CIBSE Building Simulation Group: 8th February 2017

Simulation for overheating risk in the built environment

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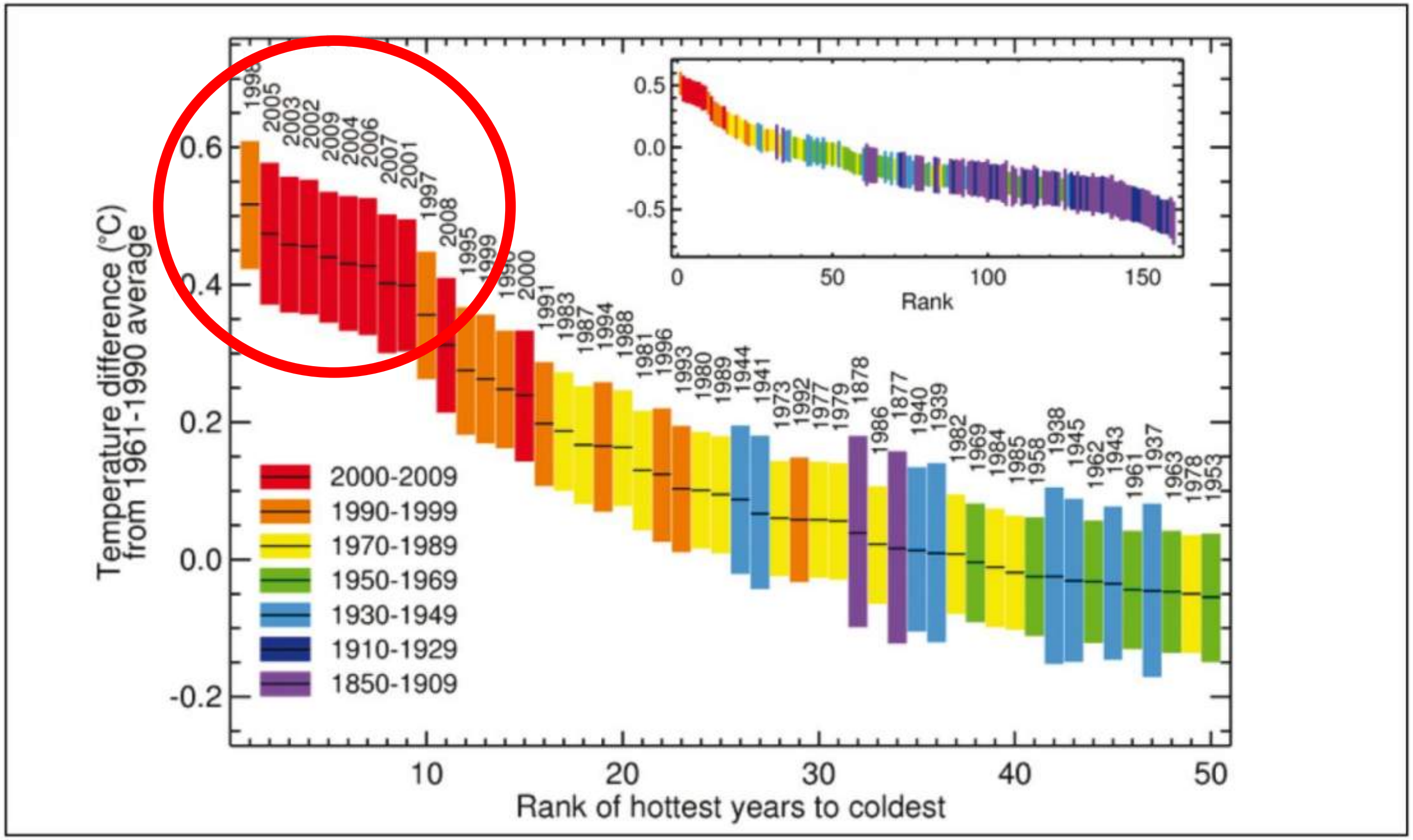
NASA Image of Greenland Melt Ponds

Overheating risk is not static and is highly uncertain

Average changes:

- Approx. 0.5˚C increase since 1950s
- Approx. 1.0˚C increase since 1850s

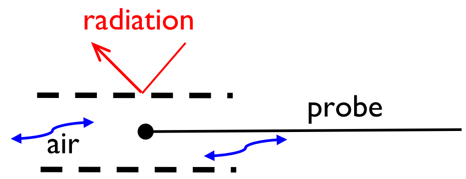
Figure 1.1 Global annual average temperatures, ranked hottest to coldest (source: The Meteorological (Met) Office, Hadley Centre)



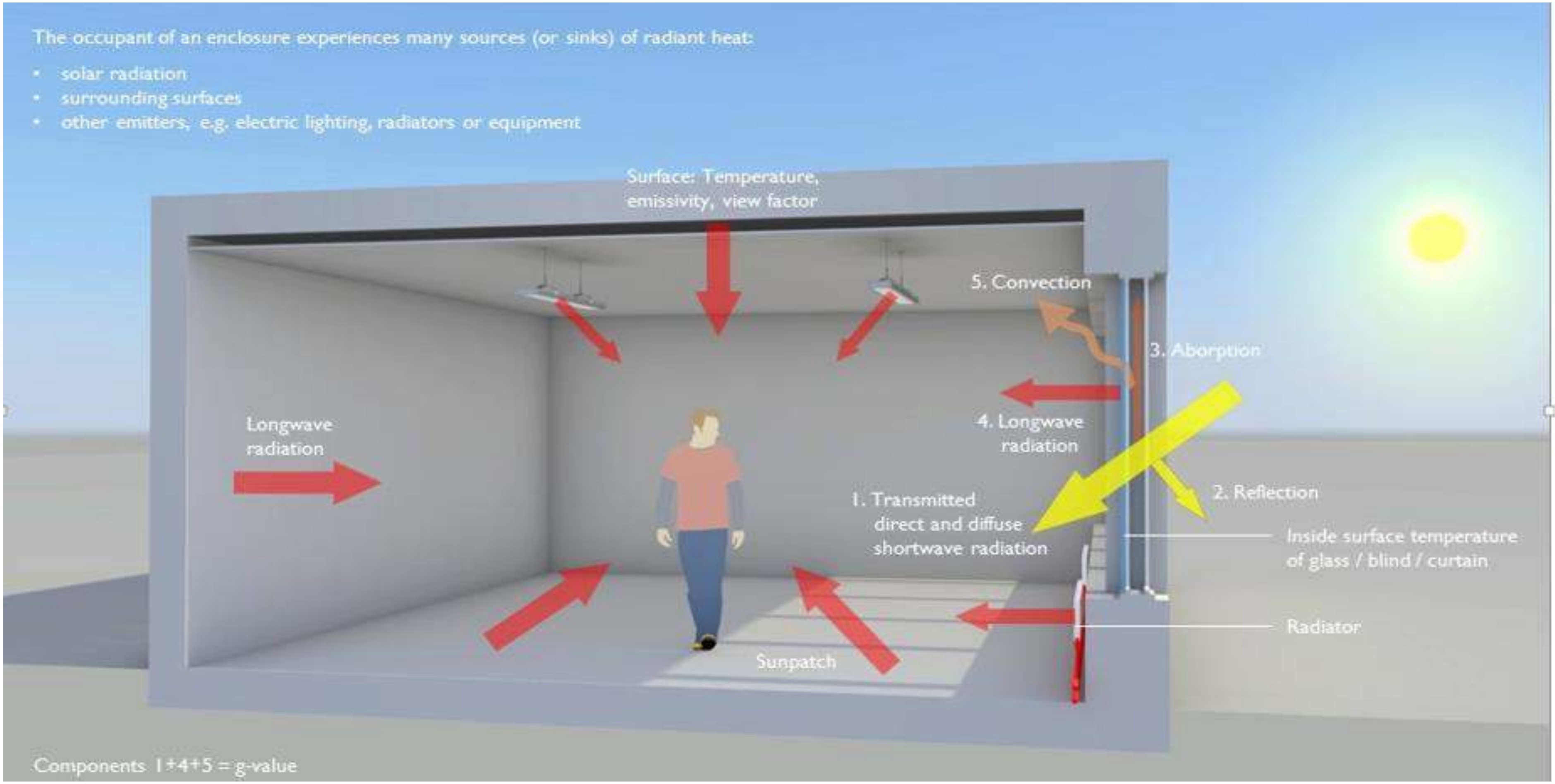
Ranking the hottest years since 1850 shows that most of the hottest years occurred in the last 10 years

Air, mean radiant and operative temperatures

1. Air (dry bulb) temperature – sensor reflects surrounding radiation

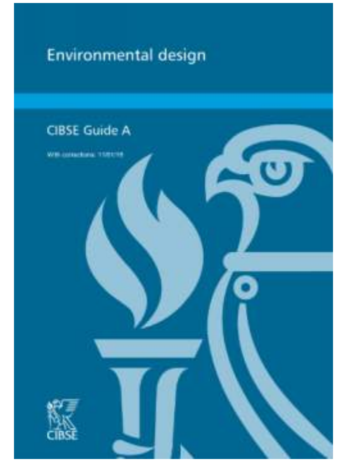


2. Mean radiant temperature – many direct and indirect sources



3. Operative temperature, previously called dry resultant temperature, combines air and mean radiant temperature with velocity (average value when velocity is less than 0.1m/s).

CIBSE Guide A – detail not to be forgotten



Calculation of mean radiant temperature (A5 glossary)

In calculations of thermal comfort (overheating for example) it is necessary to include any shortwave radiation that falls on the occupant in the calculation of mean radiant temperature.

Calculation of operative temperature

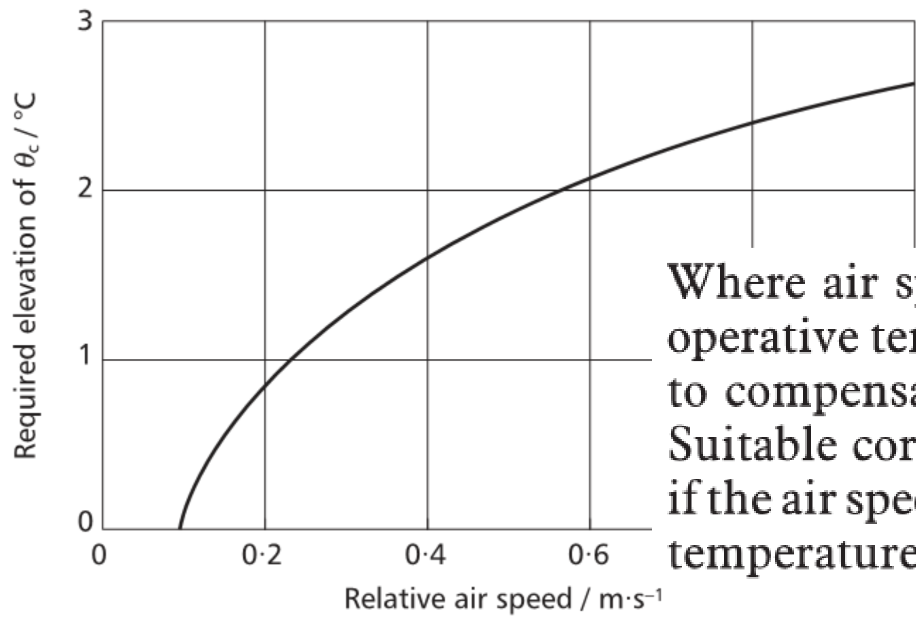


Figure 1.1 Correction to operative temperature (θ_c) to take account of air movement (see note in section 1.3.1.2)

$$\theta_c = \frac{\theta_{ai}\sqrt{(10\,v)} + \theta_r}{1 + \sqrt{(10\,v)}} \qquad (5.10)$$

Where air speeds in a room are greater than 0.1 $m{\cdot}s^{-1}$ the operative temperature may be raised from its 'still air' value to compensate for the cooling effect of the air movement. Suitable corrections are given in Figure 1.1. (For example, if the air speed were raised from 0.1 to 0.6 $m{\cdot}s^{-1}$ the operative temperature for comfort would rise by some 2 K.)

