97)	50 (44)	100 (88)	60 (53)

Notes:

(1) Figures in parenthesis are adjusted heat gains based on normal percentage of men, women and children for the applications listed. This is based on the heat gain for women and children of 85% and 75% of that of an adult male.

(2) For restaurant serving hot meals add 10 W sensible and 10 W latent for food per individual.

04 Thermal Balance - Occupants

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

Image 31: Table 6.20 Equipment Gains, (Chartered Institution of Building Services Engineers, 2019)

Appliance	Energy rate / W		Rate of heat gain / W (sensible radiant)
	Rated	Standby	
— double sided 900 mm (clamshell down)*	31710	2345	528
— double sided 900 mm (clamshell up)*	31710	4308	1436
— flat 900 mm	26376	5979	1084
Oven:			
— combi (combi-mode)*	22185	1758	117
— combi (convection mode)	22185	1700	293
— convection full-size	12895	3488	293
Steam kettle:			
— large (225 L) simmer lid down*	42495	1583	0
— small (38 L) simmer lid down*	15240	967	88
— small (150 L) simmer lid down	29307	1260	0
Freezer (small)	791	322	147
Reach-in refrigerator*	1407	352	88

I believe the data given in Table 6.3 within CIBSE Guide A gives the most accurate values for occupant heat gain based on whether the occupant is male, female or a child; as well as a variance based on the temperature of the room. (Chartered Institution of Building Services Engineers, 2019)

Image 32: (Chartered Institution of Building Services Engineers, 2019)

range of values of 8–12 $W \cdot m^{-2}$ for the lighting heat gain allowance is based on fluorescent lamps with high frequency ballasts. The upper value is appropriate to older installations and the lower to current guidance in the *The SLL Code for Lighting* (SLL, 2012). LED lamps are becoming more common and these values can be reduced by up to 50% if these lamps are used.

04 Thermal Balance - Occupants

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

The table advices a reduction of internal gains of 85% for females and 75% for children if the occupants are known. The table also advices a variance of sensible heat emission based on internal temperature, of which 20 degrees - 22 degrees are relevant to this scenario. See appendix item 4 for Table 6.3 from CIBSE guide A

(Chartered Institution of Building Services Engineers, 2019)

Image 33: (HM Government, 2018; Chartered Institution of Building Services Engineers, 2019; Cardiff University, 2019)

	Adaptive Comfort Temp		Qo based on occupants			Watts	Watts
	oC	Qo* (Watts)	1 male	1 female**	4 children***	Qo Max	Qo Av
January	19.96529	110	110	93.5	330	533.5	93.5
February	19.97031	110	110	93.5	330	533.5	93.5
March	20.24731	110	110	93.5	330	533.5	93.5
April	20.55116	110	110	93.5	330	533.5	93.5
May	21.34884	110	110	93.5	330	533.5	93.5
June	22.11584	100	100	85	300	485	85
July	22.71469	100	100	85	300	485	235
August	22.62796	100	100	85	300	485	235
September	21.91023	100	100	85	300	485	85
October	21.0326	110	110	93.5	330	533.5	93.5
November	20.33168	110	110	93.5	330	533.5	93.5
December	20.1004	110	110	93.5	330	533.5	258.5

* Based on Table 6.3 from CIBSE Guide A for 'Standing, light work, walking' sensible heat gain (W)

** Heat gain for women at 85% of given CIBSE data based on an adult male

*** Heat gain for children at 75% of given CIBSE data based on an adult male

04 Thermal Balance - Equipment Gain

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

Qi = Lighting loads + equipment loads

Based on CIBSE Guide A Table 6.20 kitchen radiant heat gain. See appendix item 4:
Estimated average heat load from equipment in kitchen space (based on items on standby, ie not worst case): TV @ 35 Watts, freezer @ 147 Watts, fridge @ 88 Watts, oven @ 293, toaster @ 59 Watts, kettle @ 29 Watts (Chartered Institution of Building Services Engineers, 2019)
CIBSE Guide A recommends the value of 8-12 W/m2 for lighting gains, but with a deduction of 50% for LED lamps, which applies to this scenario @ 4W/m2 (Chartered Institution of Building Services Engineers, 2019)

Image 34: (Chartered Institution of Building Services Engineers, 2019)

		Watts	Watts	Watts	Watts
	% time lighting used	Av Lighting*	Max Lighting**	Av Equipment***	Max Equipment****
January	50.00%	188	376	80	651
February	50.00%	188	376	80	651
March	50.00%	188	376	80	651
April	50.00%	188	376	80	651
May	25.00%	94	376	80	651
June	25.00%	94	376	80	651
July	25.00%	94	376	80	651
August	25.00%	94	376	80	651
September	50.00%	188	376	80	651
October	50.00%	188	376	80	651
November	50.00%	188	376	80	651
December	50.00%	188	376	80	651

* Based on summer vs winter hours of daylight and assumed occupant response @ CIBSE Guide A value of 4w/m2

** Based on all lighting on @ CIBSE Guide A value of 4w/m2

*** Based on an average of 3 hours of kitchen use as per values from table 6.20 CIBSE guide A

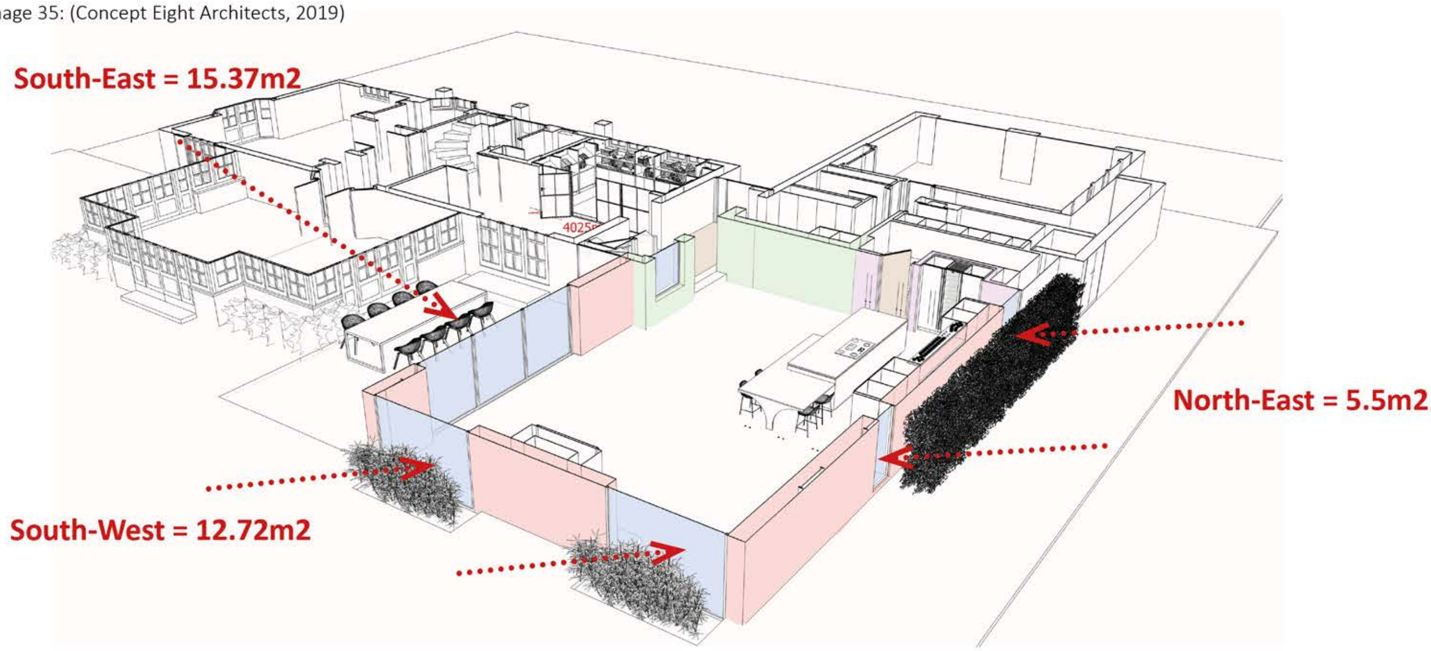
****Based on all equipment on as per values from table 6.20 CIBSE guide A

04 Thermal Balance - Solar

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

Qs = I ø * Tg * Ag

Image 35: (Concept Eight Architects, 2019)



Total irradiance figures (beam and diffuse) are the daily mean values taken from CIBSE guide A from the London Weather Centre. See appendix item 3 for full values.
All glazing specification is double glazed (See item 1 & 2 of appendix). See above for glazing sizes and orientations.

