EMS717U/EMS717P
Renewable Energy Resources

Building Energy Efficiency (1)

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Content

- Net zero and building sector
- Thermal comfort:
- Factors affecting thermal comfort.
- Humidity and measurement
- Psychrometric chart and its use
- Human body energy balance and thermal comfort
- Design for thermal comfort
- Heating and cooling loads
- Building energy efficiency

Energy in building sector

- **Purpose of buildings**

- **home, office,**
- **car, train, aeroplane, space station**
- **lab, clean room**

80% of time is in a space.

Energy consumption, CO2 emission, strategy

According to the Carbon Trust (CTG005, 2007):

- **"*around 40% of commercial floor space is expected to be air-conditioned by 2020, compared with only 10% at the end of 1994*".**
- **The annual electricity consumption will increase four-fold by 2020 to nearly 64 TWh from 13.3 TWh at the end of 1994, with corresponding CO_2 increasing from 2 Megatonnes per year to over 9 Megatonnes per year (Hitchin (2000)).**

In response to an EU directive, the *Energy Performance of Buildings Directive* (EPBD) legislation came into force in January 2006.

- **The UK Government's *Low Carbon Transition Plan*, committed the UK to achieving a 34% cut in CO_2 emissions over 1990 levels by 2020 and 80% by 2050.**
- **Net zero emissions of greenhouse gases by 2050.**

Strategies:

- **Carbon Trust: "Energy efficiency measures are expected to deliver half of the necessary improvements" (CTG005, 2007).**
- **UK's Renewable Energy Strategy (2009) and Roadmap (2011): 15% of the UK's energy consumption from renewable sources by 2020.**

Thermal Comfort - 1

- **Definition of thermal comfort**

- **A principal purpose of heating, ventilation, and air-conditioning systems is to provide conditions for human thermal comfort.**

- **A widely accepted definition is:**

  Thermal Comfort is that condition of mind that expresses satisfaction with the thermal environment (ASHRAE Standard 55).

  This definition leaves open what is meant by condition of mind or satisfaction, but it correctly emphasises that the judgment of comfort is a cognitive process involving many inputs influenced by physical, physiological, psychological, and other processes.

Thermal Comfort - 2

- **Factors affecting thermal comfort**

- **<u>Main factors</u>**

  Metabolism

  mechanical work

  temperature

  velocity

  clothing

  surrounding surface temperature

  humidity

- **<u>Secondary factors</u>**

  Day-to-day variation, age, sex, seasonal and circadian rhythms, etc.

Thermal Comfort - 3

- **Humidity**

- Humidity ratio $$w = 0.622 \frac{P_w}{P - P_w}$$
  g/kg (dry air)

- Relative humidity $$\phi = \left. \frac{P_w}{P_{ws}} \right|_{T,P}$$
  How is a state close to the saturation state?

- Wet-bulb temperature
  Adiabatic saturation

- Dew-point temperature
  Saturation (cooling) at constant pressure

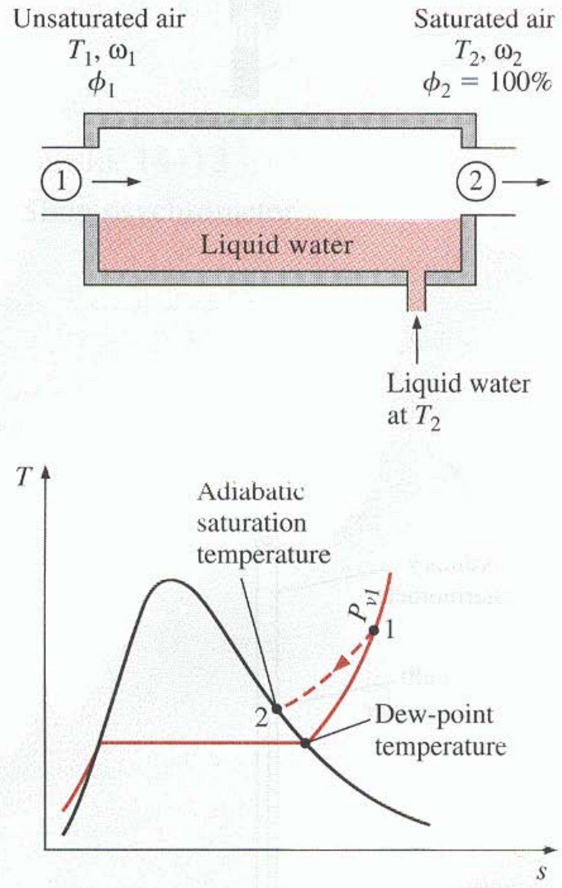


FIGURE 14–11
The adiabatic saturation process and its representation on a *T-s* diagram of water.

Thermal Comfort - 4

- **Measurement of humidity**

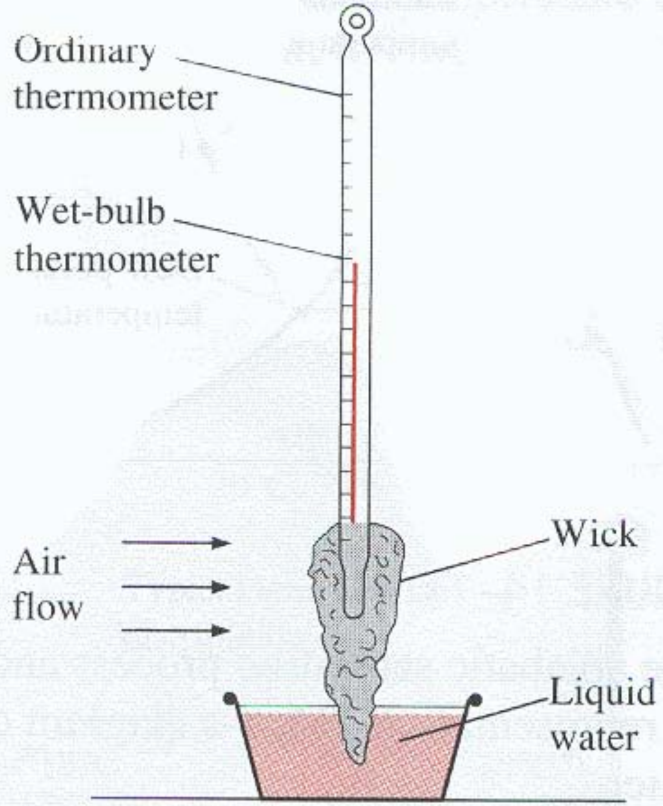


FIGURE 14–12

A simple arrangement to measure the wet-bulb temperature.