Mechanically cooled buildings (1.5.3.3)

The predicted indoor temperature or values of PMV should not exceed the tabulated values for more than 3% of occupied hours. For summer conditions simulations should be made using design summer years as recommended in CIBSE TM48 (CIBSE, 2009).

Naturally ventilated buildings (1.5.3.4)

References TM 52 (later slide)

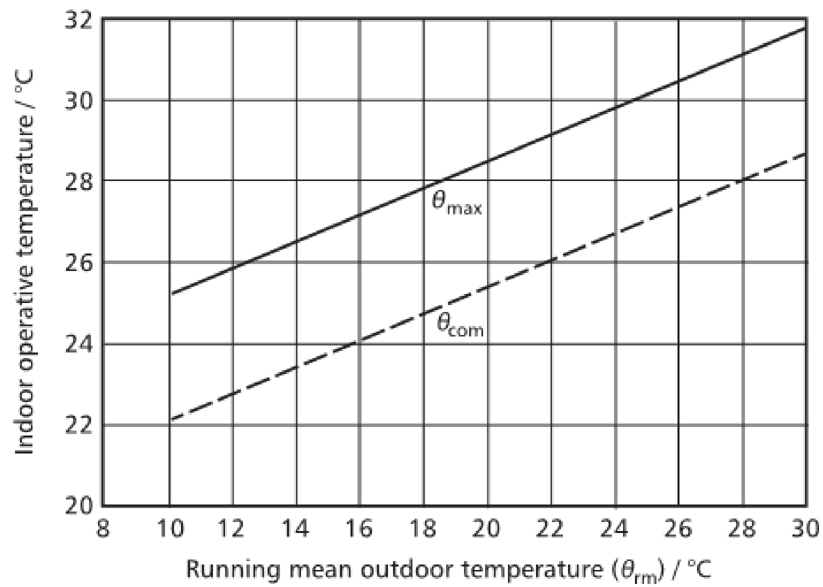
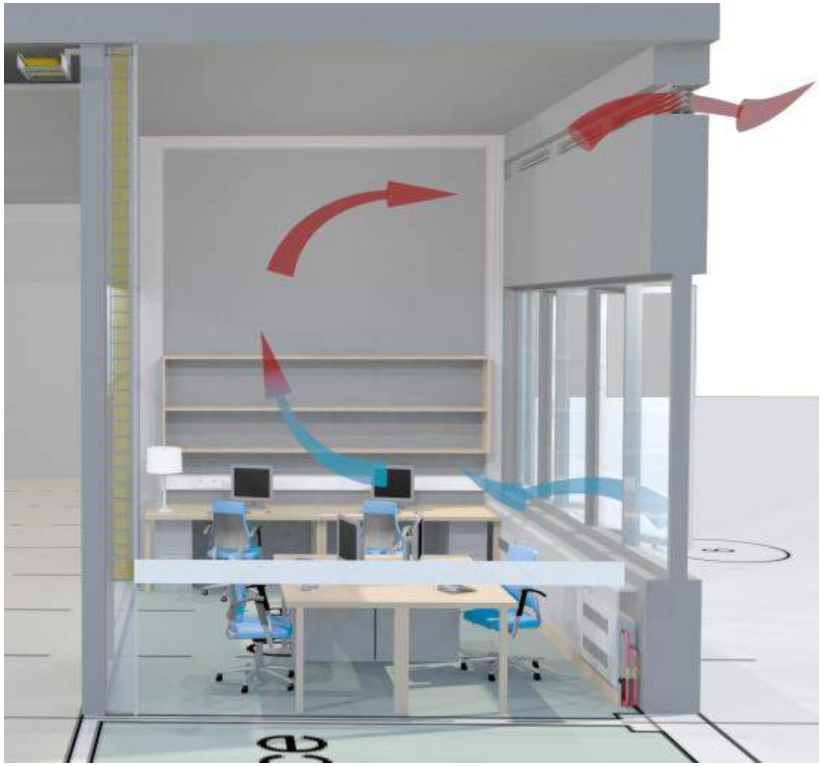


Figure 1.8 Limiting values for the operative temperature (θ_{max}) to avoid overheating in free-running mode as a function of the exponentially-weighted running mean of the external temperature (θ_{rm}) (after BS EN 15251 (BSI, 2007) using values for category II)

Free running naturally ventilated office space case study



	Windows*	Louvres
$12m^2$ office (1 to 4 people)	$0.90m^2$	$0.25m^2$
$18m^2$ office (4 people)	$1.35m^2$	$0.375m^2$
$24m^2$ office (5 people)	$1.80m^2$	$0.50m^2$

Overheating risk assessment of sample office space using single point operative temperature thresholds and ***current*** (Design Summer Year) DSY climate

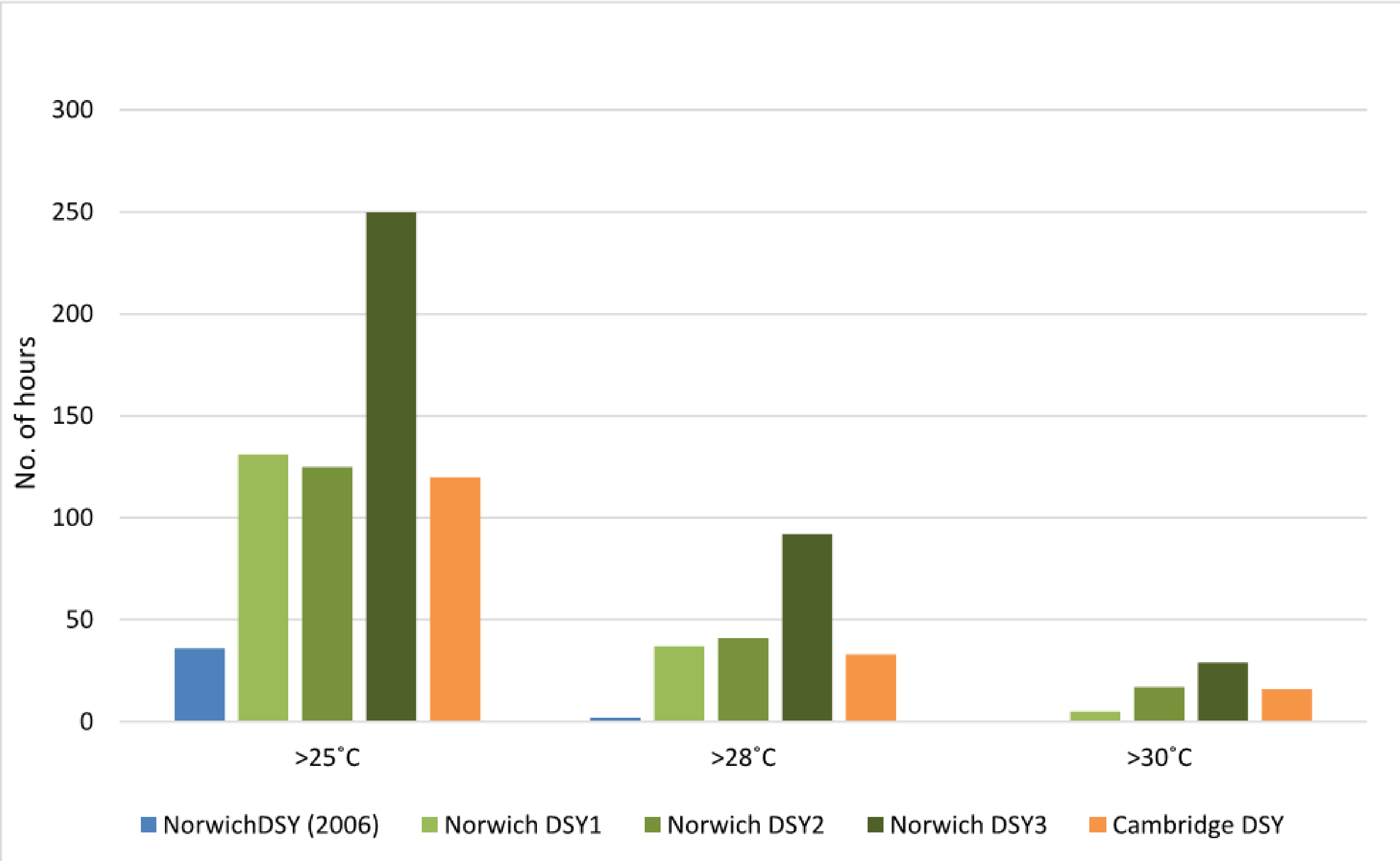


Figure 2: Weather file comparison showing the number of hours over 25, 28 and 30˚C in the old Norwich DSY (CIBSE, 2006), the new Norwich DSY1, DSY2 and DSY3 (CIBSE, 2016) and Cambridge DSY

Overheating risk assessment of sample office space using single point operative temperature thresholds and ***future*** (Design Summer Year) DSY climate