Image 36: (Chartered Institution of Building Services Engineers, 2019; The British Fenestration Rating Council, 2020)

	I (W/m2)* NE	A (m2) Area	I (W/m2)* SE	A (m2) Area	I (W/m2)* SW	A (m2) Area	T**	(W/K) Sum
January	0	5.5	88	15.37	87	12.72	0.5	1229.6
February	2	5.5	106	15.37	110	12.72	0.5	1519.71
March	12	5.5	129	15.37	142	12.72	0.5	1927.485
April	29	5.5	126	15.37	129	12.72	0.5	1868.5
May	57	5.5	115	15.37	113	12.72	0.5	1759.205
June	56	5.5	111	15.37	110	12.72	0.5	1706.635
July	49	5.5	114	15.37	92	12.72	0.5	1595.96
August	1	5.5	118	15.37	121	12.72	0.5	1679.14
September	0	5.5	132	15.37	125	12.72	0.5	1809.42
October	0	5.5	118	15.37	123	12.72	0.5	1689.11
November	0	5.5	93	15.37	94	12.72	0.5	1312.545
December	0	5.5	87	15.37	83	12.72	0.5	1196.475

* (Daily mean)
**https://www.bfrc.org/ratings - The British Fenestration Rating Council give a G-Value of 0.5 for solar glazing

Glazing ratios:
Total glazing area = 33m2
Floor area = 94m2
33/94 = 36%

Image 37: Table 1.12 Approximate Diffuse Tranmittance for Various Glazing Types (Chartered Institution of Building Services Engineers, 2019)

Table 1.12 Approximate diffuse transmittances for various glazing types (clean)

Glazing type	Diffuse transmittance
Clear glazing:	
— single	0.8
— double	0.7
Double glazing, low emissivity	0.69
Double glazing with light shelf:	
— internal light shelf only	0.55
— internal and external light shelves	0.4
Double glazing with coated prismatic glazing	0.3
Double glazing with prismatic film	0.55
Double glazing with solar control mirrored louvres	0.3

05 Balancing the equation - Scenario 1 - Average conditions in a steady state

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

(∑ UA + Cvq + nV/3) (Tei - Teo) + Qs + Qo + Qi

Based on the above collated data we can bring this together to produce the following heat balance:

Image 38: Average Scenario, (Chartered Institution of Building Services Engineers, 2019; The British Fenestration; MET Office, 1981-2010; MET Office, 2018 Rating Council, 2020; Cardiff University, 2019; Kingspan, 2019; British Gypsum, 2019; HM Government, 2018)

'Average' Scenario	To	Comfort CIBSE Ti	ΔT	Watts Qs	Qf Glazing	Watts Qf Other	Watts Qv	Watts Qo	Watts Qi	Watts Average Heating/Cooling	Days	KW Hours Total Monthly Heating/Cooling Load
January	4.9	19.97	-15.07	1229.60	40.61	86.37	101.00	93.50	268.00	1843.53	31.00	1371.59
February	4.7	19.97	-15.27	1519.71	40.61	86.37	101.00	93.50	268.00	1600.16	28.00	1075.31
March	6.9	20.25	-13.35	1927.49	40.61	86.37	101.00	93.50	268.00	753.98	31.00	560.96
April	8.8	20.55	-11.75	1868.50	40.61	86.37	101.00	93.50	268.00	449.07	30.00	323.33
May	12.6	21.35	-8.75	1759.21	40.61	86.37	101.00	93.50	174.00	-32.12	31.00	-23.89
June	15.7	22.12	-6.42	1706.64	40.61	86.37	101.00	85.00	174.00	-502.93	30.00	-362.11
July	17.9	22.71	-4.81	1595.96	40.61	86.37	101.00	235.00	174.00	-907.29	31.00	-675.02
August	17.6	22.63	-5.03	1679.14	40.61	86.37	101.00	235.00	174.00	-941.85	31.00	-700.74
September	14.9	21.91	-7.01	1809.42	40.61	86.37	101.00	85.00	268.00	-564.21	30.00	-406.23
October	11.2	21.03	-9.83	1689.11	40.61	86.37	101.00	93.50	268.00	191.06	31.00	142.15
November	7.6	20.33	-12.73	1312.55	40.61	86.37	101.00	93.50	268.00	1228.56	30.00	884.57
December	5.9	20.10	-14.20	1196.48	40.61	86.37	101.00	258.50	268.00	1514.48	31.00	1126.77

From this data we can conclude that during the months of November - February a heating load will be required, whilst in the months of June-September a cooling load will be required.

Current Scenario: Total annual cooling and heating demand = 7652 KWatt Hours

Image 39

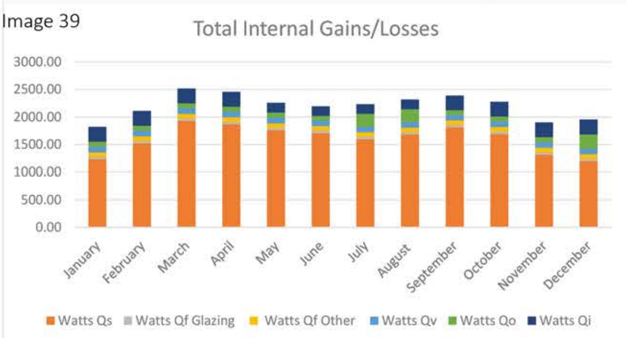
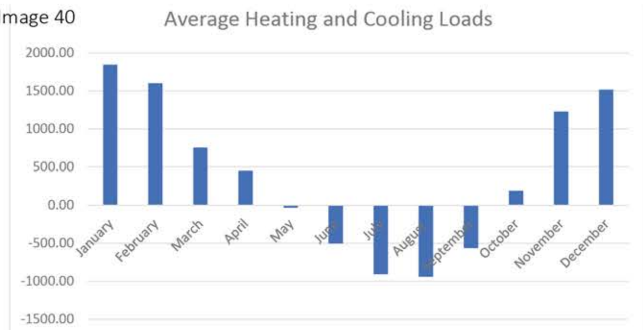


Image 40



Re-balance 1: Increase ventilation rate in June-September to decrease cooling load.

Total annual cooling and heating demand = 5453 KWatt Hours

Image 41

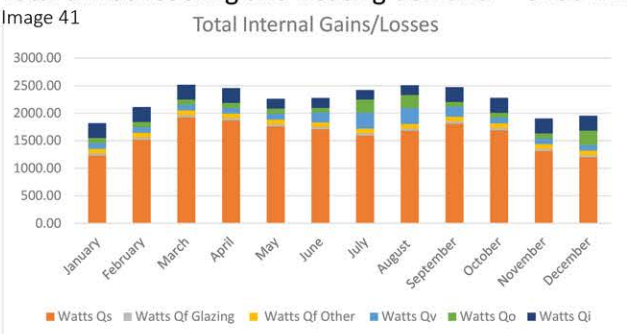
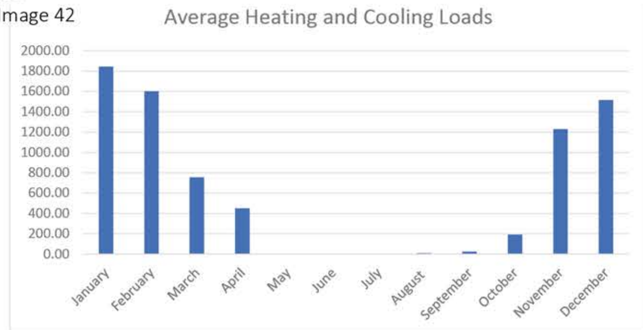


Image 42



Re-balance 2: Varying g-value monthly to improve loads.

