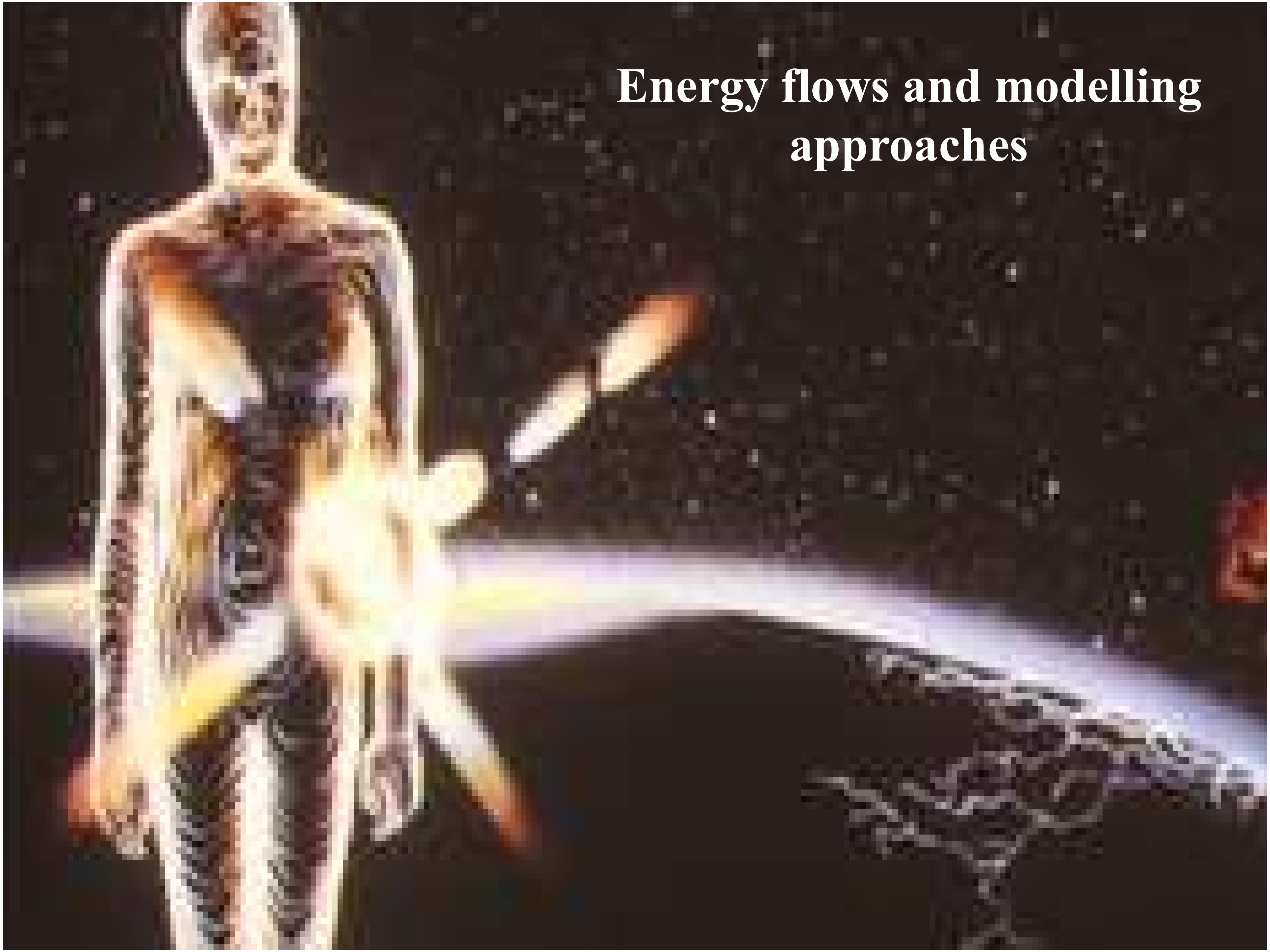
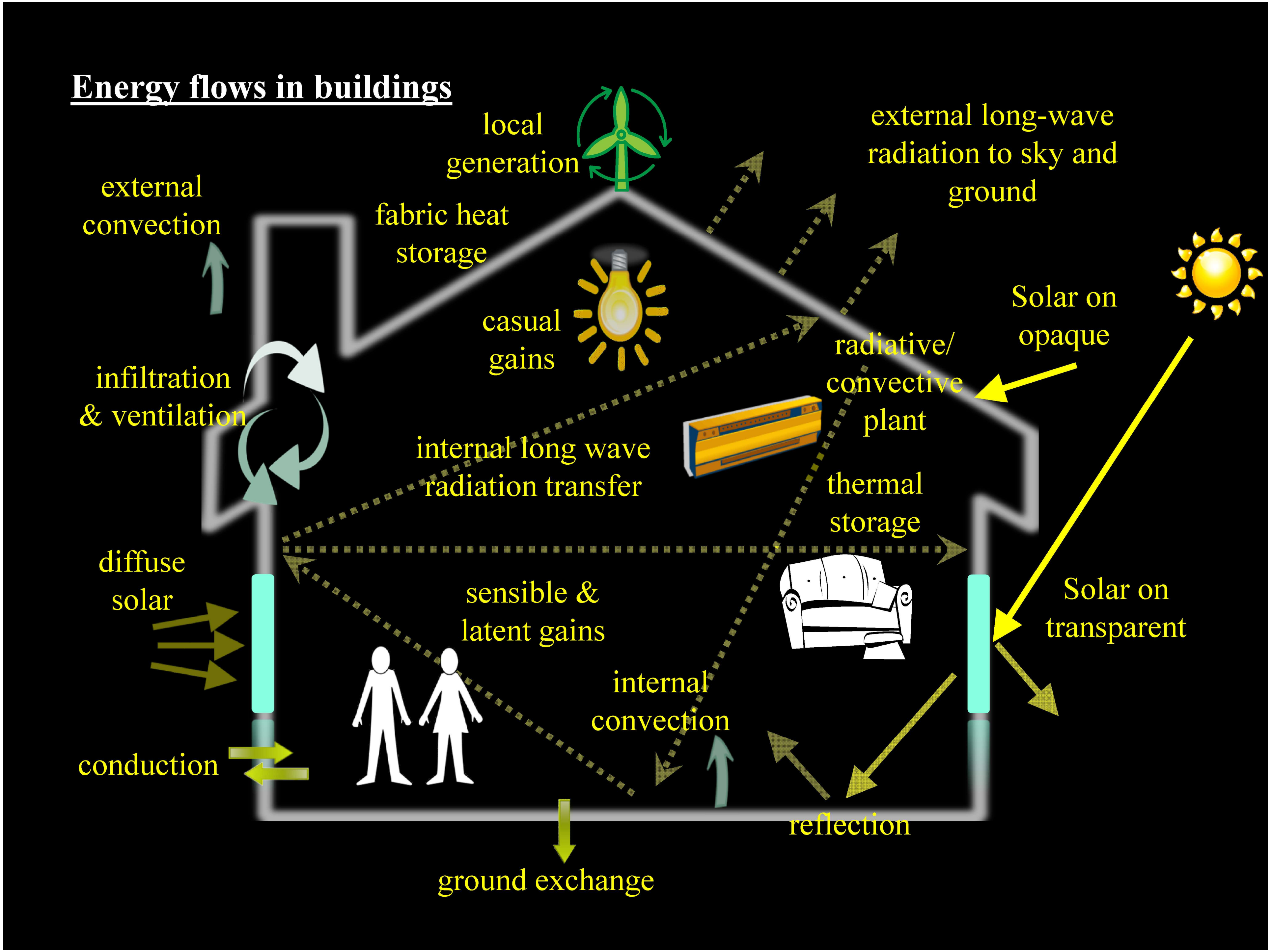
Energy flows and modelling approaches