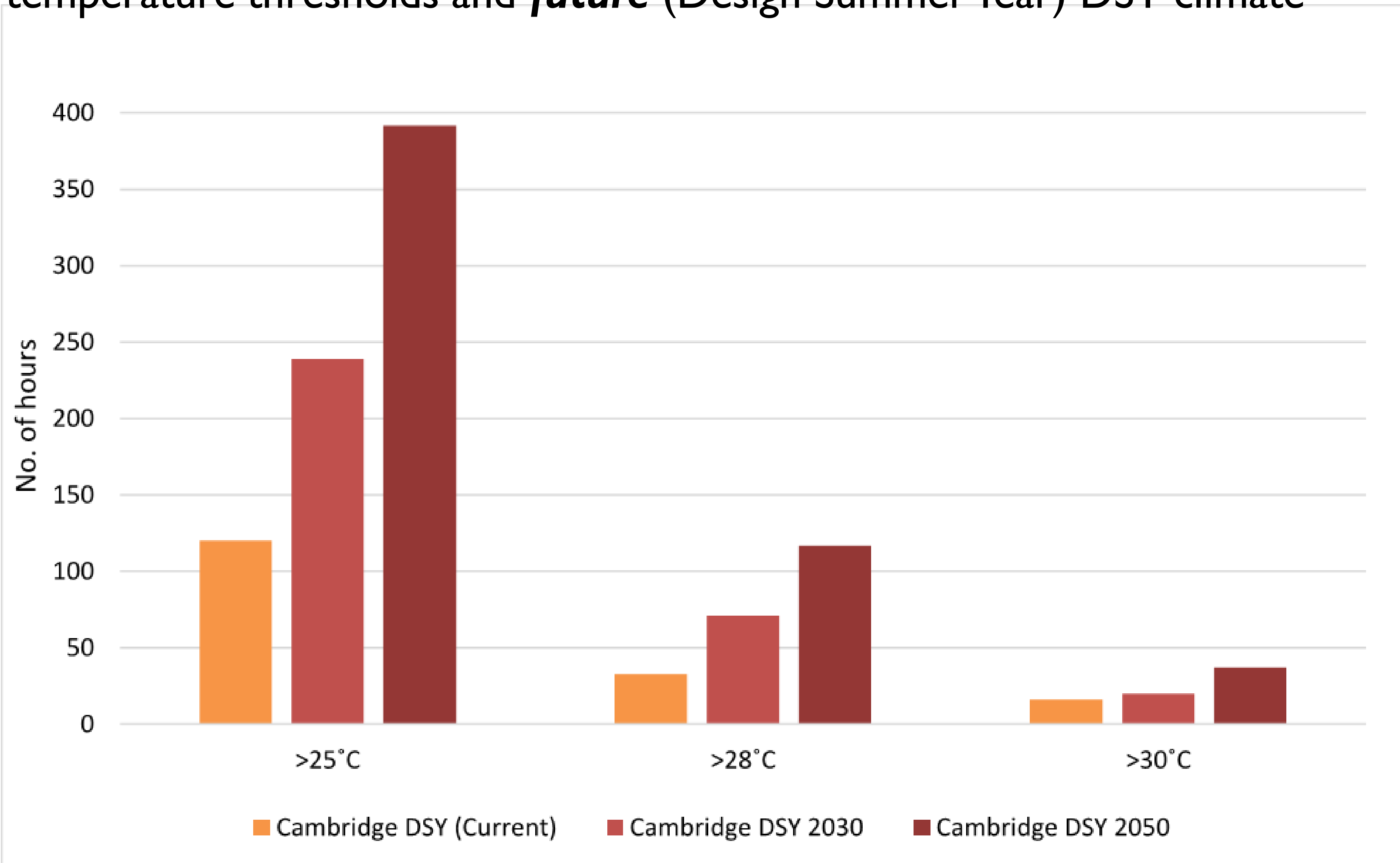


Figure 3: Weather file comparison showing the number of hours over 25, 28 and 30˚C in the Cambridge DSY weather files for the current climate and for 2030 and 2050 future climate projections

Overheating risk assessment using TM 52 criteria

There are three criteria for overheating and **at least two** of the three criteria must be achieved in order to comply with Adaptive Comfort:

$$T_{max} = 0.33T_{rm} + 21.8$$

Criterion 1 – Hours of Exceedance (H_e)

The first criterion sets a limit for the number of hours (H_e) that the operative temperature can exceed the threshold comfort temperature (upper limit of the range of comfort temperature) by 1K or more during the occupied hours of a typical non-heating season (1st May to 30th September). The number of hours (i.e. H_e=hours of exceedance) during which ΔT is greater than or equal to 1K during the period May to September inclusive shall not be more than 3% of occupied hours. ΔT is defined as operative temperature less the maximum acceptable temperature ($\Delta T = T_{op} - T_{max}$,). ΔT is rounded to the nearest whole degree.

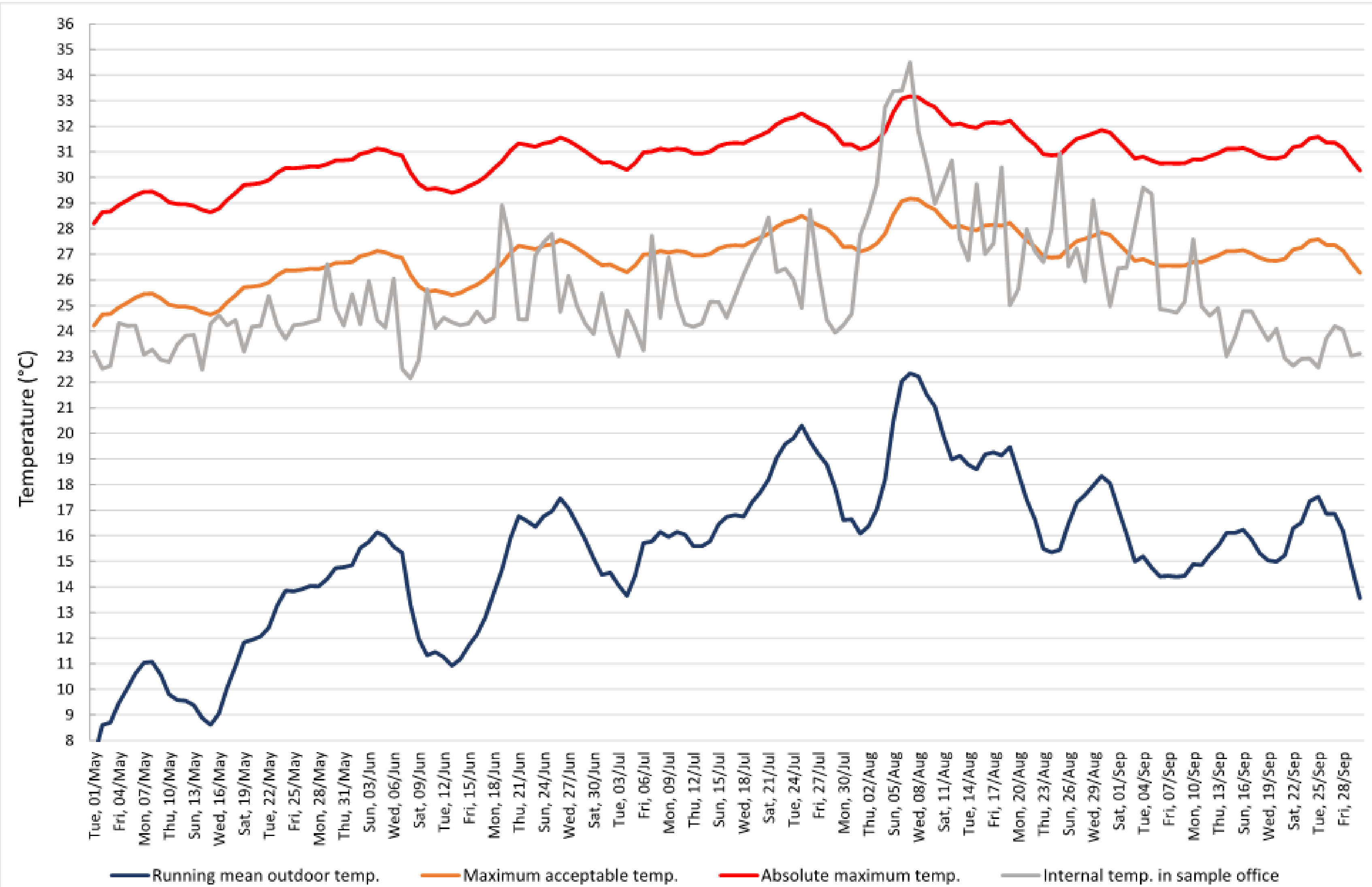
Criterion 2 – Daily Weighted Exceedance (W_e)

The second criterion deals with the severity of overheating within any one day, which can be as important as its frequency, the level of which is a function of both temperature rise and its duration. The sum of the weighted exceedance for each degree K above T_{max} (1K, 2K and 3K) shall be less than or equal to 6 in any one day; where $W_e = \Sigma H_e(1,2,3)*(\Delta T)(1,2,3)$ and ΔT (T_{op}-T_{max}), rounded to a whole number.

Criterion 3 – Upper Limit Temperature (T_{upp})

The third criterion sets an absolute maximum daily temperature for a room, beyond which the level of overheating is unacceptable. To set an absolute maximum value for the indoor operative temperature the value of ΔT (T_{op}-T_{max}) shall not exceed 4K.

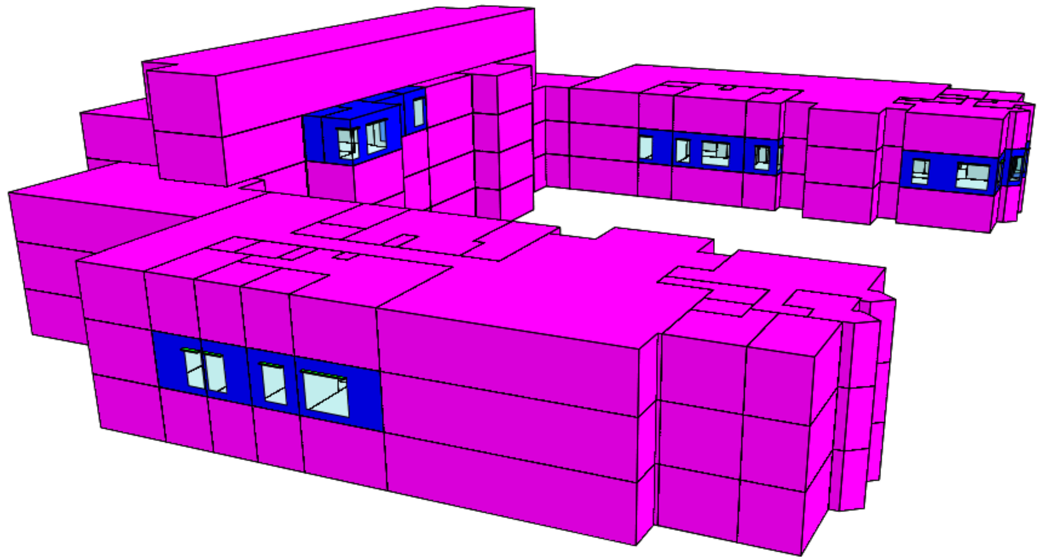
TM 52 predictions for sample office (one climate file)



