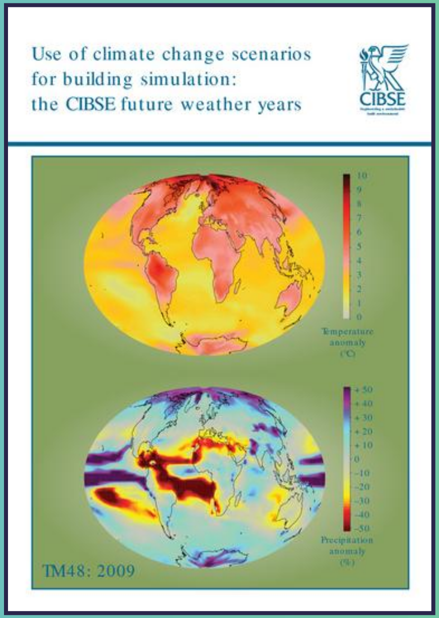
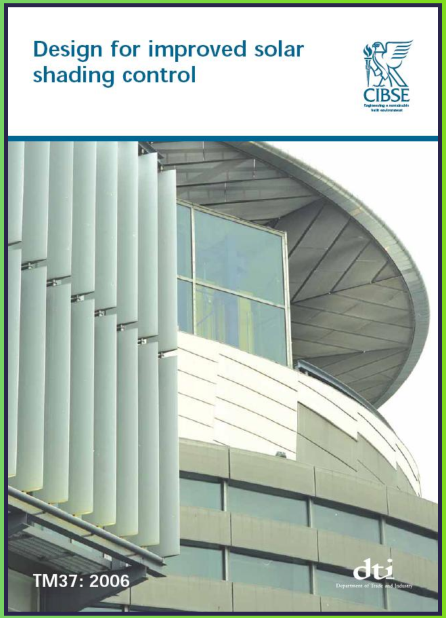
How Can We Improve Building Thermal Simulation Software





Ant Wilson

Director/AECOM Fellow

Building Engineering

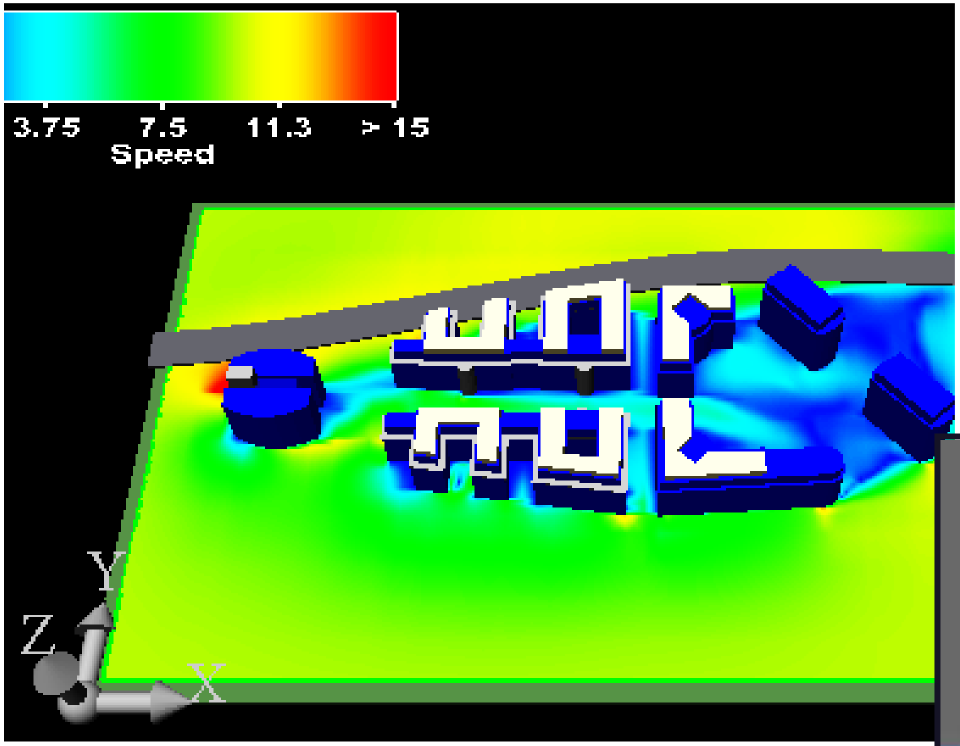
AECOM

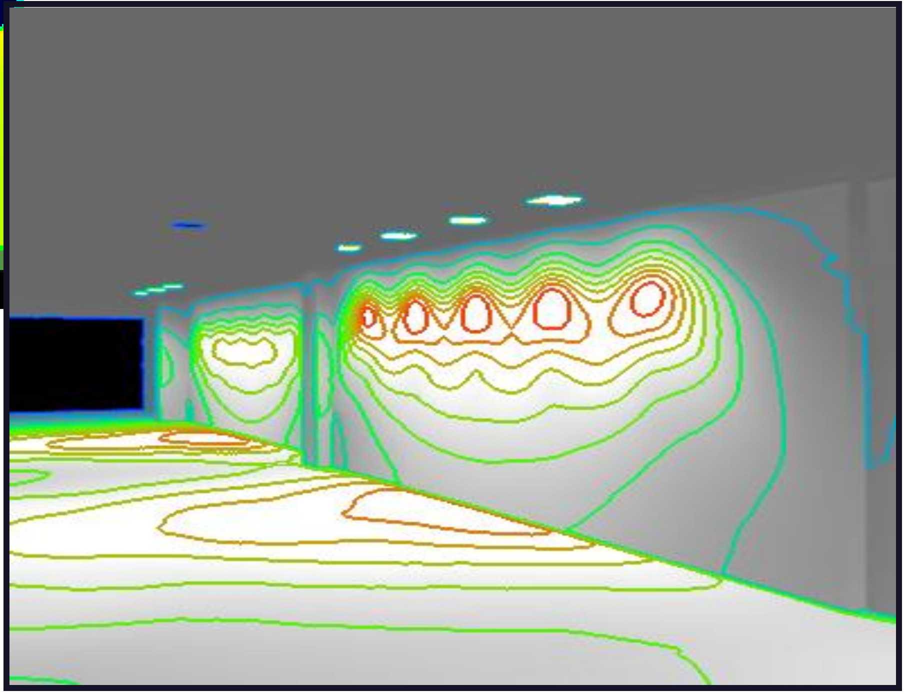
7th November 2013

UK GREEN BUILDING COUNCIL Gold Leaf Member

AECOM

Computer Modelling – Design or Energy Simulation





First Law of Thermodynamics

The first law of thermodynamics is the application of the conservation of energy principle to heat and thermodynamic processes:

The change in internal energy of a system is equal to the heat added to the system minus the work done by the system.

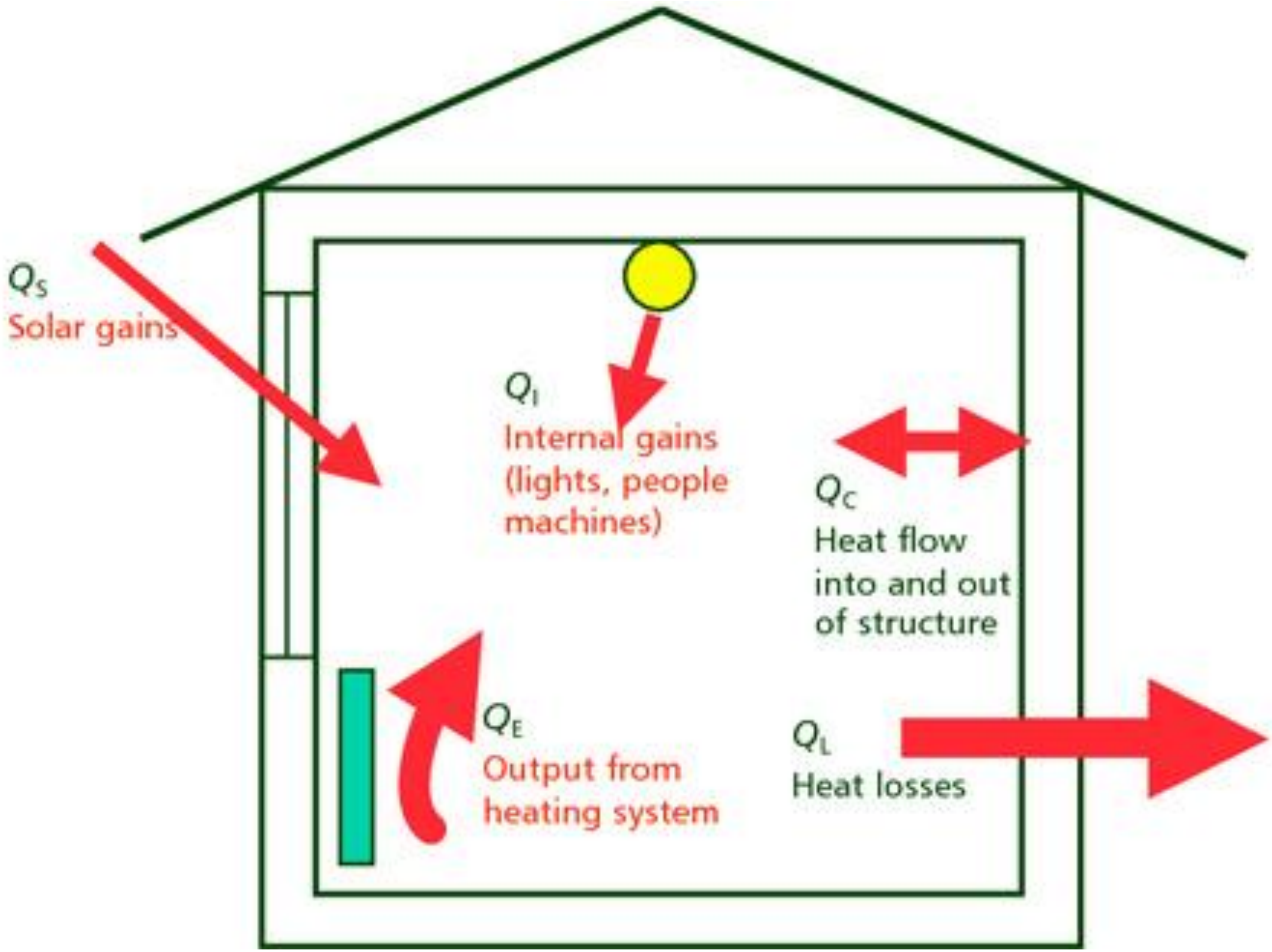
$$\Delta U = Q - W$$

Change in internal energy

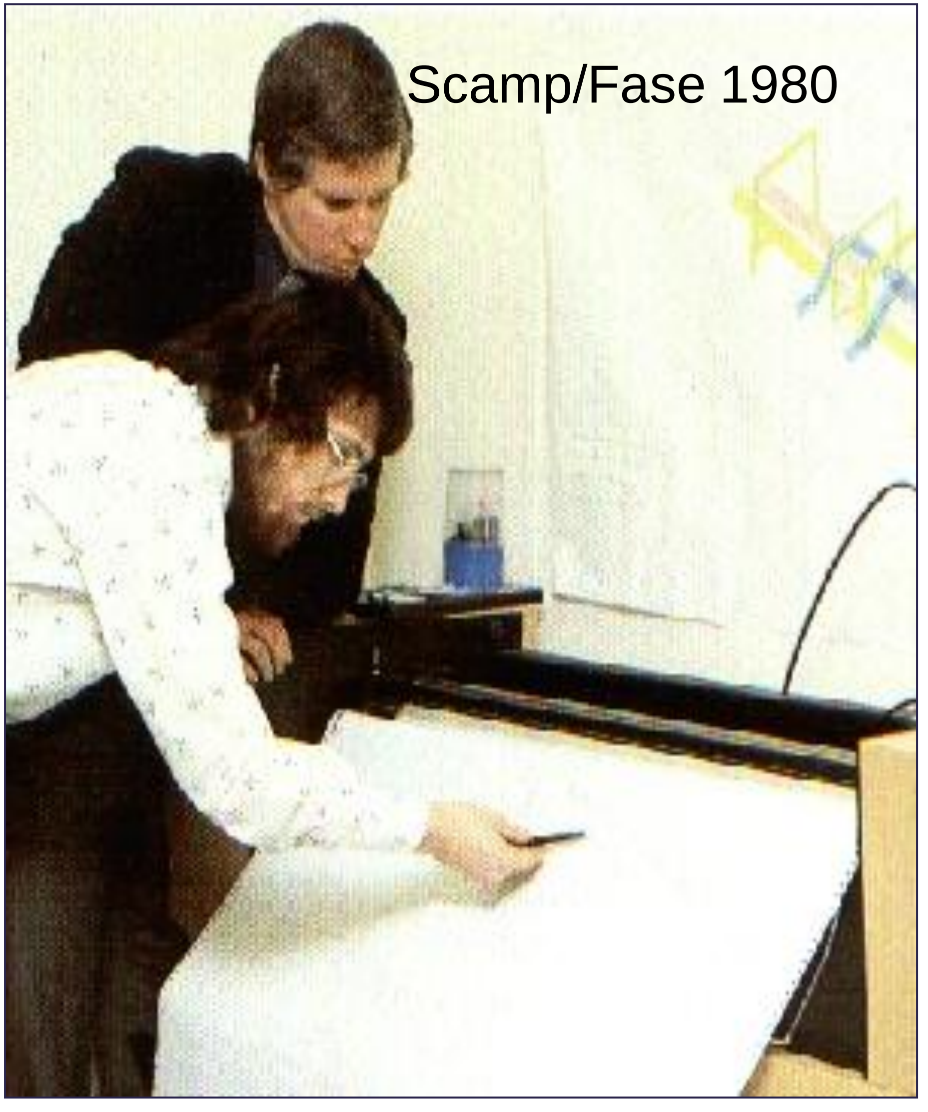
Heat added to the system

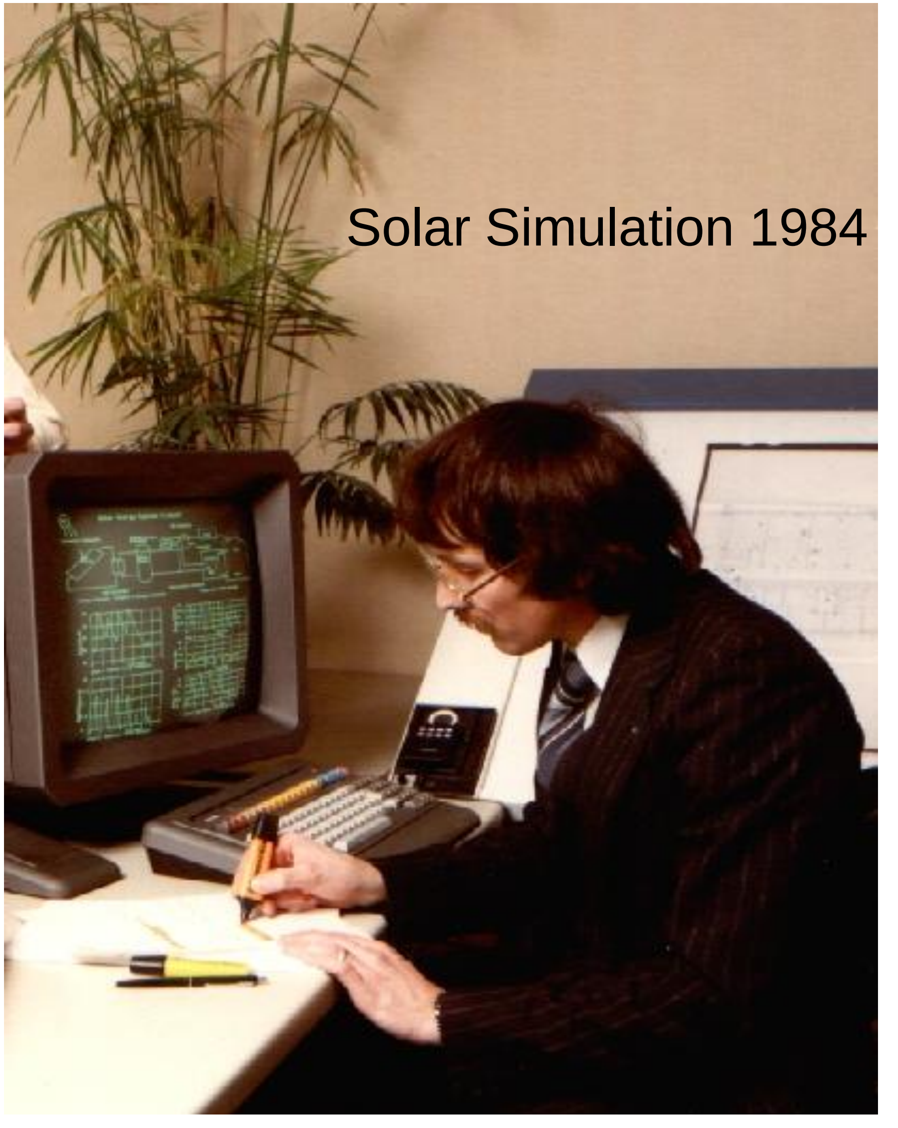
Work done by the system

Energy Balance for a Heated Building



The Early Days – Faber Computer Operations

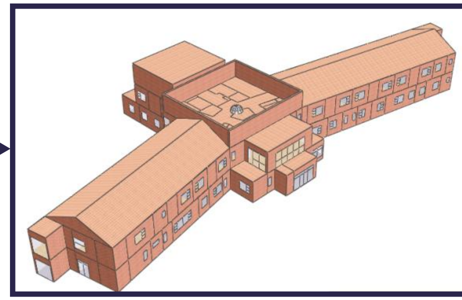




Cost / Benefit Analysis Used to Determine Target

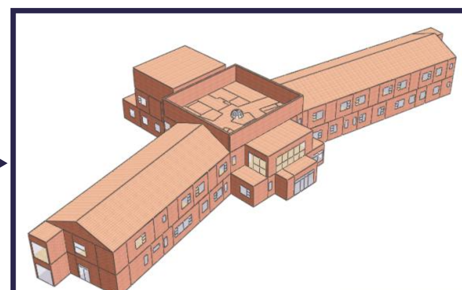
Concurrent Notional Recipe Approach

Actual U-values and efficiencies →



Actual Building → BER

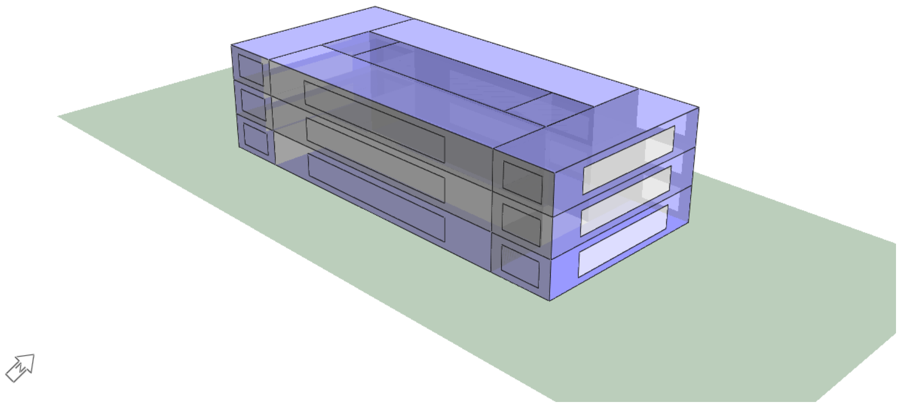
Actual size, shape, orientation, uses, weather and system types but.... ....notional U-values and efficiencies →