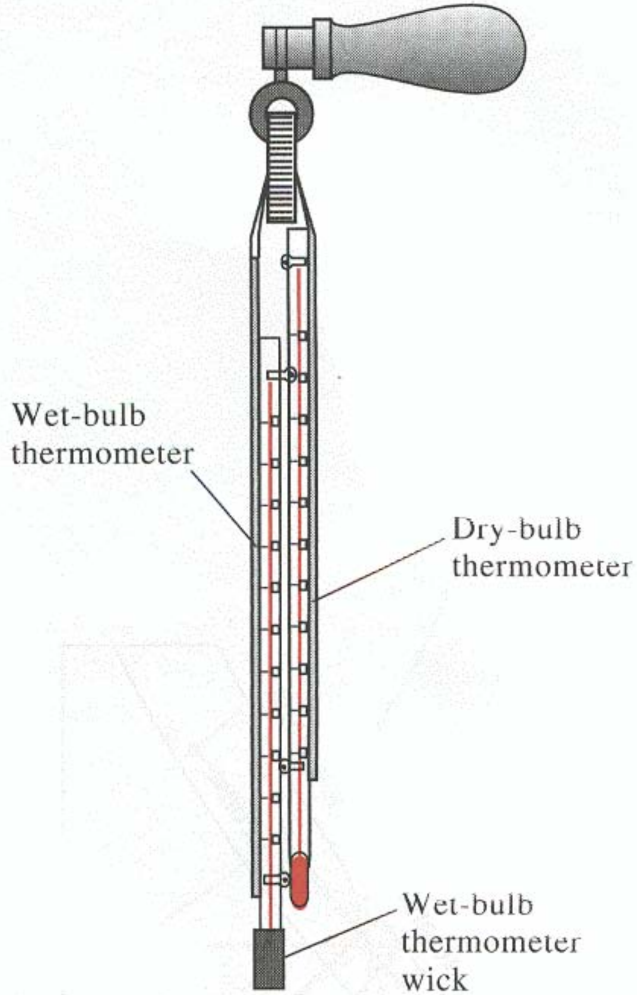
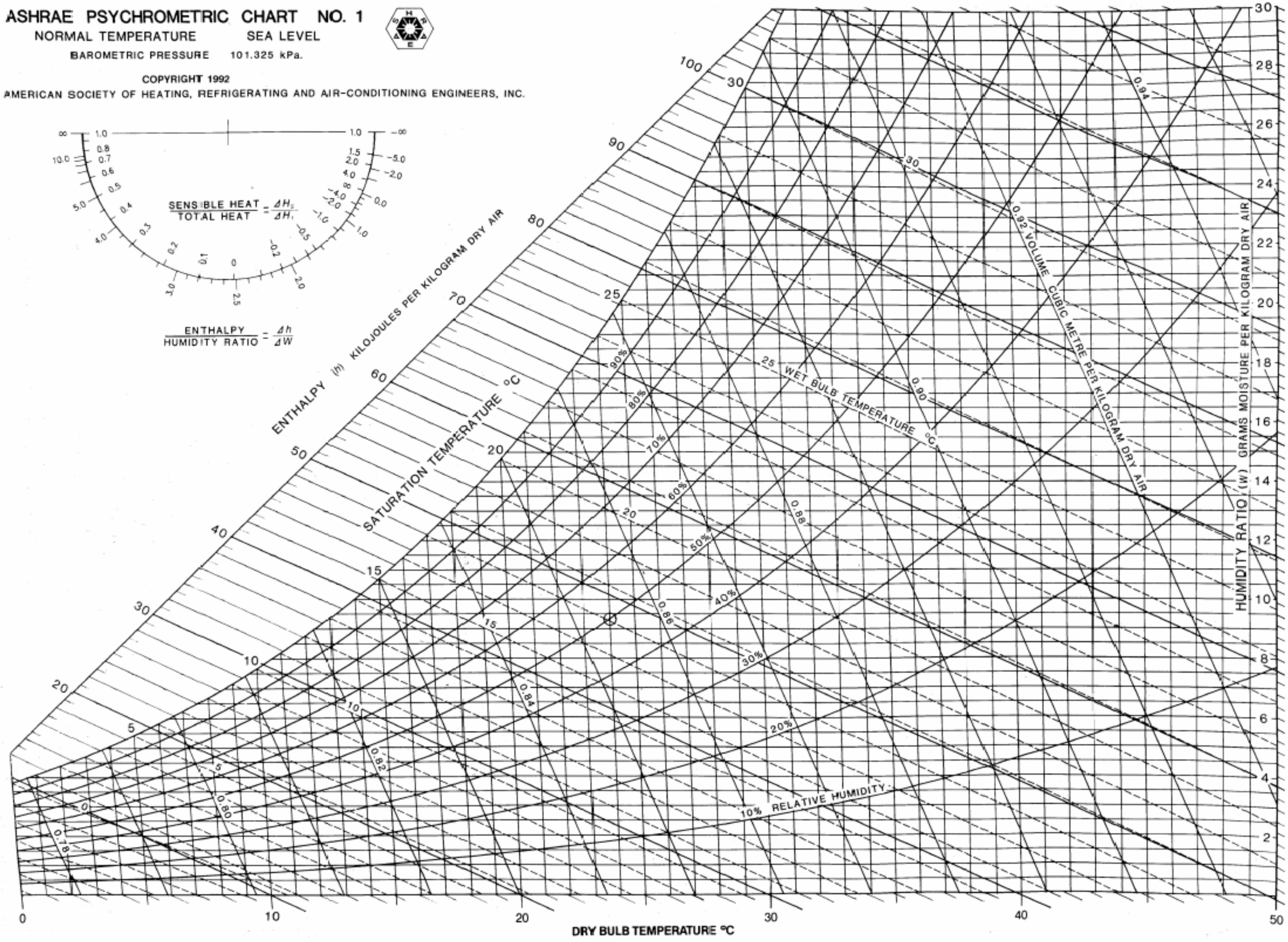


FIGURE 14–13

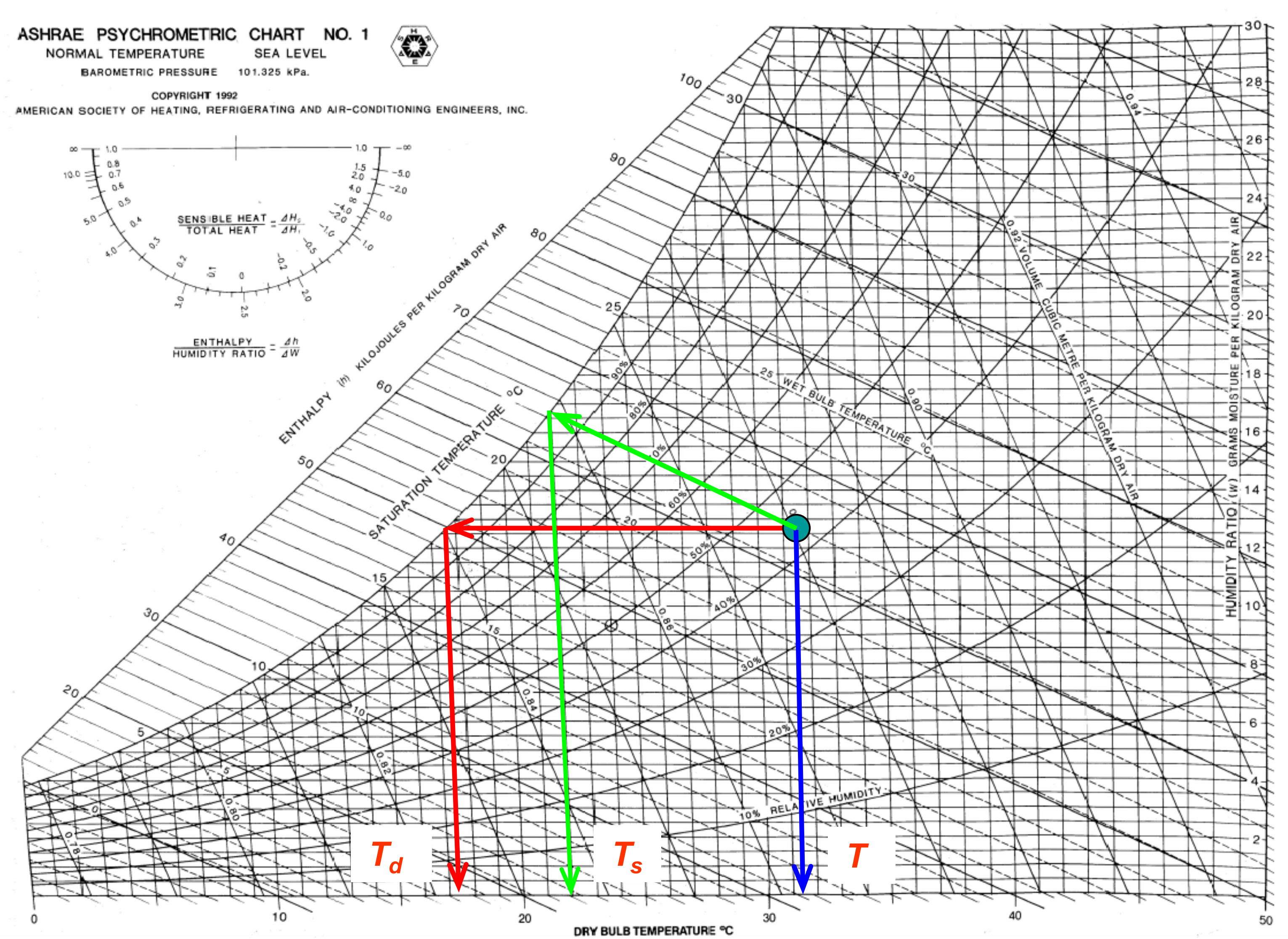
Sling psychrometer.