Total annual cooling and heating demand = 3551 KWatt Hours

Image 43

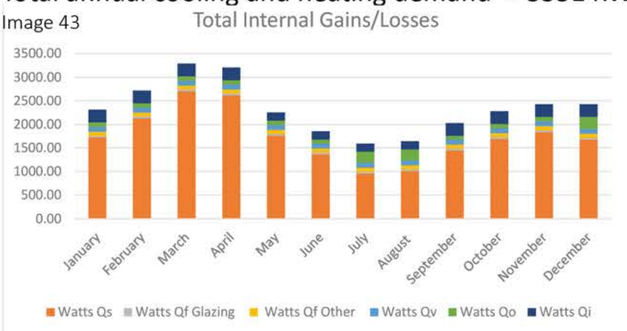
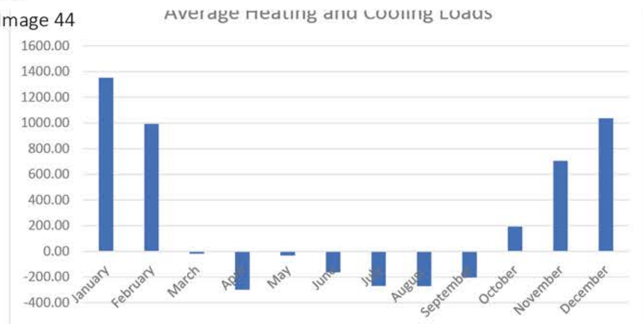


Image 44



05 Balancing the equation - Scenario 1 - Average conditions in a steady state

Qf + Qv + Qs + Qc + Qh + Qo + Qi = 0

(∑ UA + <u>Cvq + nV/3)</u> (Tei - Teo) + Qs + Qo + Qi

Re-balance 3: Varying U-value and g-value monthly to improve loads.
Total annual cooling and heating demand = 2788 KWatt Hours

Image 45

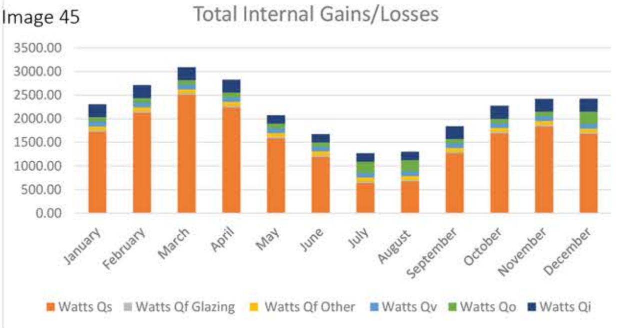


Image 46

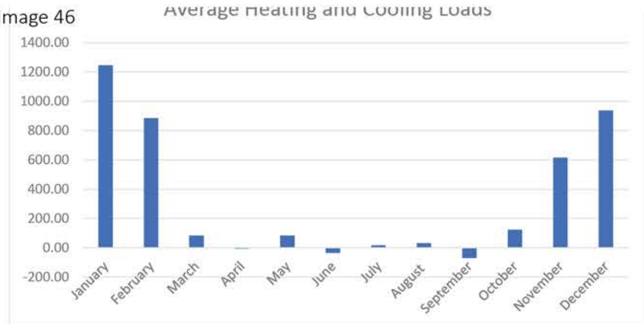


Image 39-46: Total Internal Gains/Losses, Average Heating and Cooling Loads, (Chartered Institution of Building Services Engineers, 2019; The British Fenestration; MET Office, 1981-2010; MET Office, 2018 Rating Council, 2020; Cardiff University, 2019; Kingspan, 2019; British Gypsum, 2019; HM Government, 2018)

04 Thermal Balance - Scenario 2 - Worst case conditions in a steady state

(∑ UA + <u>Cvq + nV/3)</u> (Tei - Teo) + Qs + Qo + Qi

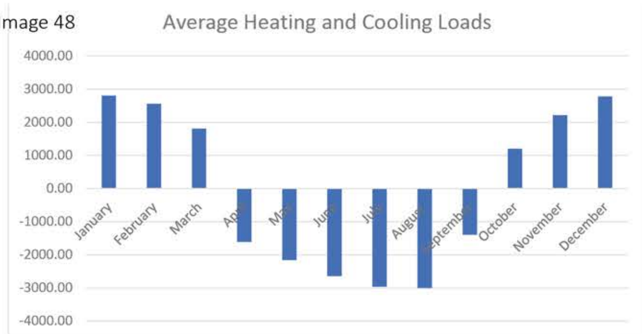
Image 47-48 Total Internal Gains/Losses, Average Heating and Cooling Loads, (Chartered Institution of Building Services Engineers, 2019; The British Fenestration; MET Office, 1981-2010; MET Office, 2018 Rating Council, 2020; Cardiff University, 2019; Kingspan, 2019; British Gypsum, 2019; HM Government, 2018)

Worst Case' Scenario		Comfort CIBSE		Watts	Watts		Watts	Watts	Watts	Watts Average		KW Hours Total Monthly
	To	Ti	ΔT	Qs	Qf Glazing	Qf Other	Qv	Qo	Qi	Heating/Cooling	Days	Heating/Cooling Load
January	2.3	19.97	-17.67	1229.60	40.61	86.37	101.00	0.00	0.00	2797.79	31.00	2081.56
February	2.1	19.97	-17.87	1519.71	40.61	86.37	101.00	0.00	0.00	2554.42	28.00	1716.57
March	3.9	20.25	-16.35	1927.49	40.61	86.37	101.00	0.00	0.00	1799.43	31.00	1338.77
April	14.2	20.55	-6.35	1868.50	40.61	86.37	101.00	533.50	651.00	-1605.04	30.00	-1155.63
May	17.9	21.35	-3.45	1759.21	40.61	86.37	101.00	533.50	651.00	-2157.43	31.00	-1605.13
June	21	22.12	-1.12	1706.64	40.61	86.37	101.00	533.50	651.00	-2636.74	30.00	-1898.45
July	23.5	22.71	0.79	1595.96	40.61	86.37	101.00	533.50	651.00	-2959.50	31.00	-2201.87
August	23.2	22.63	0.57	1679.14	40.61	86.37	101.00	533.50	651.00	-2994.06	31.00	-2227.58
September	14.9	21.91	-7.01	1809.42	40.61	86.37	101.00	533.50	651.00	-1395.71	30.00	-1004.91
October	8.4	21.03	-12.63	1689.11	40.61	86.37	101.00	0.00	0.00	1190.91	31.00	886.04
November	4.9	20.33	-15.43	1312.55	40.61	86.37	101.00	0.00	0.00	2205.62	30.00	1588.05
December	2.7	20.10	-17.40	1196.48	40.61	86.37	101.00	0.00	0.00	2770.52	31.00	2061.27

Worst Case Scenario: Total annual cooling and heating demand = 17454 KWatt Hours

Image 47

Image 48



Based on the findings in scenario 1, average conditions, to improve the heating and cooling loads for summer and winter months, I must manipulate the glazing in order to improve positive gains in the winter whilst decreasing them in the summer. The solar gains in the summer would be easier to reduce with solar shading to the facade, but the heating load in the cold months is proving the hardest aspect to improve on. This is due to a combination of low helpful internal gains from equipment and occupants due to the nature of the building use, combined with the large expanse of glass in this area and the associated fabric losses. However by focusing on negating the need for summer cooling and slightly improving the need for winter heating through the manipulation of the glazing, the loading can be reduced from 7562 to 2788 KWatt Hours each year.

06 Current Practice

Facade glazing manipulation to respond to Summer and Winter scenarios

Case Study 1: Passive House, Karawitz Architecture
Case Study 2:The Environmental Building Research Establishment, collaboration between the Building Research Establishment Energy Conversation Support Unit and the Energy Efficient Office of the Future

Case Study 1: Passive House, Karawitz Architecture

This Passive House design in 2009 Karawitz Architecture, located in France had achieved a PHI certification through the use of its bamboo panelled second skin to protect the south elevation from solar gains (ArchiDaily, 2010) . The moveable system can be opened and closed by it's occupants to alter the daylight into the adjoining spaces.

Image 49 and 50: (ArchiDaily, 2010)

Manually controlled screens do have their disadvantages, as described in Environmental design, An Introduction for Architects and engineers,
'Fixed external louvres have a principal disadvantage of an unavoidable reduction in passive solar gain and daylight..they may also be ineffective at many time of the year and restrict views..' (Randall Thomas, Max Fordhams, 1999) .
They also rely on the human inhabitants responding to the external conditions at their own will.

Case Study 2:The Environmental Building Research Establishment, collaboration between the Building Research Establishment Energy Conversation Support Unit and the Energy Efficient Office of the Future

The research building uses mechanically controlled louvres on the external elevations with 10mm toughened clear float glass with white ceramic on the downward facing side. The combination in transparencys allows for light transmission of 40% and a reflectance of 50%. Rather than risking human error or interference, solar and external light levels control the the louvres position. (Randall Thomas, Max Fordhams, 1999. PP 208-209)

Image 51 & 52: (Randall Thomas, Max Fordhams, 1999)

07 Best Practice

Facade glazing manipulation to respond to Summer and Winter scenarios

Case Study 1: HCL Architects - Integrated PV
Case Study 2: Angule-selective transparent solar thermal facade collectors

Case Study 1: HCL Architects - Integrated PVs and Angle-selective transparent BIPV-system

HCL have built two houses in Fulham, London, which use photovoltaic panels as external privacy screens. The screens are south facing and provide privacy as well as acting as a solar shading device. (Pamela Buxton, 2019)