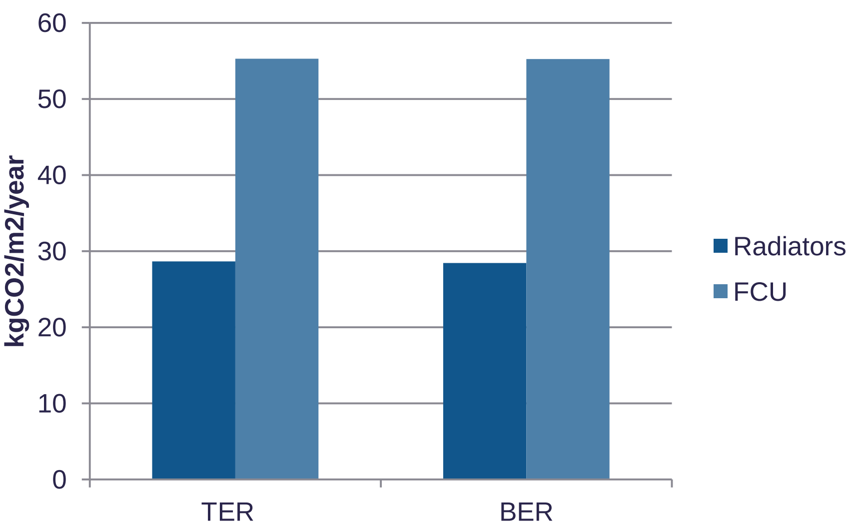
Notional Building → TER

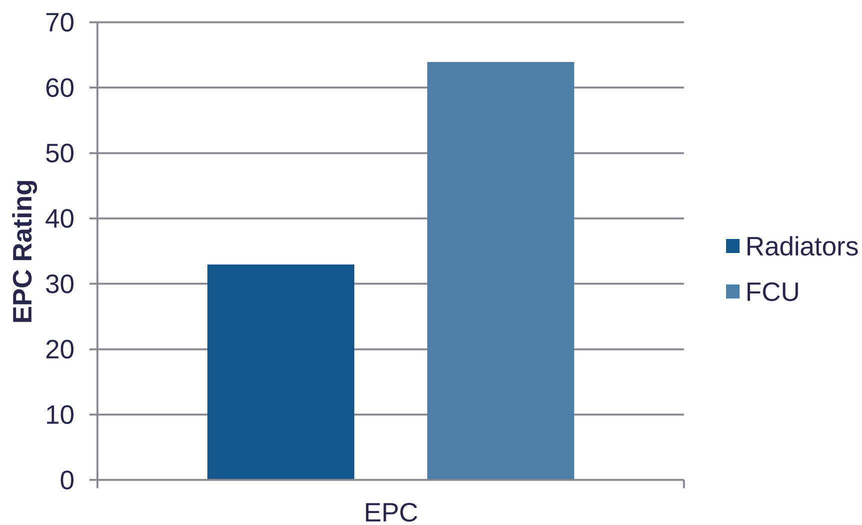
BER ↔ TER

Impact of HVAC selection on EPC Rating



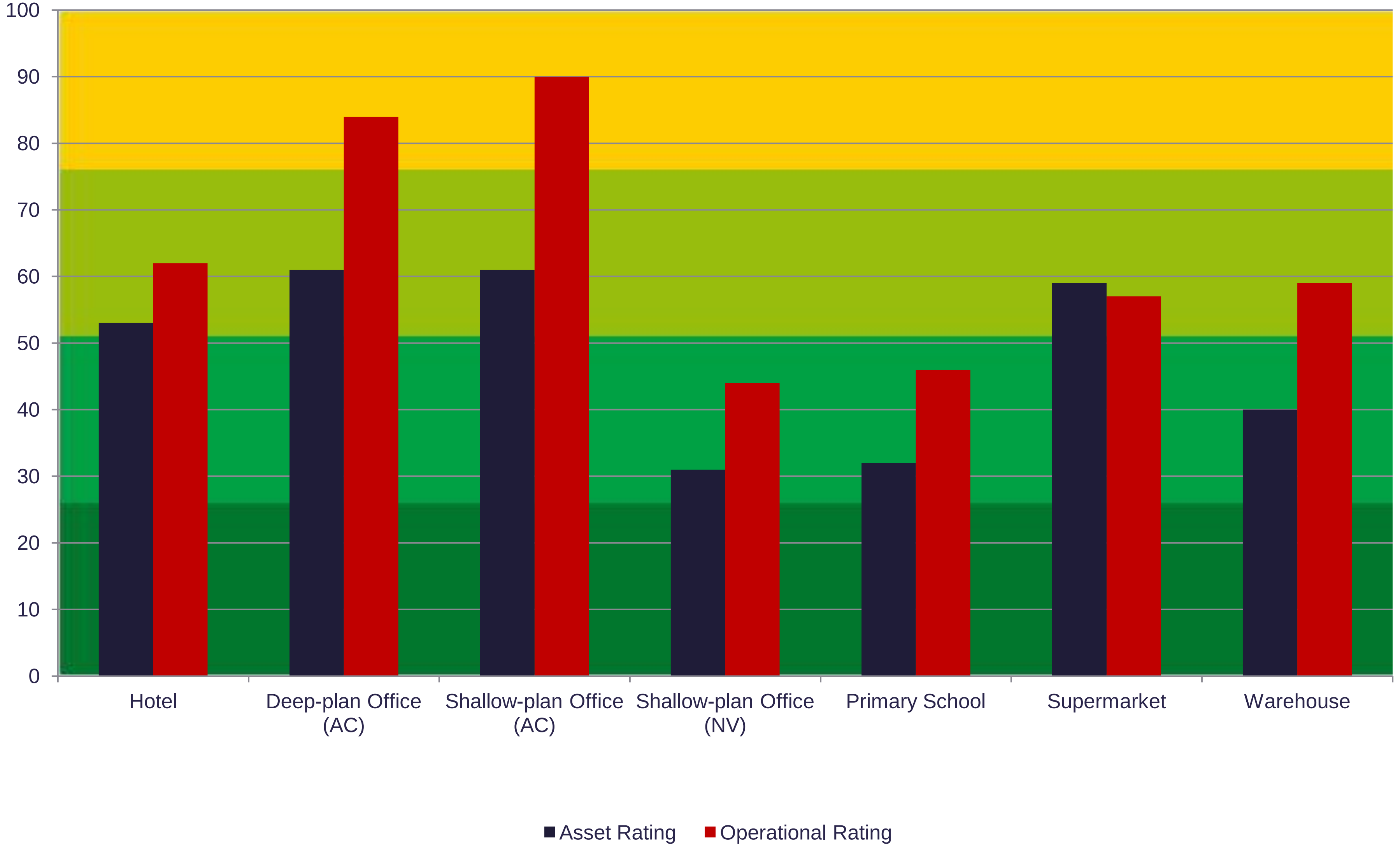
- 2100m² office building
- Two models:
  1. Radiator heated only
  2. Fan Coil Units
- Both models 'just-comply' with Building Regulations Part L2006



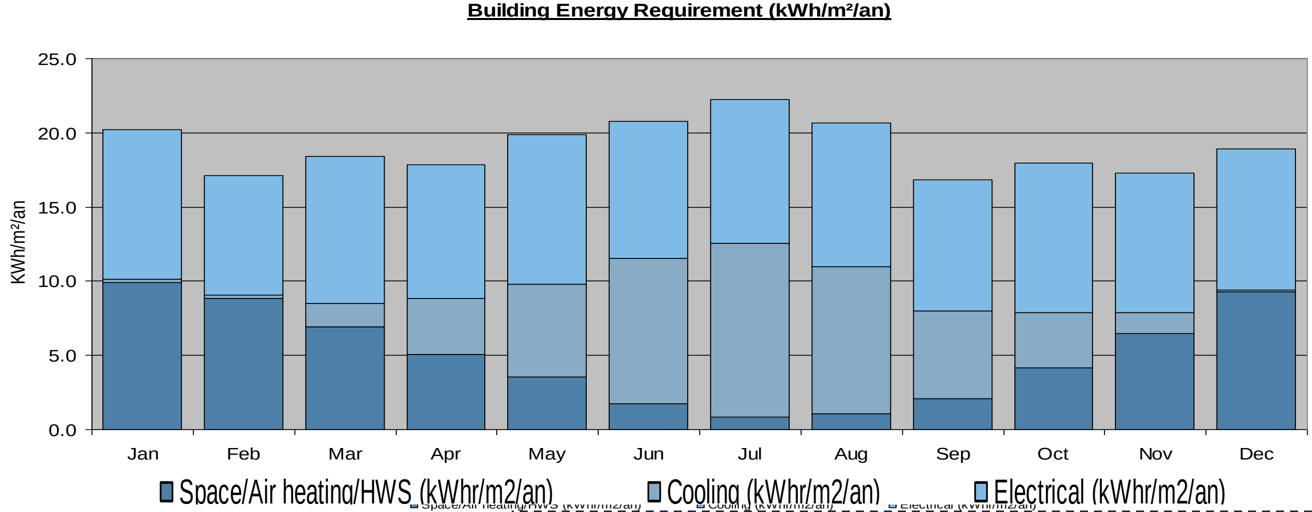


Improving DTM Software

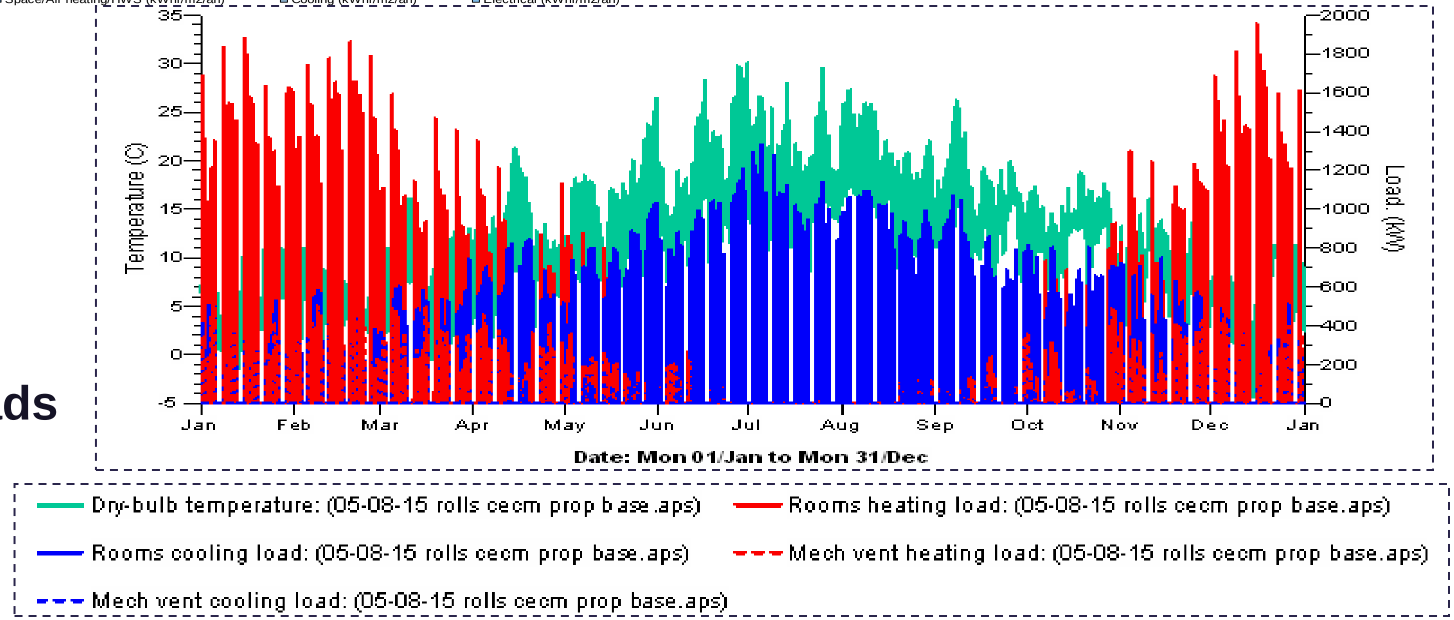
Operational Ratings for Typical Buildings when run with NCM Templates



Building Energy Loading



IES – Thermal Loads



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SBEM Main Calculation Output

SBEM Main Calculation Output Document

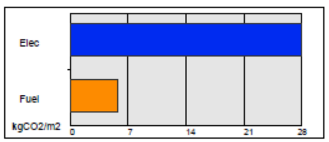
Mon Oct 21 14:13:07 2013 v4.1.e.5

Building name

Test Example Case for Project

SBEM is an energy calculation tool for the purpose of assessing and demonstrating compliance with Building Regulations (Part L for England and Wales, Section 6 for Scotland, Part F for Northern Ireland, Part L for Republic of Ireland and Building Bye-laws Jersey Part 11) and to produce Energy Performance Certificates and Building Energy Ratings. Although the data produced by the tool may be of use in the design process, **SBEM is not intended as a building design tool.**

Building Energy Performance and CO2 emissions

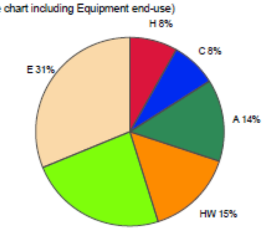


2 kgCO2/m2 displaced by the use of renewable sources.

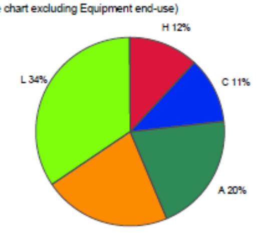
Building area is 18766.4 m2

Annual Energy Consumption

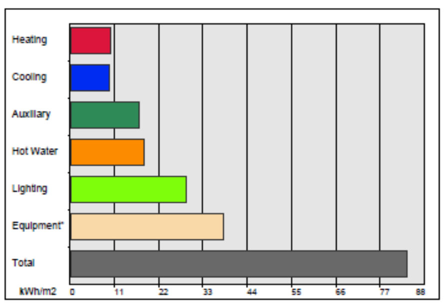
(Pie chart including Equipment end-use)

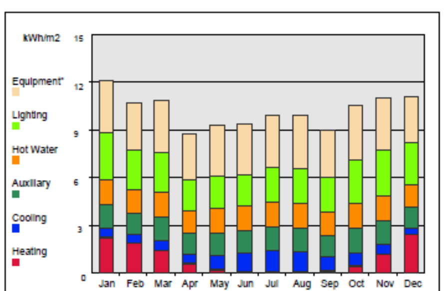


(Pie chart excluding Equipment end-use)

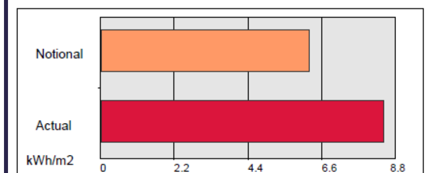


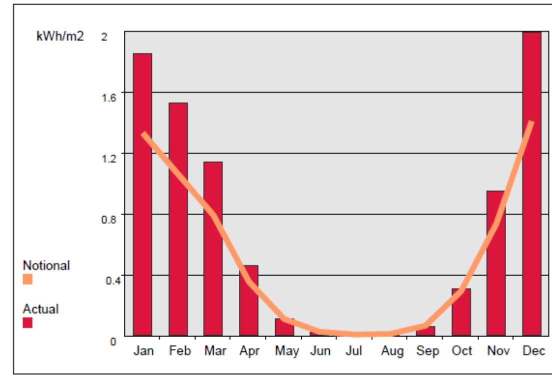
(*) Although energy consumption by equipment is shown in the graphs, the CO2 emissions associated with this end-use have not been taken into account when producing the rating.



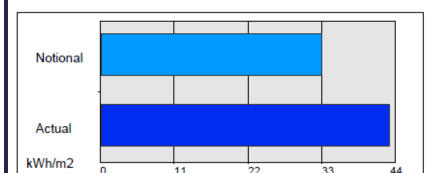


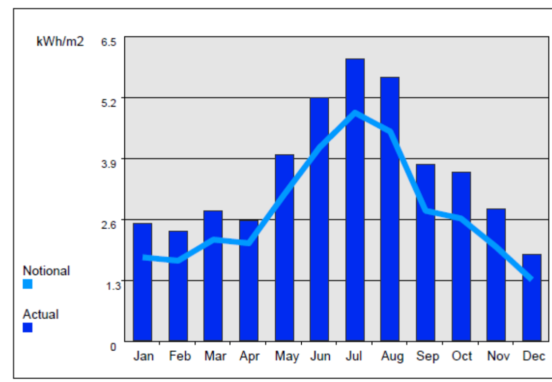
Annual Heating Demand





Annual Cooling Demand





BRUKL Output Document

BRUKL Output Document

HM Government

Compliance with England and Wales Building Regulations Part L 2010

Criterion 1: The calculated CO_2 emission rate for the building should not exceed the target

The building does not comply with England and Wales Building Regulations Part L 2010

1.1	CO_2 emission rate from the notional building, $kgCO_2/m^2$.annum	27.1
1.2	Target CO_2 emission rate (TER), $kgCO_2/m^2$.annum	27.1
1.3	Building CO_2 emission rate (BER), $kgCO_2/m^2$.annum	31.3
1.4	Are emissions from the building less than or equal to the target?	BER > TER
1.5	Are as built details the same as used in the BER calculations?	Separate submission

Criterion 2: The performance of the building fabric and the building services should achieve reasonable overall standards of energy efficiency

2.a Building fabric

Element	$U_{a\text{-}Limit}$	$U_{a\text{-}Calc}$	$U_{i\text{-}Calc}$	Surface where the maximum value occurs*
Wall**	0.35	0.2	0.2	GFBM0000_W2_-1
Floor	0.25	0.14	0.22	1VD_0001_F_5
Roof	0.25	0.22	0.22	GFRC0000_C_5
Windows***, roof windows, and rooflights	2.2	1.01	1.3	GFRT0000_W3-W0
Personnel doors	2.2	-	-	"No external personnel doors"
Vehicle access & similar large doors	1.5	-	-	"No external vehicle access doors"
High usage entrance doors	3.5	-	-	"No external high usage entrance doors"

$U_{a\text{-}Limit}$ = Limiting area-weighted average U-values [W/(m²K)]
$U_{a\text{-}Calc}$ = Calculated area-weighted average U-values [W/(m²K)] $U_{i\text{-}Calc}$ = Calculated maximum individual element U-values [W/(m²K)]

* There might be more than one surface where the maximum U-value occurs.
** Automatic U-value check by the tool does not apply to curtain walls whose limiting standard is similar to that for windows.
*** Display windows and similar glazing are excluded from the U-value check.
N.B.: Neither roof ventilators (inc. smoke vents) nor swimming pool basins are modelled or checked against the limiting standards by the tool.

Air Permeability	Worst acceptable standard	This building
$m^3/(h.m^2)$ at 50 Pa	10	10