TM 52 analysis results two climate files compared

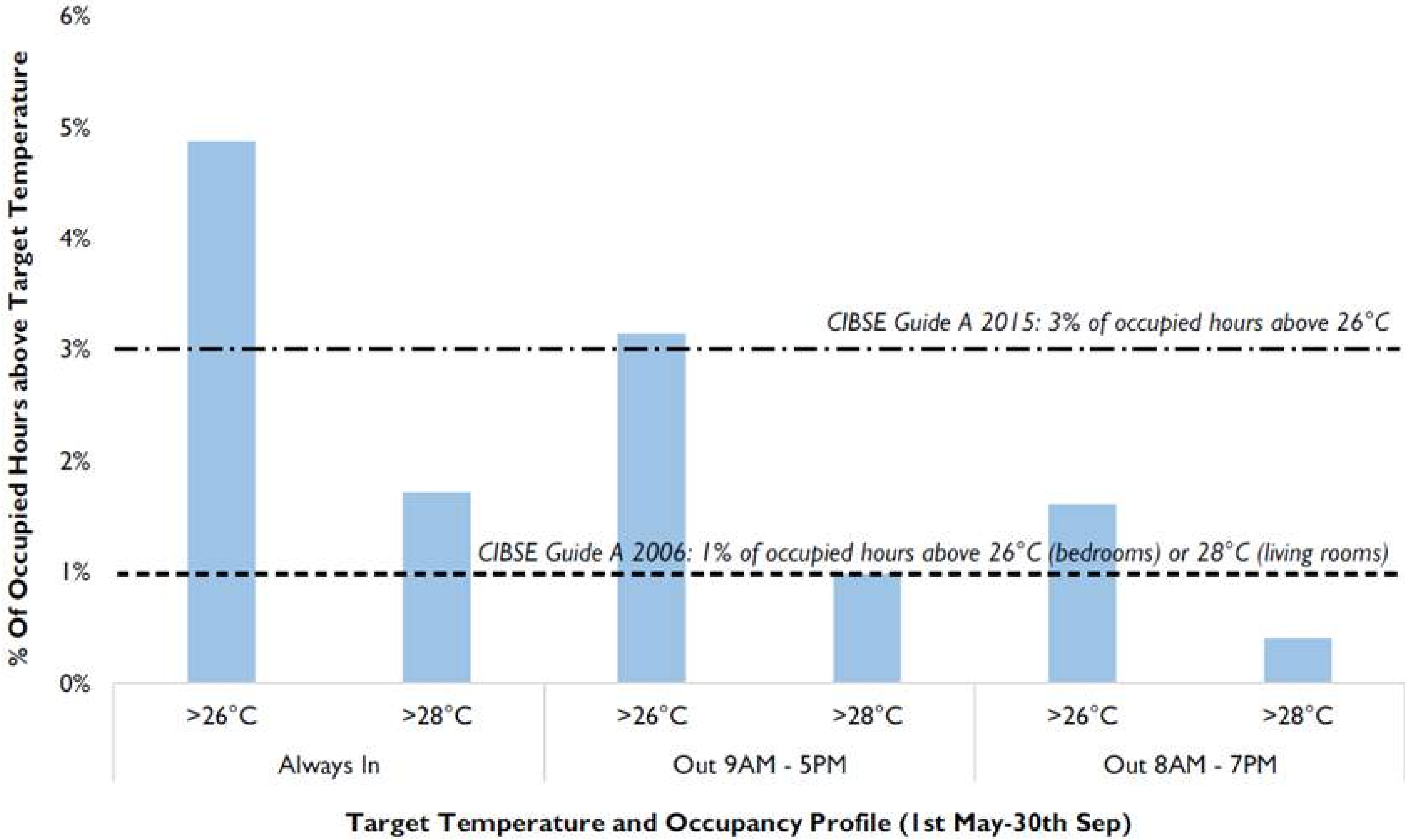
		Criterion 1 (%Hrs T_{op}-T_{max}>=1K)	Criterion 2 (Max. Daily Deg.Hrs)	Criterion 3 (Max. ΔT)	**Compliance with TM52?***	Peak temperature (˚C)
	Target	*3*	*6*	*4*	***Pass***	*n/a*
Norwich DSY (2006)	1p Office - 3.2m	1	10	3	**Pass**	29.7
	4p Office - 3.2m	2.7	17	3	**Pass**	30.5
	5p Office - 3.2m	2.6	17	3	**Pass**	30.3
	1p Office - 4.5m	0.5	7	2	**Pass**	29.4
	4p Office - 4.5m	2.2	17	3	**Pass**	30.1
	5p Office - 4.5m	2	15	3	**Pass**	30.0
	1p Office - 3.1m	0.6	7	2	**Pass**	29.5
	4p Office - 3.1m	2.3	17	3	**Pass**	30.3
	5p Office - 3.1m	2.1	16	3	**Pass**	30.1
Cambridge DSY	1p Office - 3.2m	2.7	23	4	**Pass**	32.8
	4p Office - 3.2m	5.3	30	6	**Fail**	34.5
	5p Office - 3.2m	4.6	29	5	**Fail**	34.3
	1p Office - 4.5m	1.8	18	3	**Pass**	31.9
	4p Office - 4.5m	3.9	26	5	**Fail**	33.5
	5p Office - 4.5m	3.6	26	5	**Fail**	33.4
	1p Office - 3.1m	2.1	21	4	**Pass**	32.0
	4p Office - 3.1m	4.1	29	5	**Fail**	33.7
	5p Office - 3.1m	3.8	28	5	**Fail**	33.5

Residential apartments case study



- Central London location
- Serviced by MVHR units with additional summer boost
- Overheating assessment for planning process didn't state climatic scenario so many tested to aid discussions with design team

Review of climate file and occupancy profiles



Under CIBSE Guide A method difficult to comply due to high outside air temperatures within the climate file

UHI and different ventilation modes

16 rooms assessed in 5 apartments comparing baseline climate with urban heat island (UHI) variants

DSY 1 – moderately warm summer

DSY 2 – short intense warm spell

DSY 3 – long, less intense warm spell

HOARE LEA

Climate File	DSY05 (1989) - Heathrow Baseline		1989 – London DSY 1 + UHI		2003 – London DSY 2 + UHI		1976 - London DSY 3 + UHI	
Ventilation mode	CIBSE Guide A 2015	CIBSE TM52	CIBSE Guide A 2015	CIBSE TM52	CIBSE Guide A 2015	CIBSE TM52	CIBSE Guide A 2015	CIBSE TM52
Sealed façade + mechanical ventilation	7/16	-	0/16	-	0/16	-	0/16	-
Openable windows + mechanical ventilation	16/16	16/16	14/16	16/16	12/16	11/16	11/16	12/16
Natural ventilation	-	16/16	-	16/16	-	11/16	-	12/16

TM52 method provided greater flexibility for the development to comply although still does not comply to more onerous climate scenarios

Some other overheating risk assessment methods (sector & compliance-based)

Building Bulletin 101 (Ventilation of School Buildings)

Internal **air** temperature to meet at least 2 out of the following 3 criteria (May to September, 9:30 to 3:30pm):

1. Not to exceed 28°C for more than 120 hours (i.e. over 15% of occupied hours)
2. Not to exceed external temperature by more than 5°C
3. Never to exceed 32°C

Weather data: Test Reference Year

BCO 2009

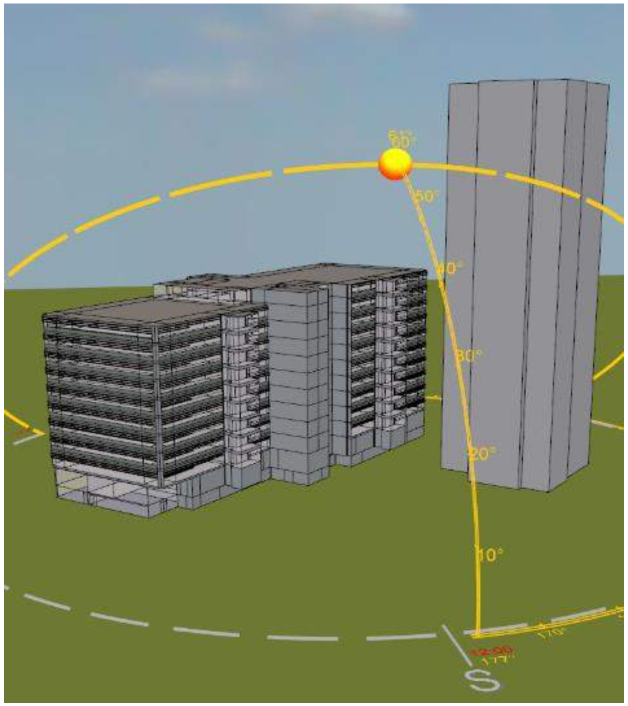
Summer internal **air** temperature: 24°C ±2°C

Look to limit operative temperature to 26-27°C at the perimeter

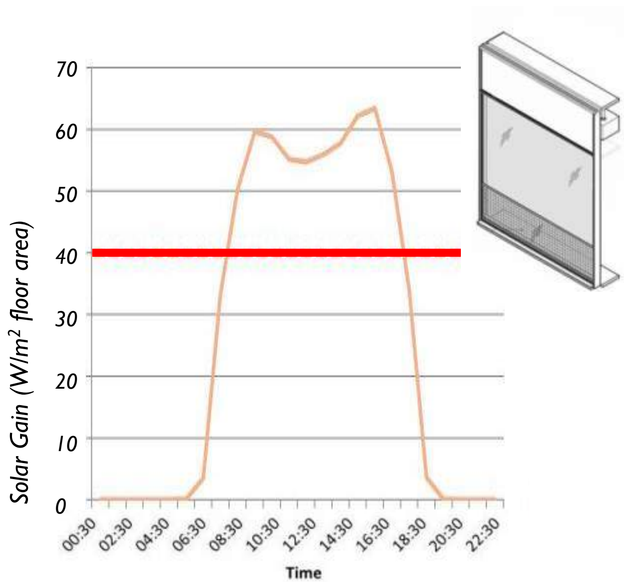
Part L 1 (SAP) assessment	CIBSE comfort assessment method
Regulatory requirement in Part L1A	Not mandatory for building regulations compliance
Simple calculation to determine the effects of solar gains in summer, taken as a proxy for overheating risk (Part L criterion 3)	Assessment using dynamic thermal model
'High' risk is deemed to fail Part L criterion 3	Exceeding specific indoor operative temperatures for percentage of occupied hours
Low cost assessment. Should be carried out for normal Part L compliance.	Relatively high cost of assessment due to additional briefing, dynamic thermal modelling and analysis.