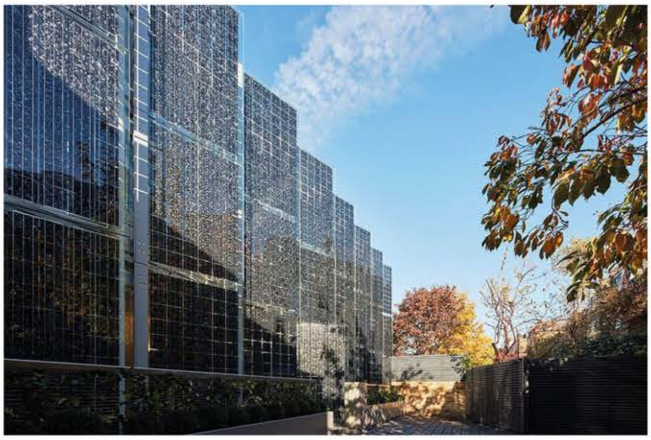



Image 53 & 54: (Pamela Buxton, 2019)

There are more developed versions of this concept with integrate the PV element incorporated within the construction fabrics themselves. The next development from this is an angle-selective transparent BIPV-system developed by F. Frontini:
'This can be used as a substitute for transparent fabrics, screen-printed glazing or static blinds. The efficiency is higher than the efficiency of conventional solar-control systems'. (Tilmann E.Kuhn, 2017)

Case Study 2: 4.3.6. Angle-selective transparent solar thermal facade collectors

Angle-selectie solar thermal collectors combines various technologies in order to create visual connections to the outside, provide solar and glar control and to create a supply of energy from solar thermal heat. This provides energy in both summer and winter months for cooling and heating respectively. Tilman highlights 'The solar radiation coming from directions with high solar profile angles is selectively shielded by the external surface of the absorber, while visibility through the collector is retained in the horizontal or downward directions for people inside the building.' (Tilmann E.Kuhn, 2017)

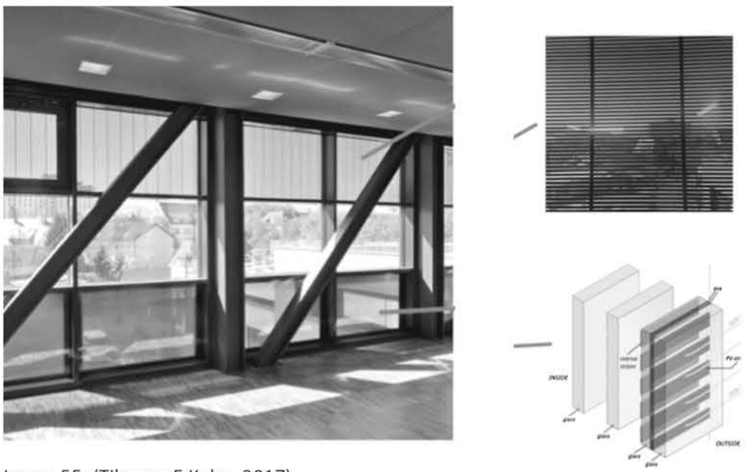


Image 55: (Tilmann E.Kuhn, 2017)

08 Conclusion

This report shows when building in a temperature climate, a responsive and adjustable strategy is required. In order to minimise the heating and cooling loads of the selected space, we should controll and manipulate a responsive facade system. This ensures useful winter solar gains are enhanced and unwanted summer solar gains can be minimised.

Fixed elements over the glazing such as louvres or elements that require human interaction in order to provide successful results would not be suitable; and an automatically responsive system such as the angle-selective transparent solar thermal facade collectors would be more appropriate. These would then also provide any energy required for worst-case scenarios with heating and cooling demands would likely be high, resulting in a non-comfortable environment without the use of mechanical heating or cooling systems.

The limitations of this report come from the available data, which may be quickly outdated and irrelevant. With regulations constantly changing and improving, these findings could become redundant or based on incorrect standards and guidance. As mentioned previously, the damage to the environment already incurred from global warming is not represented within the time range of the weather data, which is likely to carry on changing at an alarming rate into the future unless action is taken quickly to de-carbonise the industrial world.

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MAXLIGHT

Window Energy Performance

WER Window Energy Rating – In accordance with Approved Document L 2013

WER U-value of window calculated using methods and conventions set out in BR443
Standard patio door configuration to a specimen size – 2.0m wide and 2.0m high

Glass:	Supplier:	Saint Gobain
	Specifications:	10/14/6 Planitherm + Argon
	Area:	3.418m²
	Centre pane U-value:	1.0 W/m²K
Frame:	System:	Maxlight 2-panel sliding doors
	Profiles:	MXL01/MXL021/MXL03/MXL042
	Area:	0.544m²
	Heat transfer coefficient:	2.6 W/m²K
Spacer:	Supplier:	Swissspacer
	Product:	Advanced Warm Edge
	Length of thermal bridge:	11.056m
	Heat Transfer:	0.0472 W/m²K

$$U_{w} = \frac{1.0\ W/m^2K \times 3.418m^2 + 2.6\ W/m^2K \times 0.544m^2 + 11.056m \times 0.0472\ W/m^2K}{3.418m^2 + 0.544m^2} = 1.351\ W/m^2K$$

U-Value: **1.3 W/m²K**

Unit 29-32, Victoria Industrial Estate
Victoria Road, London W3 6UU
T 020 8896 0700
F 020 8993 0268
E sales@maxlight.co.uk
W www.maxlight.co.uk

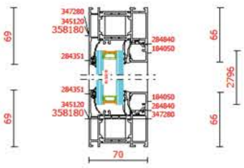
Unit overview

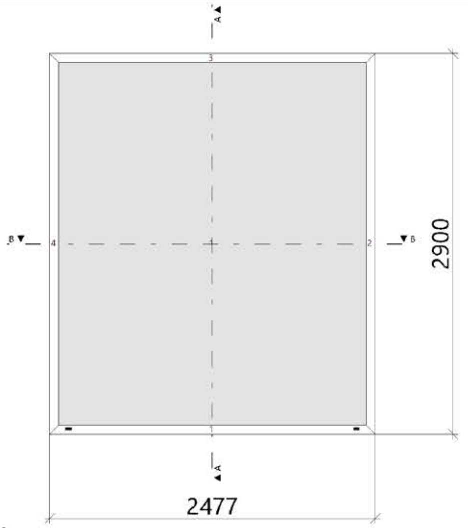
(V.Kolobanovs/Bespoke glazing design/Private Residentual Property - Cobham)/FF-W01/+++

Project number:	V.Kolobanovs/Bespoke glazing design/Private Residentual Property - Cobham	Project name:	
Item number:	GF-W02	Item description:	
Profile system:	Schüco AWS/ADS 70.HI	Number:	2
Creation date:	31/10/2019 (Vadim Kolobanov)	Last change:	20/11/2019 (Vadim Kolobanov)
Total width:	2,477.0 mm	Total height:	2,900.0 mm
Surface finish ins.:	Powder, various RAL 9004 Signal black	Surface finish outs.:	Powder, various RAL 9004 Signal black
Weight per item:	23.833 kg	Total weight:	47.666 kg

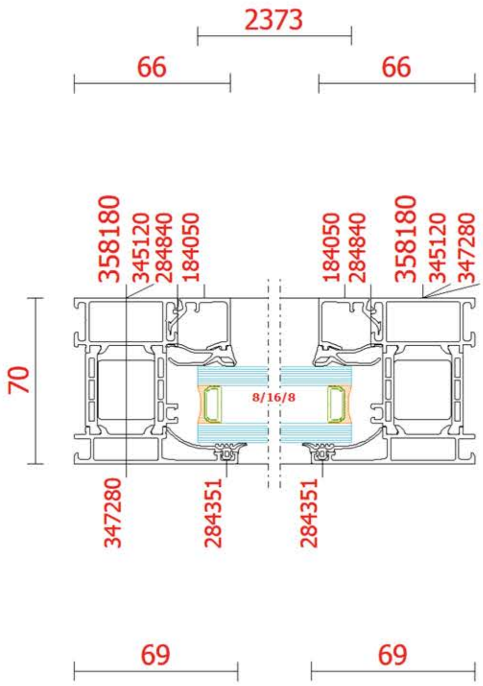
U values

Total (Uw,BW):	1.1 W/(m²K)	Profiles (Uf):	1.6 W/(m²K)
Glass (Ug):	1.0 W/(m²K)	Glass edge seal (Psi):	0.048 W/mK (Various)





A



B

Number	Art no	Description	Profile position	Dim.	Cut

Table 2.13(g) Design 97.5 percentile of beam and diffuse irradiance on vertical and horizontal surfaces: London area (London Weather Centre) (1996–2005)