Improving DTM Software

Four Key Areas That Can Be Improved

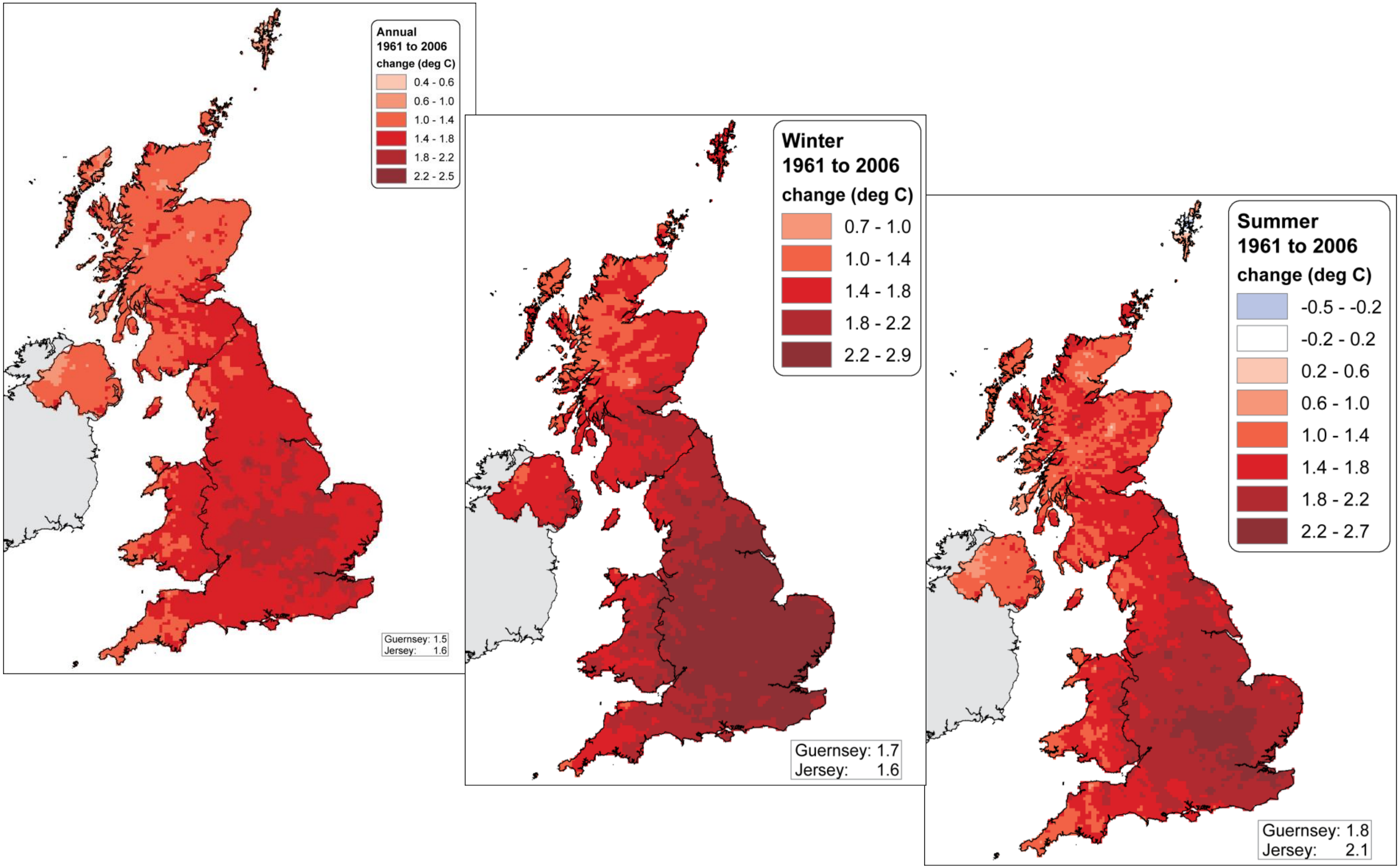
Climate data

Occupancy and internal heat gains

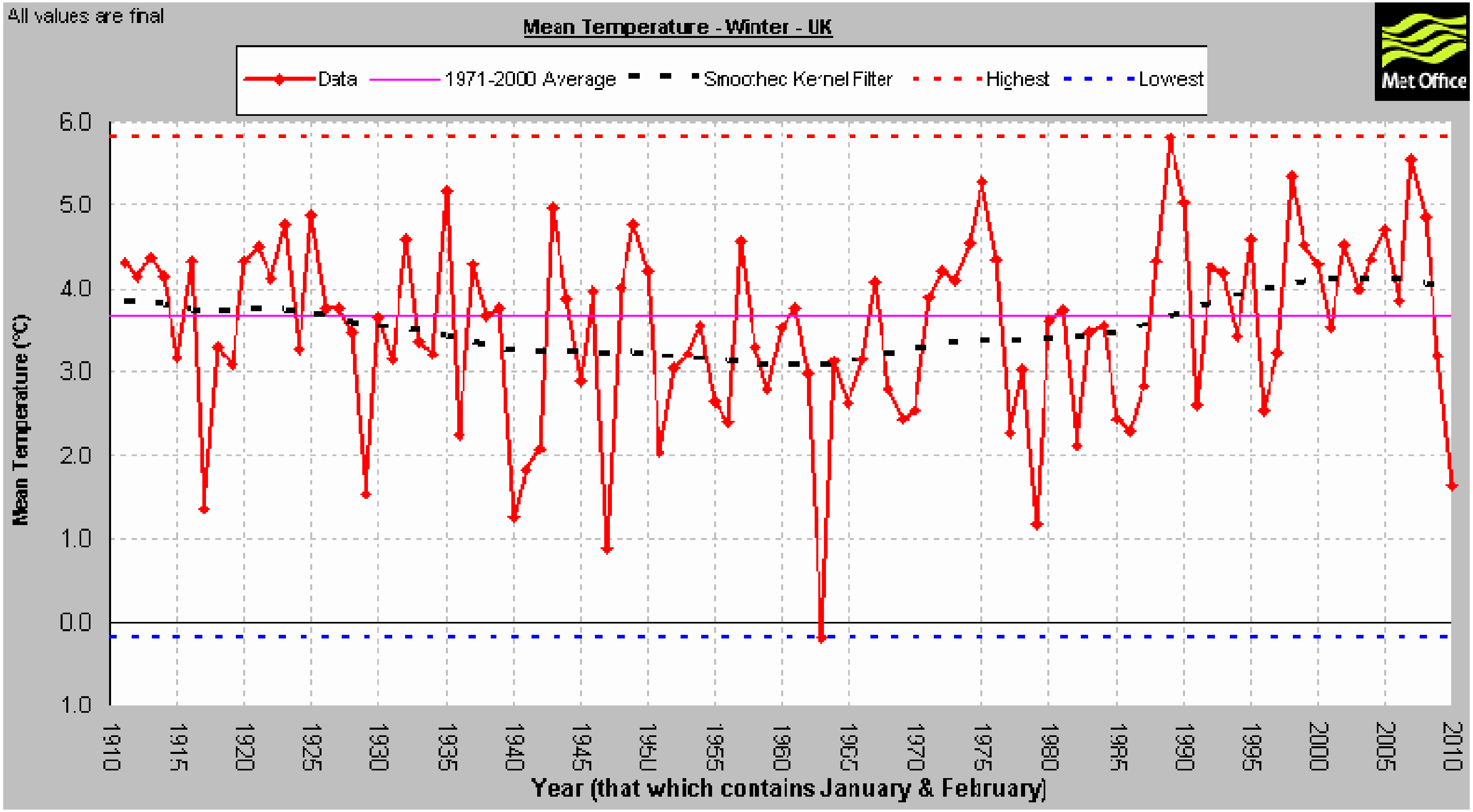
System performance

Thermal properties of building materials

Changes in Average Temperatures from 1961 to 2006



Mean UK Winter (January and February) Temperatures from 1910 - 2010

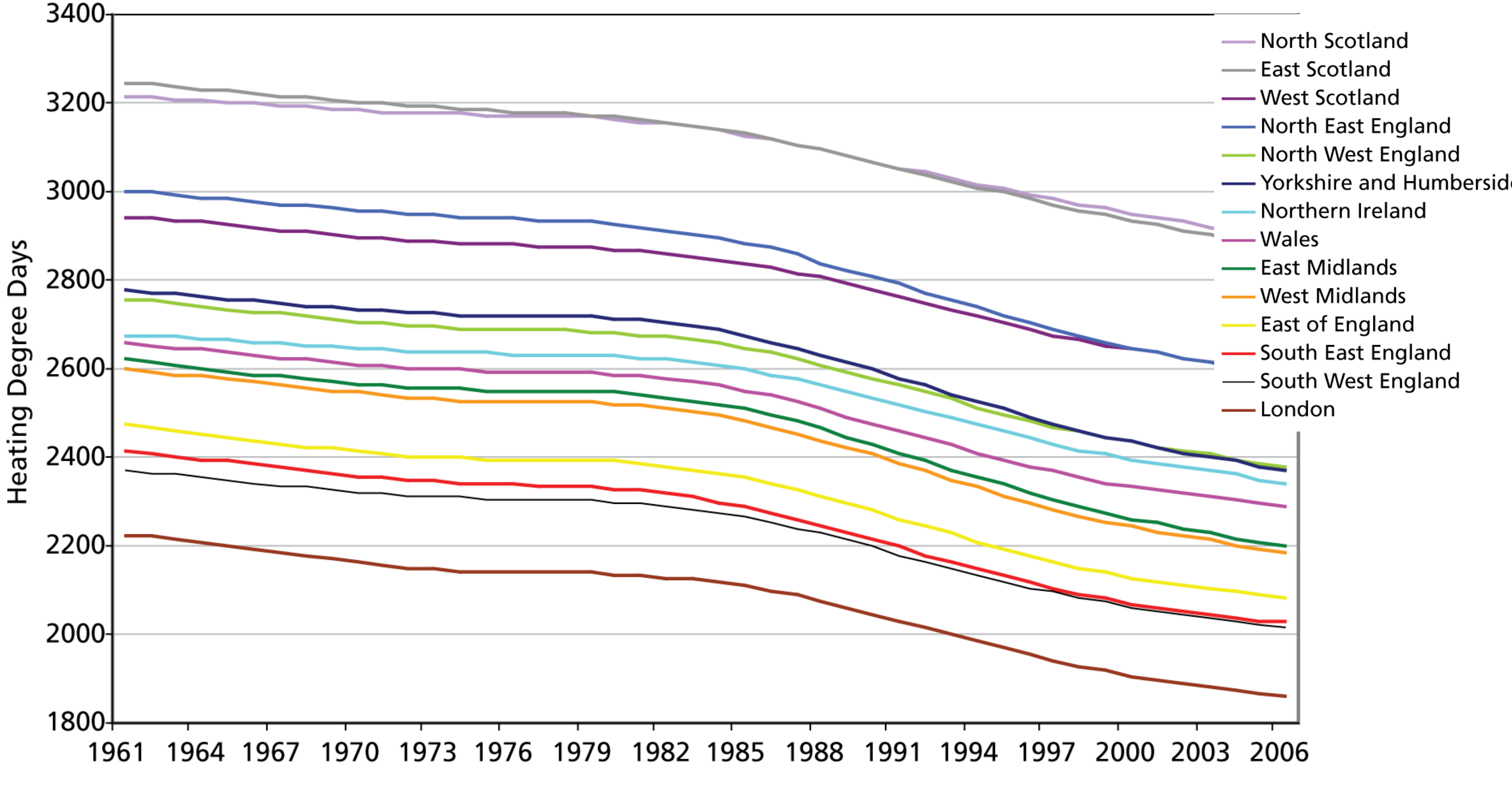


UK Weather Statistic for 2010 With Coldest December

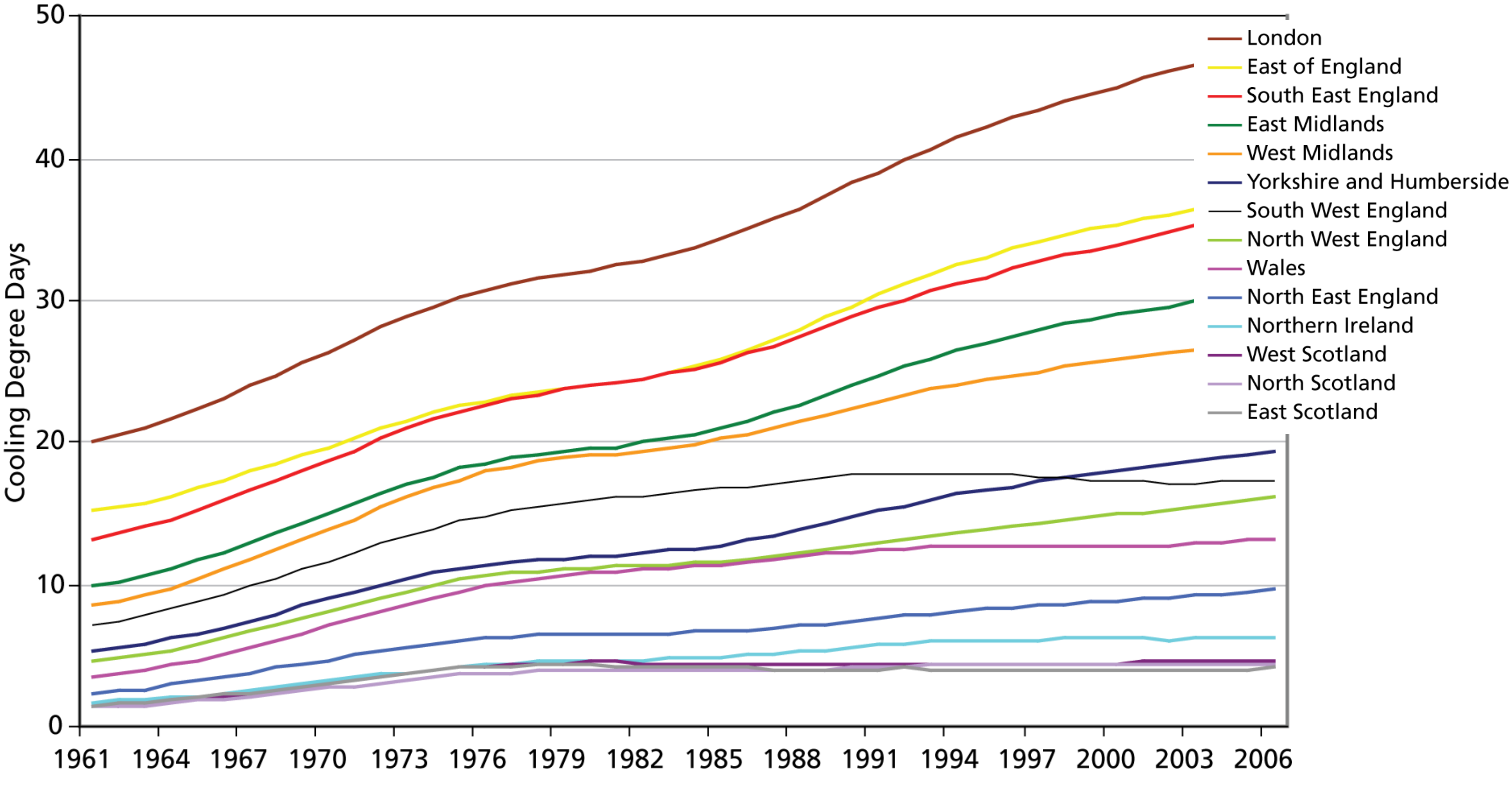
Provisional 2010	Mean temperature (deg C)		Sunshine duration		Precipitation	
	Actual	Difference from normal (71-00)	Actual (hours)	Percentage of normal (71-00) (%)	Actual (mm)	Percentage of normal (71-00) (%)
UK	8.0	-0.6	1477.2	108	940.1	83
England	8.8	-0.6	1578.7	109	722.2	86
Wales	8.2	-0.7	1612.6	116	1118.3	78
Scotland	6.5	-0.7	1277.3	107	1233.8	81
Northern Ireland	8.0	-0.7	1442.9	116	1047.4	94

Provisional Dec 2010	Mean temperature (deg C)		Sunshine duration		Precipitation	
	Actual	Difference from normal (71-00)	Actual (hours)	Percentage of normal (71-00) (%)	Actual (mm)	Percentage of normal (71-00) (%)
UK	-1.0	-5.2	53.4	139	47.4	38
England	-0.5	-5.2	52.6	118	34.8	38
Wales	-0.4	-5.2	61.3	159	53.0	31
Scotland	-1.9	-5.0	48.2	167	63.1	37
Northern Ireland	-0.6	-5.4	78.7	232	66.5	56

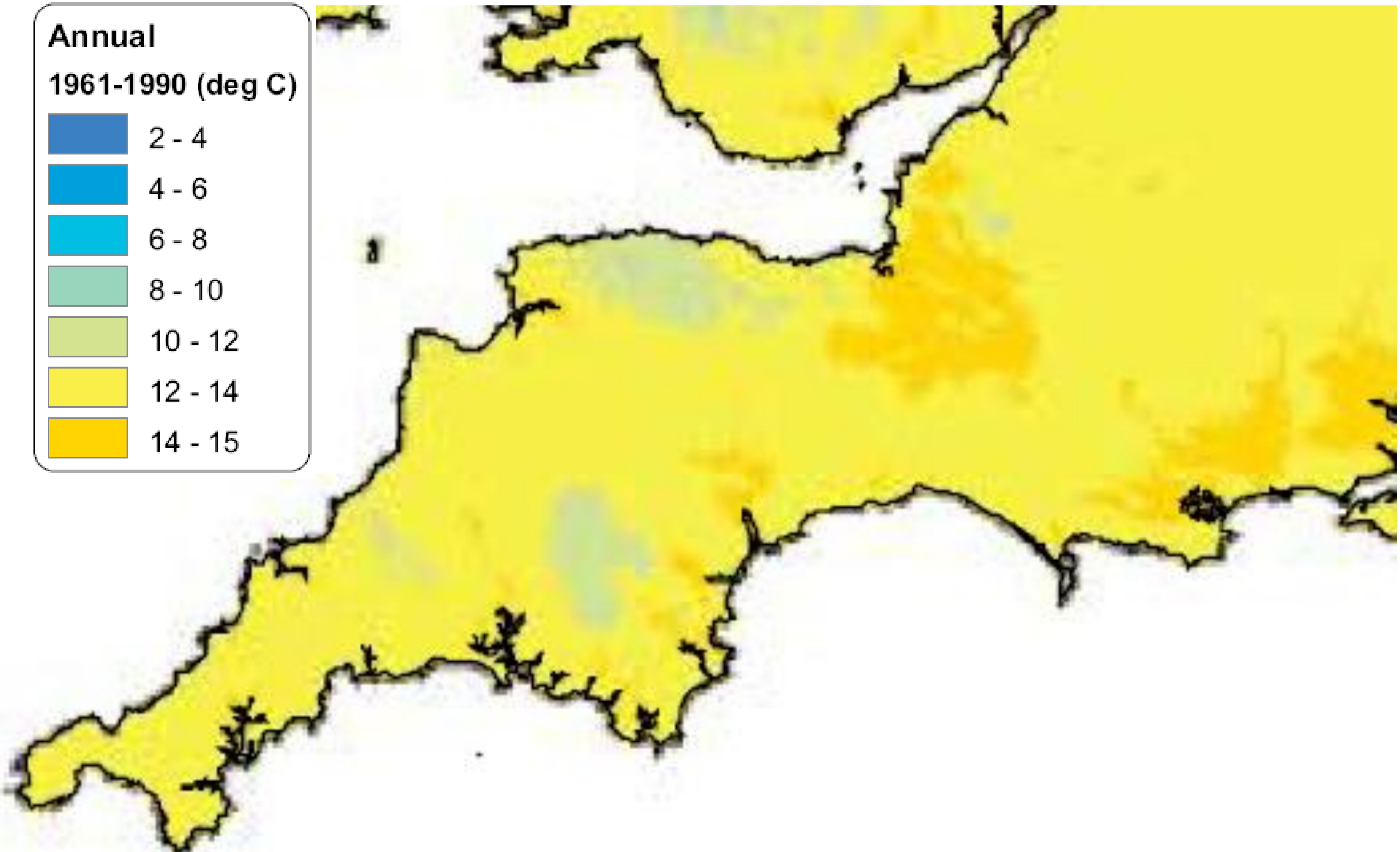
Reduction in Heating Demand from Weather over 45 Years



Increase in Cooling Demand from Weather over 45 Years



Average Temperatures in the South West



CIBSE Design Summer Year Data

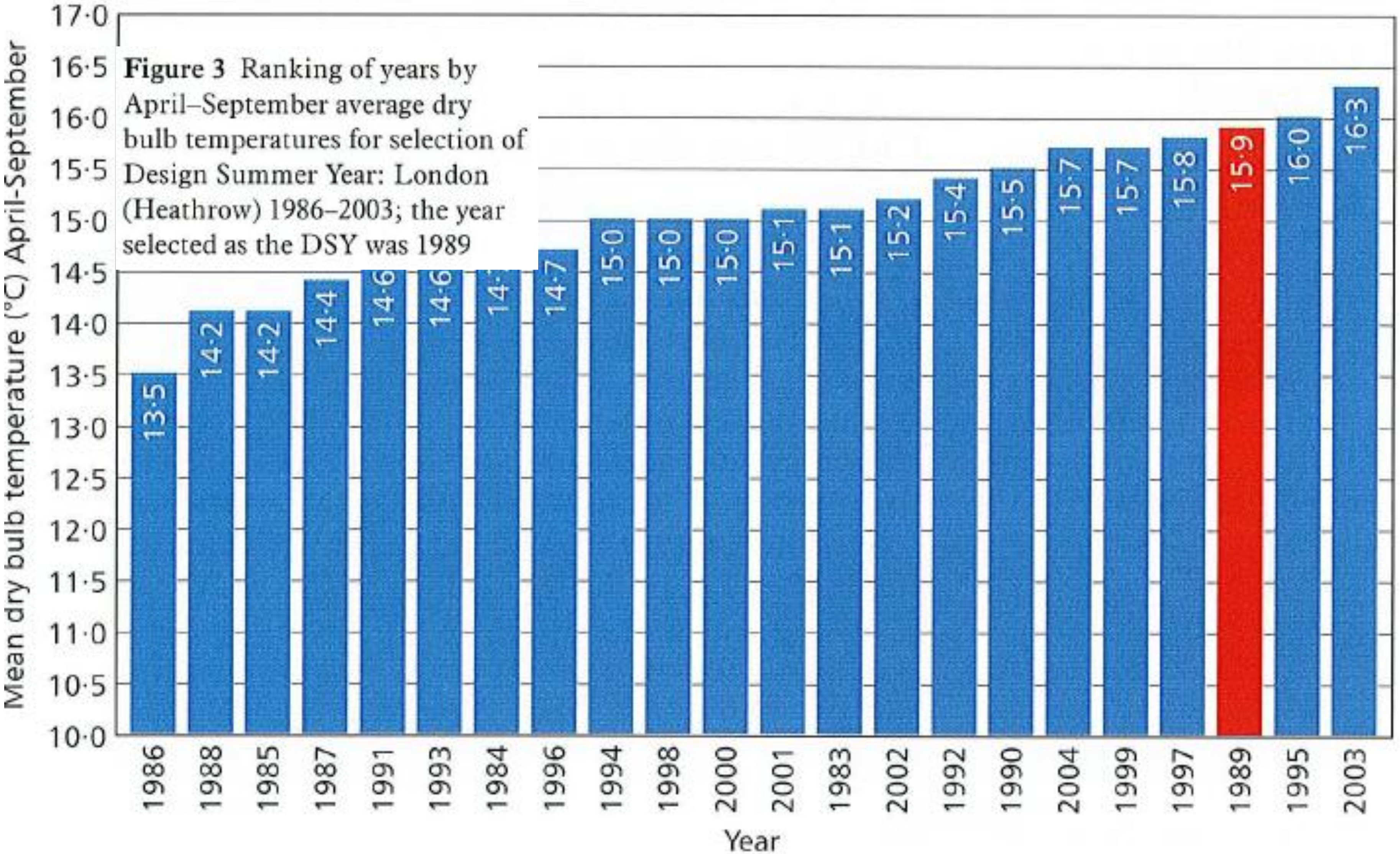
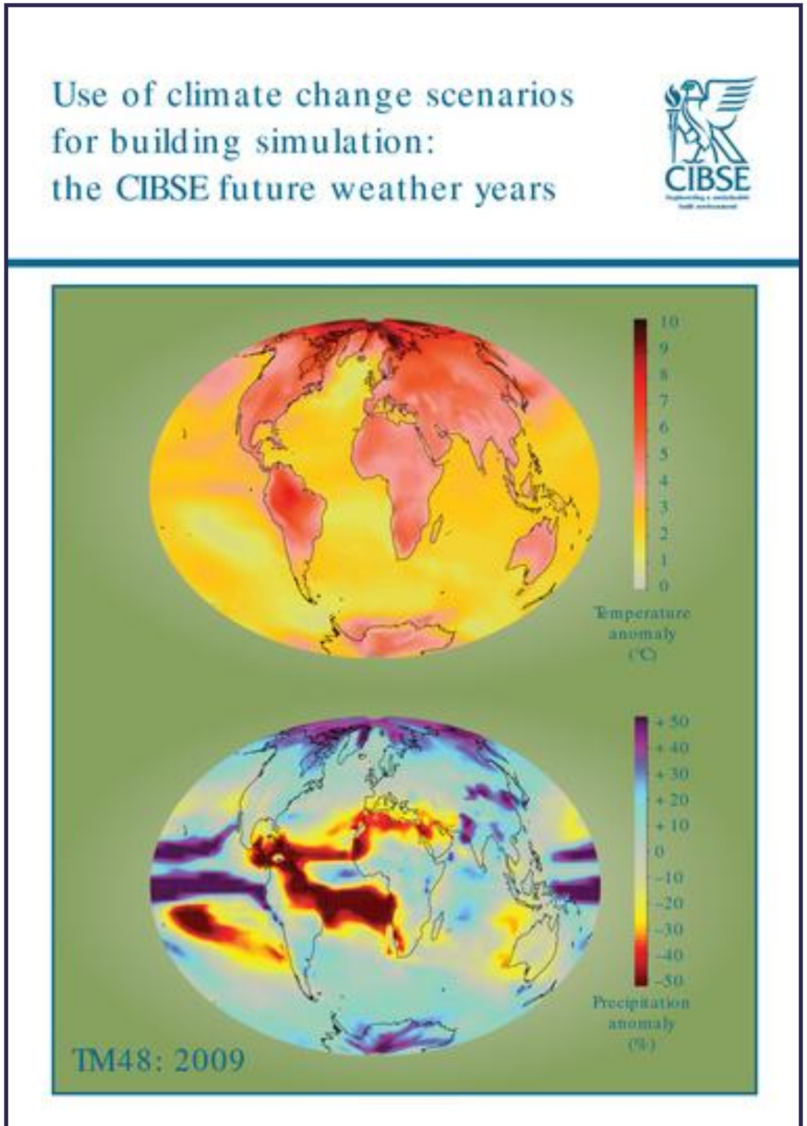


Figure 3 Ranking of years by April–September average dry bulb temperatures for selection of Design Summer Year: London (Heathrow) 1986–2003; the year selected as the DSY was 1989