Simulation for solar gains in a commercial office development

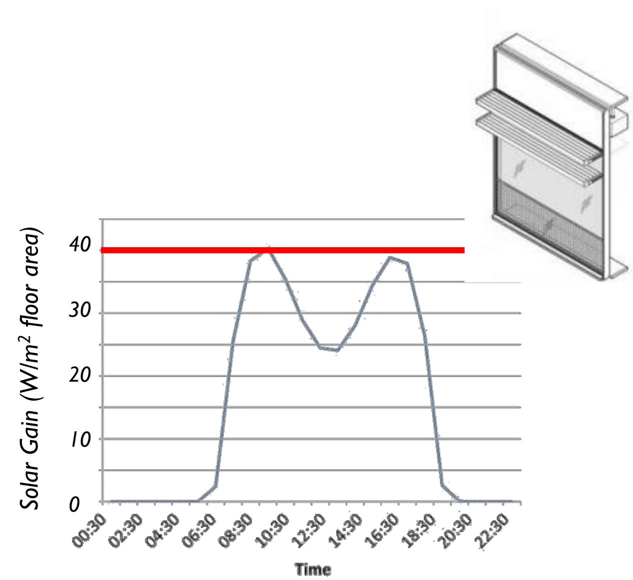
In order to get chilled beam with displacement ventilation system to work there was a need to limit solar gains



Option 1 – No Shading

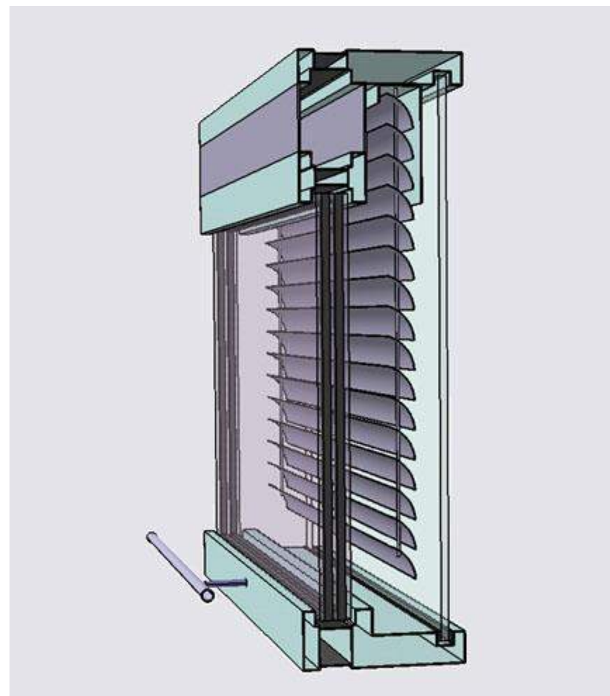


Option 2 – Brise Soleil

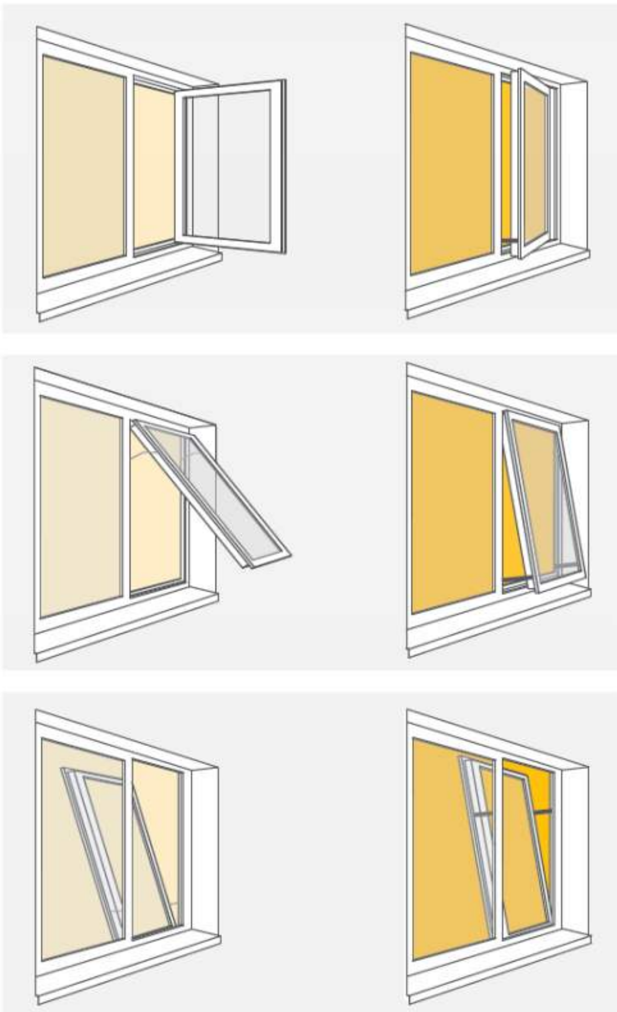


Innovation – closed cavity façade (CCF) with automated interstitial blinds

- Significant R&D required to capture heat transfer through CCF system
- Challenge for blind system simulation includes operation of blinds as a function of incident solar gains / resulting daylighting levels and then correlating changes in internal heat (artificial lighting) gains which also vary with blind operation
- Calculation showed similar performance to brise soleil system, CCF system allowing floor to ceiling glazing which was the architectural preference



How wide open is a window (effectively)?



Side-hung windows

When fully open, side-hung windows have the capacity to allow a high level of ventilation. However, they are particularly vulnerable to driving rain and difficult to clean.

Top-hung windows

Top-hung windows have the potential to allow high rates of air flow. However, due to security and safety concerns, the length of the throw of the stays is often restricted.

Tilt and turn windows

If well designed, this type of window can offer versatility with regard to the types of air flow that can be provided.

Stays prevent window opening wide

Flow rate = Factor x Pressure difference

Velocity (x area)

Pressure loss e.g. due to turbulence

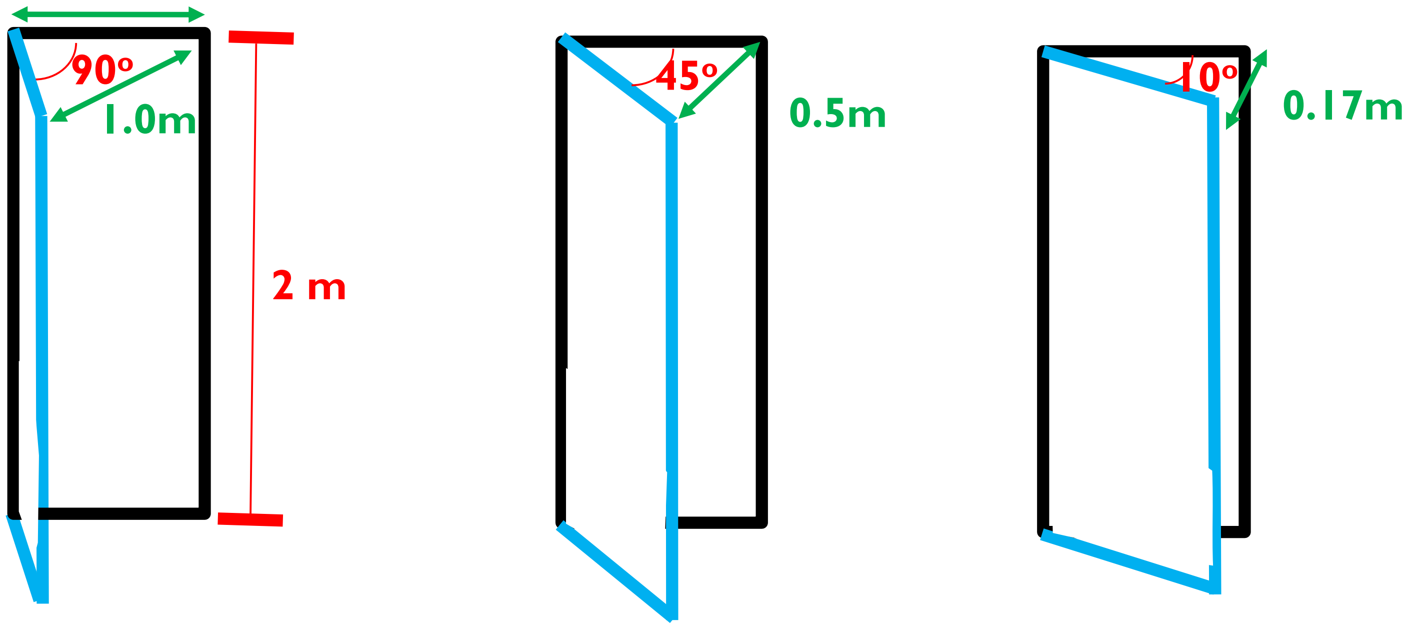
Discharge coefficient (Cd)

Effective area (NOT width x height)

Either directly put into model or via Cd

Definition of area for ventilation openings

Effect of opening a window on ventilation performance
(excluding top and bottom of window for illustration purposes)



Window Open 90º **Window Open 45º** **Window Open 10º**

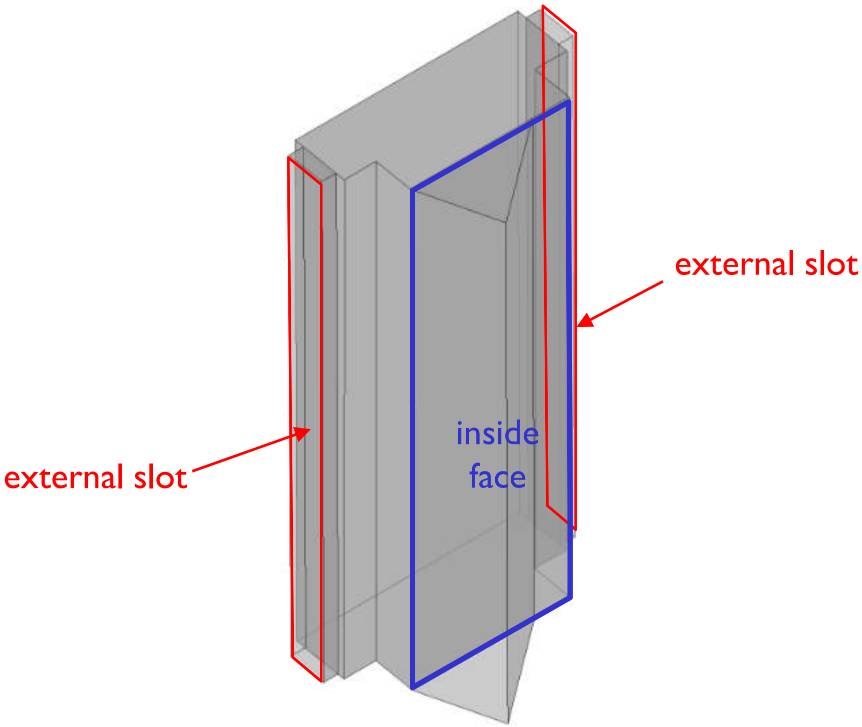
Open area (OA)= 2m^2
Discharge coefficient (C_d) = 0.6
Effective area (C_d*OA)= 1.2m^2

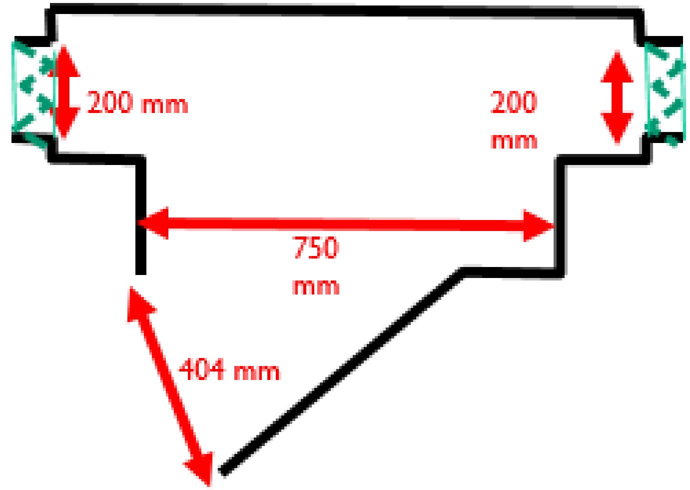
Open area (OA)= 1m^2
Discharge coefficient (C_d) = 0.6
Effective area (C_d*OA)= 0.6m^2

Open area (OA)= 0.34m^2
Discharge coefficient (C_d) = 0.6
Effective area (C_d*OA)= 0.2m^2

In reality different flow patterns and resulting turbulence / pressure losses will generate different discharge coefficients

Calculation of effective area for ventilation openings (vent unit)