Energy flows in buildings
local generation
external long-wave radiation to sky and ground
external convection
fabric heat storage
casual gains
Solar on opaque
radiative/ convective plant
infiltration & ventilation
internal long wave radiation transfer
thermal storage
diffuse solar
sensible & latent gains
Solar on transparent
internal convection
conduction
reflection
ground exchange

Energy flows in plant and systems

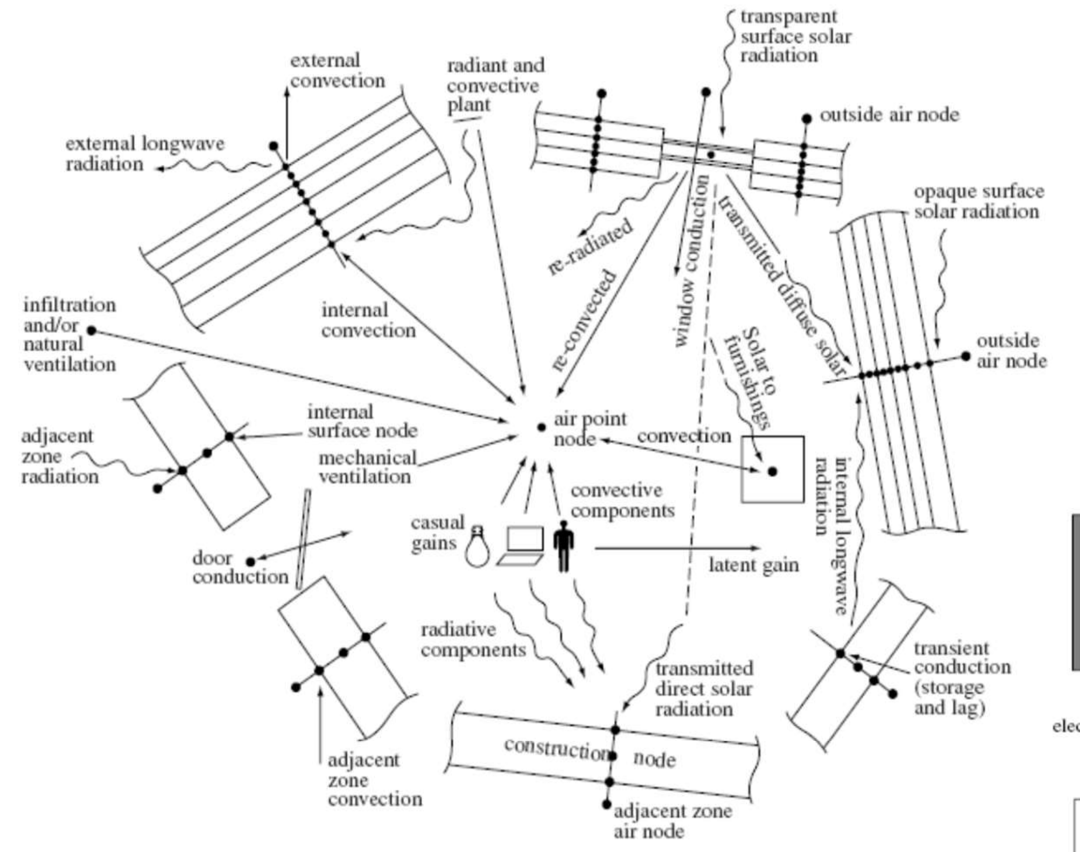


Figure 1.1: Typical building energy flowpaths.

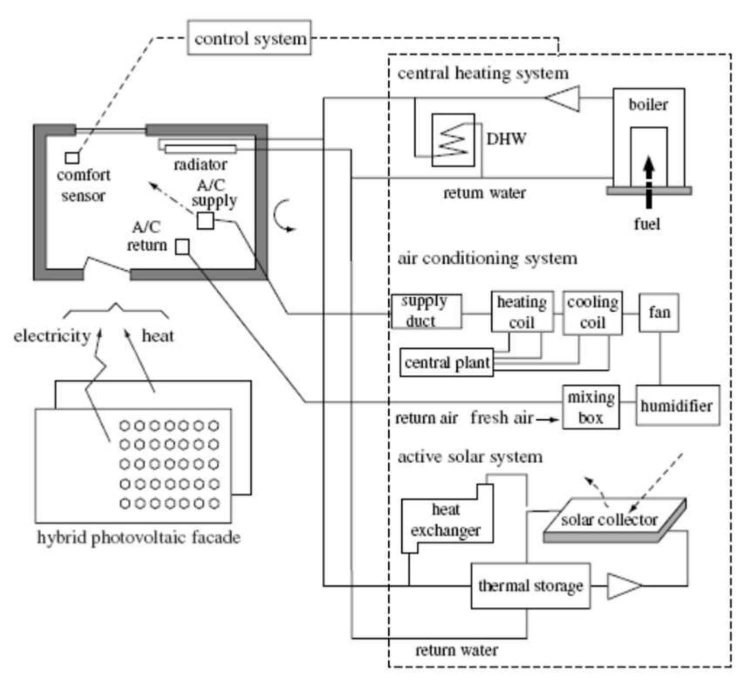


Figure 1.2: Typical HVAC systems.

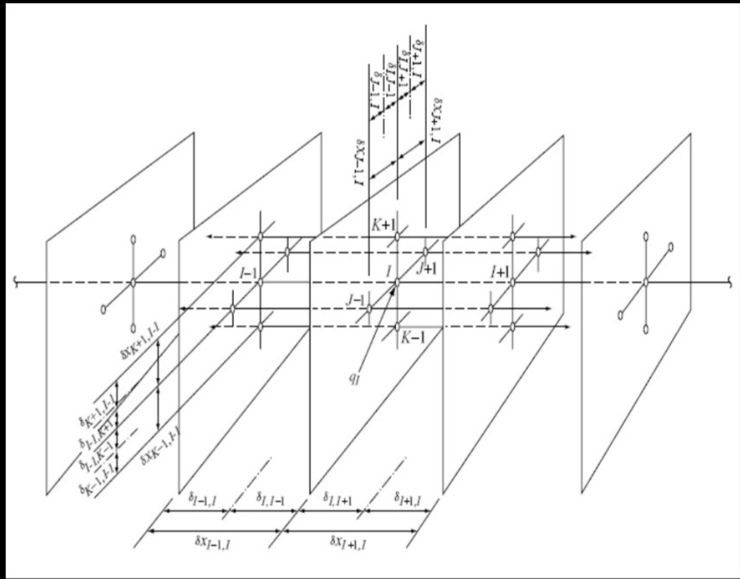
- Buildings and systems are strongly coupled and must be handled simultaneously.

- Plant components can be treated in the same manner as building zones.