Highest and Lowest Temperature Changes by 2080

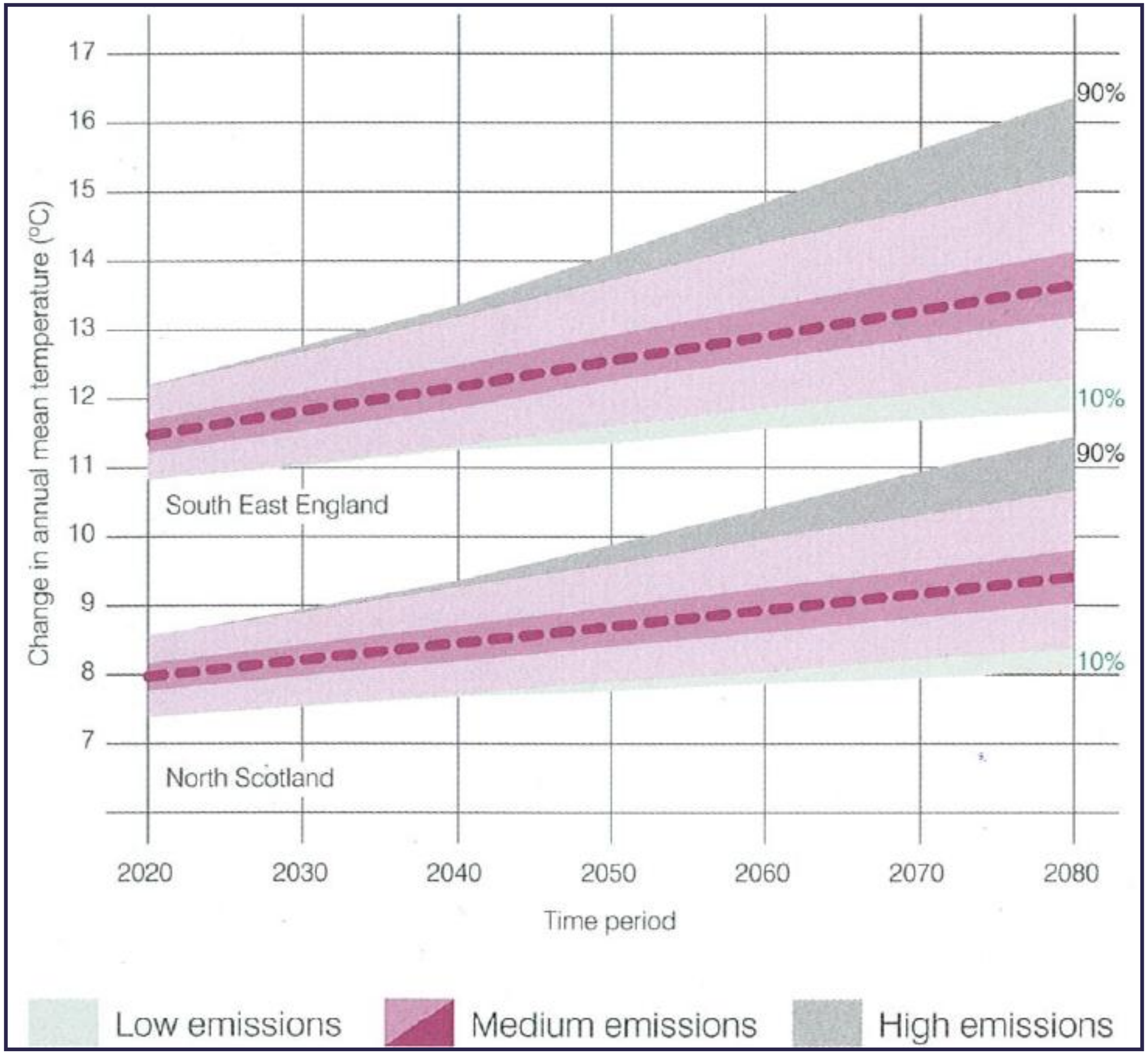
Variable		Mean temperature, winter			Mean temperature, summer			Mean daily maximum temperature, winter			Mean daily maximum temperature, summer			Mean daily minimum temperature, winter			Mean daily minimum temperature, summer		
Probability level		10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
High emissions	Highest change in UK	2.2	3.8	5.8	2.9	5.3	8.4	1.6	3.4	6.1	3.0	6.8	11.7	2.0	4.2	7.0	2.8	5.3	8.8
	Lowest change in UK	1.0	2.1	3.5	1.6	3.1	5.0	1.1	2.3	3.9	1.2	3.5	6.3	0.8	2.4	4.3	1.7	3.3	5.6
Medium emissions	Highest change in UK	1.7	3.1	4.8	2.2	4.2	6.8	1.3	2.9	5.1	2.2	5.4	9.5	1.5	3.5	5.9	2.0	4.1	7.1
	Lowest change in UK	0.8	1.8	3.1	1.2	2.5	4.1	0.8	2.0	3.4	1.1	2.8	5.0	0.6	2.1	3.7	1.3	2.7	4.5
Low emissions	Highest change in UK	1.5	2.7	4.1	1.4	3.1	5.3	1.3	2.6	4.3	1.4	4.1	7.5	1.4	2.9	4.8	1.4	3.2	5.6
	Lowest change in UK	0.8	1.7	2.7	0.8	1.9	3.2	0.9	1.8	3.0	0.7	2.1	3.9	0.7	2.0	3.3	0.9	2.1	3.5

CIBSE TM48: 2009

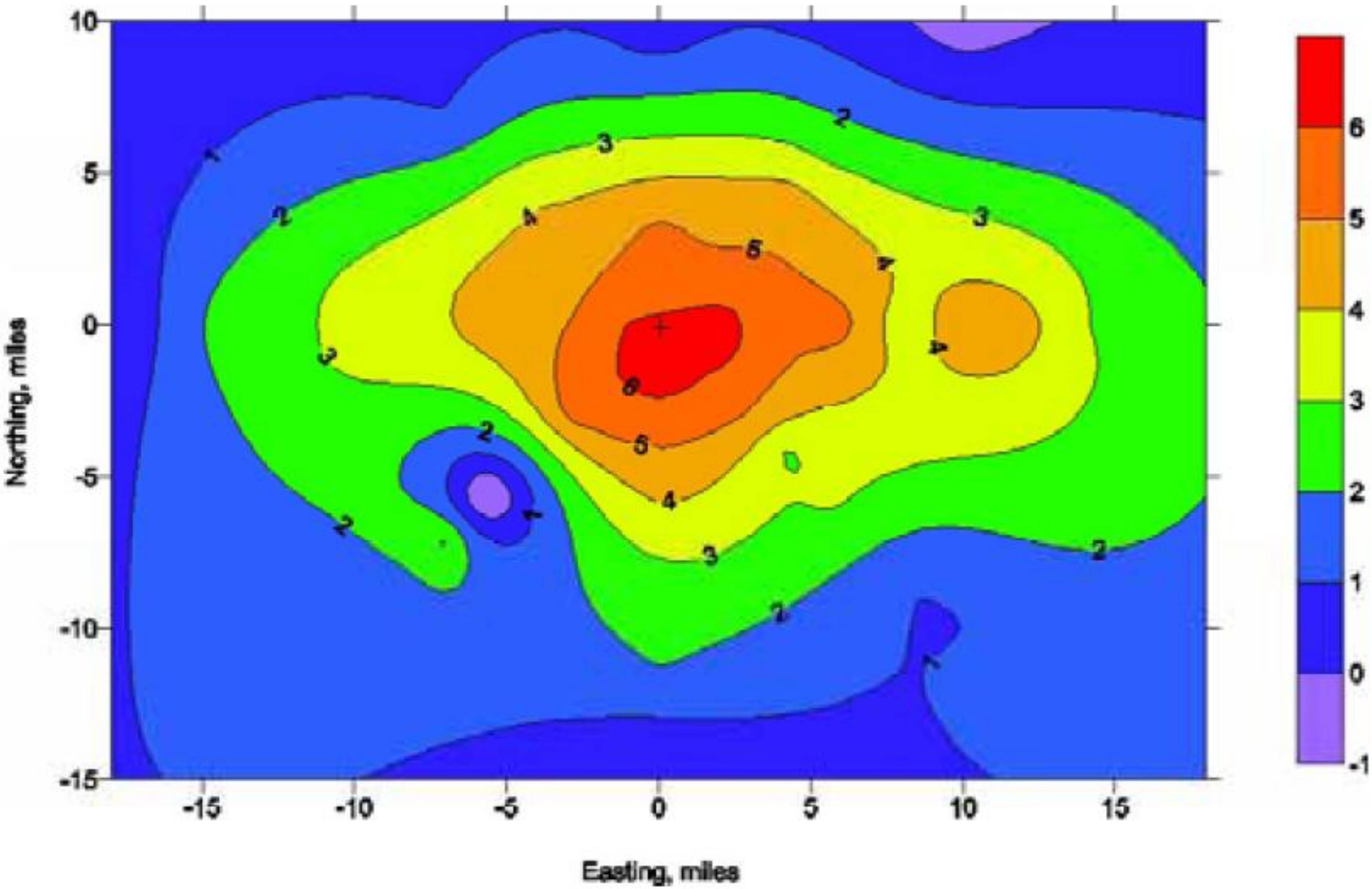


Contents

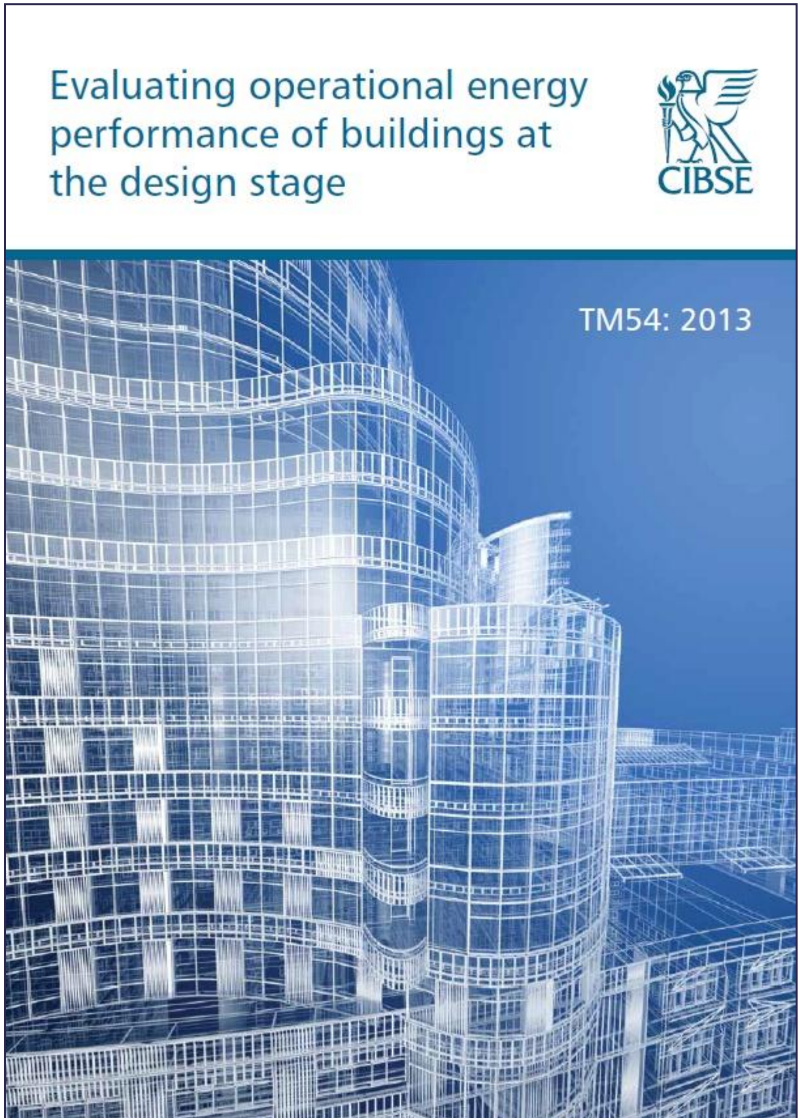
UKCP – Changes in Absolute Annual Mean Temperatures (All Scenarios)



Temperature Heat Island Effect in London

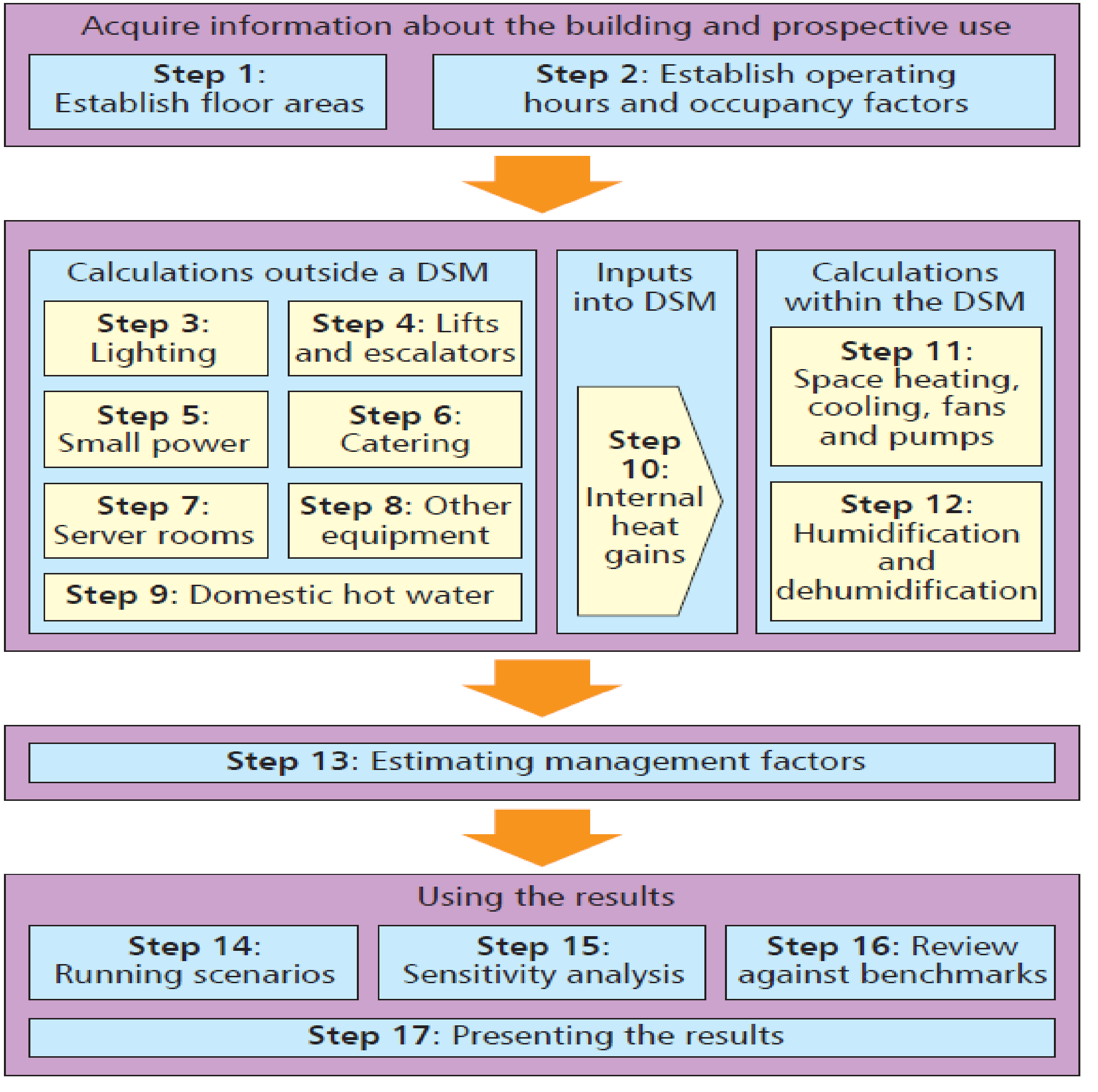


Purpose of CIBSE TM54: 2013

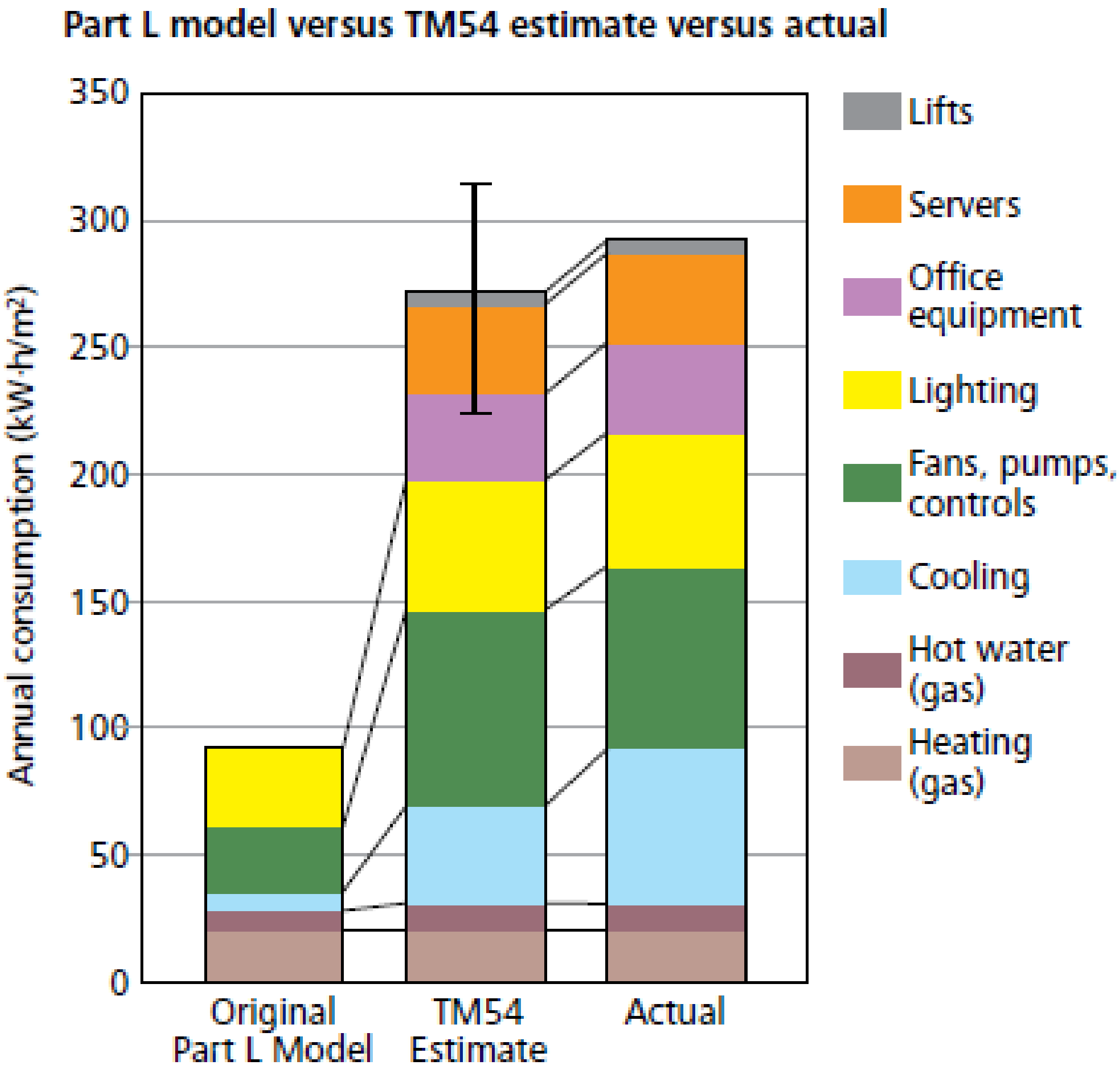


- Provide a methodology to calculate operational energy use
- Demonstrate that energy performance is dependent on how the building is occupied, run and maintained, as well as how it is designed and constructed.

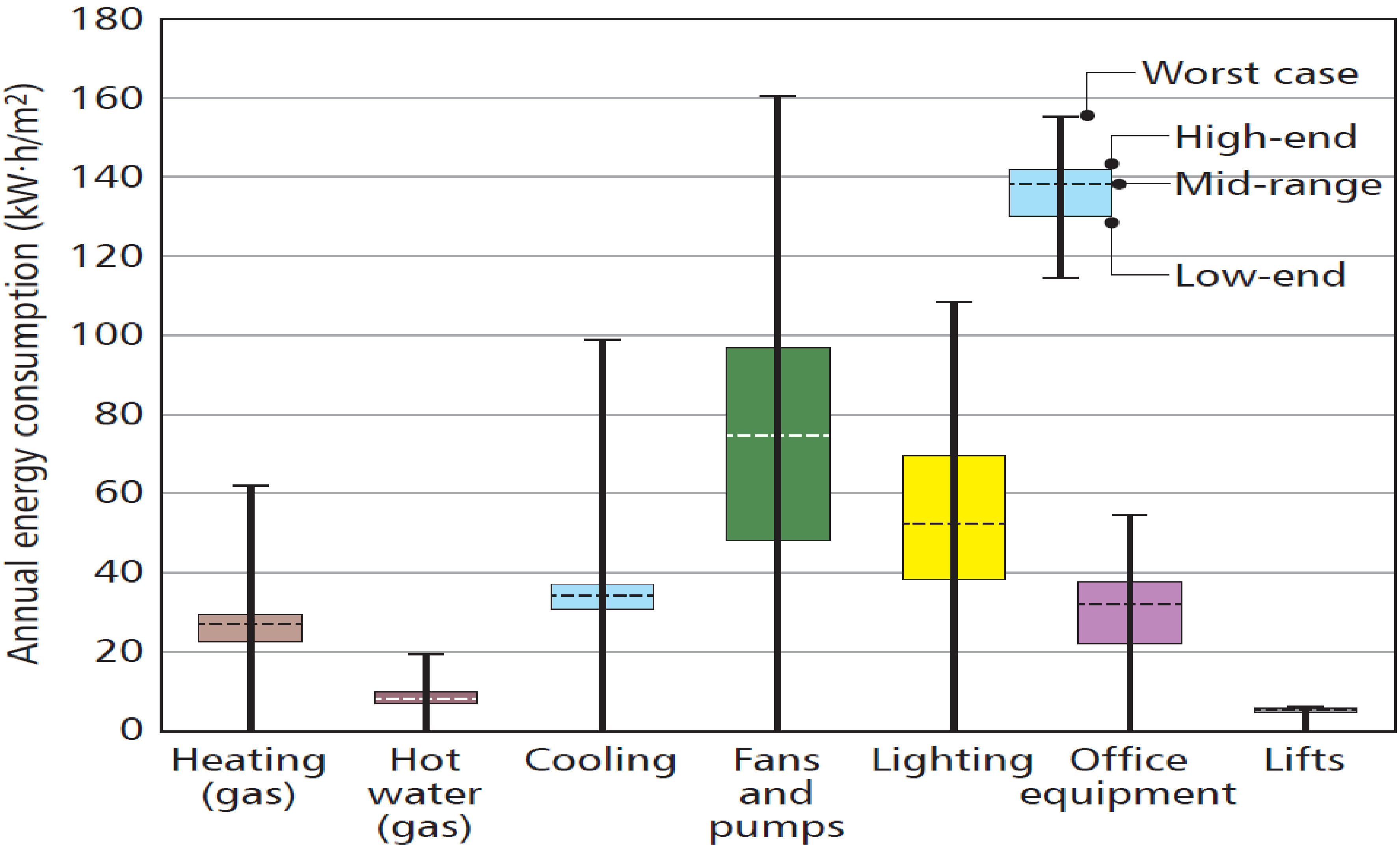
Methodology Within CIBSE TM54: 2013



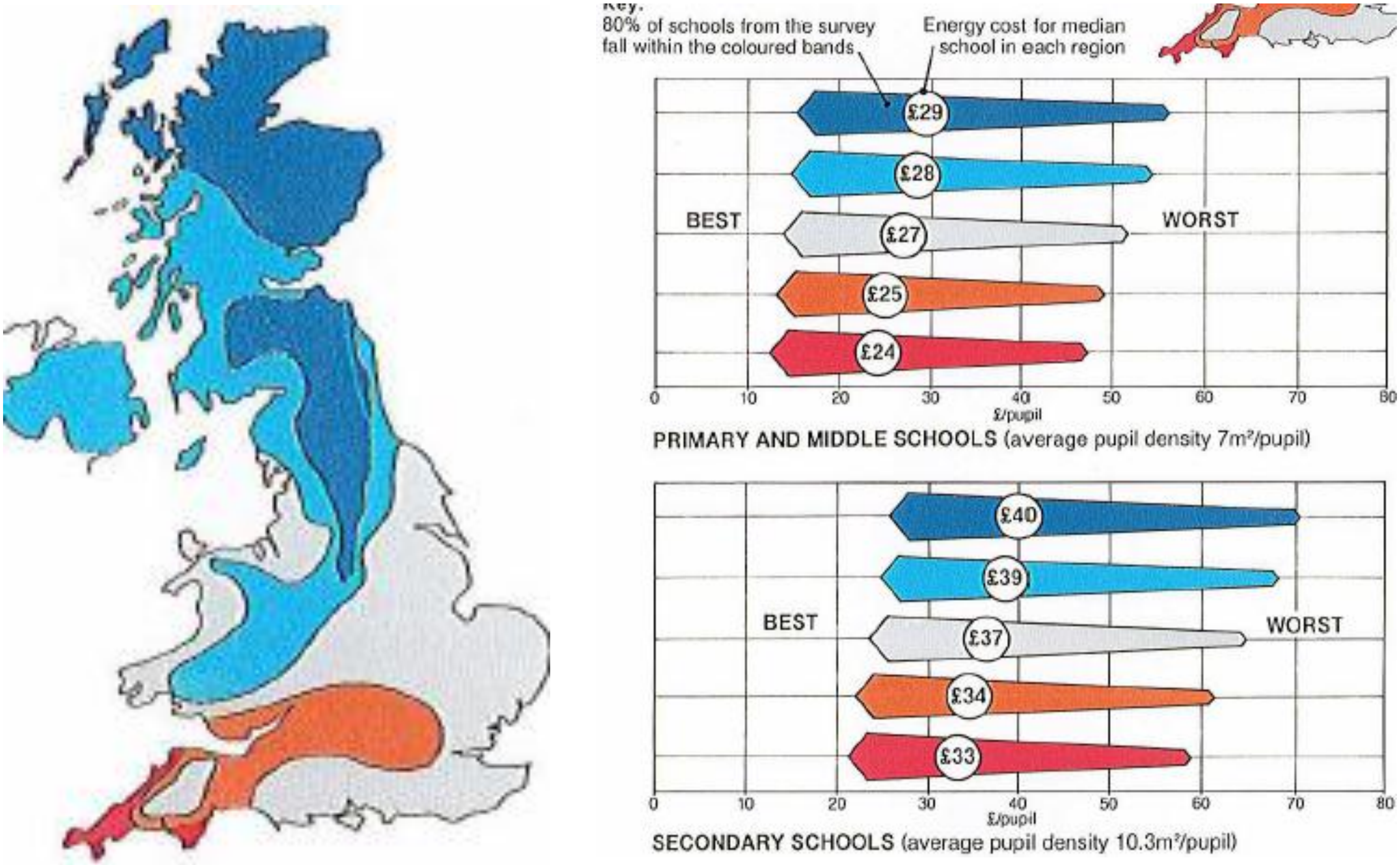
CIBSE TM54: 2013 Estimate of Annual Energy Consumption