Psychrometric chart



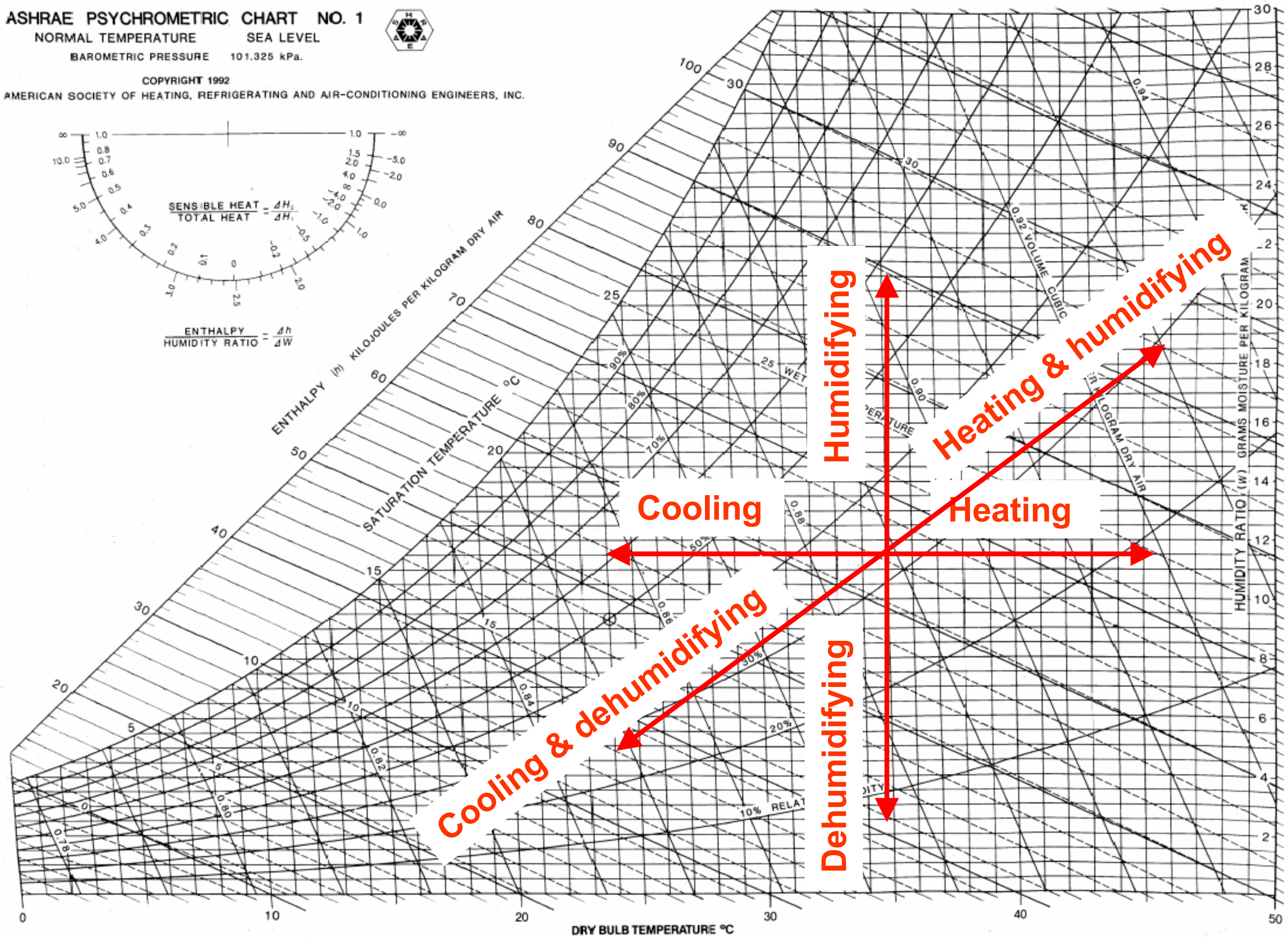
Thermal Comfort - 5

- **Psychrometric chart**



Thermal Comfort - 5

- **Psychrometric chart**



Thermal Comfort - 6

- **Energy balance**

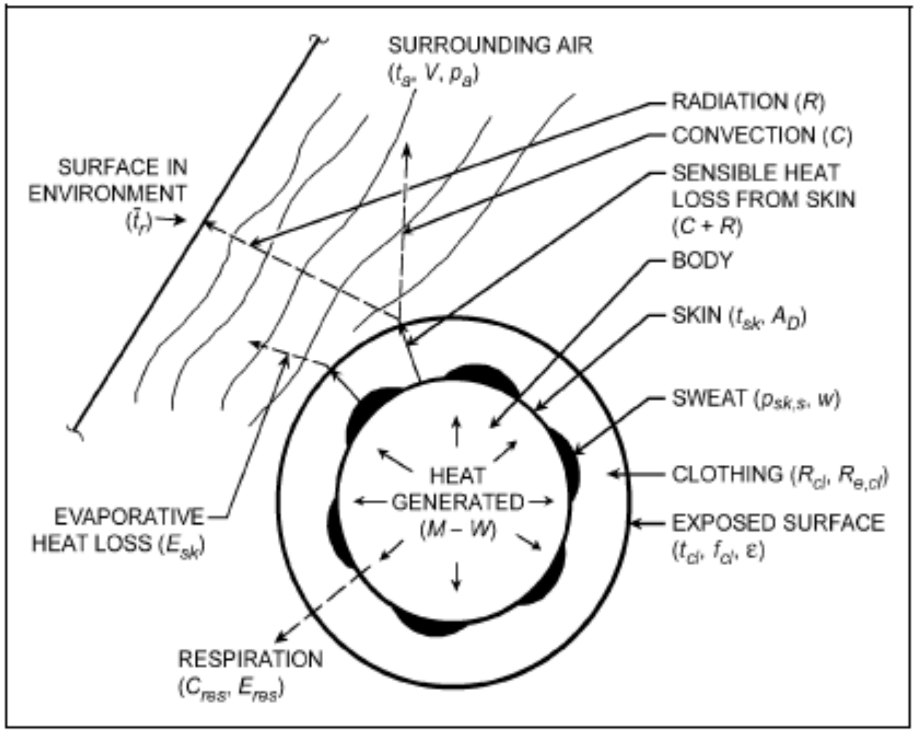


Fig. 1 Thermal Interaction of Human Body and Environment

$$M - W = q_{sk} + q_{res} + S$$
$$= (C + R + E_{sk}) + (C_{res} + E_{res}) + (S_{sk} + S_{cr})$$

where

M = rate of metabolic heat production, W/m^2
W = rate of mechanical work accomplished, W/m^2
q_{sk} = total rate of heat loss from skin, W/m^2
q_{res} = total rate of heat loss through respiration, W/m^2
$C + R$ = sensible heat loss from skin, W/m^2
E_{sk} = total rate of evaporative heat loss from skin, W/m^2
C_{res} = rate of convective heat loss from respiration, W/m^2
E_{res} = rate of evaporative heat loss from respiration, W/m^2
S_{sk} = rate of heat storage in skin compartment, W/m^2
S_{cr} = rate of heat storage in core compartment, W/m^2

Thermal Comfort - 7

- **Conditions for thermal comfort**

ASHRAE thermal sensation scale

+3	hot
+2	warm
+1	slightly warm
0	neutral
-1	slightly cool
-2	cool
-3	cold

Table 9 Equations for Predicting Thermal Sensation (Y) of Men, Women, and Men and Women Combined

Exposure Period, h	Subjects	Regression Equations[a, b] t = dry-bulb temperature, °C; p = vapor pressure, kPa
1.0	Men	$Y = 0.220\,t + 0.233\,p - 5.673$
	Women	$Y = 0.272\,t + 0.248\,p - 7.245$
	Both	$Y = 0.245\,t + 0.248\,p - 6.475$
2.0	Men	$Y = 0.221\,t + 0.270\,p - 6.024$
	Women	$Y = 0.283\,t + 0.210\,p - 7.694$
	Both	$Y = 0.252\,t + 0.240\,p - 6.859$
3.0	Men	$Y = 0.212\,t + 0.293\,p - 5.949$
	Women	$Y = 0.275\,t + 0.255\,p - 8.622$
	Both	$Y = 0.243\,t + 0.278\,p - 6.802$

[a] Y values refer to the ASHRAE thermal sensation scale.
[b] For young adult subjects with sedentary activity and wearing clothing with a thermal resistance of approximately 0.5 clo, $\bar{t}_r \approx \bar{t}_a$ and air velocities < 0.2 m/s.