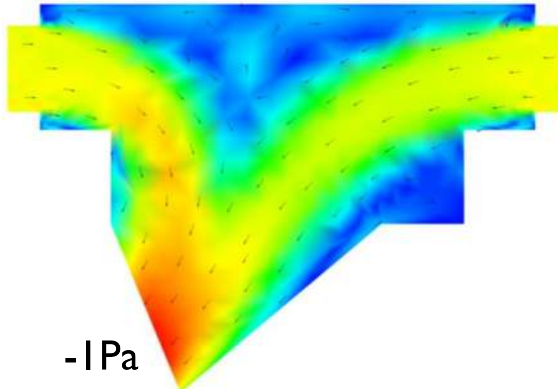
Internal face area = 0.750m wide*2.45m high = 1.8m²
Open area (OA)= 54% of internal face area

- External opening (slots) - on two sides with 50% open porous mesh (possible insect mesh)
- Internal zone – geometry generates turbulence (possible attenuation elements)
- Internal opening (face) - openable panel (possible grille and/or damper system)

Calculation of effective area for ventilation openings (vent unit)

Example without wind

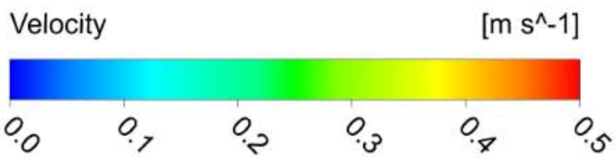
0Pa



0Pa

-1Pa

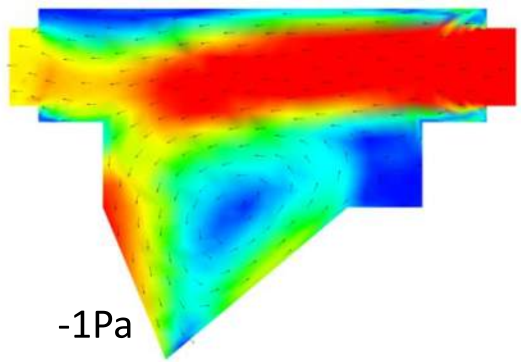
Flow rate = 0.147m³/s



Different pressure differences generate different flow rates leading to pressure-flow curve and calculation for effective area

Example with wind

-2Pa



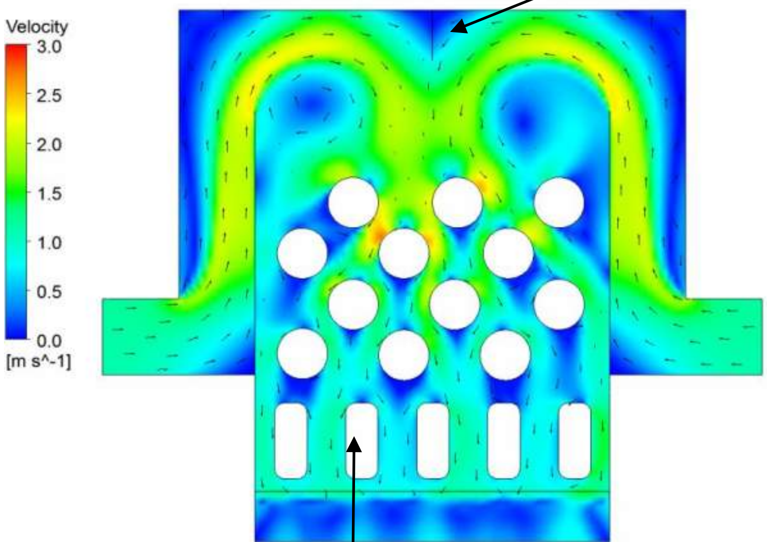
2Pa

-1Pa

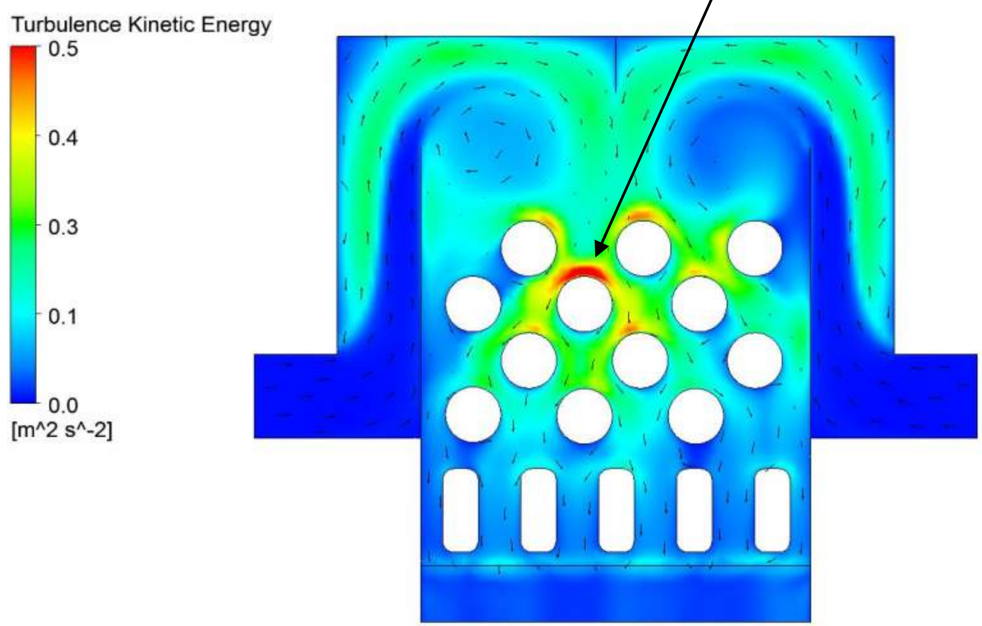
Manufacturer's data on discharge coefficients may only be available for single components and not the full system.

Reducing overheating risk by increasing effective area

angle increases flow rate and therefore increases effective area



attenuation elements generate turbulence, reduce flow rate and therefore reduce effective area



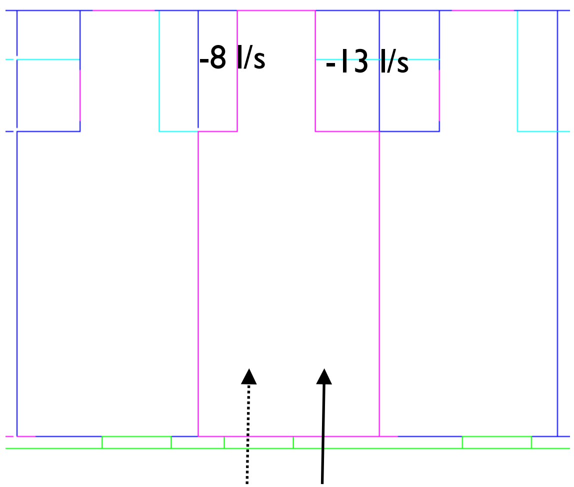
any grille insert would reduce flow rate and therefore reduce effective area

open area representation for grille?

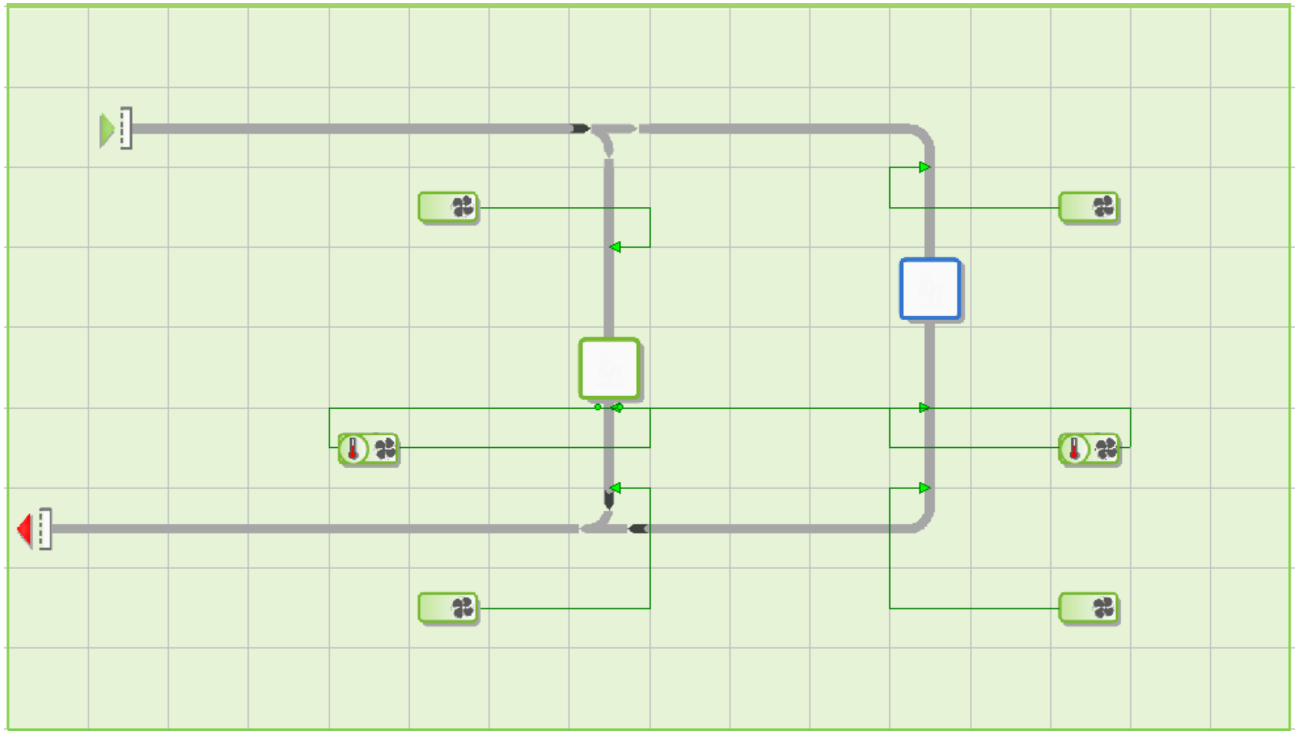
Student residence with extract only ventilation system case study

- Continuous mechanical extract system through bathroom and kitchenette
- Air path via fixed louvre with additional summer ventilation via openable windows