New and renewables energy systems

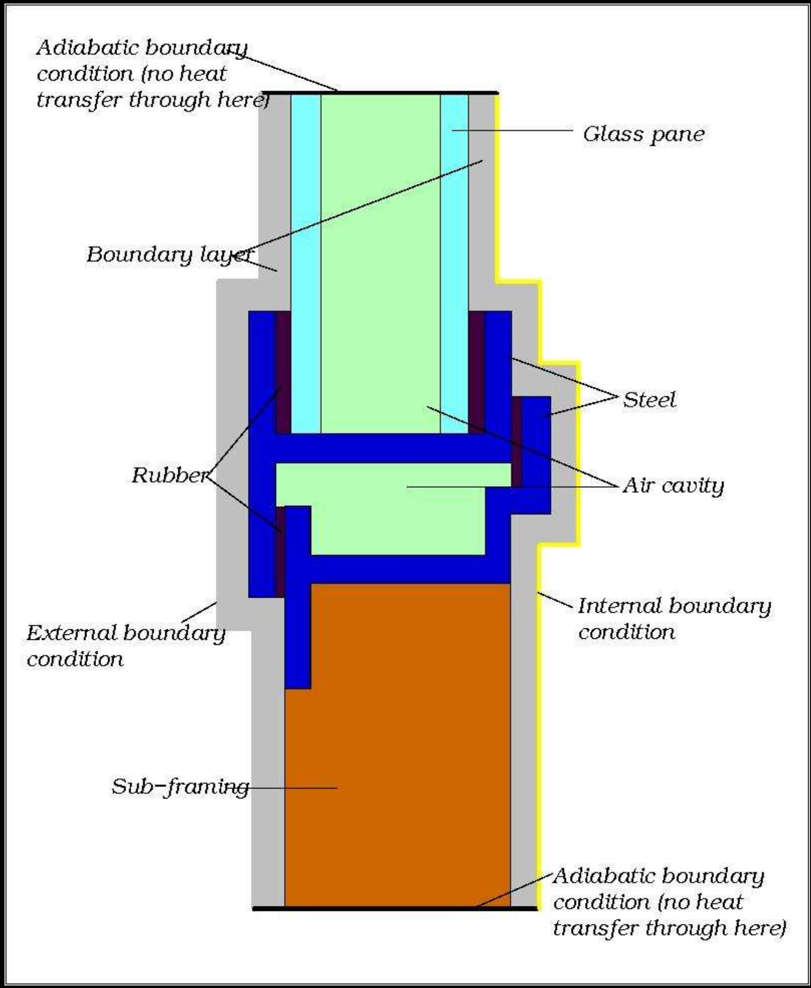
- Future cities may well have a greater level of new and renewable energy systems deployment.
  - Distributed generation with the grid connection of medium-to-large scale hydro stations, bio-gas plant and wind farms.
  - Embedded generation with local deployments of combined heat and power plant, district heating schemes, heat pumps, photovoltaic components, hydrogen fuel cells, *etc*.
- Such systems can be treated in the same manner as building zones.

Flow-path: transient conduction



- Lies at the heart of an energy model ($q_{I\rightarrow?}$).
- The process by which a fluctuation of heat flux at one boundary of a solid material finds its way to another boundary, being diminished in magnitude and shifted in time due to the material's thermal inertia.
- Is a function of the temperature and heat flux excitations at exposed surfaces, the possible generation of heat within the fabric, the temperature- and moisture-dependent (and therefore time-dependent) hygro-thermal properties of the individual materials, and the relative position of these materials.
- Sometimes important to consider heat flow in more than one direction (e.g. in cases where thermal bridging might be expected to occur).
- Governed by conductivity, k (W/m.K), density, ρ (kg/m^3) and specific heat capacity, C (J/kg.K).
- Derived properties used to direct material selection, e.g.:
  - materials with high thermal diffusivity transmit a boundary heat flux fluctuation faster;
  - materials with high thermal effusivity absorb a surface heat flux more readily.

3D conduction and thermal bridging



Flow-path: transient conduction

Material	Conductivity (W/m.K)	Diffusivity (m^2/s)	Effusivity ($J/m^2\ °C^{1/2}$)	Surface absorptivity (-)	Surface emissivity (-)
X	0.85	3.2×10^{-7}	5.3×10^{3}	0.7	0.8
Y	1.65	0.8×10^{-4}	6.7	0.3	0.4

- ❑ Y transmits a heat flux fluctuation the fastest because the thermal diffusivity is highest.
- ❑ Y absorbs a surface heat flux less readily because the thermal effusivity is lowest.
- ❑ Y conducts heat more readily because the conductivity is highest.
- ❑ Y absorbs less radiation in the short-wave part of the solar spectrum because the surface absorptivity is lowest.
- ❑ Y reflects more radiation in the long-wave part of the electromagnetic spectrum because the surface emissivity is lowest.

Flow-path: surface convection

- The process by which heat flux is exchanged between a surface and the adjacent air layer ($q_{I \rightarrow I+1}$).