Month	Orientation		Daily mean irradiance (W·m⁻²) and mean hourly irradiance (W·m⁻²) for the 21st day of the given month																			
			Mean	0230	0330	0430	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930	2030
January	Normal to beam		333	0	0	0	0	0	0	0	381	632	680	681	608	350	0	0	0	0	0	0
	N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	15	0	0	0	0	0	0	23	42	56	66	66	56	42	21	0	0	0	0	0
	NE	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	15	0	0	0	0	0	0	23	42	56	66	66	56	42	21	0	0	0	0	0
	E	Beam	22	0	0	0	0	0	0	0	218	227	84	0	0	0	0	0	0	0	0	0
		Diffuse	20	0	0	0	0	0	0	23	101	98	74	66	56	42	21	0	0	0	0	0
	SE	Beam	88	0	0	0	0	0	0	0	369	559	512	394	229	55	0	0	0	0	0	0
		Diffuse	34	0	0	0	0	0	0	23	142	170	168	143	100	59	21	0	0	0	0	0
Sunrise: 0752	S	Beam	124	0	0	0	0	0	0	0	304	563	641	641	542	278	0	0	0	0	0	0
Sunset: 1630		Diffuse	43	0	0	0	0	0	0	23	124	171	197	197	168	121	21	0	0	0	0	0
	SW	Beam	87	0	0	0	0	0	0	0	60	238	394	512	538	338	0	0	0	0	0	0
		Diffuse	34	0	0	0	0	0	0	23	59	100	142	169	168	138	21	0	0	0	0	0
	W	Beam	21	0	0	0	0	0	0	0	0	0	0	84	219	200	0	0	0	0	0	0
		Diffuse	20	0	0	0	0	0	0	23	42	56	66	74	97	99	21	0	0	0	0	0
	NW	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	15	0	0	0	0	0	0	23	42	56	66	66	56	42	21	0	0	0	0	0
	Horiz.	Beam	38	0	0	0	0	0	0	3	75	173	214	214	167	69	2	0	0	0	0	0
	Horiz.	Diffuse	24	0	0	0	0	0	0	37	75	84	97	97	85	78	34	0	0	0	0	0
	Horiz.	Global	63	0	0	0	0	0	0	41	151	257	311	311	252	147	36	0	0	0	0	0
February	Normal to beam		419	0	0	0	0	0	0	294	562	685	701	701	682	615	364	0	0	0	0	0
	N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	28	0	0	0	0	0	20	49	68	89	104	107	88	68	48	20	0	0	0	0
	NE	Beam	2	0	0	0	0	0	0	41	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	28	0	0	0	0	0	20	64	68	89	104	107	88	68	48	20	0	0	0	0
	E	Beam	38	0	0	0	0	0	0	229	336	258	90	0	0	0	0	0	0	0	0	0
		Diffuse	35	0	0	0	0	0	20	119	138	133	109	107	88	68	48	20	0	0	0	0
Sunrise: 0702	SE	Beam	106	0	0	0	0	0	0	284	526	582	499	372	217	55	0	0	0	0	0	0
Sunset: 1725		Diffuse	50	0	0	0	0	0	20	134	181	205	209	183	123	72	48	20	0	0	0	0
	S	Beam	150	0	0	0	0	0	0	172	407	566	615	615	563	446	212	0	0	0	0	0
		Diffuse	60	0	0	0	0	0	20	102	154	201	237	244	200	158	107	20	0	0	0	0
	SW	Beam	110	0	0	0	0	0	0	0	50	218	371	499	579	576	351	0	0	0	0	0
		Diffuse	51	0	0	0	0	0	20	49	73	124	178	215	204	186	145	20	0	0	0	0
	W	Beam	42	0	0	0	0	0	0	0	0	0	0	0	90	257	368	284	0	0	0	0
		Diffuse	36	0	0	0	0	0	20	49	68	89	104	112	132	141	127	20	0	0	0	0
	NW	Beam	2	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0
		Diffuse	28	0	0	0	0	0	20	49	68	89	104	107	88	68	63	20	0	0	0	0
	Horiz.	Beam	74	0	0	0	0	0	1	67	191	288	324	324	287	210	83	1	0	0	0	0
	Horiz.	Diffuse	43	0	0	0	0	0	33	92	108	131	157	163	131	104	87	33	0	0	0	0
	Horiz.	Global	117	0	0	0	0	0	34	159	299	419	481	487	418	314	171	34	0	0	0	0
March	Normal to beam		520	0	0	0	0	0	353	586	693	751	795	824	803	754	668	531	0	0	0	0
	N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	40	0	0	0	0	23	51	77	98	113	122	123	114	98	76	50	25	1	0	0
	NE	Beam	12	0	0	0	0	0	156	132	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	43	0	0	0	0	24	97	99	98	113	122	123	114	98	76	50	27	1	0	0
	E	Beam	67	0	0	0	0	0	326	465	422	288	104	0	0	0	0	0	0	0	0	0
		Diffuse	53	0	0	0	0	25	146	176	169	149	118	123	114	98	76	50	29	1	0	0
Sunrise: 0601	SE	Beam	129	0	0	0	0	0	305	525	601	587	509	375	192	5	0	0	0	0	0	0
Sunset: 1814		Diffuse	62	0	0	0	0	24	140	190	206	207	194	167	128	81	76	50	26	1	0	0
	S	Beam	172	0	0	0	0	0	105	278	429	542	615	637	579	466	317	158	0	0	0	0
		Diffuse	69	0	0	0	0	23	83	133	171	198	214	216	200	170	131	84	25	1	0	0
	SW	Beam	142	0	0	0	0	0	0	0	5	180	362	527	626	654	599	459	0	0	0	0
		Diffuse	63	0	0	0	0	24	51	77	84	128	166	196	208	206	191	157	27	1	0	0
	W	Beam	79	0	0	0	0	0	0	0	0	0	0	107	307	459	530	491	0	0	0	0
		Diffuse	54	0	0	0	0	25	51	77	98	113	122	118	149	169	176	165	29	1	0	0
	NW	Beam	16	0	0	0	0	0	0	0	0	0	0	0	0	0	151	236	0	0	0	0
		Diffuse	44	0	0	0	0	24	51	77	98	113	122	123	114	98	97	103	26	1	0	0
	Horiz.	Beam	140	0	0	0	0	12	85	223	343	434	492	510	464	374	255	128	31	0	0	0
	Horiz.	Diffuse	57	0	0	0	0	35	94	120	140	153	159	157	148	132	111	81	33	1	0	0
	Horiz.	Global	197	0	0	0	0	47	179	343	483	587	652	668	612	506	366	209	64	1	0	0

Table continues

Table 2.13(g) Design 97.5 percentile of beam and diffuse irradiance on vertical and horizontal surfaces: London area (London Weather Centre) (1996–2005) — *continued*