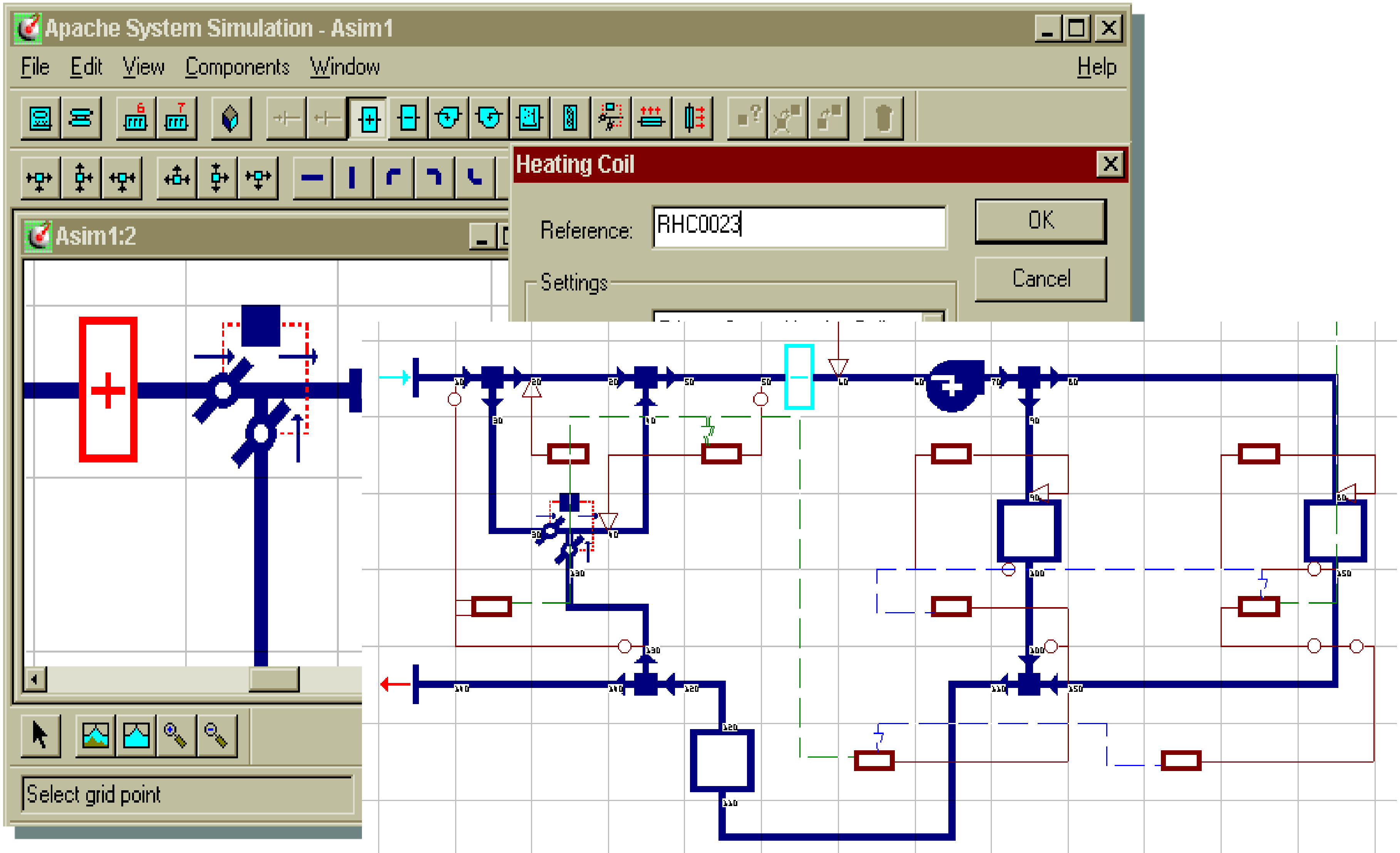
Running Scenarios following CIBSE TM54: 2013



Schools Old Energy Consumption Guide

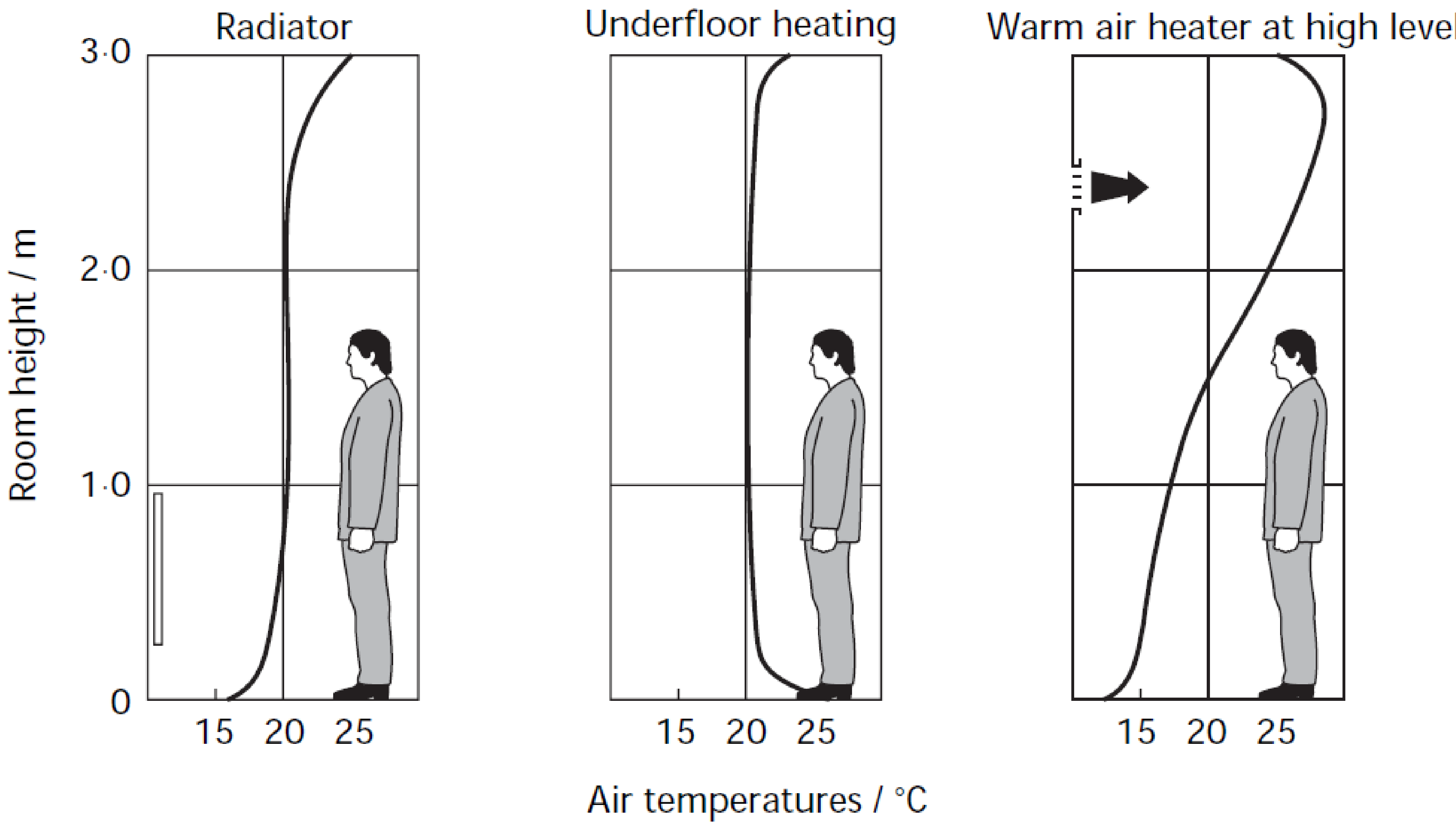


APSIM HVAC System Network and Controls



Building Services Engineering

Vertical Air Temperature Distribution with HVAC Systems

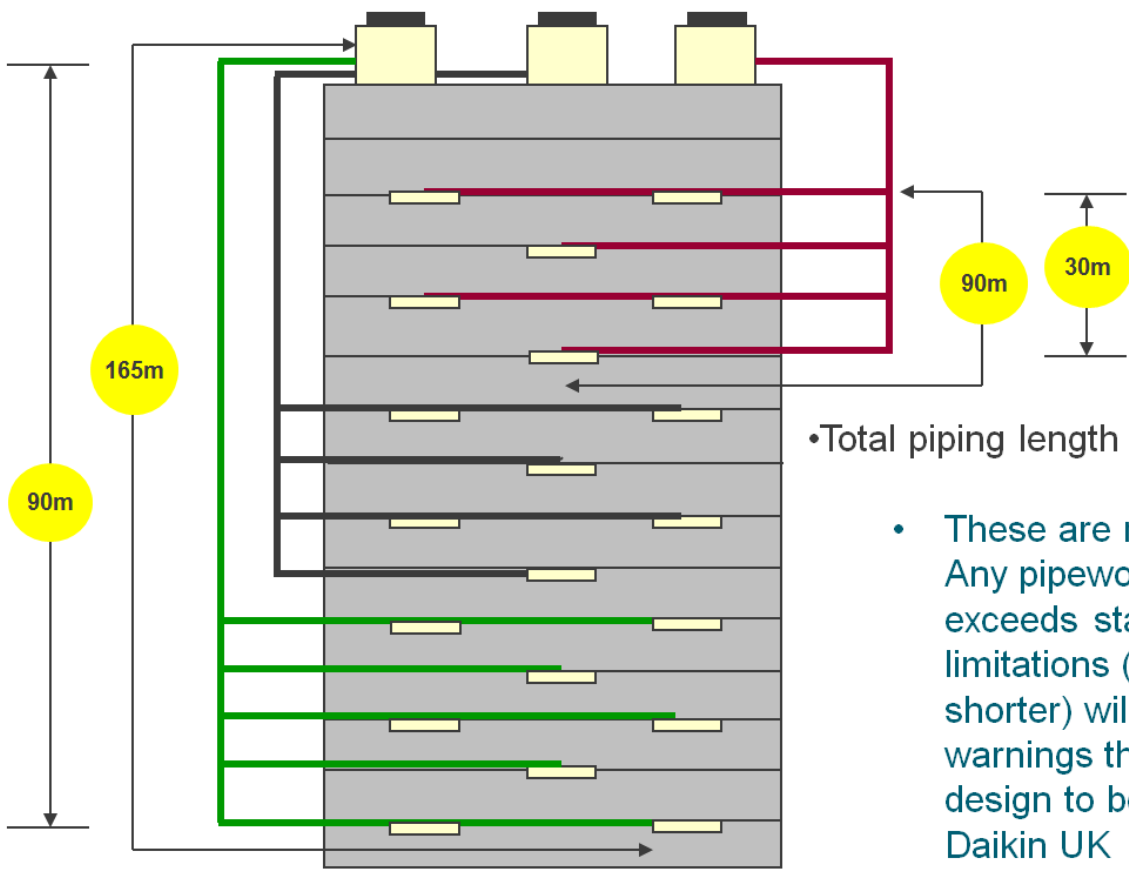


How Does Cooling Actually Perform

DAIKIN

your comfort. our world.

Maximum Pipework limitations

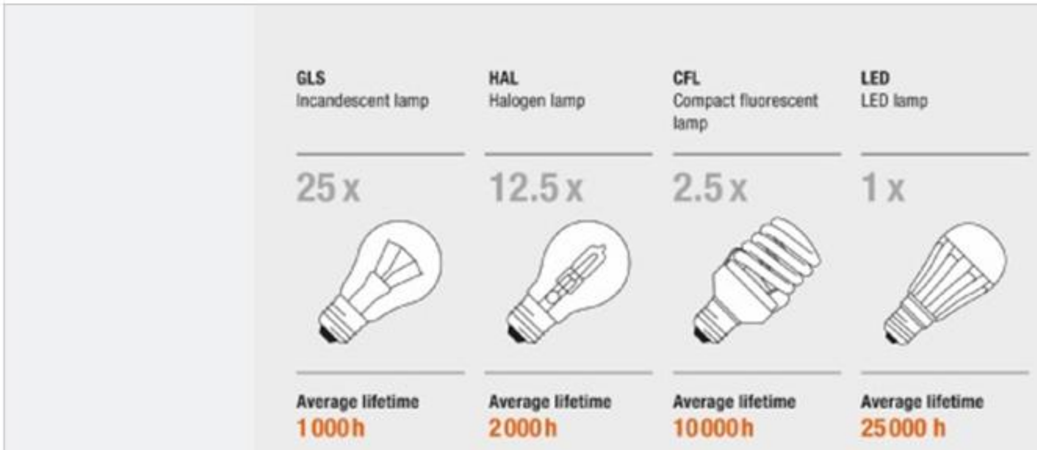


•Total piping length 1000m

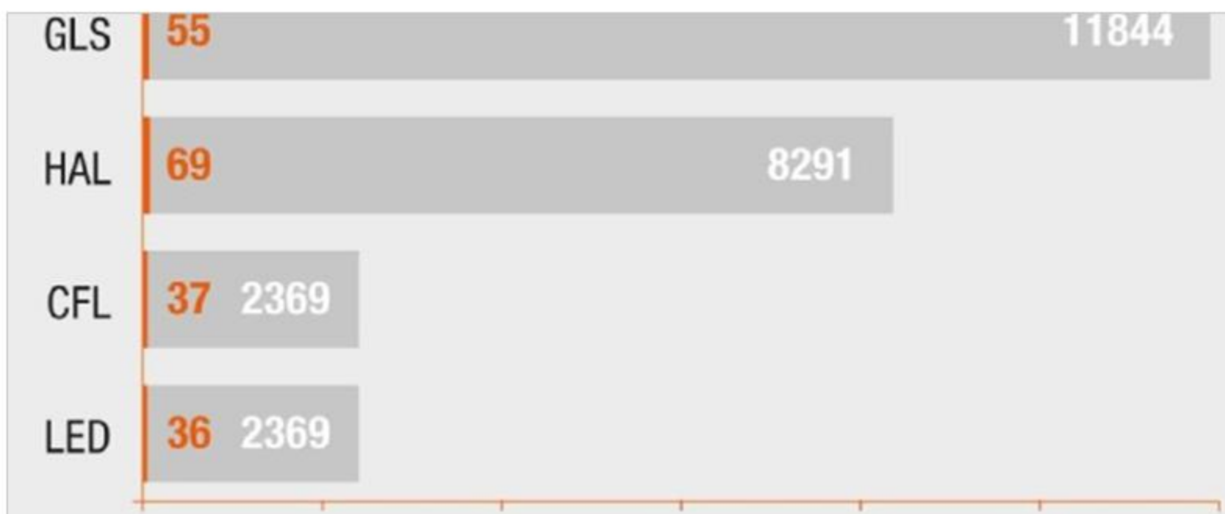
- These are maximums – Any pipework that exceeds standard limitations (which are shorter) will raise warnings that require the design to be checked by Daikin UK

Lighting Equipment and Light Loss Factors

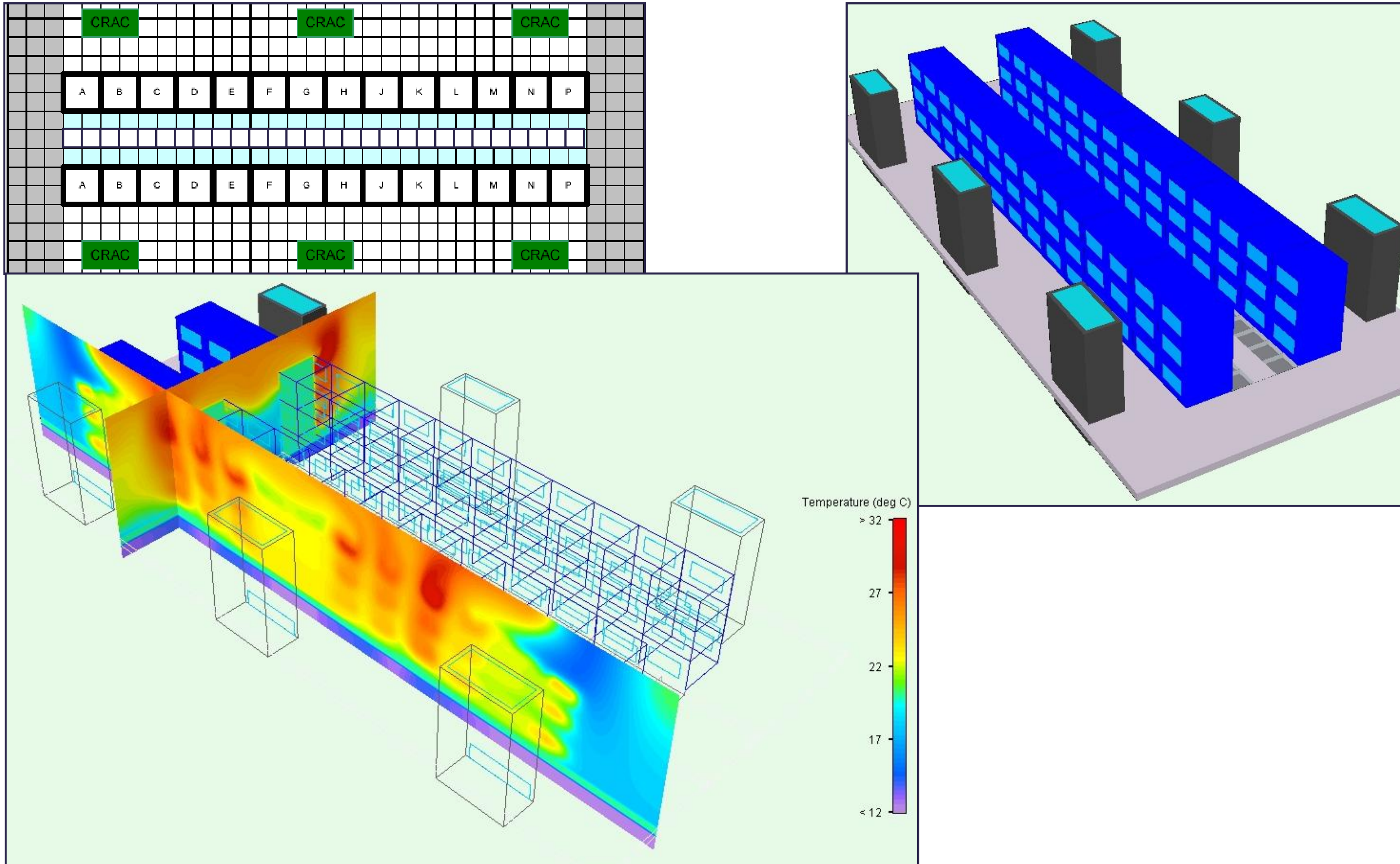
Number of lamps required for 25 000 hours of light