- At external surfaces convection is wind induced and considered as forced.

- At internal surfaces either natural or forced air movement can occur depending on the location of mechanical equipment.

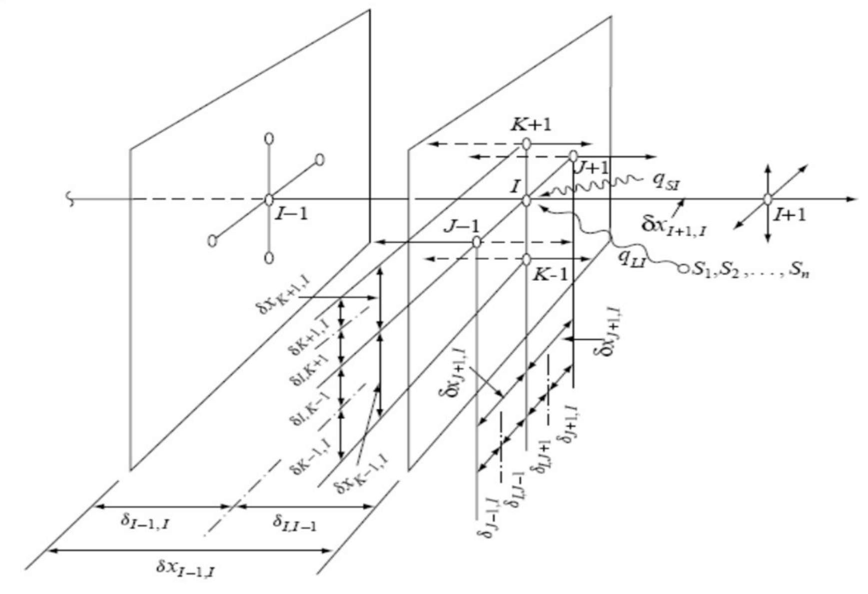


Figure 3.9: Surface energy balance nodal scheme.

- The governing parameter is the convection coefficient, h_c ($W/m^2.K$), which depends on surface-to-air temperature difference, surface roughness, direction of heat flow and surface dimensions.

Flow-path: long-wave radiation exchange

- Function of surface temperature, emissivity, the extent to which surfaces are in visual contact (represented by a view factor), and the nature of the surface reflection (diffuse, specular or mixed).

- Will tend to establish surface temperature equilibrium by cooling hot surfaces and heating cold ones (q_{IJ}).

- Important where temperature asymmetry prevails, as in passive solar buildings where an attempt is made to capture solar energy at some selected surface.

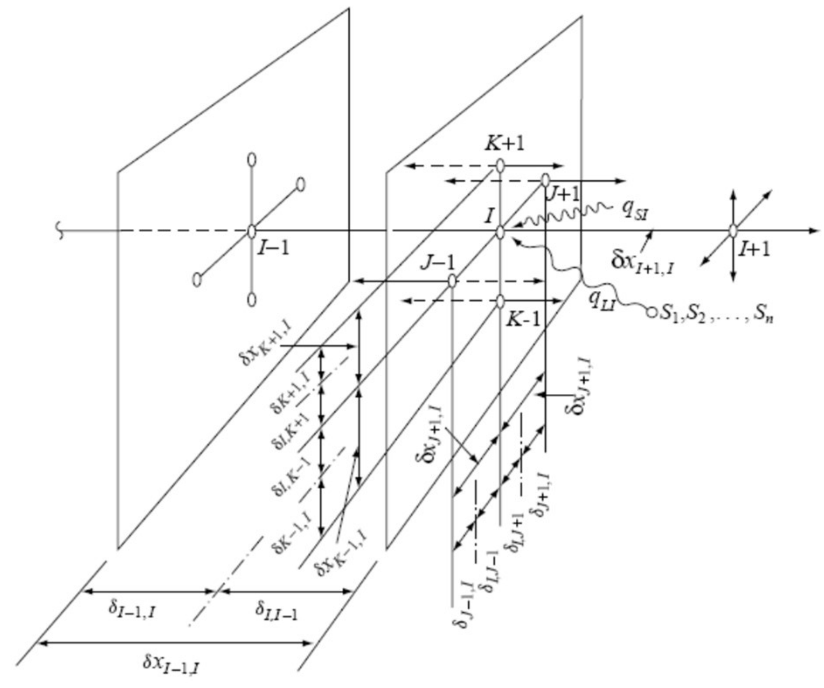


Figure 3.9: Surface energy balance nodal scheme.

- A standard energy efficiency measure is to upgrade windows with glazings incorporating a low emissivity coating to increase the reflection of long-wave radiation flux and so act to break inter-surface heat exchange.