Thermal Comfort - 8

- **Conditions for thermal comfort**

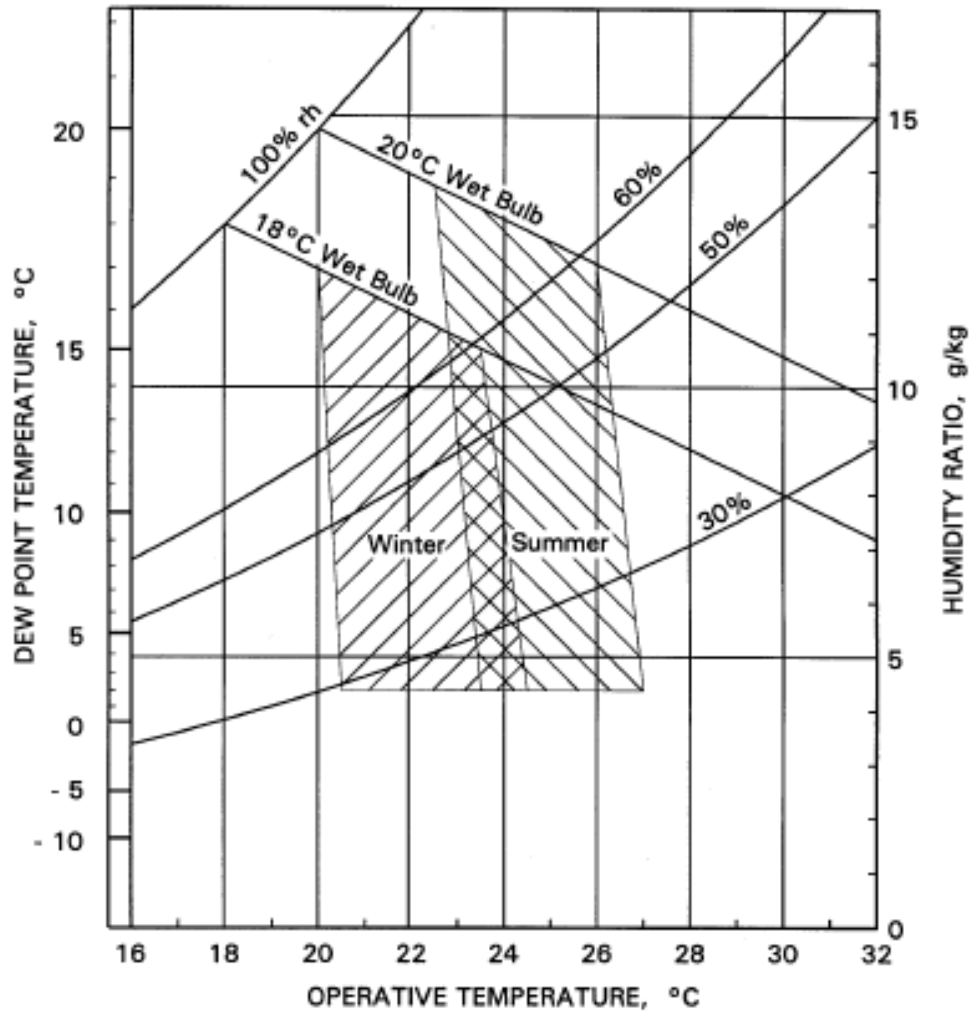


Fig. 5 ASHRAE Summer and Winter Comfort Zones
(Acceptable ranges of operative temperature and humidity for people in typical summer and winter clothing during primarily sedentary activity.)

Thermal Comfort - 9

- **Prediction of thermal comfort: PMV-PPD model**

$$\begin{aligned} M - W = {} & 3.96 \times 10^{-8} f_{cl}[(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] \\ & + f_{cl} h_c (t_{cl} - t_a) \\ & + 3.05[5.73 - 0.007(M - W) - p_a] \\ & + 0.42[(M - W) - 58.15] \\ & + 0.0173M(5.87 - p_a) \\ & + 0.0014M(34 - t_a) \end{aligned} \tag{58}$$

Equation (58) is expanded to include a range of thermal sensations by using a **predicted mean vote (PMV) index**. The PMV index predicts the mean response of a large group of people according to the ASHRAE thermal sensation scale. Fanger (1970) related PMV to the imbalance between the actual heat flow from the body in a given environment and the heat flow required for optimum comfort at the specified activity by the following equation:

$$\text{PMV} = [0.303\exp(-0.036M) + 0.028]L \tag{62}$$

where L is the thermal load on the body, defined as the difference between internal heat production and heat loss to the actual environment for a person hypothetically kept at comfort values of t_{sk} and E_{rsw} at the actual activity level. Thermal load L is then the difference between the left and right sides of Equation (58) calculated for the actual values of the environmental conditions. As part

After estimating the PMV with Equation (62) or another method, the **predicted percent dissatisfied** (PPD) with a condition can also be estimated. Fanger (1982) related the PPD to the PMV as follows:

$$\text{PPD} = 100 - 95\exp[-(0.03353\text{PMV}^4 + 0.2179\text{PMV}^2)] \tag{64}$$

where dissatisfied is defined as anybody not voting −1, +1, or 0. This relationship is shown in Figure 13. A PPD of 10% corresponds to the PMV range of ±0.5, and even with PMV = 0, about 5% of the people are dissatisfied.

The **PMV-PPD model** is widely used and accepted for design and field assessment of comfort conditions. ISO *Standard* 7730 includes a short computer listing that facilitates computing PMV and PPD for a wide range of parameters.