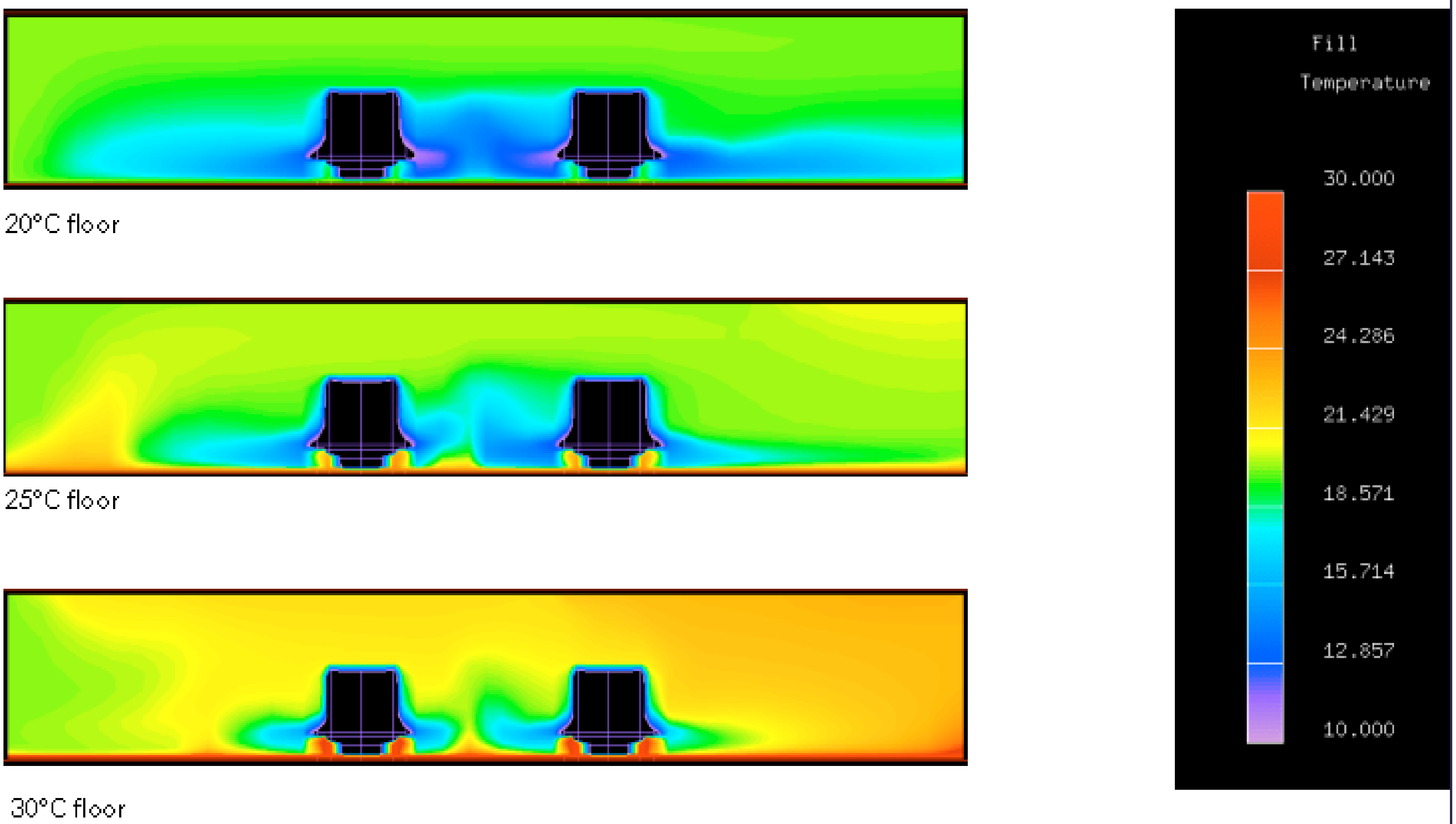
Cumulated Energy Demand based on 25 000 hours of light



CFD Analyses for Standard Data Centre



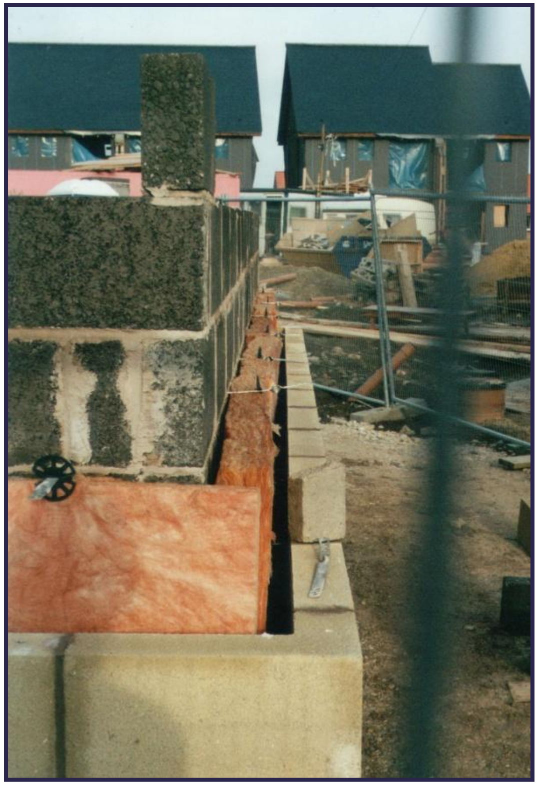
CFD Analysis of Store Food Layout with Underfloor Heating



- Floor temperature of 30°C gives acceptable conditions

Fabric Checks Have a Way to Go!!

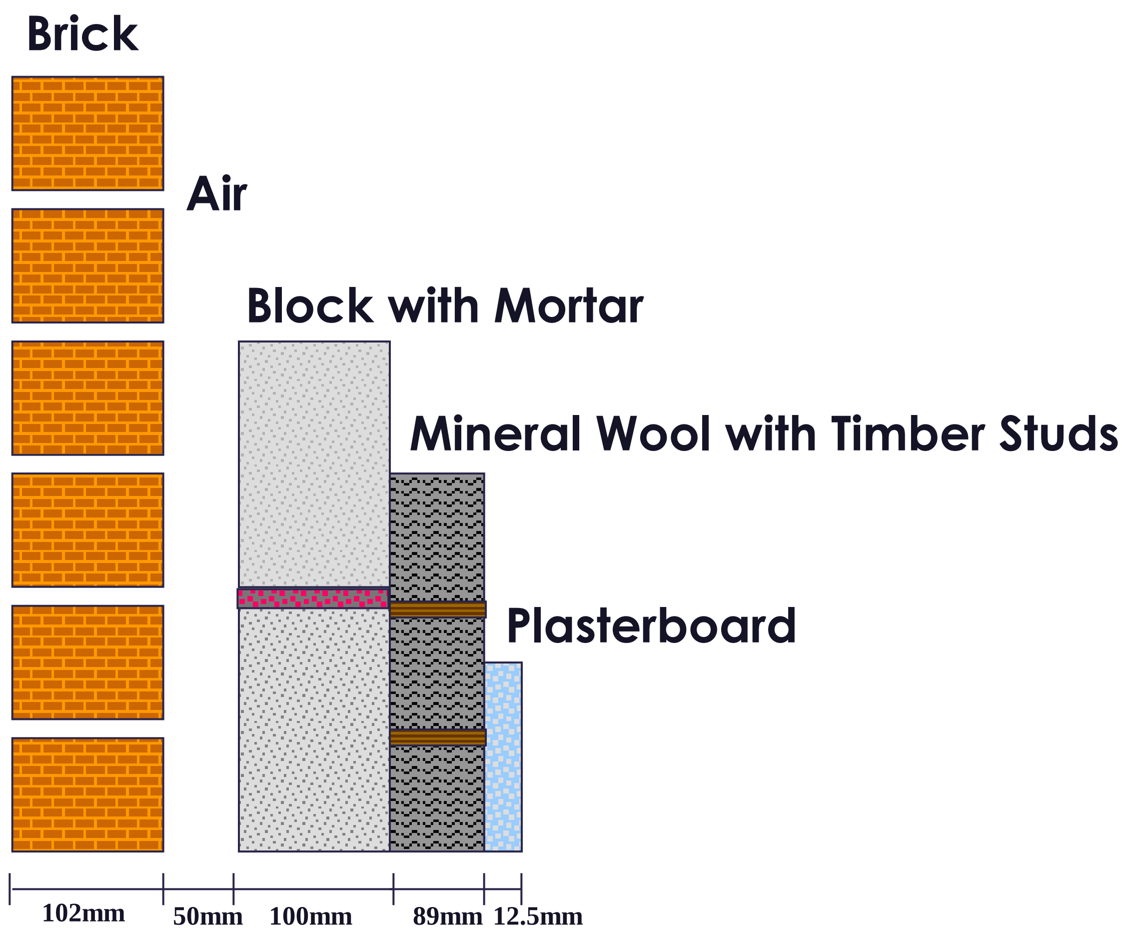
(Hens et. al. 2007)



U Values

Construction	Calculated	Measured values	
		Good workmanship	Poor workmanship
Full fill Min fibre	0.22	0.22	0.395
Partial Fill XPS rigid board	0.21	0.24	0.985

Example – Cavity Wall U-value Calculation



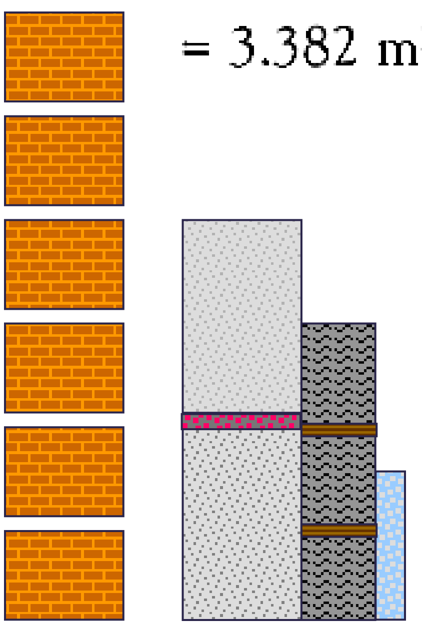
Improving DTM Software

Upper Resistance Limit

Combining these resistances we obtain:

$$R_{upper} = \frac{1}{\frac{F_1}{R_1} + \frac{F_2}{R_2} + \frac{F_3}{R_3} + \frac{F_4}{R_4}} = \frac{1}{\frac{0.818}{3.783} + \frac{0.062}{2.988} + \frac{0.112}{2.126} + \frac{0.008}{1.331}}$$

$= 3.382\ m^2\ K/W.$



R1 U-value would be 0.26 W/m²K
As most people would

R1 U-value would be 0.30 W/m²K
To 1995 proportional area method

U-value of the Wall

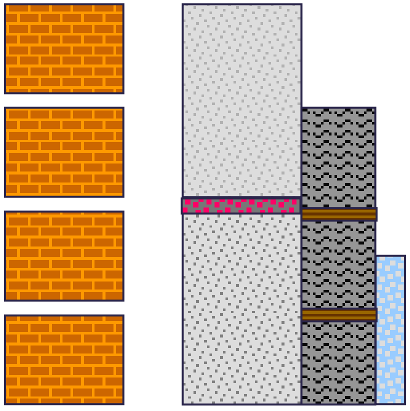
The effect of air gaps or mechanical fixings[2] should be included in the U-value unless they lead to an adjustment in the U-value of less than 3%.

$U = 1 / R_T + \Delta U_g$ (if ΔUg is not less than 3% of $1 / R_T$)

$U = 1 / R_T$ (if ΔU_g is less than 3% of $1 / R_T$)

In this case $\Delta U_g = 0.003$ W/m²K and $1 / R_T = 0.315$ W/m²K.
Since ΔUg is less than 3% of $(1 / R_T)$,

$U = 1 / R_T = 1 / 3.170 = 0.32$ W/m²K (expressed to two decimal places)



U-value would be 0.26 W/m²K
As most people calculate it

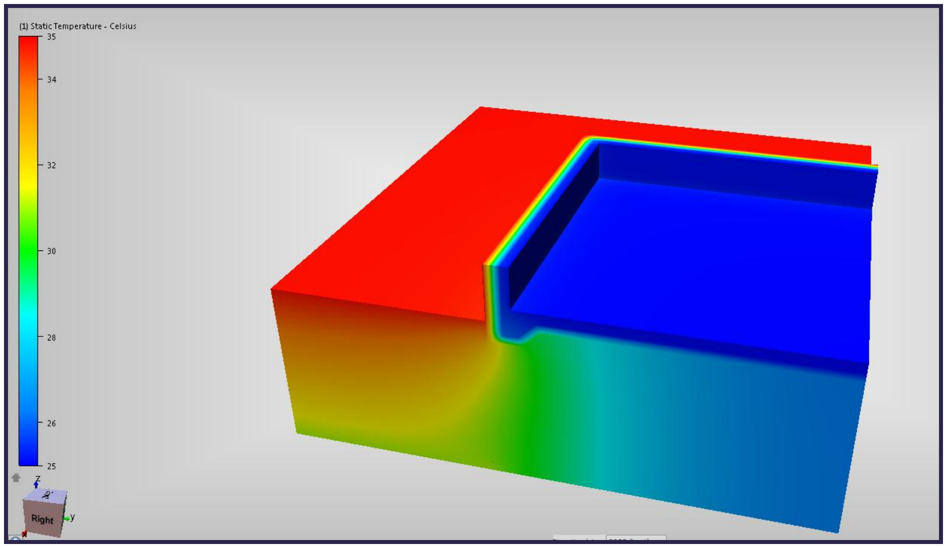
U-value = 0.30 W/m²K for Part L 1995 proportional area method

U-value = 0.32 W/m²K from Part L 2002

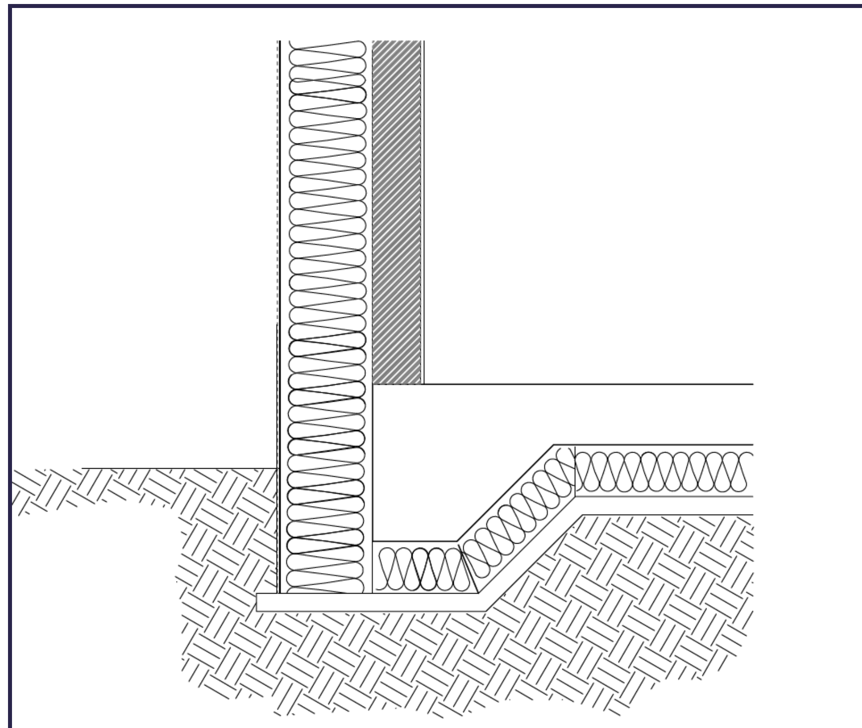
Passive House Project Case Study

Super insulation and thermal mass, allow the building envelope to decouple the internal environment from the harsh external conditions

Envelope meets or exceeds values recommended by Passivhaus Institute	
Walls and roof	0.09 W/m²K
Floor	0.10 W/m²K
Glazing	1.00 W/m²K



Images shows cut-away of conduction model of wall and ground floor for average summer conditions



CIBSE Guide A10

Vapour Resistivity

Values of vapour resistivity for common materials are given in Table A10.4 under two headings; "minimum" and "typical".

The "minimum" values are the smallest values found in relevant literature[2,3] and should not be used for general calculations. The "typical" values are taken from the middle of the range of values for each material and may be used for calculation in the absence of more specific data. However, it should be borne in mind that individual samples of material may exceed these typical values by a factor of two or more.

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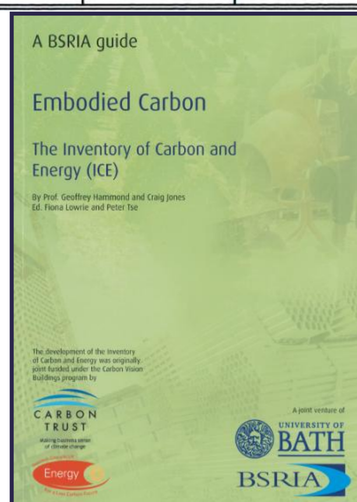
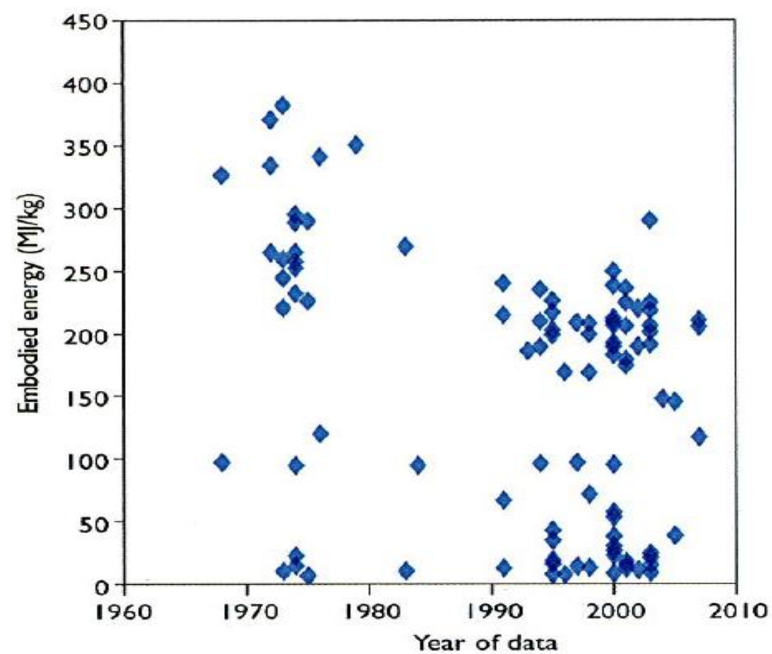
Embodied Energy Data for Aluminium

Aluminium						
Embodied Energy (EE) Database Statistics - MJ/Kg						
Main Material	**No. Records**	**Average EE**	**Standard Deviation**	**Minimum EE**	**Maximum EE**	**Comments on the Database Statistics:**
Aluminium	111	157·1	104·7	8·0	382·7	
General	**111**	**157·1**	**104·7**	**8·0**	**382·7**	
50% Recycled	4	108·6	53·4	58·0	184·0	
Other Specification	3	146·5	79·3	55·0	193·5	
Predominantly Recycled	28	17·9	8·7	8·0	42·9	
Unspecified	14	169·1	67·0	68·0	249·9	
Virgin	62	224·1	68·5	39·2	382·7	

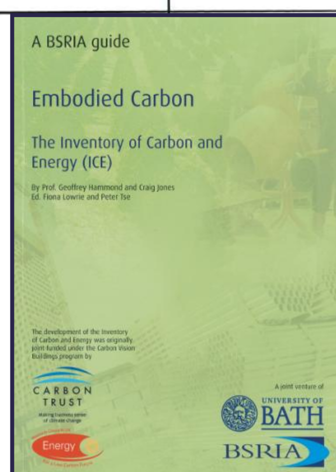


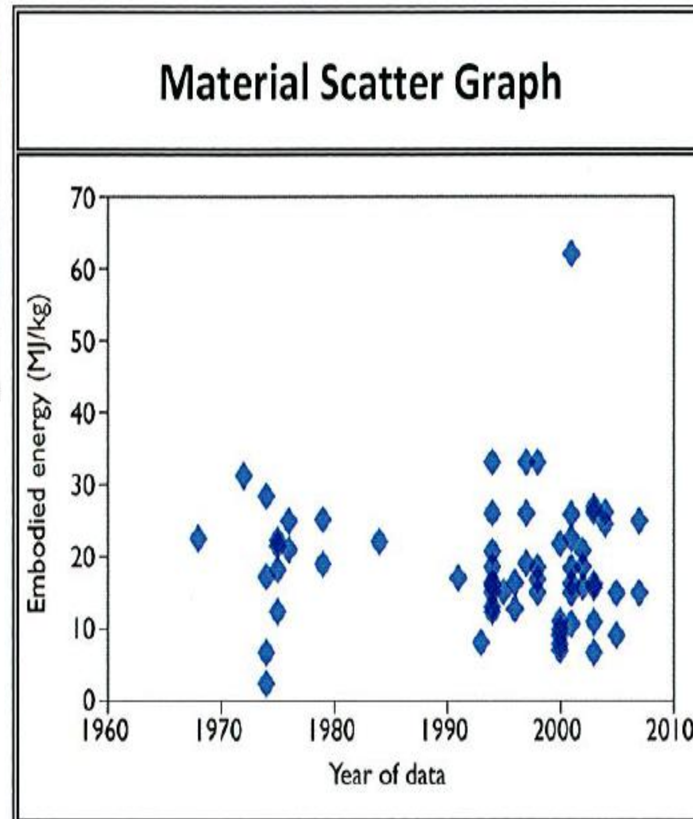
Material Scatter Graph



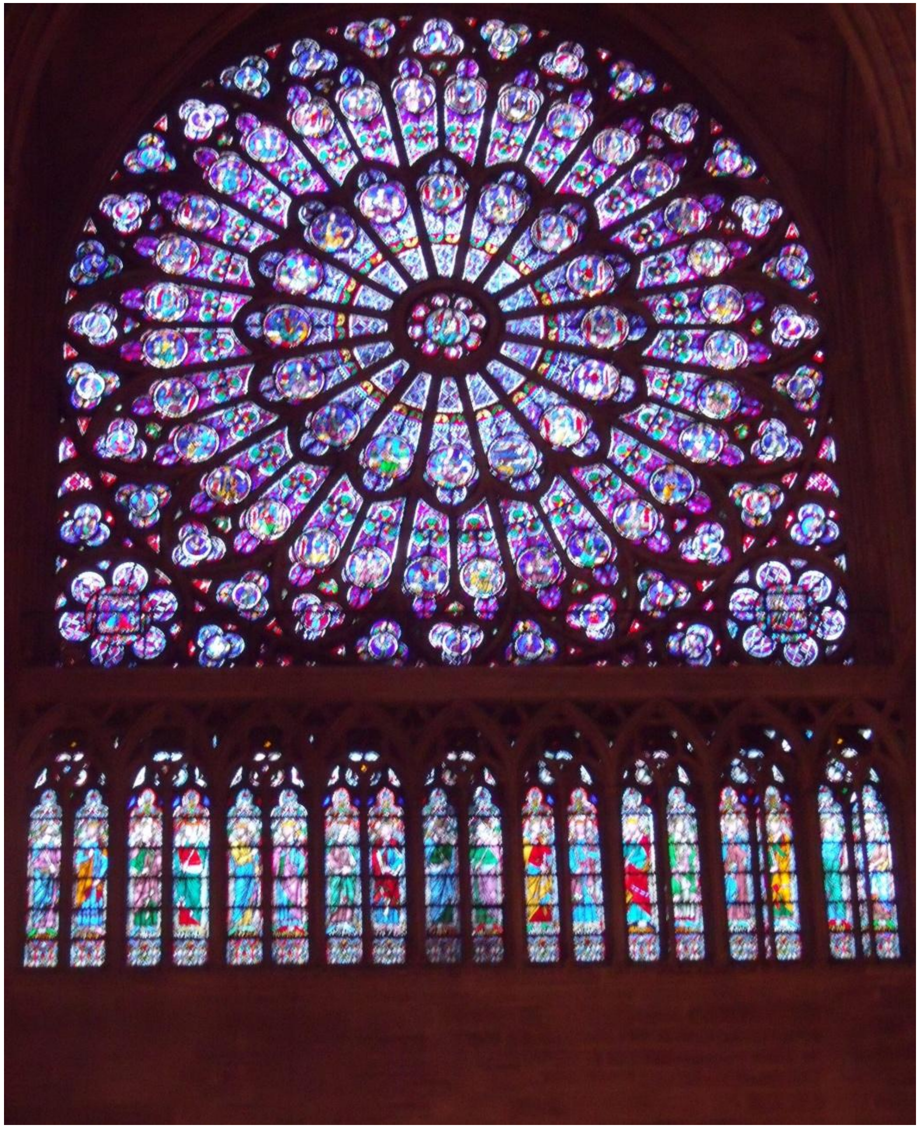
Embodied Energy Data for Glass

Glass						
Embodied Energy (EE) Database Statistics - MJ/Kg						
Main Material	**No. Records**	**Average EE**	**Standard Deviation**	**Minimum EE**	**Maximum EE**	**Comments on the Database Statistics:**
Glass	97	20·08	9·13	2·56	62·10	
Glass, Fibreglass	**22**	**25·58**	8·53	**11·00**	**41·81**	
Market Average	1	30·00	30·00	30·00	-	
Predominantly Recycled	2	11·90	11·90	11·90	-	
Unspecified	16	26·24	8·41	11·00	41·81	
Virgin	3	24·85	10·25	17·60	32·10	
Glass, General	**75**	**18·50**	**8·73**	**2·56**	**62·10**	
50% Recycled	1	7·00	7·00	7·00	-	
Market Average	4	16·81	5·87	12·30	25·09	





How Would You Analyse These Façades?