Bathroom and kitchenette extract



Fixed louvre and openable window

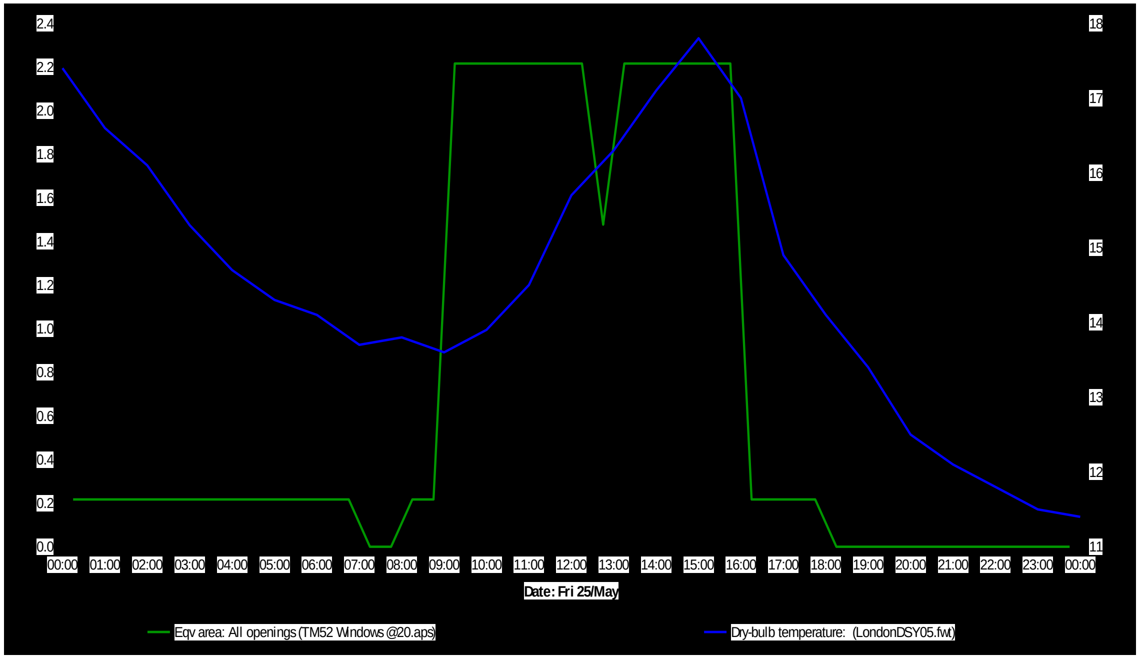


HVAC system generated in dynamic thermal model

- Solution required a combination of a dynamic thermal systems and multi-zonal airflow models
- Includes models for air movement via openable windows/louvres and extract air systems
- All units shown to be compliant in at least two out of three TM52 criteria

Solution controls in a school building (I)

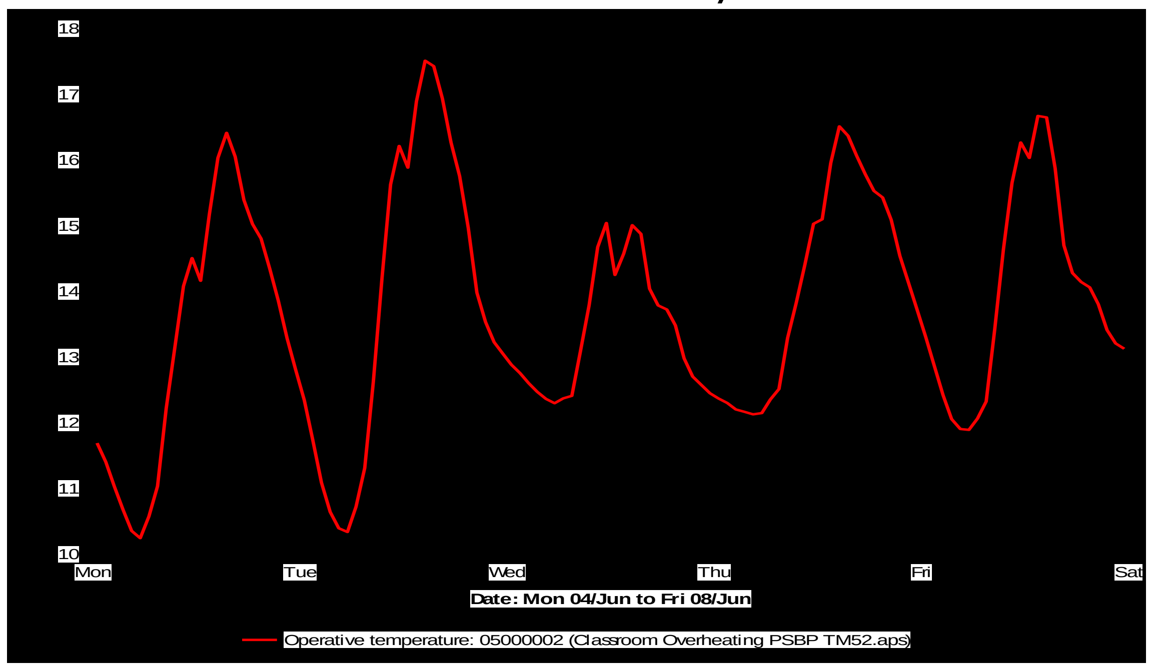
- Insufficient consideration of how the space would be operated undermined the validity of the overheating test
- Large dedicated ventilation panels which were crudely controlled to be fully open anytime the room temperature was above 20°C
- Vents being fully open despite external temperatures being below 16°C all morning leading to violation of the EFA requirements to control cold draughts
- Correcting the window operation to control cold draughts led to increased overheating due to reduced cooling of the thermal mass during the early part of the day



Ventilation free area (green) vs external dry bulb temp (blue)

Solution controls in a school building (II)

- Classrooms have NVHR fans running at maximum non-stop (24/7)
- With window openings and high thermal mass this sailed through the EFA tests with report submitted to design team in support of the design
- Once controls were corrected to be representative it failed
- Poor consideration of controls can lead to spaces being over-ventilated or over-cooled in the model thereby allowing the overheating test to be more readily passed leading to increased overheating risk in operation.
- Where hybrid approaches are used the controls must avoid conflicts and correctly account for the handover from one system to another.



No overheating here!

(Occupied operative temperatures 13 to 17°C…in June!)

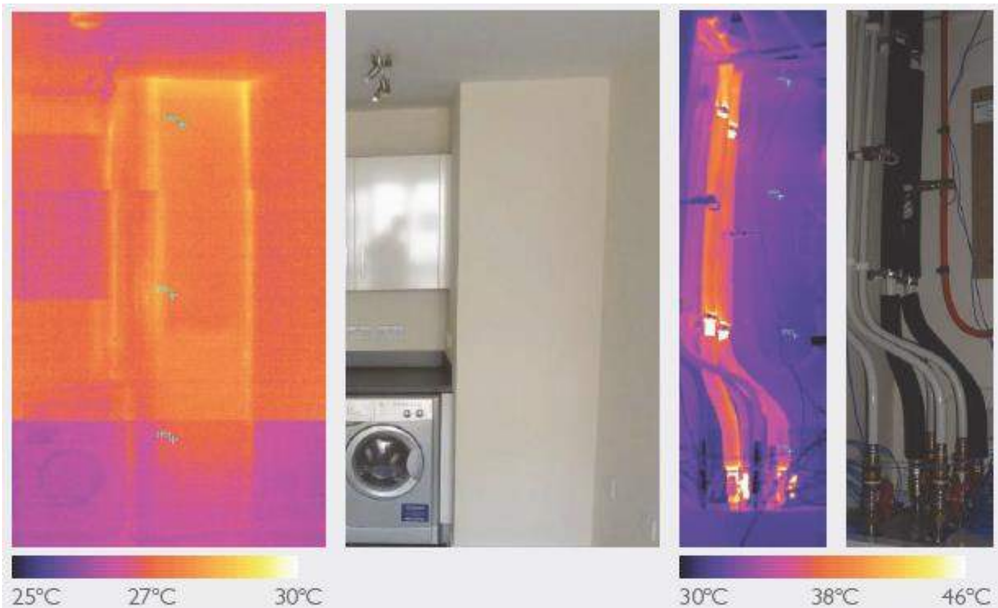
Capture of realistic internal heat gains - overheating from building services

Clients, in particular Housing Associations and residential developers, are increasingly concerned about overheating in new apartments (both in communal areas / corridors and within the dwellings)

Potential causes of residential overheating complaints:

- Internal gains from equipment
- Heating pipes in corridors (…continual circulation of LPHW)
- Poorly insulated heat interface units
- Poorly installation of thermal insulation
- Radiant heat from underfloor heating

Heat emissions from building services installations



- Poorly insulated heating pipes can generate warm conditions in residences
- Many community heating systems are operating 24hrs/day

Sensitivity testing of inputs may reduce risk of underestimating overheating risk and provide focus

Hot water cylinder

How should known variations in measured external surface temperatures influence our approach to assessing overheating risk?

Free air temperature 25°C

Flat – internal temperature 27°C

Balcony structure 56°C

Wall, brick 38°C

Wall, painted 28°C

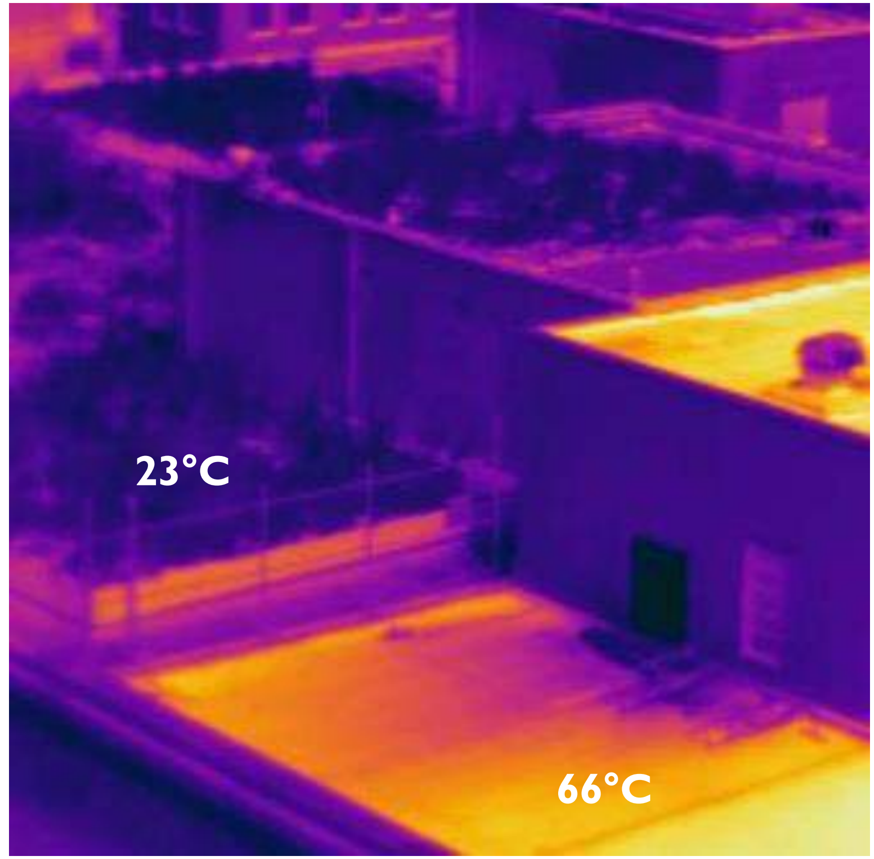
Flagstones 57°C

Pavement 44°C

- More checks on outside conditions and surface properties?
- Greater resolution in model?