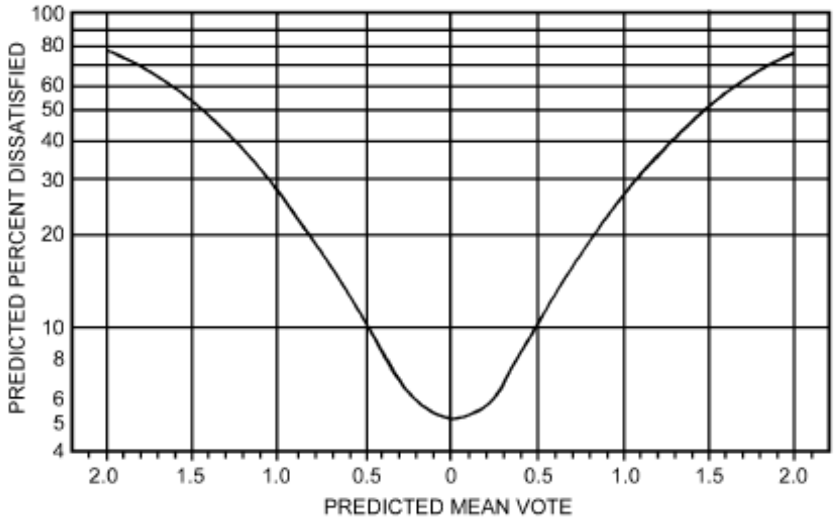
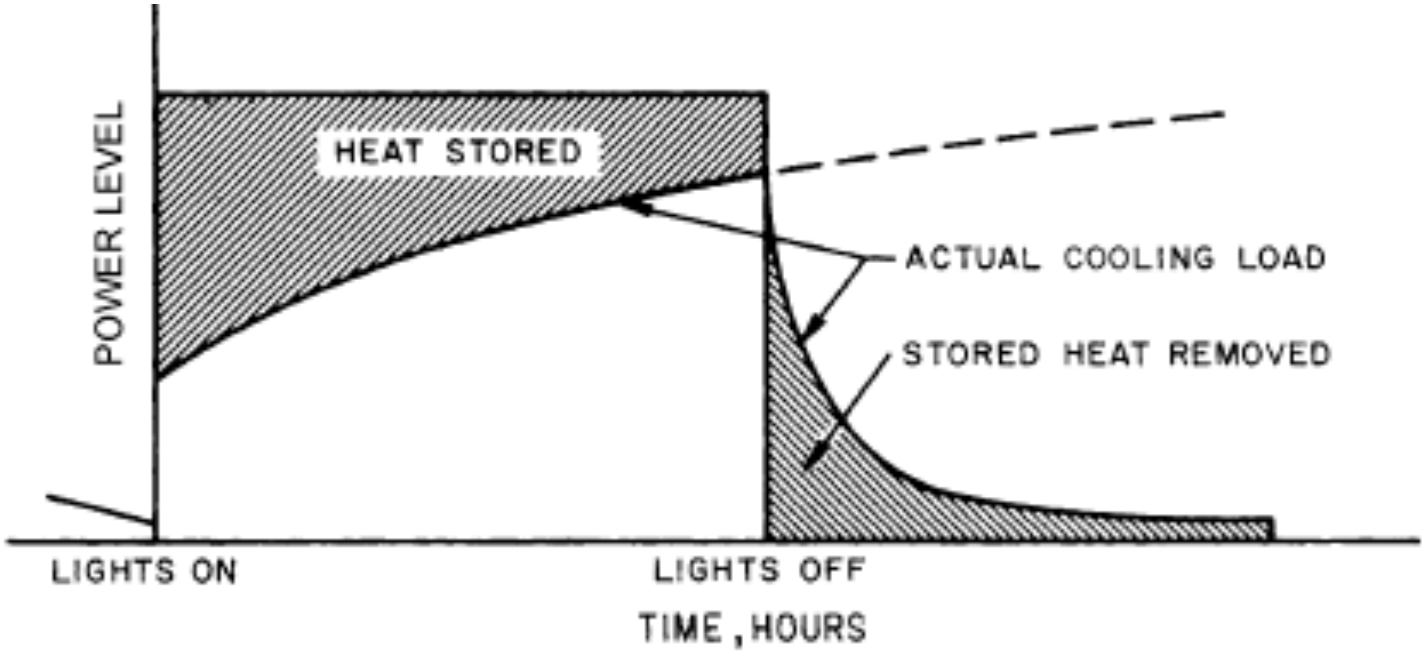
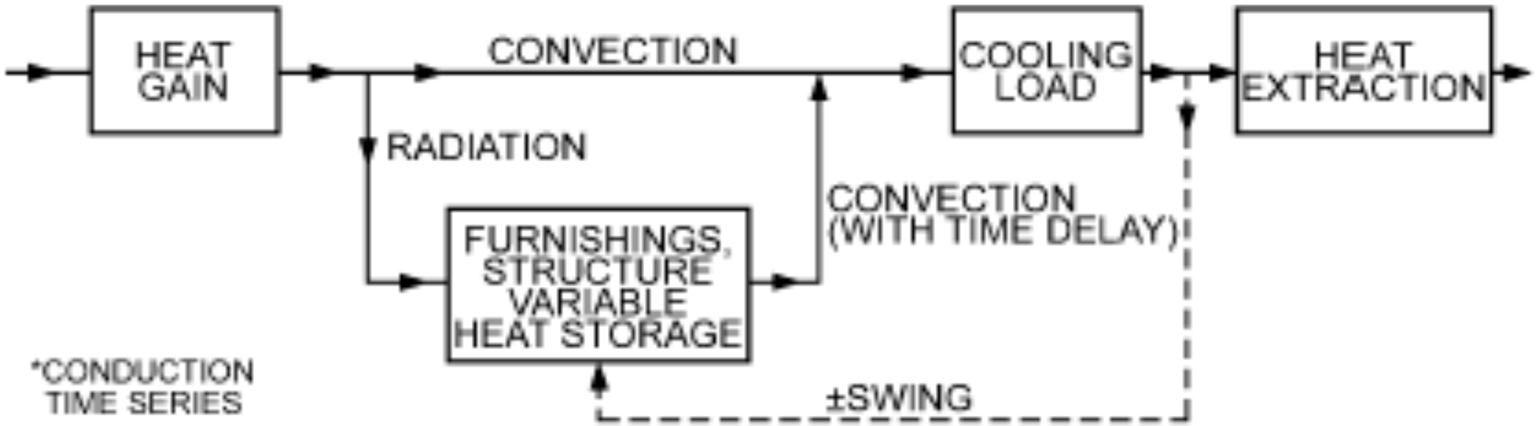


Fig. 13 Predicted Percentage of Dissatisfied (PPD) as Function of Predicted Mean Vote (PMV)