Month	Orientation		Daily mean irradiance ($W \cdot m^{-2}$) and mean hourly irradiance ($W \cdot m^{-2}$) for the 21st day of the given month																			
			Mean	0230	0330	0430	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930	2030
April	Normal to beam		478	0	0	0	0	259	500	650	742	799	824	816	784	744	671	548	314	0	0	0
	N	Beam	1	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	9	0	0	0
		Diffuse	56	0	0	0	19	57	80	104	124	140	150	149	140	124	104	79	56	20	0	0
	NE	Beam	29	0	0	0	0	182	261	201	60	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	61	0	0	0	19	110	139	131	114	140	150	149	140	124	104	79	51	20	0	0
	E	Beam	86	0	0	0	0	251	453	505	442	299	105	0	0	0	0	0	0	0	0	0
		Diffuse	71	0	0	0	19	131	187	196	187	168	138	149	140	124	104	79	51	20	0	0
Sunrise: 0451	SE	Beam	126	0	0	0	0	173	379	513	565	540	443	291	114	0	0	0	0	0	0	0
Sunset: 1906		Diffuse	75	0	0	0	19	107	169	198	211	213	201	173	134	124	104	79	51	20	0	0
	S	Beam	137	0	0	0	0	0	83	221	357	464	521	516	455	357	227	90	0	0	0	0
		Diffuse	74	0	0	0	19	51	95	136	171	199	215	214	198	171	135	93	51	20	0	0
	SW	Beam	129	0	0	0	0	0	0	0	0	117	294	439	530	566	529	415	209	0	0	0
		Diffuse	75	0	0	0	19	51	80	104	124	134	173	200	212	211	197	170	115	20	0	0
	W	Beam	90	0	0	0	0	0	0	0	0	0	0	104	294	443	521	496	305	0	0	0
		Diffuse	71	0	0	0	19	51	80	104	124	140	150	138	168	187	196	189	143	20	0	0
	NW	Beam	32	0	0	0	0	0	0	0	0	0	0	0	0	61	208	287	222	0	0	0
		Diffuse	62	0	0	0	19	51	80	104	124	140	150	149	140	114	131	140	118	20	0	0
	Horiz.	Beam	192	0	0	0	4	62	196	345	477	578	630	624	567	479	357	216	76	4	0	0
	Horiz.	Diffuse	79	0	0	0	30	97	132	152	168	181	190	191	182	167	149	126	95	31	0	0
	Horiz.	Global	271	0	0	0	34	159	329	497	645	759	820	814	750	647	506	342	171	36	0	0
May	Normal to beam		497	0	0	0	379	505	593	646	706	730	725	719	713	687	652	607	524	265	0	0
	N	Beam	13	0	0	0	118	60	0	0	0	0	0	0	0	0	0	0	63	83	0	0
		Diffuse	73	0	0	18	78	84	102	126	144	157	165	165	158	145	126	101	83	73	18	0
	NE	Beam	57	0	0	0	333	375	336	234	102	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	81	0	0	20	142	168	170	160	140	157	165	165	158	145	126	101	74	43	18	0
	E	Beam	107	0	0	0	353	470	514	481	403	262	89	0	0	0	0	0	0	0	0	0
		Diffuse	90	0	0	20	148	193	213	215	202	181	153	165	158	145	126	101	74	43	20	0
Sunrise: 0358	SE	Beam	115	0	0	0	166	290	391	446	469	424	326	198	52	0	0	0	0	0	0	0
Sunset: 1955		Diffuse	88	0	0	18	92	145	183	207	215	213	201	176	141	145	126	101	74	43	20	0
	S	Beam	96	0	0	0	0	0	39	150	260	338	372	369	330	252	151	40	0	0	0	0
		Diffuse	80	0	0	18	43	74	98	141	172	196	210	211	198	175	140	97	74	43	18	0
	SW	Beam	113	0	0	0	0	0	0	0	0	54	200	323	414	456	450	400	300	116	0	0
		Diffuse	87	0	0	20	43	74	102	126	144	139	176	201	215	218	207	183	145	84	18	0
	W	Beam	103	0	0	0	0	0	0	0	0	0	0	88	256	392	485	526	487	246	0	0
		Diffuse	89	0	0	20	43	74	102	126	144	157	165	154	183	204	215	212	194	126	20	0
	NW	Beam	54	0	0	0	0	0	0	0	0	0	0	0	0	99	237	344	389	232	0	0
		Diffuse	80	0	0	18	43	74	102	126	144	157	165	165	158	142	159	169	169	122	20	0
	Horiz.	Beam	223	0	0	17	74	175	293	404	518	591	616	611	578	504	409	300	182	52	17	0
	Horiz.	Diffuse	102	0	1	24	77	123	159	187	201	214	226	228	220	207	186	156	121	84	25	0
	Horiz.	Global	324	0	1	42	151	298	451	592	720	805	842	839	797	712	595	456	303	135	42	0
June	Normal to beam		487	0	0	0	269	477	624	708	761	785	802	787	771	745	712	650	503	180	0	0
	N	Beam	13	0	0	0	92	73	0	0	0	0	0	0	0	0	0	0	77	61	0	0
		Diffuse	74	0	0	23	86	97	107	127	144	156	162	163	157	145	127	105	96	79	11	0
	NE	Beam	56	0	0	0	238	359	362	269	127	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	82	0	0	23	132	175	175	160	141	156	162	163	157	145	127	105	81	51	11	0
	E	Beam	105	0	0	0	244	434	529	515	425	276	96	0	0	0	0	0	0	0	0	0
		Diffuse	89	0	0	23	134	196	213	210	196	175	147	163	157	145	127	105	81	51	11	0
Sunrise: 0340	SE	Beam	111	0	0	0	108	255	386	459	474	426	331	192	35	0	0	0	0	0	0	0
Sunset: 2023		Diffuse	86	0	0	22	91	147	180	199	205	202	187	166	134	145	127	105	81	51	11	0
	S	Beam	91	0	0	0	0	0	17	134	245	327	373	366	321	240	135	18	0	0	0	0
		Diffuse	77	0	0	23	52	82	95	133	163	184	195	196	186	164	132	93	81	51	11	0
	SW	Beam	110	0	0	0	0	0	0	0	0	36	196	325	418	464	462	402	269	72	0	0
		Diffuse	85	0	0	23	52	82	107	127	144	132	164	189	204	207	198	179	147	82	11	0
	W	Beam	103	0	0	0	0	0	0	0	0	0	0	94	271	416	518	551	458	163	0	0
		Diffuse	88	0	0	23	52	82	107	127	144	156	162	148	177	198	210	212	197	112	11	0
	NW	Beam	55	0	0	0	0	0	0	0	0	0	0	0	0	125	271	377	378	159	0	0
		Diffuse	81	0	0	22	52	82	107	127	144	156	162	163	157	142	160	173	176	111	11	0
	Horiz.	Beam	248	0	0	5	64	184	331	466	582	658	704	691	647	570	469	344	194	43	0	0
	Horiz.	Diffuse	100	0	0	36	100	140	161	177	188	198	201	207	203	193	176	155	136	102	18	1
	Horiz.	Global	348	0	0	41	164	324	492	644	770	857	905	897	850	763	645	500	330	145	19	1

Table continues

Table 2.13(g) Design 97.5 percentile of beam and diffuse irradiance on vertical and horizontal surfaces: London area (London Weather Centre) (1996–2005) — *continued*

Month	Orientation		Daily mean irradiance (W·m^{-2}) and mean hourly irradiance (W·m^{-2}) for the 21st day of the given month																			
			Mean	0230	0330	0430	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930	2030
July	Normal to beam		442	0	0	0	207	408	582	677	745	788	754	802	788	572	673	227	133	159	0	0
	N	Beam	7	0	0	0	65	49	0	0	0	0	0	0	0	0	0	0	16	50	0	0
		Diffuse	71	0	0	13	70	89	102	123	140	151	161	158	151	151	124	108	92	65	11	0
	NE	Beam	49	0	0	0	182	303	330	246	108	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	78	0	0	13	108	163	170	156	135	151	161	158	151	151	124	108	73	42	11	0
	E	Beam	99	0	0	0	193	379	504	504	425	283	92	0	0	0	0	0	0	0	0	0
		Diffuse	86	0	0	13	111	185	212	211	196	172	149	158	151	151	124	108	73	42	11	0
Sunrise: 0406	SE	Beam	114	0	0	0	90	233	382	466	493	457	338	221	57	0	0	0	0	0	0	0
Sunset: 2007		Diffuse	85	0	0	13	78	142	182	203	209	203	195	165	132	151	124	108	73	42	11	0
	S	Beam	99	0	0	0	0	0	37	156	272	364	385	410	364	209	155	15	0	0	0	0
		Diffuse	78	0	0	13	43	76	99	137	166	187	204	197	186	185	137	125	73	42	11	0
	SW	Beam	92	0	0	0	0	0	0	0	0	57	207	359	458	379	464	149	76	70	0	0
		Diffuse	83	0	0	13	43	76	102	123	140	132	170	189	203	227	203	169	111	71	11	0
	W	Beam	70	0	0	0	0	0	0	0	0	0	0	98	283	327	501	197	124	148	0	0
		Diffuse	82	0	0	13	43	76	102	123	140	151	161	143	172	214	211	184	127	97	11	0
	NW	Beam	29	0	0	0	0	0	0	0	0	0	0	0	0	83	244	129	99	140	0	0
		Diffuse	76	0	0	13	43	76	102	123	140	151	161	158	151	154	156	162	118	94	11	0
	Horiz.	Beam	212	0	0	2	41	142	288	425	548	639	642	682	640	420	422	112	46	31	1	0
	Horiz.	Diffuse	102	0	0	21	85	135	160	177	187	191	213	196	191	240	178	213	149	85	18	0
	Horiz.	Global	313	0	0	22	126	277	448	603	735	831	854	878	831	660	601	325	196	116	19	0
August	Normal to beam		449	0	0	0	0	184	471	640	757	780	733	680	791	774	602	492	286	0	0	0
	N	Beam	1	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	8	0	0	0
		Diffuse	57	0	0	0	14	63	86	108	124	138	149	152	137	123	110	85	60	19	0	0
	NE	Beam	27	0	0	0	0	130	246	199	63	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	62	0	0	0	14	103	149	138	113	138	149	152	137	123	110	85	54	20	0	0
	E	Beam	81	0	0	0	0	179	425	496	451	292	94	0	0	0	0	0	0	0	0	0
		Diffuse	71	0	0	0	14	119	198	205	187	165	141	152	137	123	110	85	54	20	0	0
Sunrise: 0453	SE	Beam	118	0	0	0	0	122	355	503	575	525	393	242	114	0	0	0	0	0	0	0
Sunset: 1913		Diffuse	76	0	0	0	14	101	179	207	210	207	200	180	131	123	110	85	54	20	0	0
	S	Beam	129	0	0	0	0	0	77	215	362	451	462	429	457	370	203	81	0	0	0	0
		Diffuse	74	0	0	0	14	53	102	141	170	194	214	220	192	168	144	101	54	19	0	0
	SW	Beam	121	0	0	0	0	0	0	0	0	112	260	365	533	588	474	372	191	0	0	0
		Diffuse	77	0	0	0	14	53	86	108	124	132	174	206	206	208	209	180	118	20	0	0
	W	Beam	85	0	0	0	0	0	0	0	0	0	0	87	296	461	468	445	278	0	0	0
		Diffuse	72	0	0	0	14	53	86	108	124	138	149	147	163	185	207	199	146	20	0	0
	NW	Beam	30	0	0	0	0	0	0	0	0	0	0	0	0	64	187	257	202	0	0	0
		Diffuse	63	0	0	0	14	53	86	108	124	138	149	152	137	111	140	149	122	20	0	0
	Horiz.	Beam	182	0	0	0	1	45	186	341	489	565	561	521	573	499	321	194	69	4	0	0
	Horiz.	Diffuse	83	0	0	0	24	106	147	162	164	178	203	220	174	160	170	143	103	31	0	0
	Horiz.	Global	265	0	0	0	25	151	333	504	654	743	764	741	747	659	491	337	172	35	0	0
September	Normal to beam		463	0	0	0	0	0	608	631	700	708	704	700	680	652	591	504	0	0	0	0
	N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	41	0	0	0	5	23	49	77	98	113	122	122	114	99	77	50	24	4	0	0
	NE	Beam	17	0	0	0	0	0	271	144	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	44	0	0	0	5	26	104	98	98	113	122	122	114	99	77	50	28	4	0	0
	E	Beam	77	0	0	0	0	0	562	500	426	271	92	0	0	0	0	0	0	0	0	0
		Diffuse	55	0	0	0	5	31	168	175	168	149	120	122	114	99	77	50	30	4	0	0
Sunrise: 0542	SE	Beam	132	0	0	0	0	0	523	563	605	551	448	317	161	3	0	0	0	0	0	0
Sunset: 1804		Diffuse	63	0	0	0	5	28	160	189	204	205	192	166	130	85	77	50	27	4	0	0
	S	Beam	159	0	0	0	0	0	178	296	430	508	542	539	488	401	278	148	0	0	0	0
		Diffuse	68	0	0	0	5	23	83	131	169	196	211	211	197	170	131	84	24	4	0	0
	SW	Beam	125	0	0	0	0	0	0	0	3	167	318	446	529	565	529	434	0	0	0	0
		Diffuse	63	0	0	0	5	26	49	77	83	128	166	192	205	204	188	155	28	4	0	0
	W	Beam	70	0	0	0	0	0	0	0	0	0	0	91	260	397	469	466	0	0	0	0
		Diffuse	54	0	0	0	5	31	49	77	98	113	122	121	150	169	175	163	30	4	0	0
	NW	Beam	15	0	0	0	0	0	0	0	0	0	0	0	0	0	135	225	0	0	0	0
		Diffuse	44	0	0	0	5	28	49	77	98	113	122	122	114	99	99	102	27	4	0	0
	Horiz.	Beam	134	0	0	0	0	65	150	244	351	413	440	437	396	327	228	124	46	0	0	0
	Horiz.	Diffuse	58	0	0	0	8	24	75	114	137	158	170	171	163	144	119	83	29	6	0	0
	Horiz.	Global	193	0	0	0	8	90	225	359	489	571	610	608	559	471	347	206	75	6	0	0