The temperature of some materials can vary by 10K or more

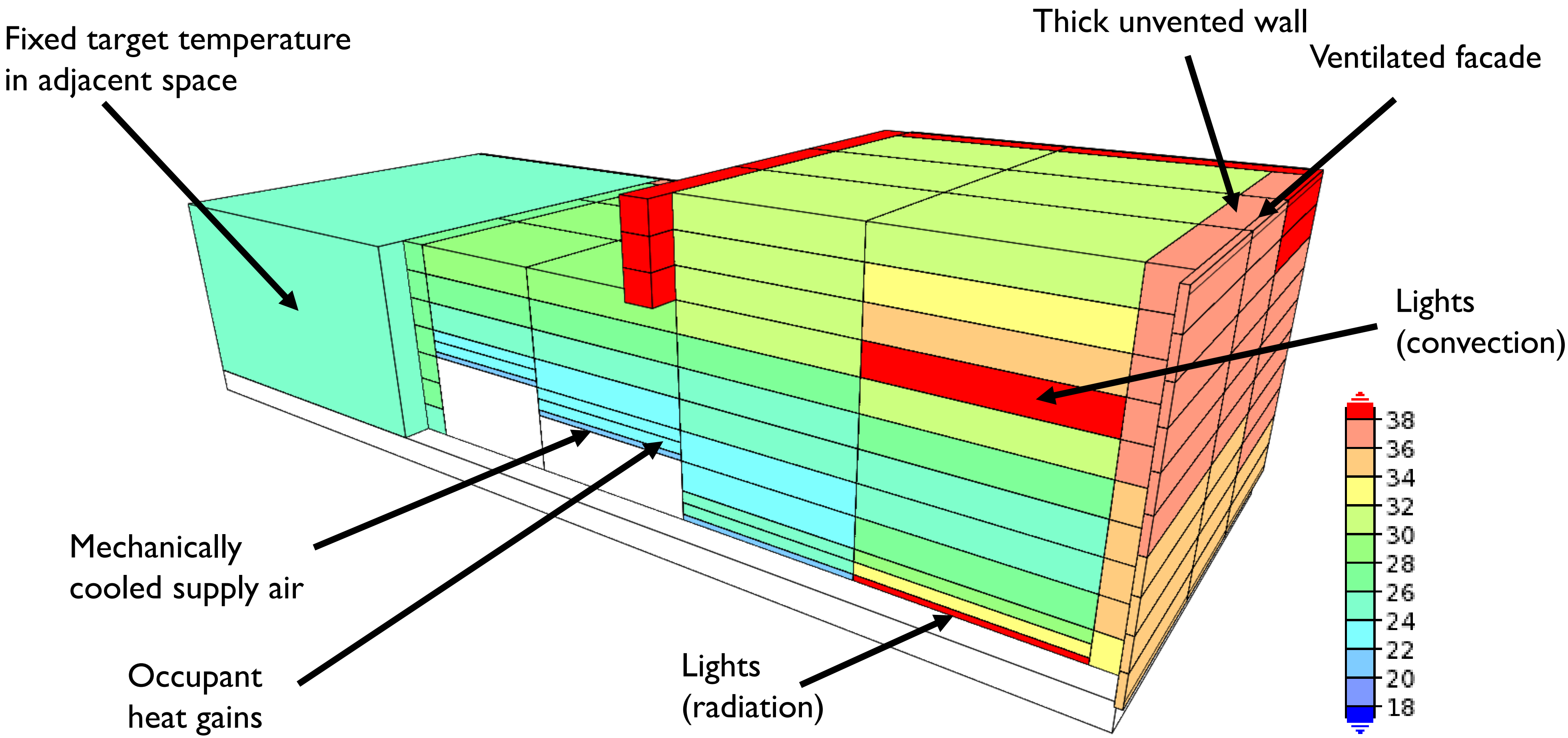
Higher risk of overheating on top floor



Implications for internal temperature of building, efficiency of roof mounted HVAC systems, energy consumption, carbon emissions, urban heat island effect

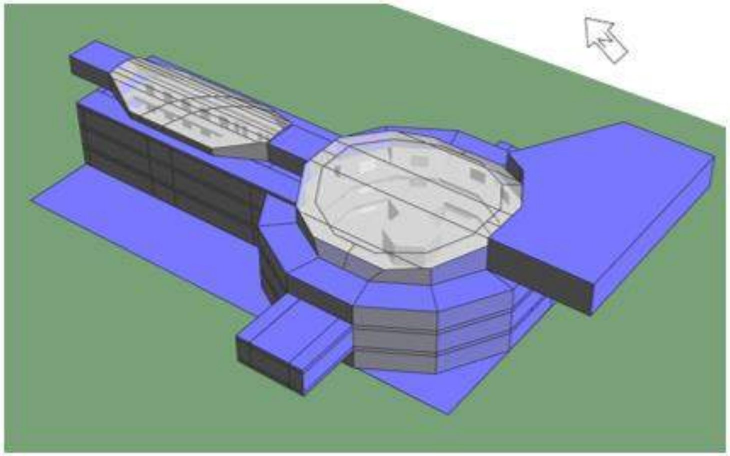
Operative temperature prediction using high resolution multi-zonal dynamic thermal model

During feasibility / concept stage sensitivity testing of envelope and systems may provide focus for positioning of the design within known limits of technique

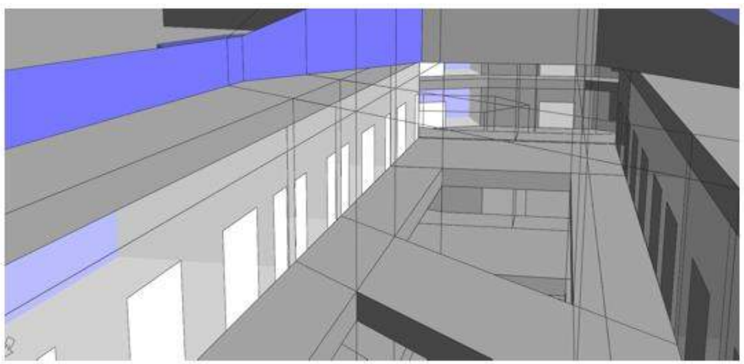


Retail development: Operative temperature prediction using CFD model coupled to a dynamic thermal model (DTM)

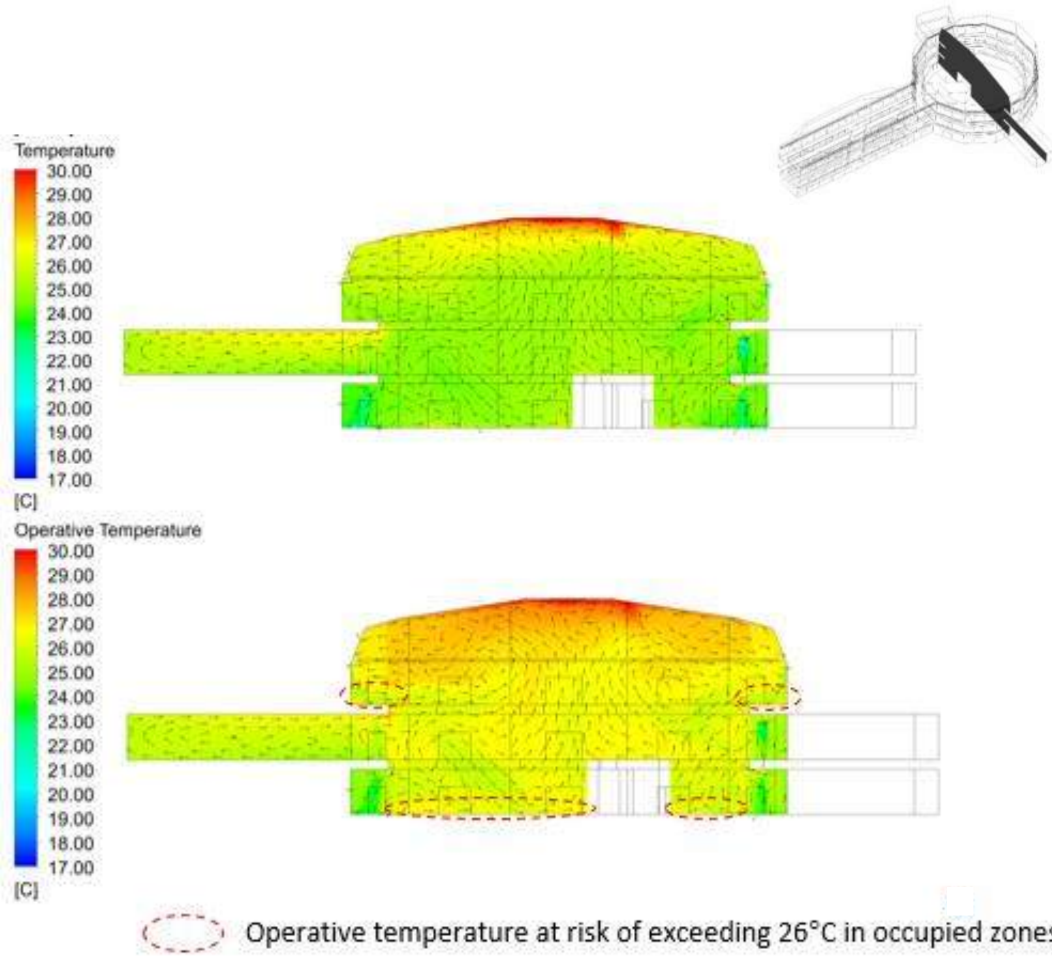
Typically DTM resolves radiant field and provides fixed surface temperatures for the CFD model. In this case mean radiant temperature by zone was also exchanged.



External view of DTM Geometry



Internal view of DTM Geometry



Final thoughts on overheating risk assessments

- Choice of software and approach. May be impacted by design stage with increasing complexity as the design develops. Appropriate disclaimers, limitations, assumptions recommended to be specified.
- Choice of climate data. How informed is the client about this choice and consequential future repercussions (e.g. requirements for adaptation or retrofitting)? Clear or partially cloudy sky?
- Choice of targets. How informed is the client about this choice and its potential impact on commercial risk or worker productivity?
- Occupant behaviour. Profiles known to have a large impact on performance gap and will also impact overheating risk.
- Internal heat gains. What's missing and how sensitive is overheating risk to the way the internal heat gains are applied (air and radiant components)?

Final thoughts on overheating risk assessments

- Treatment of surfaces (inside and out). Thermal conduction through envelope may be significant factor in overheating risk. Check U-values are appropriate (e.g. including surface orientation).
- Capture of solar gains. Is glazing and shading / blind systems effectively represented in the model? Is systems design for blind open or blind shut and does target correlate? Is g-value AND direct solar transmission for glazing element appropriately represented?
- Solution controls. How will the space be used? What are people experiencing? How will they respond to operate windows, ventilators and blinds? How should automatic controls be set up?
- Solution checking and interpretation. Even if target is based on hours exceeded over several months, a detailed review on a peak day provides additional confidence in design message. Is velocity 'guess' appropriate and how sensitive is given metric to it.
- Recommend use of CIBSE AM11 'Building Performance Modelling' (2015) for guidance.

Thank you
Any questions?

Arts, Culture and Heritage

Courts and Emergency

Data Centre and Mission Critical

Defence

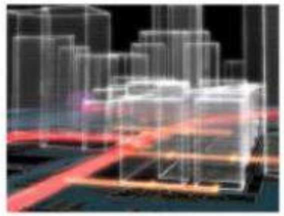
Distribution

Education

Healthcare

Hotels and Resorts

Infrastructure and Energy



Leisure

Manufacturing and Process

Prisons

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Workplace

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