Heating/Cooling Loads





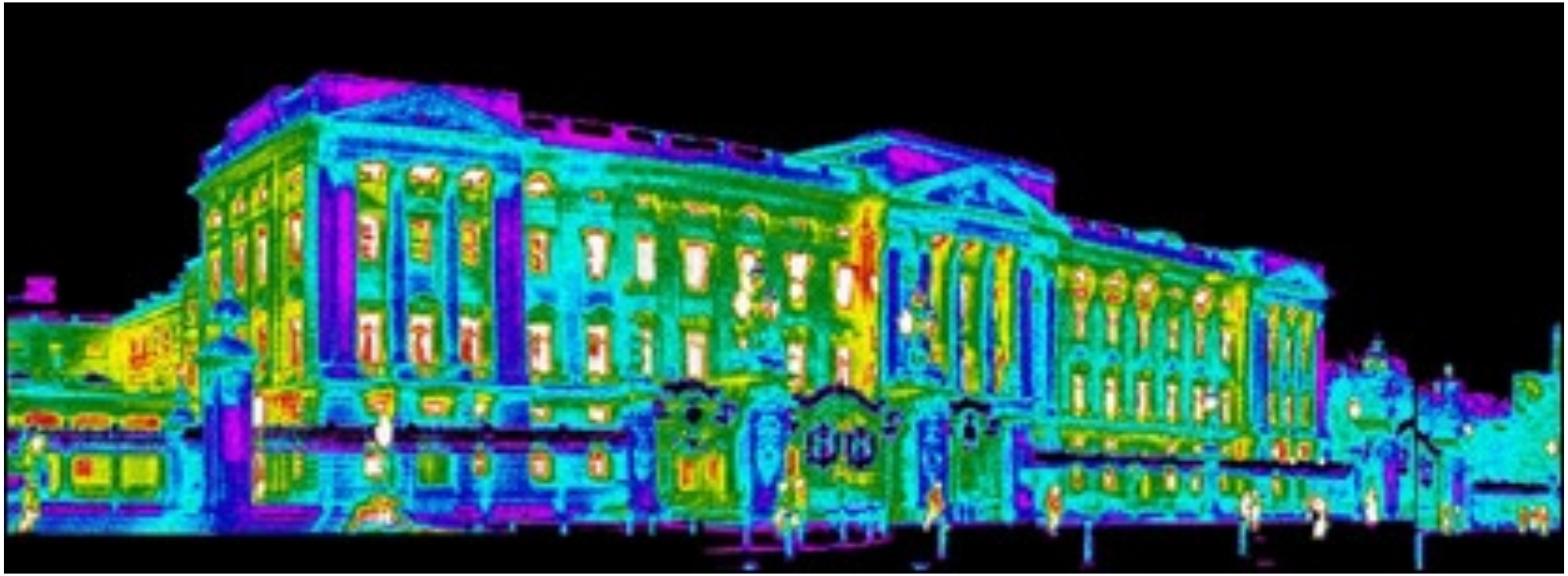
Building energy efficiency

- Building insulation
- Natural ventilation
- Renewable sources
- HVAC&R systems

Building Insulation

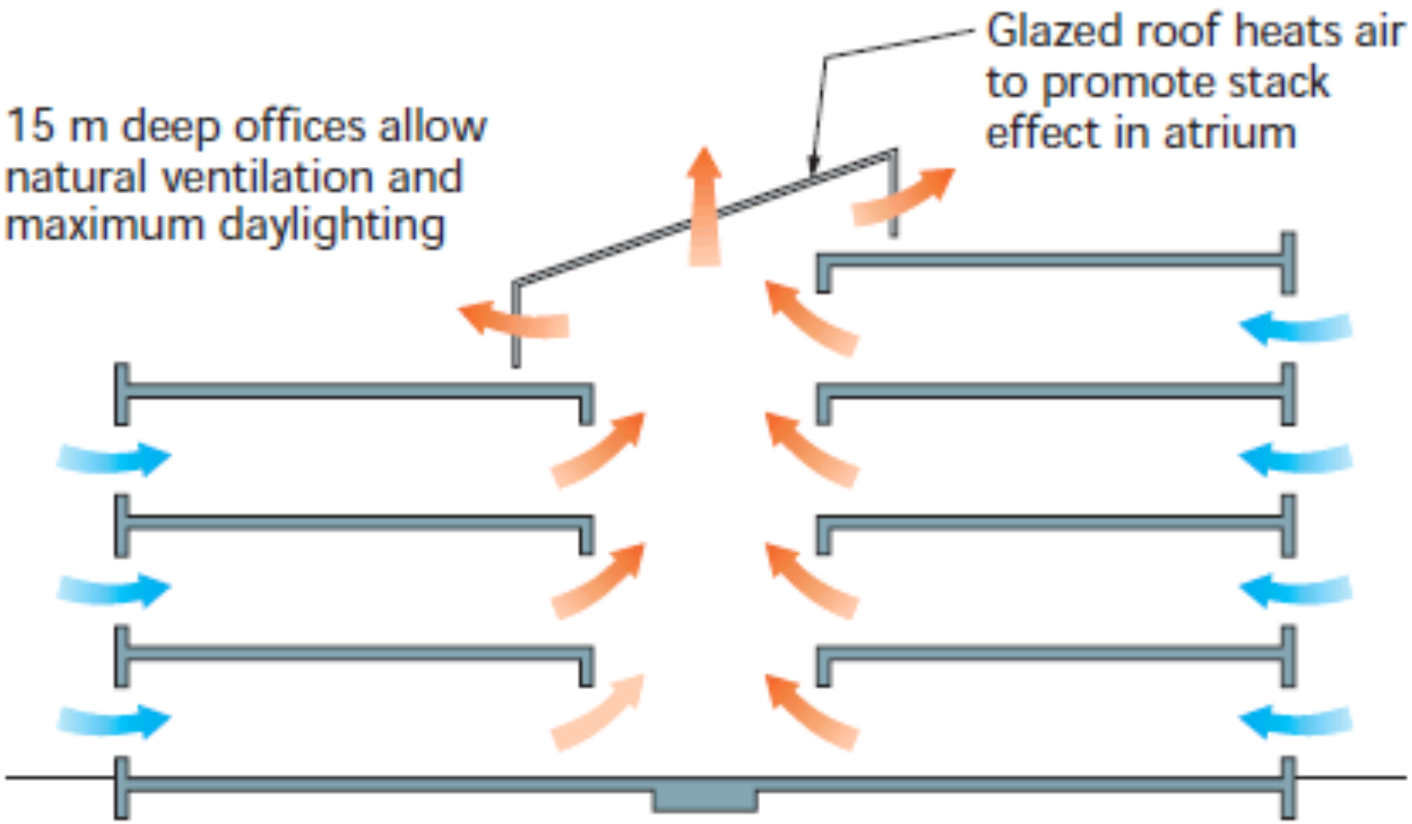
Building Regulations Part L

- Roof, walls, windows, floors, doors



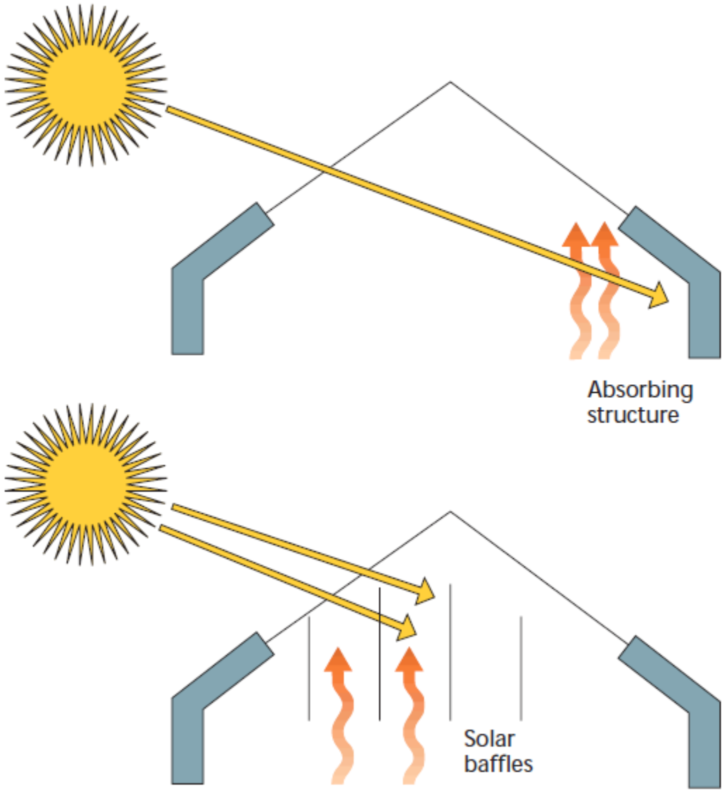
Natural ventilation driven by density difference