03

Table continues

Table 2.13(g) Design 97.5 percentile of beam and diffuse irradiance on vertical and horizontal surfaces: London area (London Weather Centre) (1996–2005) — *continued*

Month	Orientation		Daily mean irradiance ($W \cdot m^{-2}$) and mean hourly irradiance ($W \cdot m^{-2}$) for the 21st day of the given month																			
			Mean	0230	0330	0430	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930	2030
October	Normal to beam		474	0	0	0	0	0	0	567	625	635	697	709	733	668	583	0	0	0	0	0
	N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	27	0	0	0	0	2	27	47	69	85	92	92	83	68	46	26	1	0	0	0
	NE	Beam	3	0	0	0	0	0	0	79	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	27	0	0	0	0	2	27	61	69	85	92	92	83	68	46	30	1	0	0	0
	E	Beam	48	0	0	0	0	0	0	442	374	239	89	0	0	0	0	0	0	0	0	0
		Diffuse	36	0	0	0	0	2	31	146	143	126	96	92	83	68	46	30	1	0	0	0
Sunrise: 0631	SE	Beam	118	0	0	0	0	0	0	546	585	539	496	376	233	60	0	0	0	0	0	0
Sunset: 1658		Diffuse	49	0	0	0	0	2	31	171	189	192	179	153	115	71	46	26	1	0	0	0
	S	Beam	166	0	0	0	0	0	0	331	453	524	612	623	605	485	341	0	0	0	0	0
		Diffuse	58	0	0	0	0	2	27	120	160	188	203	203	188	160	120	26	1	0	0	0
	SW	Beam	123	0	0	0	0	0	0	0	56	202	369	505	623	625	562	0	0	0	0	0
		Diffuse	49	0	0	0	0	2	27	47	73	118	153	179	192	190	171	30	1	0	0	0
	W	Beam	51	0	0	0	0	0	0	0	0	0	0	91	275	400	455	0	0	0	0	0
		Diffuse	36	0	0	0	0	2	31	47	69	85	92	95	123	142	147	30	1	0	0	0
	NW	Beam	3	0	0	0	0	0	0	0	0	0	0	0	0	0	81	0	0	0	0	0
		Diffuse	27	0	0	0	0	2	31	47	69	85	92	92	83	68	60	26	1	0	0	0
	Horiz.	Beam	83	0	0	0	0	1	39	130	213	267	322	327	308	227	132	32	0	0	0	0
	Horiz.	Diffuse	39	0	0	0	0	3	33	74	104	127	131	129	115	99	73	35	2	0	0	0
	Horiz.	Global	122	0	0	0	0	4	73	204	317	394	452	456	422	326	205	67	2	0	0	0
November	Normal to beam		359	0	0	0	0	0	0	0	469	629	679	666	630	513	0	0	0	0	0	0
	N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	16	0	0	0	0	0	3	27	40	55	65	64	55	40	27	1	0	0	0	0
	NE	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	16	0	0	0	0	0	3	26	40	55	65	64	55	40	29	1	0	0	0	0
	E	Beam	24	0	0	0	0	0	0	0	268	226	83	0	0	0	0	0	0	0	0	0
		Diffuse	21	0	0	0	0	0	3	27	105	97	74	64	55	40	27	1	0	0	0	0
Sunrise: 0726	SE	Beam	93	0	0	0	0	0	0	0	454	557	511	386	238	82	0	0	0	0	0	0
Sunset: 1605		Diffuse	35	0	0	0	0	0	3	28	151	169	168	139	100	56	25	1	0	0	0	0
	S	Beam	132	0	0	0	0	0	0	0	374	561	640	628	563	409	0	0	0	0	0	0
		Diffuse	44	0	0	0	0	0	3	27	131	170	196	192	170	134	27	1	0	0	0	0
	SW	Beam	94	0	0	0	0	0	0	0	74	237	394	502	558	497	0	0	0	0	0	0
		Diffuse	35	0	0	0	0	0	3	26	57	100	142	164	169	155	29	1	0	0	0	0
	W	Beam	25	0	0	0	0	0	0	0	0	0	0	82	227	293	0	0	0	0	0	0
		Diffuse	21	0	0	0	0	0	3	27	40	55	65	73	97	107	27	1	0	0	0	0
	NW	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	16	0	0	0	0	0	3	28	40	55	65	64	55	40	25	1	0	0	0	0
	Horiz.	Beam	42	0	0	0	0	0	0	18	92	171	211	207	171	100	27	0	0	0	0	0
	Horiz.	Diffuse	24	0	0	0	0	0	5	38	68	83	96	95	83	65	35	1	0	0	0	0
	Horiz.	Global	65	0	0	0	0	0	5	56	160	254	307	302	254	165	62	1	0	0	0	0
December	Normal to beam		399	0	0	0	0	0	0	0	479	576	599	599	557	383	0	0	0	0	0	0
	N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	12	0	0	0	0	0	0	14	29	44	52	52	44	30	14	0	0	0	0	0
	NE	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	12	0	0	0	0	0	0	14	29	44	52	52	44	30	14	0	0	0	0	0
	E	Beam	23	0	0	0	0	0	0	0	267	202	72	0	0	0	0	0	0	0	0	0
		Diffuse	16	0	0	0	0	0	0	14	94	85	62	52	44	30	14	0	0	0	0	0
Sunrise: 0801	SE	Beam	87	0	0	0	0	0	0	0	466	514	457	355	220	70	0	0	0	0	0	0
Sunset: 1555		Diffuse	31	0	0	0	0	0	0	14	143	155	147	125	90	49	14	0	0	0	0	0
	S	Beam	120	0	0	0	0	0	0	0	391	525	574	574	507	313	0	0	0	0	0	0
		Diffuse	39	0	0	0	0	0	0	14	124	158	173	173	156	115	14	0	0	0	0	0
	SW	Beam	83	0	0	0	0	0	0	0	88	228	355	457	497	372	0	0	0	0	0	0
		Diffuse	30	0	0	0	0	0	0	14	49	91	125	147	154	131	14	0	0	0	0	0
	W	Beam	20	0	0	0	0	0	0	0	0	0	0	72	195	214	0	0	0	0	0	0
		Diffuse	16	0	0	0	0	0	0	14	29	44	52	62	85	88	14	0	0	0	0	0
	NW	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	12	0	0	0	0	0	0	14	29	44	52	52	44	30	14	0	0	0	0	0
	Horiz.	Beam	28	0	0	0	0	0	0	5	68	124	152	152	120	54	5	0	0	0	0	0
	Horiz.	Diffuse	18	0	0	0	0	0	0	21	49	69	79	79	70	54	21	0	0	0	0	0
	Horiz.	Global	47	0	0	0	0	0	0	26	117	193	232	232	190	108	26	0	0	0	0	0