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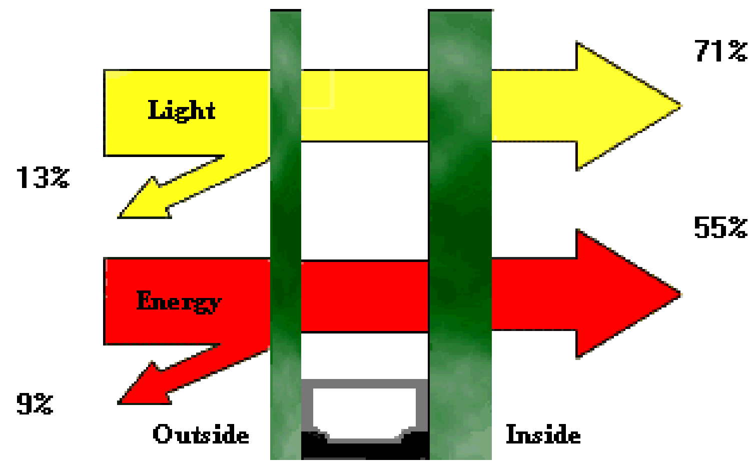
Pilkington Glazing Calculator

Glass 1: Pilkington Optifloat™ Green 4mm Cavity 1: 16 Gas 1: 90% Argon

Glass 2: Pilkington Optifloat™ Clear 8mm

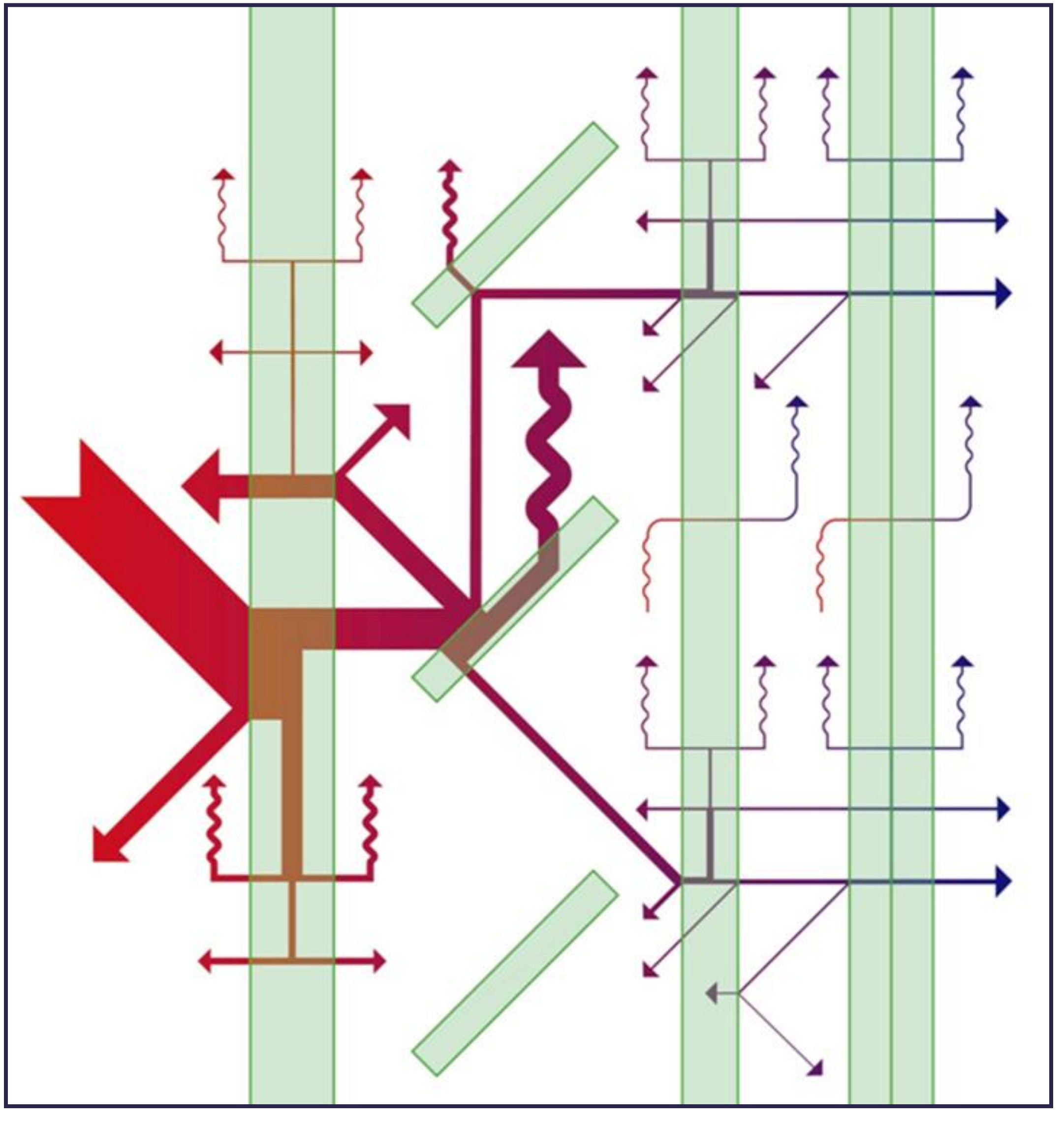
U= 2.6W/m²K



Product code	U value	UV%	Light%			Energy%			Solar factor	Shading coeff.	
	W/m²K	Tuv	LT	LR out	LR in	ET	ER	EA	g	T SC	S SC
4gn-16Ar-cl8	2.6	20	71	13	14	45	9	46	0.55	0.64	0.52

Performance code	Sound reduction		Thickness	Weight	Date
U-value/Light/Energy	Rw dB	(C;Ctr)	mm	kg/m²	
2.6/ 71/55	33	(-1 ; -4)	28	30	31/01/2007

How Does the Facade Work

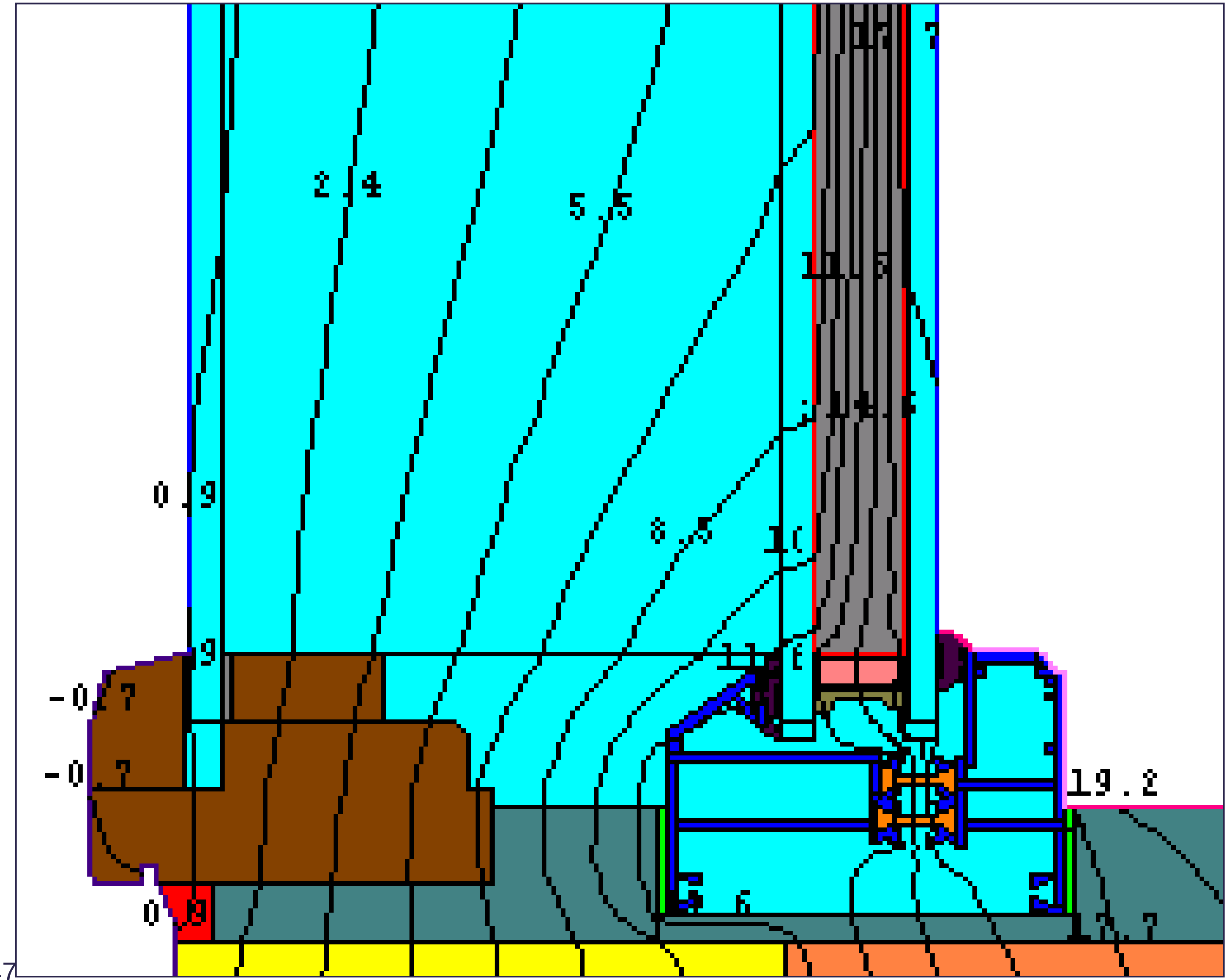


How does the Software deal with complex facades

Thanks to Mark Taylor
Allies and Morrison

Improving DTM Software

“2+1” Window Therm 2 Software Isotherm Prediction



Improving DTM Software

Technal Fxi Range of Windows

U Value Glass (centre pane)

		1.9				1.7				1.5				1.2			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FXi46	Fixed Light	2.60	2.30	2.30	2.30	2.40	2.20	2.10	2.10	2.30	2.00	2.00	2.00	2.10	1.80	1.80	1.70
	Open In	2.80	2.50	2.40	2.40	2.70	2.40	2.30	2.30	2.60	2.20	2.20	2.20	2.40	2.00	2.00	2.00
	Open Out	2.90	2.60	2.50	2.50	2.80	2.50	2.40	2.40	2.70	2.30	2.20	2.20	2.60	2.10	2.10	2.00
FXi52	Fixed Light	2.50	2.30	2.30	2.20	2.30	2.10	2.10	2.10	2.20	2.00	2.00	1.90	2.00	1.80	1.70	1.70
	Open In	2.70	2.40	2.40	2.40	2.60	2.30	2.30	2.30	2.50	2.20	2.10	2.10	2.40	2.00	1.90	1.90
	Open Out	2.80	2.50	2.50	2.50	2.70	2.40	2.30	2.30	2.60	2.30	2.20	2.20	2.50	2.10	2.00	2.00
FXi65	Fixed Light	2.30	2.20	2.10	2.10	2.10	2.00	2.00	2.00	2.00	1.80	1.80	1.80	1.90	1.60	1.60	1.60
	Open In	2.40	2.30	2.20	2.20	2.30	2.10	2.10	2.10	2.20	2.00	1.90	1.90	2.00	1.80	1.70	1.70
	Open Out	2.30	2.20	2.20	2.20	2.20	2.10	2.00	2.00	2.10	1.90	1.90	2.00	1.90	1.70	1.70	1.70

- ≤2.2
- 2.3
- 2.4
- 2.5

Size of Window

S1 = 0.75m x 0.80m
S2 = 1.20m x 1.20m
S3 = 1.23m x 1.48m
S4 = 1.00m x 2.18m

The Thermal Assessment of Curtain Walls – CWCT Guide

Appendices

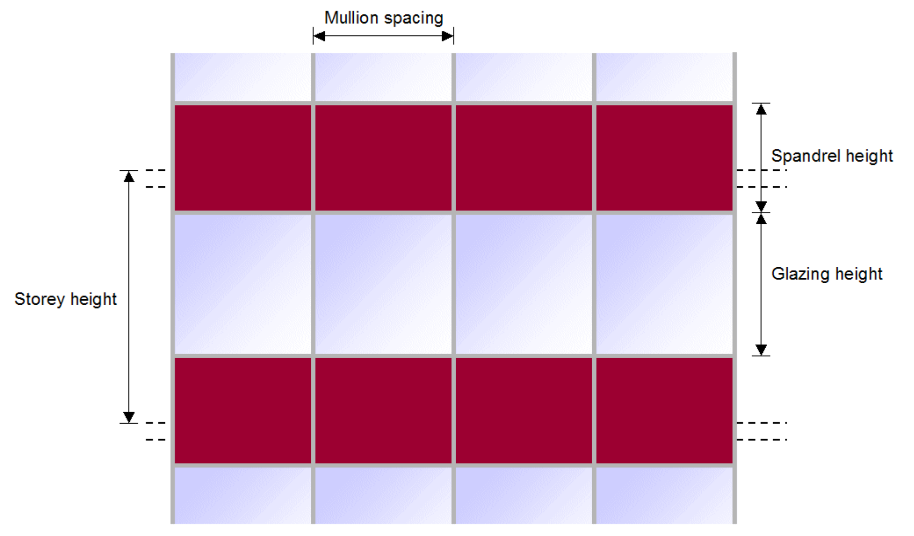
Estimating curtain wall U-values

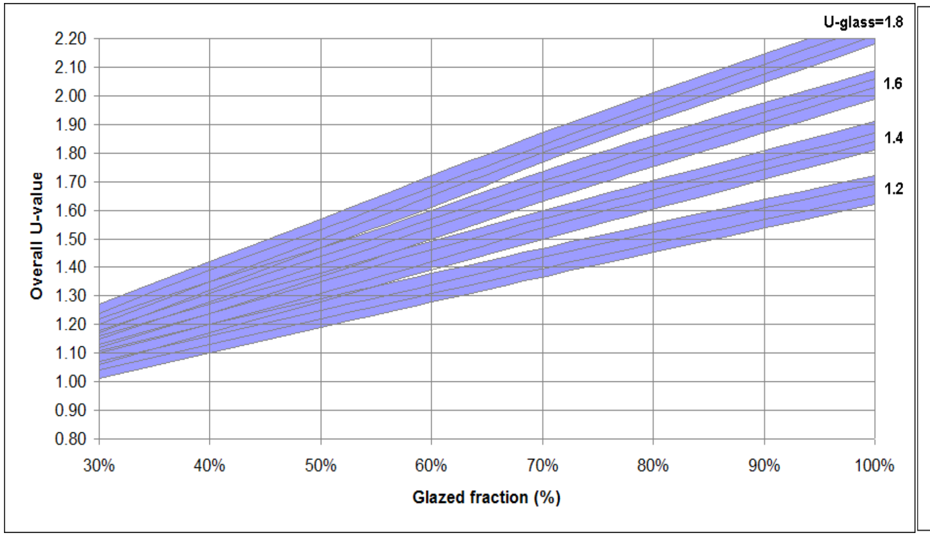
Calculating wall U-values

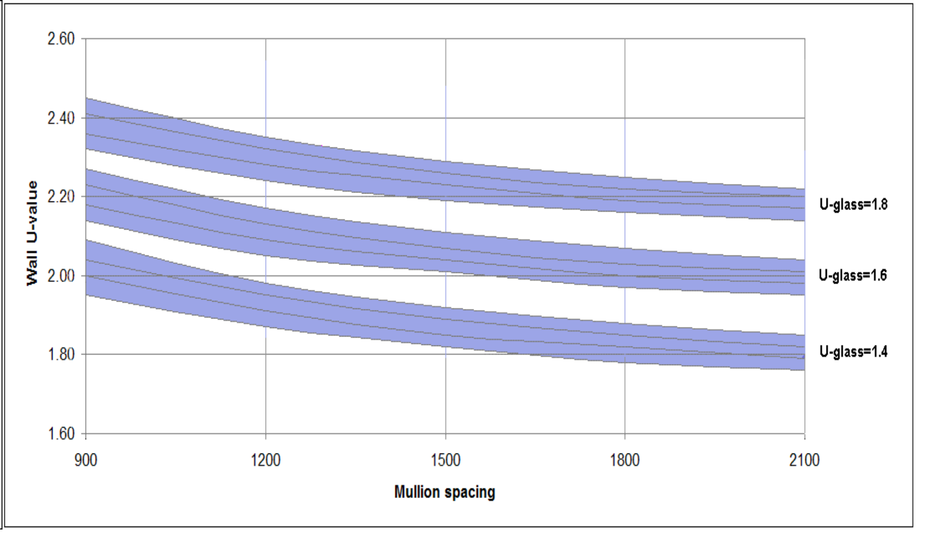
Calculating framing U-values

Calculating rainscreen U-values

Inputting data to SBEM







CIBSE TM37:2006 – Design for Improved Solar Shading Control

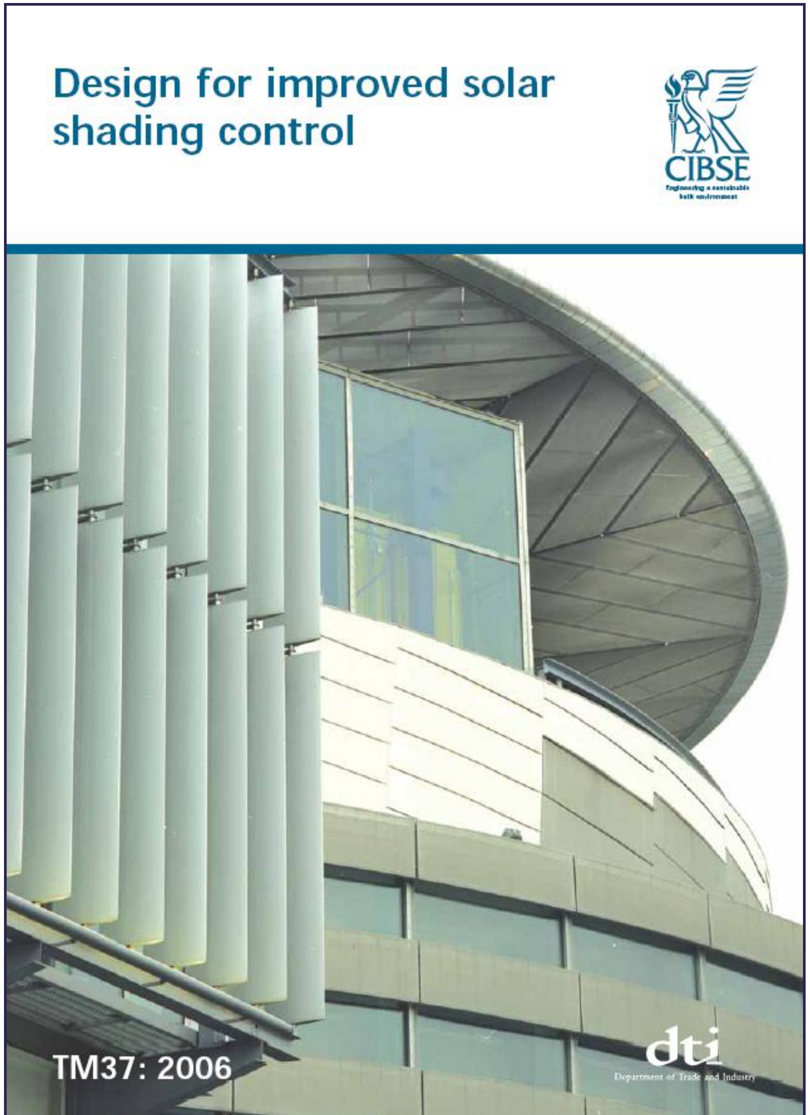


Table 5.4 Weighted average values of g_{eff} for standard 6 mm hard coat low emissivity double glazing with and without blinds

Type of glazing and blind (from outside to inside)	Value of g_{eff} for stated glazing orientation					
	North	NE/NW	E/W	SE/SW	South	Horiz.
Low-e/clear (no blind)	0.55	0.60	0.62	0.60	0.56	0.61
Occupant control:						
— low-e/clear, internal blind	0.52	0.53	0.53	0.51	0.47	0.51
— low-e/clear, mid-pane blind	0.49	0.45	0.43	0.41	0.37	0.40
— low-e/clear, external blind	0.47	0.41	0.38	0.36	0.33	0.35
Automatic control with occupant override:						
— low-e/clear, internal blind	0.52	0.50	0.48	0.46	0.43	0.46
— low-e/clear, midpane blind	0.49	0.40	0.34	0.32	0.28	0.29
— low-e/clear, external blind	0.47	0.35	0.28	0.25	0.22	0.21
Fully automatic control:						
— low-e/clear, internal blind	0.55	0.51	0.48	0.45	0.42	0.44
— low-e/clear, mid-pane blind	0.55	0.41	0.33	0.30	0.26	0.26
— low-e/clear, external blind	0.55	0.36	0.26	0.23	0.18	0.17