Chimney ventilation at Barclaycard Headquarters

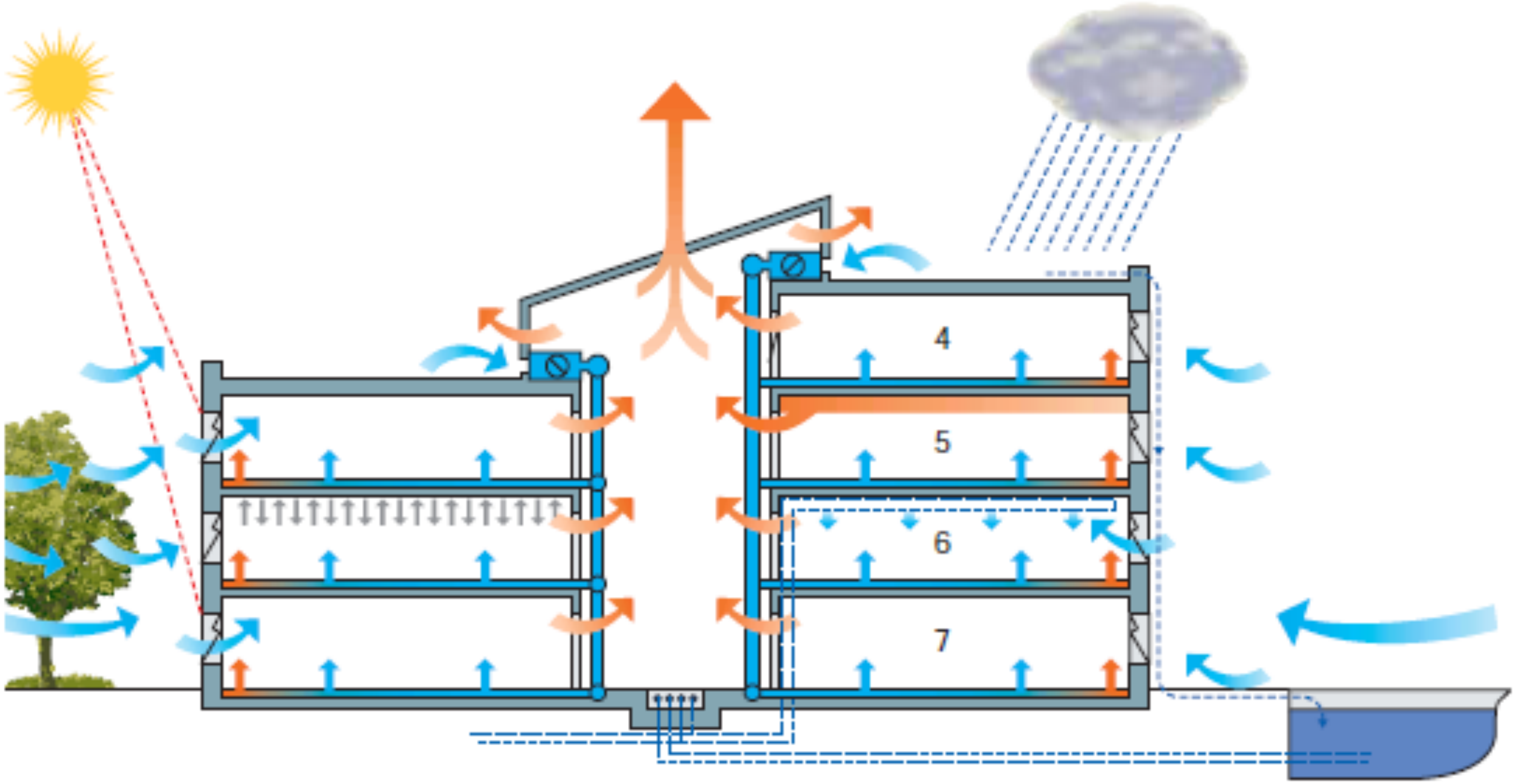


Natural ventilation driven by density difference

Solar chimneys at BRE's Environmental Builing



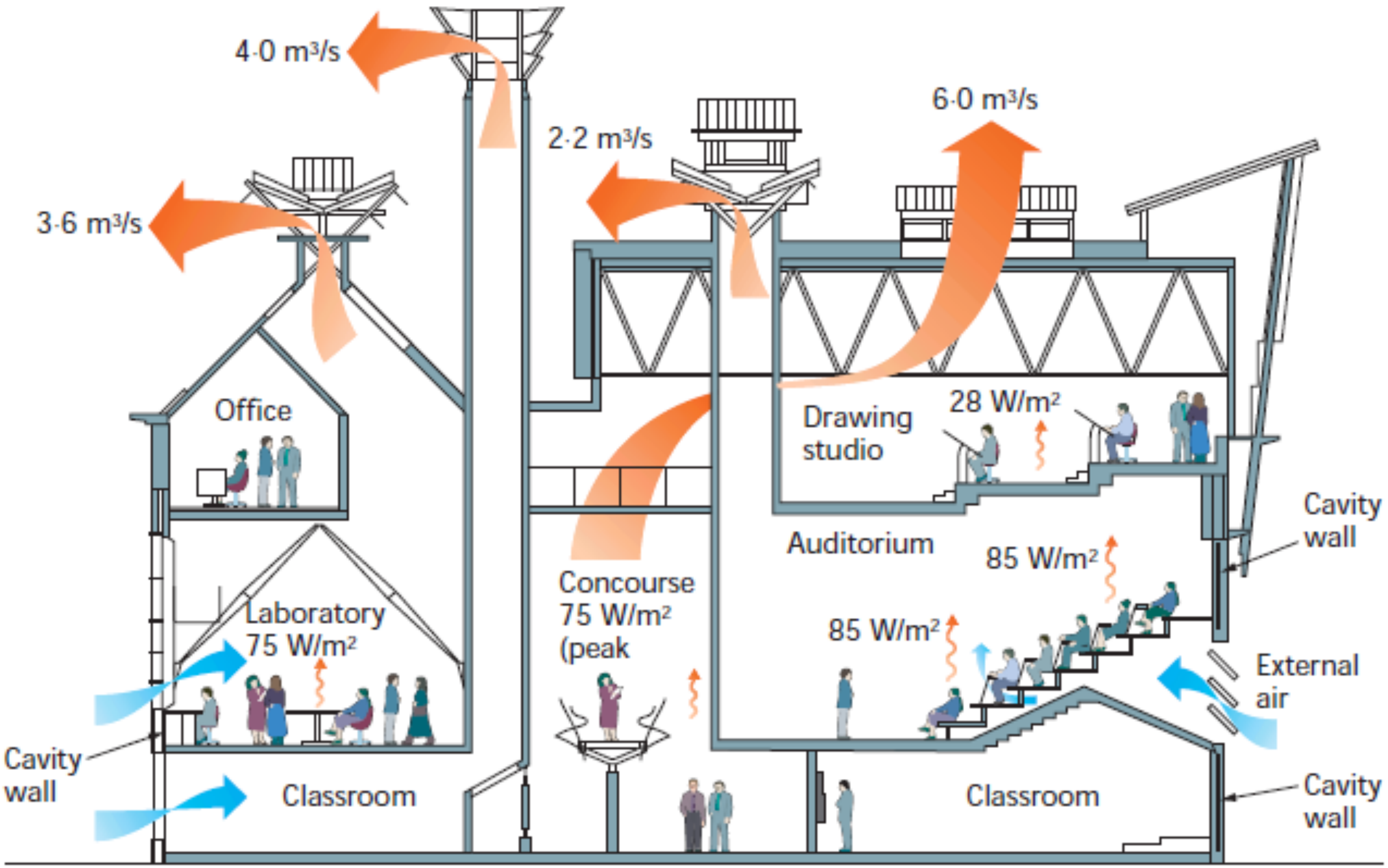
Natural ventilation of offices on a ‘green field’ site



This office building used fixed ventilators and natural ventilation to maintain indoor air quality, plus a mechanical system (supplemented by chilled beams) for summer cooling.

Natural ventilation driven by density difference and wind

Vertical shafts and terminations used to enhance natural ventilation;
Queen's Building, de Montfort University



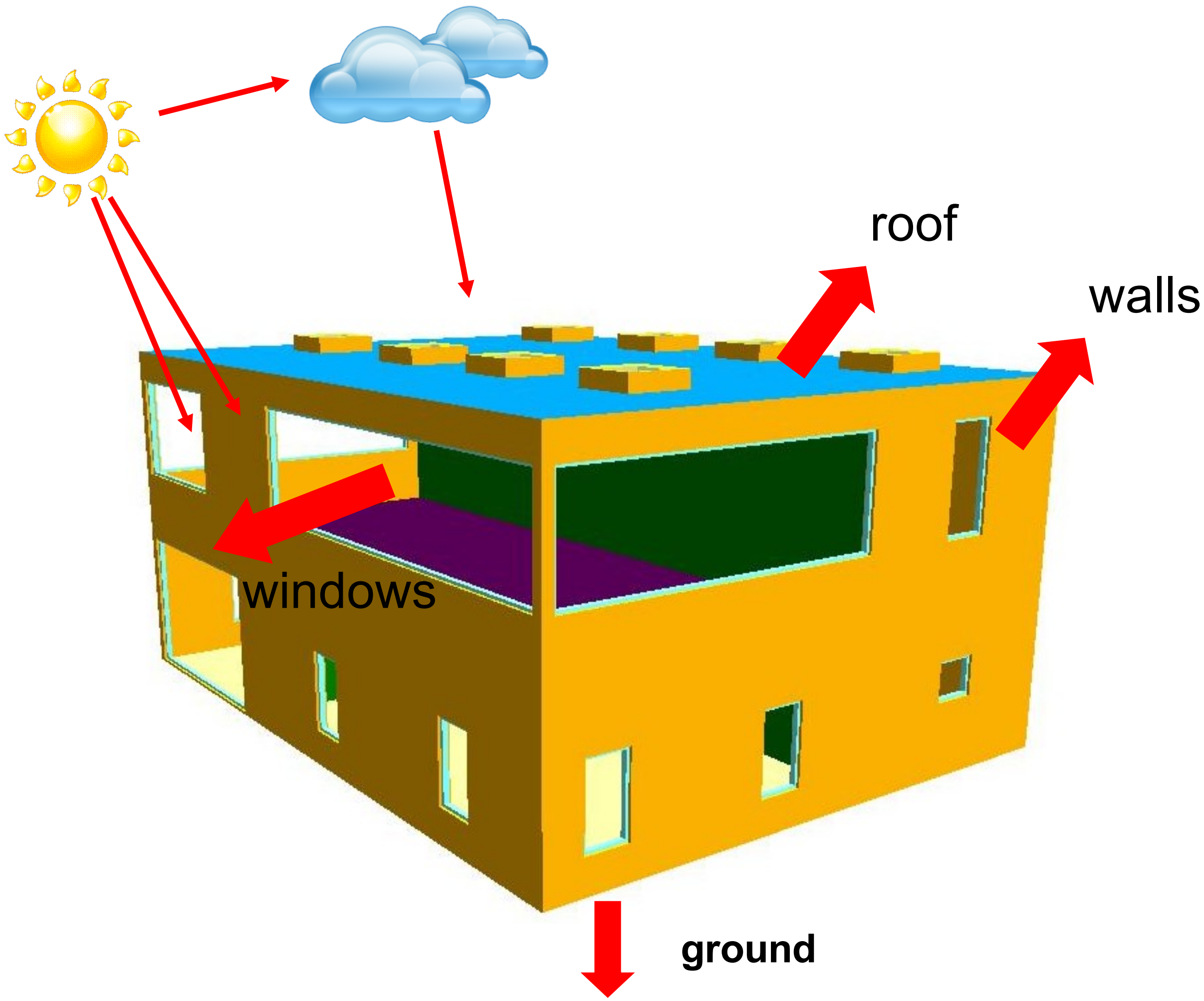
Building Energy Efficiency

- **Building envelope**
  - **U-values of the building exterior fabric (building insulation)**
  - **Internal and external lighting**
  - **Solar gains (g-Values of glazing)**
- **Building service systems**
  - **Design capacity of the system**
  - **Operation and maintenance cost of the systems**
  - **Use of renewable energy sources**

Building Energy Efficiency

1. Building load calculation (heating and cooling load (kW), annual demand (kWh))
2. Building service systems (heating and cooling, mechanical ventilation)
3. Building energy efficiency assessment (EPC assessment, Part L compliance)
4. Building energy efficiency improvement

Building Load Calculation



Gains:

Solar (direct and diffusive)

---calculated based on the orientation of the building, the transmission coefficients of the glazing and the solar angles.