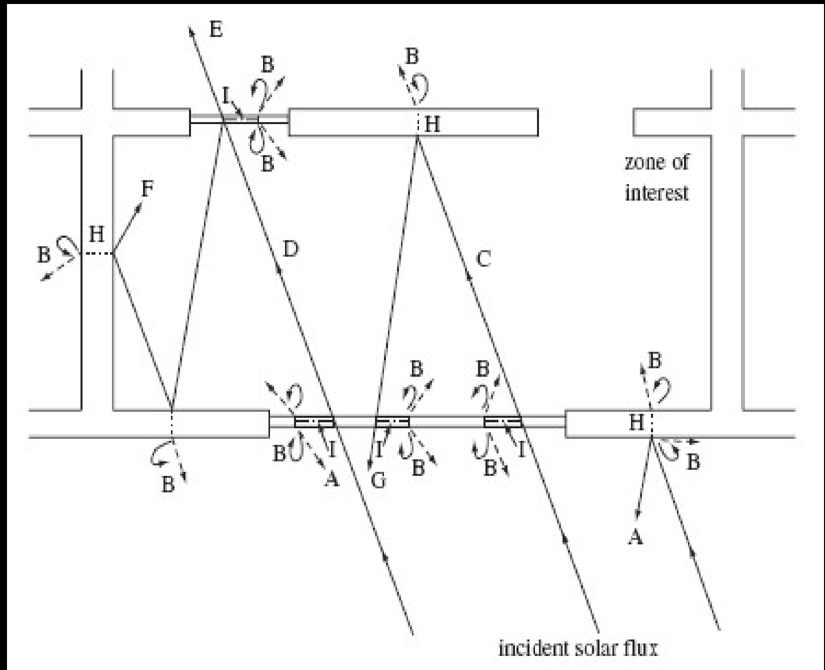
- Long-wave radiation exchange between external surfaces and the sky vault, surrounding buildings and ground can result in a substantial lowering of surface temperatures, especially under clear sky conditions and at night.

Flow-path: short-wave radiation

- Short-wave energy arrives at a surface directly from the sun and diffusely after atmospheric scatter and terrain reflections.

- By transient conduction finds its way through the fabric where it will contribute to the inside surface heat flux at some later time via convection and long-wave radiation.

- With transparent surfaces some flux is transmitted to strike internal surfaces and raise their temperature.



- Solar irradiation estimation requires the prediction of surface position relative to the solar beam, and the assessment of the changing pattern of internal/external surface insolation

- The governing thermo-physical properties include shortwave absorptivity, transmissivity and reflectivity.

Flow-path: air flow

- ❑ Three air flow paths: infiltration, zone-coupled flows and mechanical ventilation.

- ❑ Infiltration is the leakage of air from outside (through cracks and the fabric) and via the ingress of air through intentional openings referred to as natural ventilation.

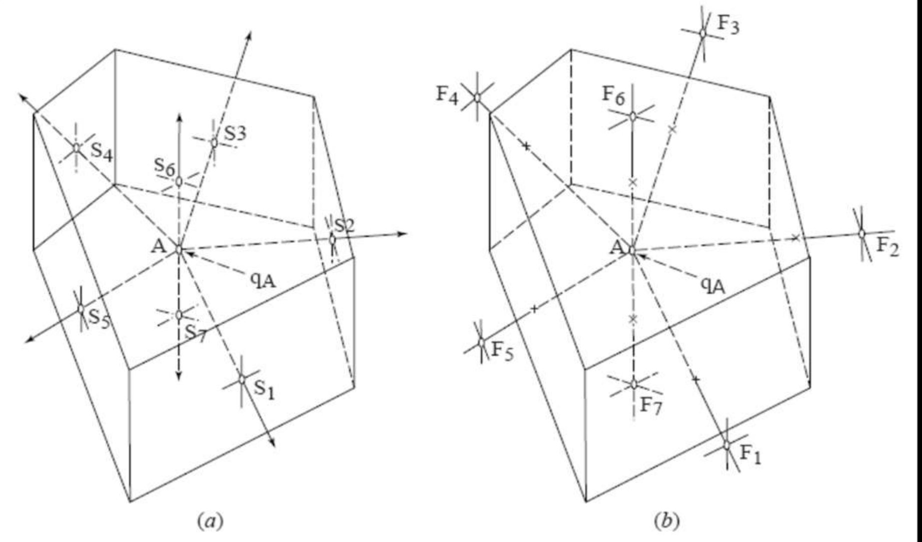


Figure 3.10: Fluid volume energy balance nodal scheme. (a) Fluid volume contained by real surfaces; convective heat transfer. (b) Fluid volumes contained by fictitious surfaces; advective heat transfer.

- ❑ Zone-coupled air flow is caused by pressure variations and by buoyancy forces resulting from the density differences associated with the temperatures of the coupled air volumes.

- ❑ Mechanical ventilation is the supply of air to satisfy a fresh air requirement.

- ❑ Random occurrences, such as occupant induced window/door opening, changes in the prevailing wind conditions, and the intermittent use of mechanical ventilation, will influence the magnitude of the air flow.