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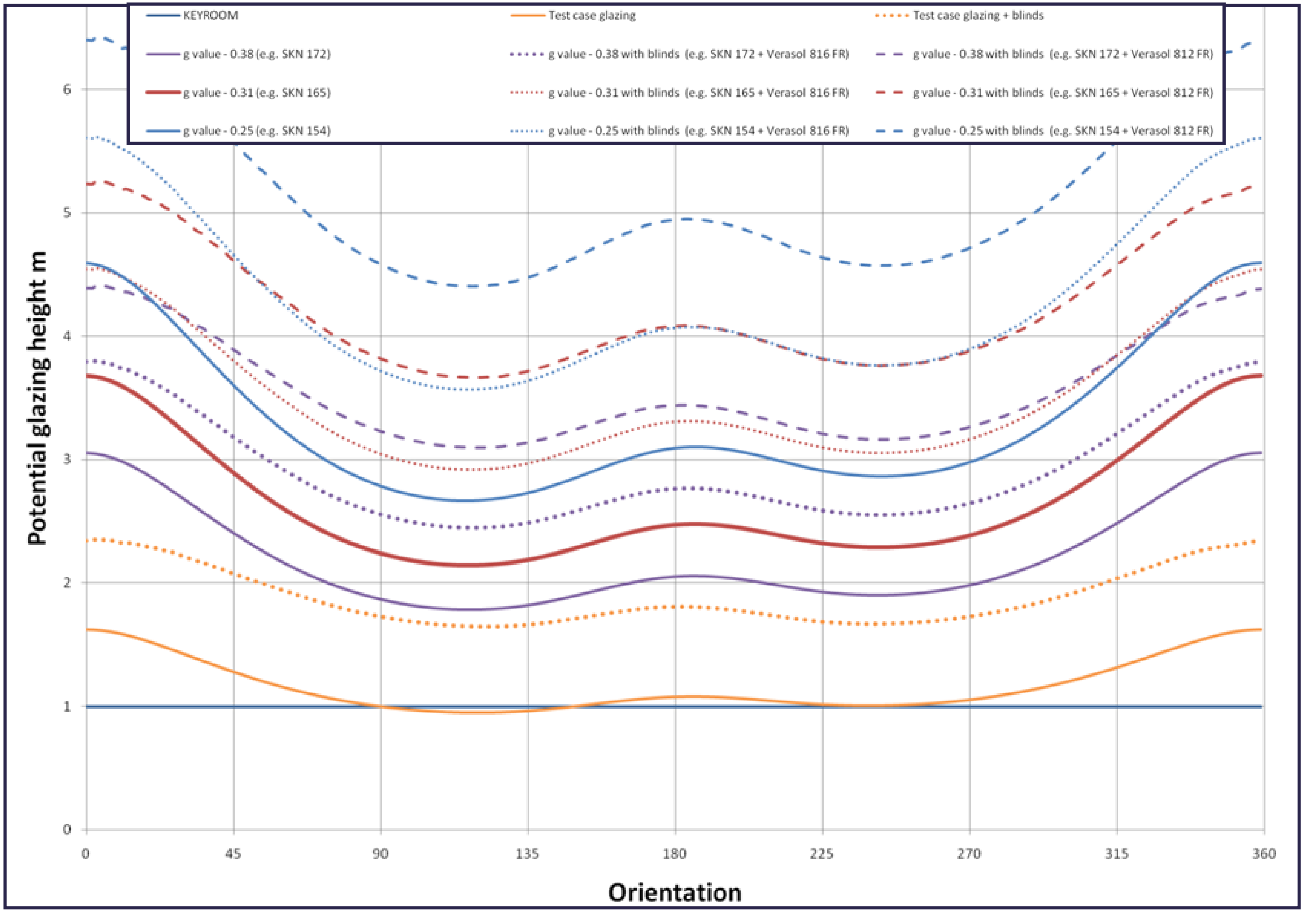
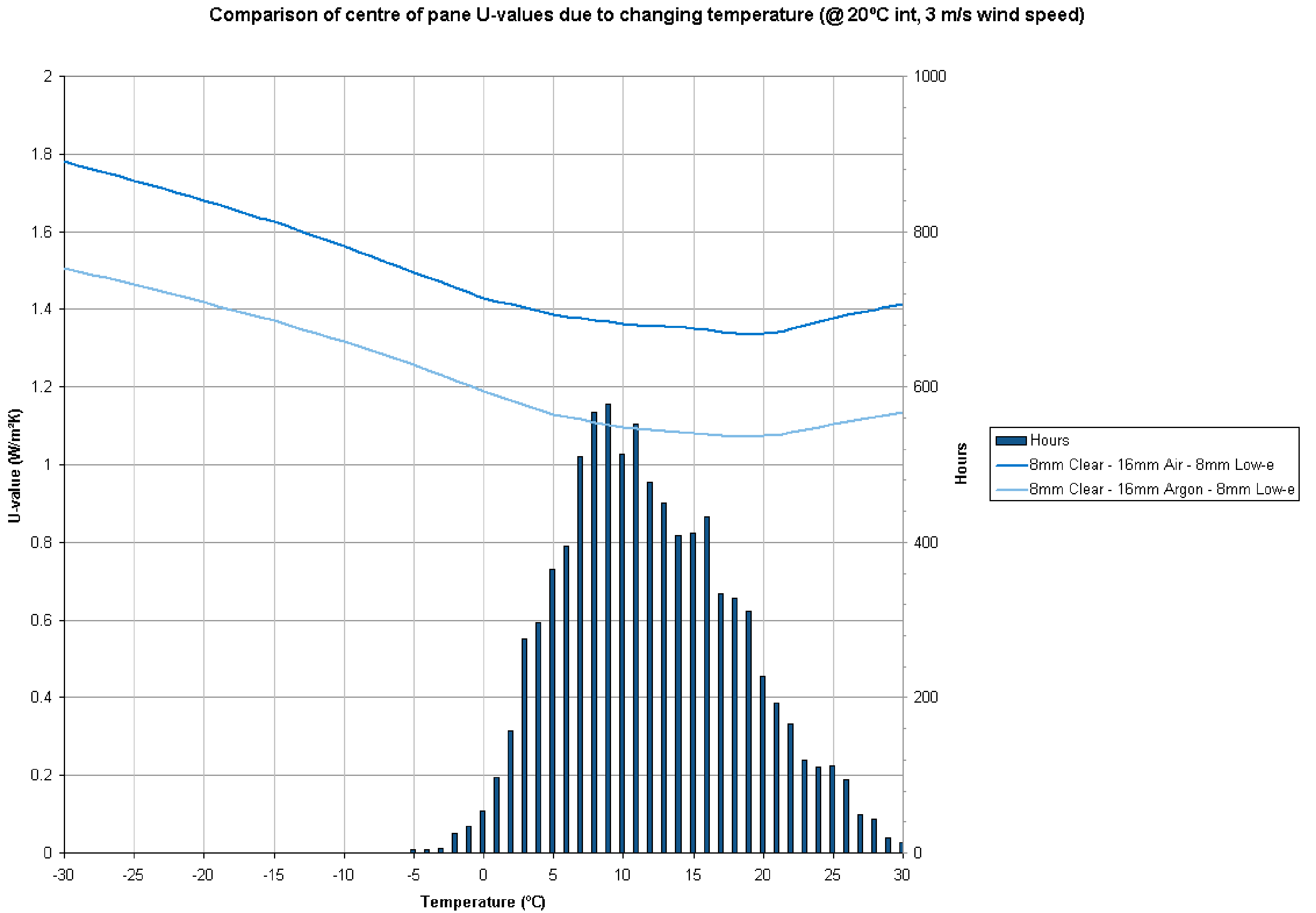
Solar Shading at De Montfort University Business & Law Building

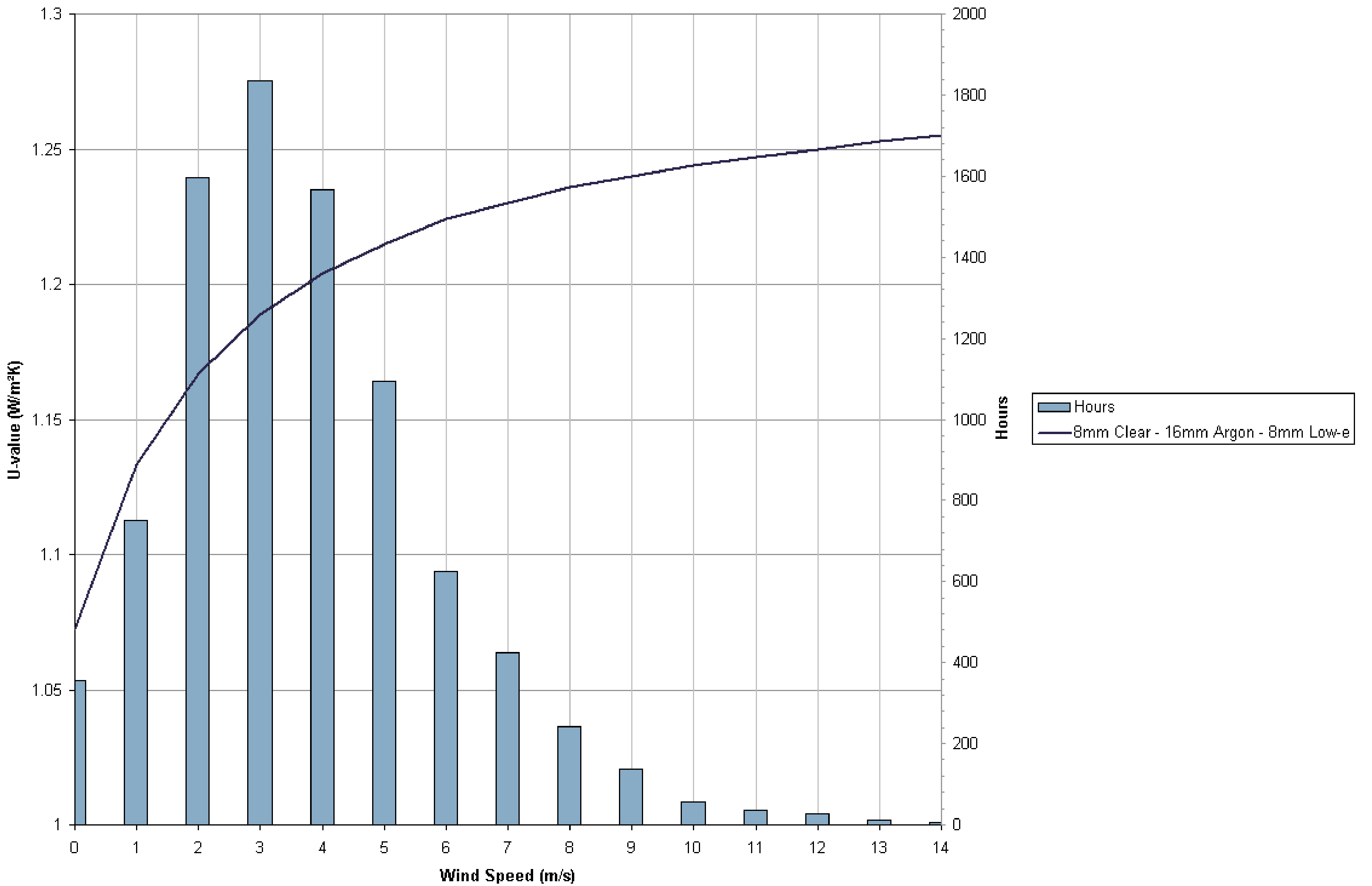
Example for London Showing Benefits of Blinds



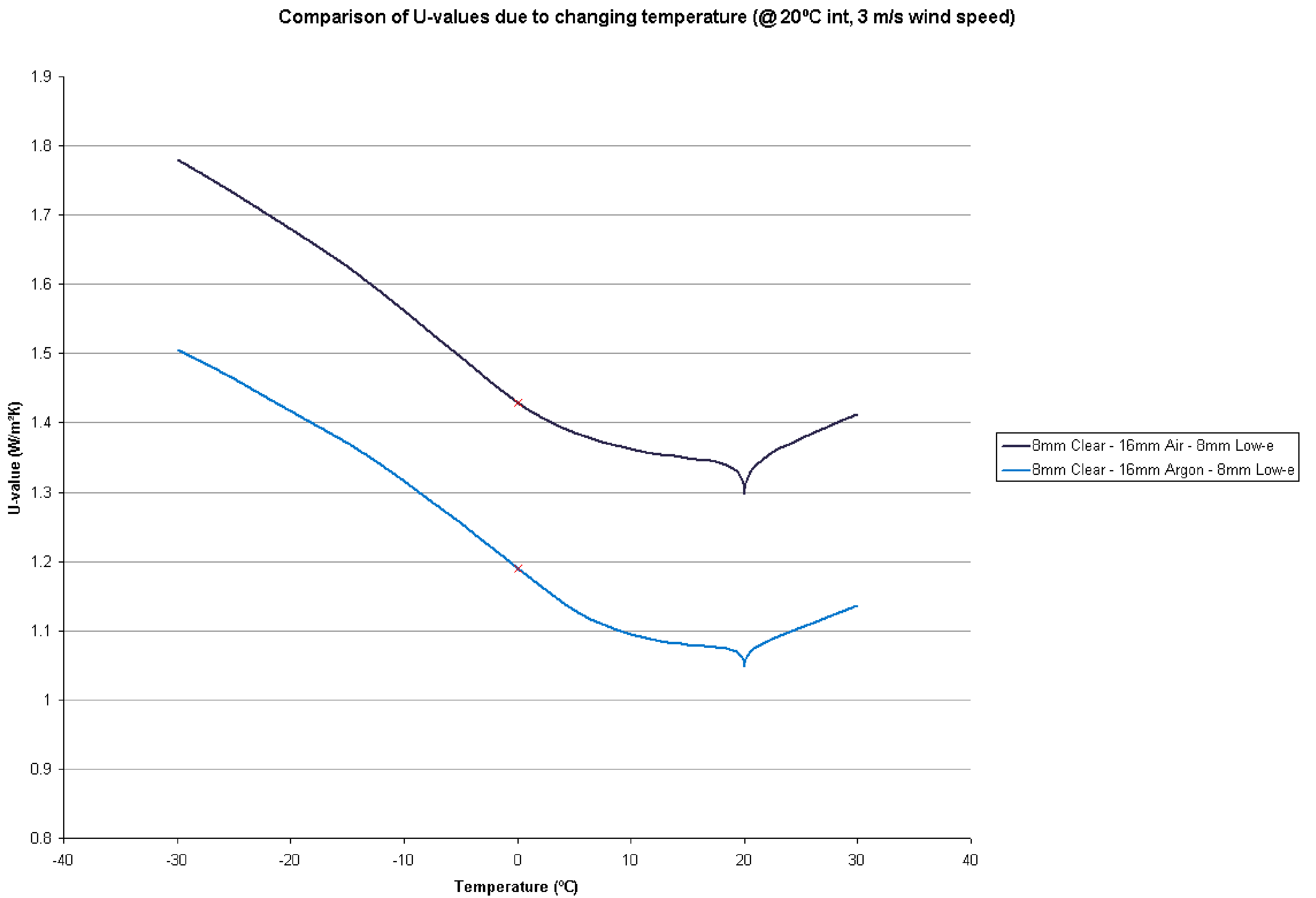
Outside Air Temperature and U-Values for Glazing



U-value of Glazing and Wind Speed

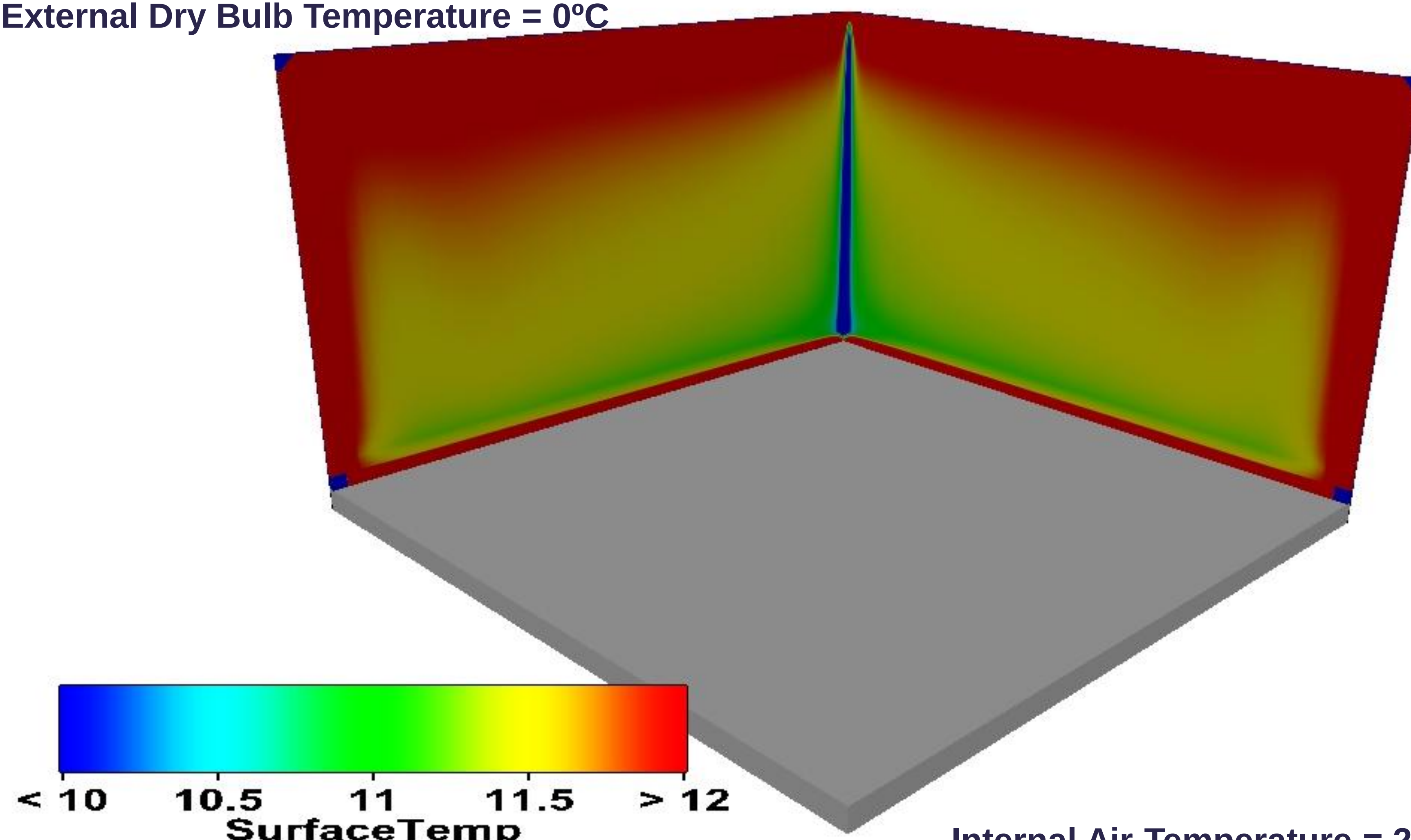


Glass Unit U-value with Outside Air Temperature



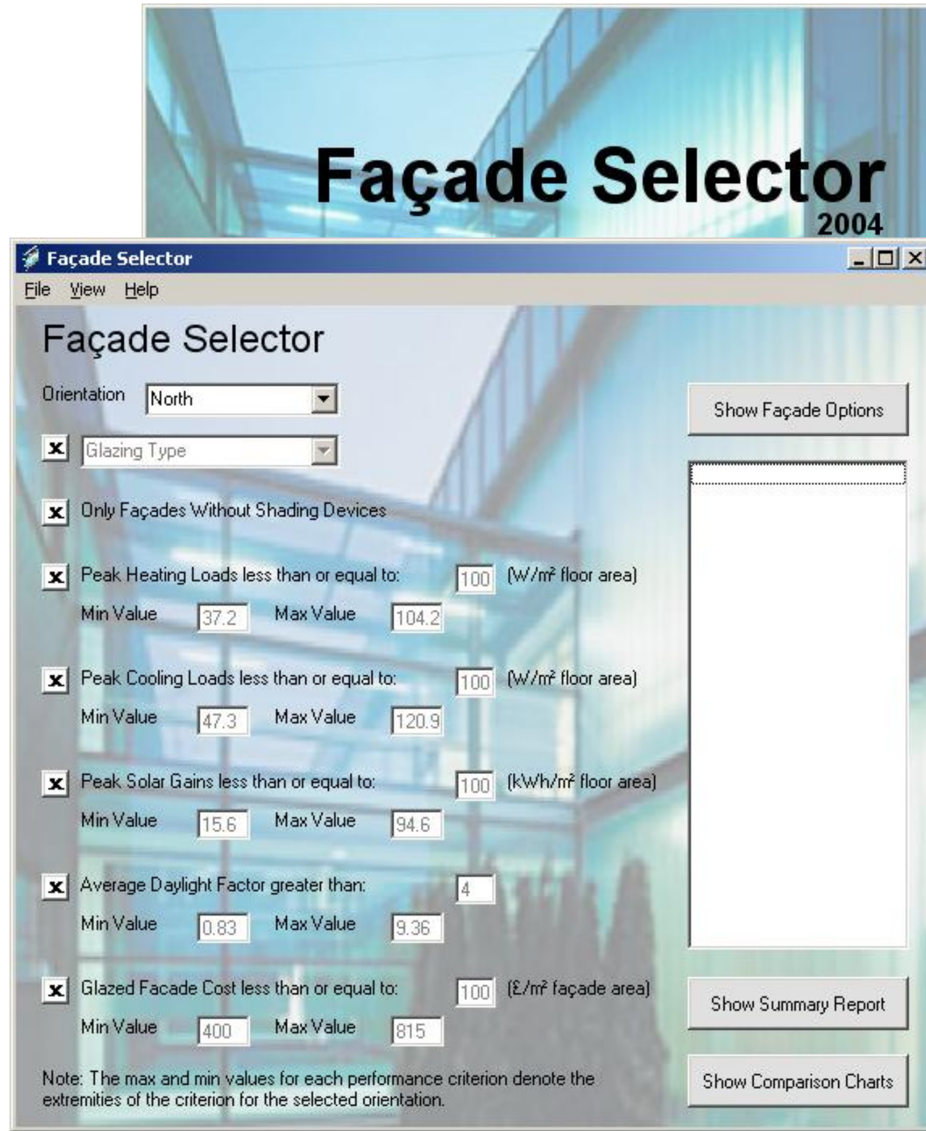
U = 2.2 W/m²K: Glazing Surface Temperatures

External Dry Bulb Temperature = 0ºC



Internal Air Temperature = 20ºC

CIBSE TM35:2004 - Façade Selector Toolkit



What Should a Roof Look Like? –Photovoltaic's on a Green Sedum Roof

CoolDeck With Phase Change in Stevenage

THANK YOU FOR LISTENING