Internal
Equipment, Lights, People

Losses:
Infiltration
Mechanical ventilation
External surfaces (walls, windows, roof and ground etc.)

Set point temperature for heating
Schedule for heating and occupancy
Test reference year (TRY) weather

Building Load Calculation

Commercial software package in building services industry

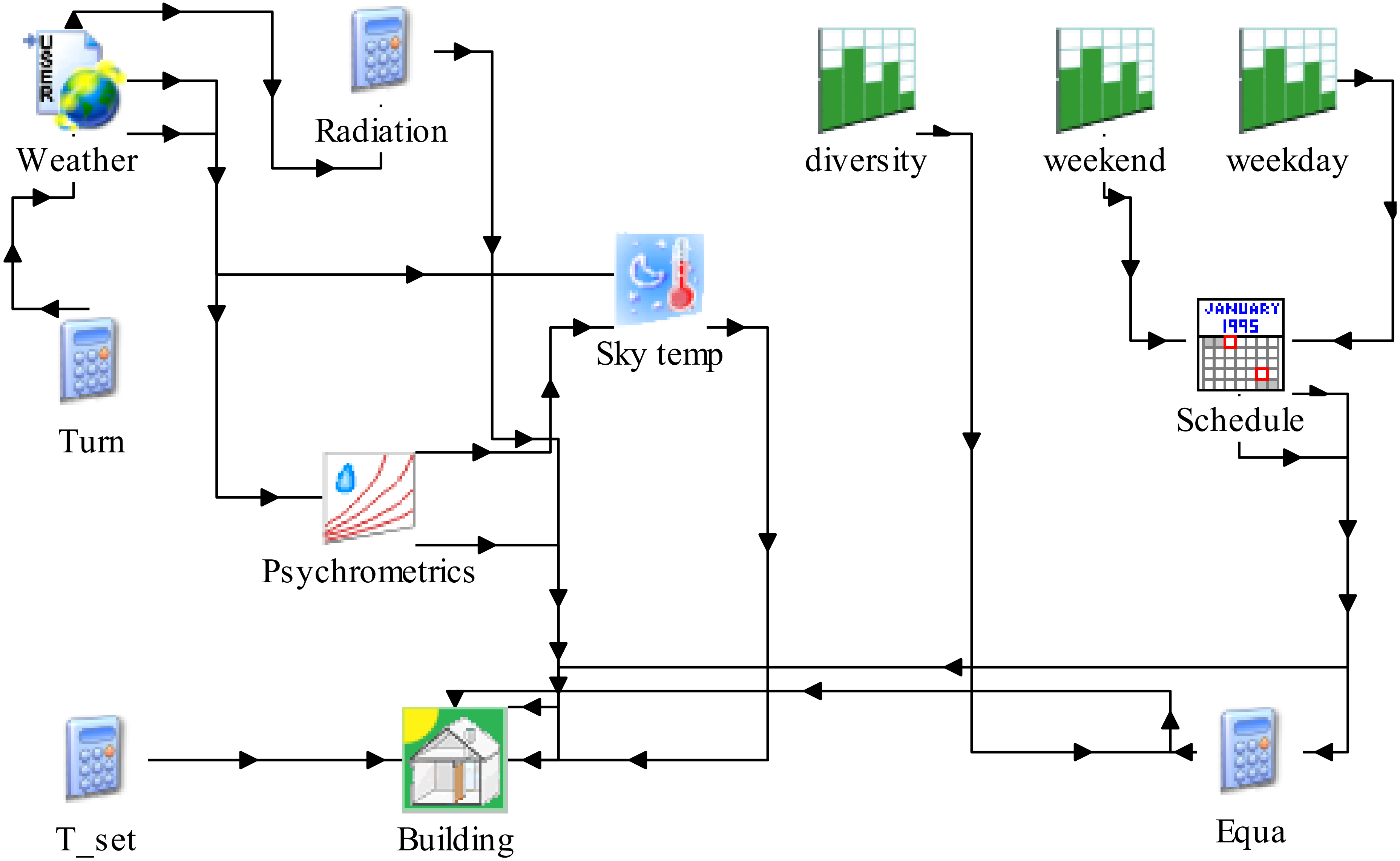
- TAS (Part L accredited)
  http://www.edsl.net/main/Software/Designer/CIBSE.aspx

- IES (Part L accredited)
  http://www.iesve.com/content/default.asp?page=

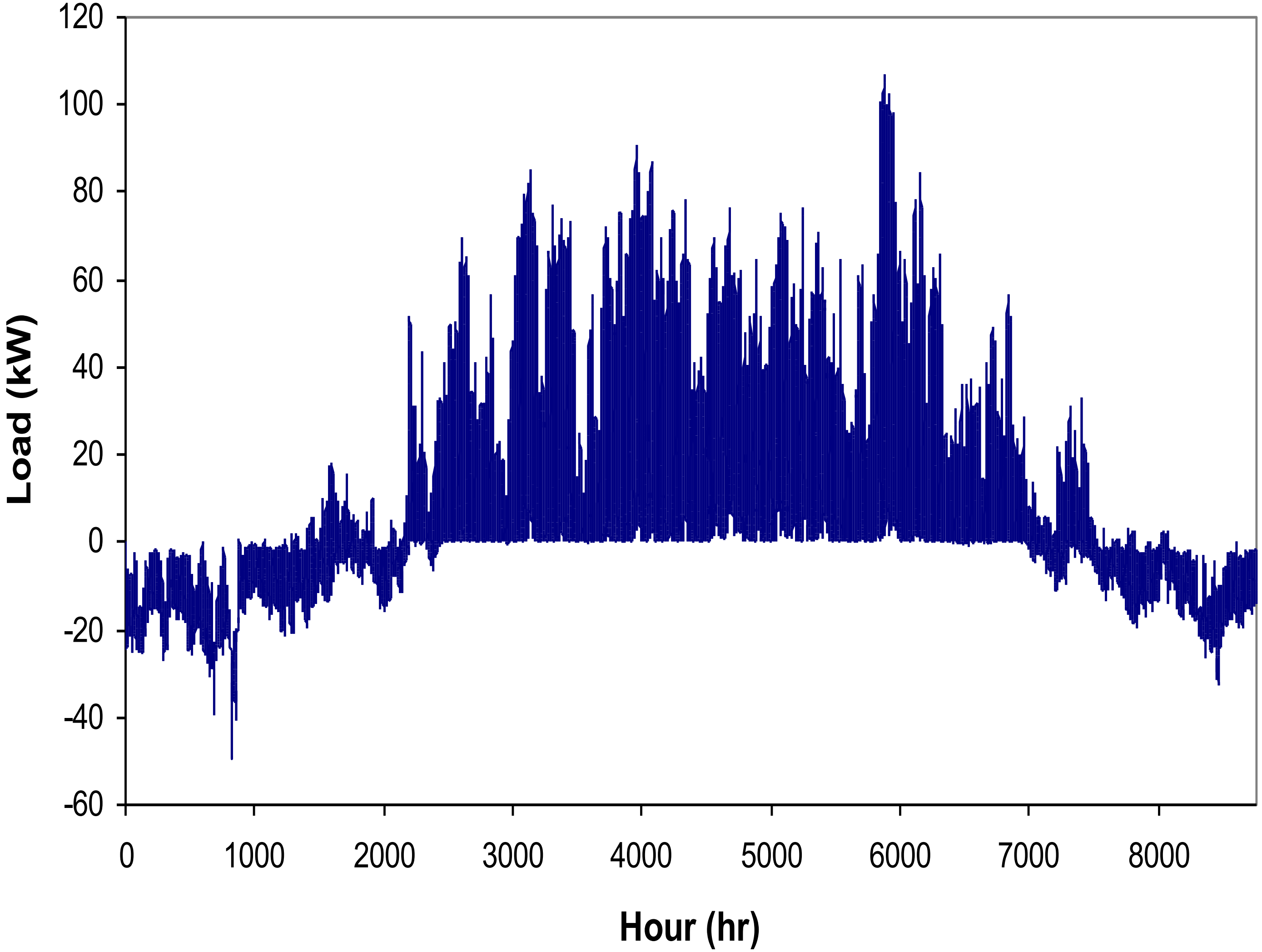
- TRNSYS

  http://www.trnsys.com/

Building Load Calculation



Building Load Calculation



1. - Heating load
2. + Cooling load
3. Integration over time to get the annual demand of heating and cooling energy