Flow-path: heat injection

- The heat gains from lighting installations, occupants, small power equipment, IT devices *etc*.
- Modelling requires knowledge of the heat (radiant and convective) and moisture emissions.
- Sources, such as luminaires and IT equipment, also require knowledge of their electrical behaviour (e.g. in the case of daylight responsive luminaire dimming).
- Other sources: electrical, chemical, photoelectric effect, *etc*.

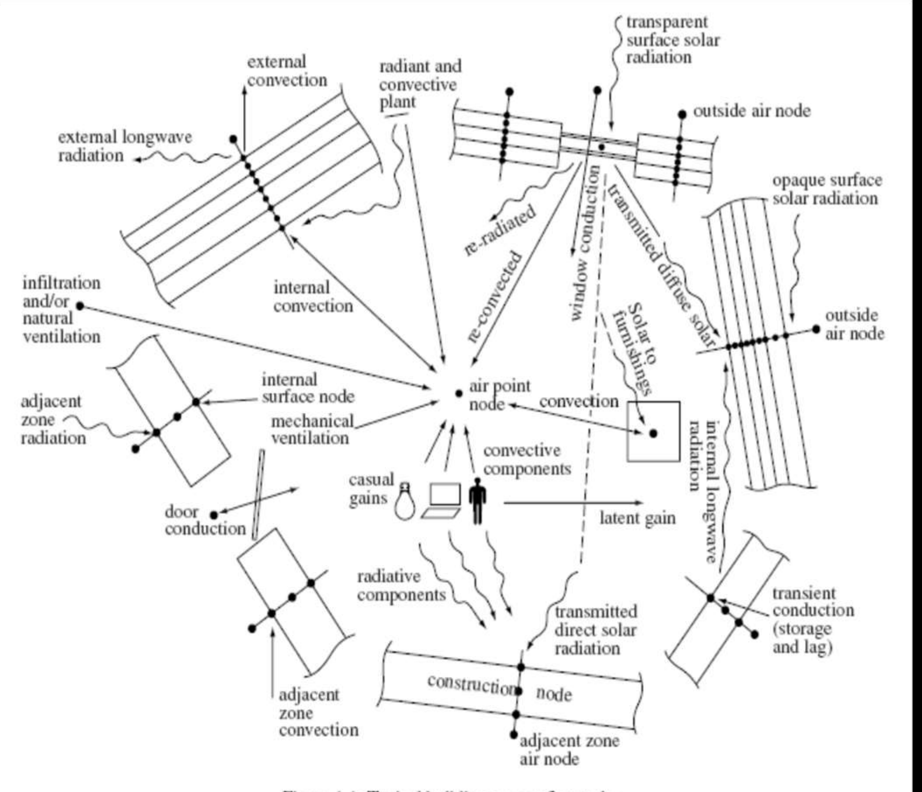
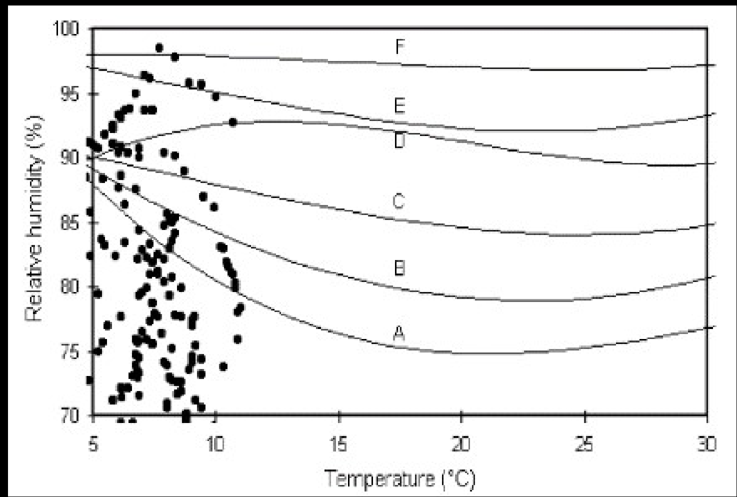


Figure 1.1: Typical building energy flowpaths.

Flow-path: mass exchange

- Transfer of air and moisture (liquid and vapour) within open pore materials.
- Moisture can be destructive within buildings.
- Fluctuations in moisture levels within the building's fabric can be problematic, leading to interstitial condensation or causing variations in material thermo-physical properties and, thereby, adversely affecting thermodynamic performance.
- Dampness and mould growth are major problems affecting a significant proportion of houses.
- High levels of airborne spores may occur due to the growth of fungus on walls and furnishings.



Control systems

- Control systems comprise control loops.