Appliance	Energy rate / W		Rate of heat gain / W				Usage factor, F_U	Radiation factor, F_R
	Rated	Standby	Sensible radiant	Sensible convective	Latent	Total		
Cabinet:								
— hot serving (large), insulated*	1993	352	117	234	0	352	0.18	0.33
— hot serving (large), uninsulated	1993	1026	205	821	0	1026	0.51	0.20
— proofing (large)*	5099	410	352	0	59	410	0.08	0.86
— proofing (small 15-shelf)	4191	1143	0	264	879	1143	0.27	0.00
Coffee brewing urn	3810	352	59	88	205	352	0.08	0.17
Drawer warmers, 2-drawer (moist holding)*	1202	147	0	0	59	59	0.12	0.00
Egg cooker	3194	205	88	117	0	205	0.06	0.43
Espresso machine*	2403	352	117	234	0	352	0.15	0.33
Food warmer: steam table (2-well-type)	1495	1026	88	176	762	1026	0.69	0.08
Freezer (small)	791	322	147	176	0	322	0.41	0.45
Hot dog roller*	996	703	264	440	0	703	0.71	0.38
Hot plate: single burner, high speed	1114	879	264	615	0	879	0.79	0.30
Hot-food case:								
— dry holding*	9115	733	264	469	0	733	0.08	0.36
— moist holding*	9115	967	264	528	176	967	0.11	0.27
Microwave oven: commercial (heavy duty)	3194	0	0	0	0	0	0	0.00
Oven: countertop conveyorized bake/finishing*	6008	3693	645	3048	0	3693	0.61	0.17
Panini*	1700	938	352	586	0	938	0.55	0.38
Popcorn popper*	586	59	29	29	0	59	0.1	0.50
Rapid-cook oven:								
— quartz-halogen*	12016	0	0	0	0	0	0	0.00
— microwave/convection*	7297	1202	293	909	0	293	0.16	0.24
Reach-in refrigerator*	1407	352	88	264	0	352	0.25	0.25
Refrigerated prep. table*	586	264	176	88	0	264	0.45	0.67
Steamer (bun)	1495	205	176	29	0	205	0.14	0.86
Toaster:								
— 4-slice pop up (large): cooking	1788	879	59	410	293	762	0.49	0.07
— contact (vertical)	3312	1553	791	762	0	1553	0.47	0.51
— conveyor (large)	9613	3019	879	2139	0	3019	0.31	0.29
— small conveyor	1700	1084	117	967	0	1084	0.64	0.11
Waffle iron	909	352	234	117	0	352	0.39	0.67

* Items with an asterisk appear only in Swierczyna et al. (2009); all others appear in both Swierczyna et al. (2008) and (2009).

Appliance	Energy rate / W		Rate of heat gain / W (sensible radiant)	Usage factor, F_U	Radiation factor, F_R
	Rated	Standby			
Broiler: underfired 900 mm	10814	9056	3165	0.84	0.35
Cheese melter*	3605	3488	1348	0.97	0.39
Fryer:					
— kettle	29014	528	147	0.02	0.28
— open deep-fat, 1-vat	14008	821	293	0.06	0.36
— pressure	13511	791	147	0.06	0.19
Griddle:					
— double sided 900 mm (clamshell down)*	21218	2022	410	0.10	0.20
— double sided 900 mm (clamshell up)*	21218	3370	1055	0.16	0.31
— flat 900 mm	17115	3370	1319	0.20	0.39
— small 900 mm*	8997	1788	791	0.20	0.44
Induction cooktop*	21013	0	0	0.00	0.00
Induction wok*	3488	0	0	0.00	0.00
Oven:					
— combi (combi-mode)*	16411	1612	234	0.10	0.15
— combi (convection mode)	16412	1612	410	0.10	0.25
— convection (full-size)	12103	1964	440	0.16	0.22
— convection (half-size)*	5510	1084	147	0.20	0.14
Pasta cooker*	22010	2491	0	0.11	0.00
Range top:					
— top off/oven on*	4865	1172	293	0.24	0.25
— 3 elements on/oven off	15005	4513	1846	0.30	0.41
— 6 elements on/oven off	15005	9730	4074	0.65	0.42
— 6 elements on/oven on	19870	10668	4250	0.54	0.40
Range: hot-top	15826	15035	3458	0.95	0.23
Rotisserie*	11107	4044	1319	0.36	0.33
Salamander*	7004	6829	2051	0.97	0.30
Steam kettle:					
— large (225 L), simmer lid down*	32414	762	29	0.02	0.04
— small (150 L), simmer lid down*	21599	528	88	0.02	0.17
Steamer: compartment (atmospheric)*	9789	4484	59	0.46	0.01
Tilting skillet/braising pan	9642	1553	0	0.16	0.00

* Items with an asterisk appear only in Swierczyna et al. (2009); all others appear in both Swierczyna et al. (2008) and (2009).

Appliance	Energy rate / W		Rate of heat gain / W (sensible radiant)	Usage factor, F_U	Radiation factor, F_R
	Rated	Standby			
Broiler:					
— batch*	27842	20280	2374	0.73	0.12
— chain (conveyor)	38685	28340	3869	0.73	0.14
— overfired (upright)*	29307	25761	733	0.88	0.03
— underfired 900 mm	28135	21658	2638	0.77	0.12
Fryer:					
— doughnut	12895	3634	850	0.28	0.23
— open deep-fat, 1 vat	23446	1377	322	0.06	0.23
— pressure	23446	2638	234	0.11	0.09
Griddle:					
— double sided 900 mm (clamshell down)*	31710	2345	528	0.07	0.23
— double sided 900 mm (clamshell up)*	31710	4308	1436	0.14	0.33
— flat 900 mm	26376	5979	1084	0.23	0.18
Oven:					
— combi (combi-mode)*	22185	1758	117	0.08	0.07
— combi (convection mode)	22185	1700	293	0.08	0.17
— convection full-size	12895	3488	293	0.27	0.08
— conveyor (pizza)	49822	20017	2286	0.40	0.11
— deck	30772	6008	1026	0.20	0.17
— rack mini-rotating*	16500	1319	322	0.08	0.24
Pasta cooker*	23446	6946	0	0.30	0.00
Range top:					
— top off/oven on*	7327	2169	586	0.30	0.27
— top: 3 burners on/oven off	35169	17614	2081	0.50	0.12
— top: 6 burners on/oven off	35169	35403	3370	1.01	0.10
— top: 6 burners on/oven on	42495	36018	3986	0.85	0.11
Range wok*	29014	25614	1524	0.88	0.06
Rethermalizer*	26376	6829	3370	0.26	0.49
Rice cooker*	10257	147	88	0.01	0.60
Salamander*	10257	9759	1553	0.95	0.16
Steam kettle:					
— large (225 L) simmer lid down*	42495	1583	0	0.04	0.00
— small (38 L) simmer lid down*	15240	967	88	0.06	0.09
— small (150 L) simmer lid down	29307	1260	0	0.04	0.00
Steamer: compartment: atmospheric*	7620	2432	0	0.32	0.00
Tilting skillet/braising pan	30479	3048	117	0.10	0.04

* Items with an asterisk appear only in Swierczyna et al. (2009); all others appear in both Swierczyna et al. (2008) and (2009).