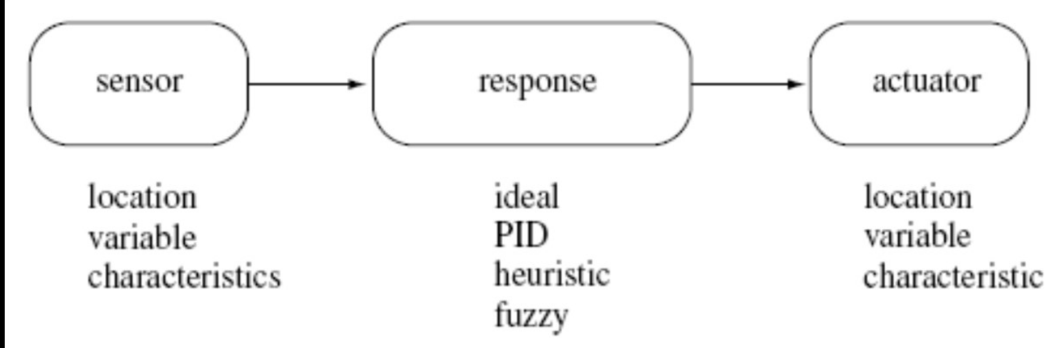
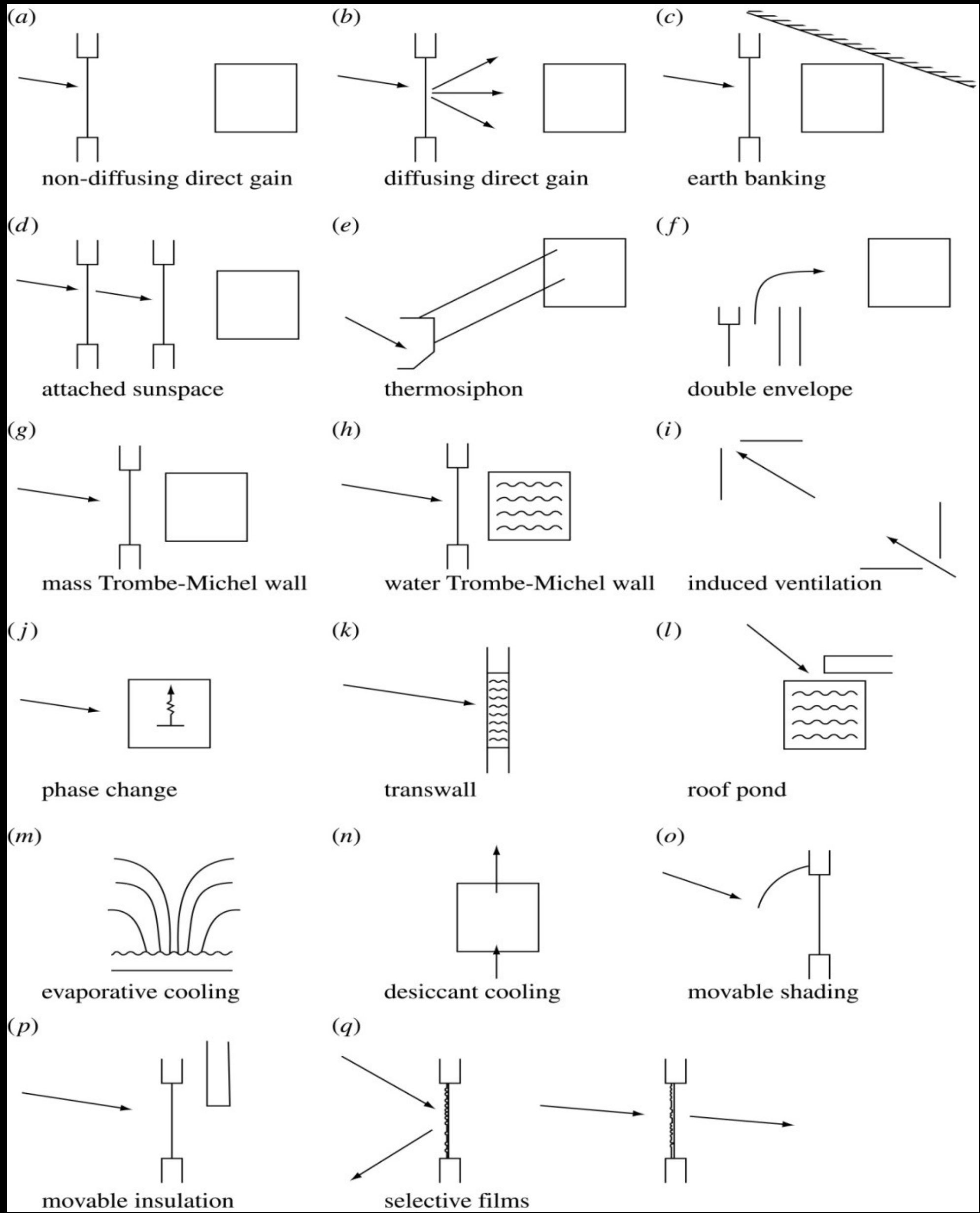


Figure 6.15: Elements of a control loop.

- Control loops comprising:
  - a sensor to measure a simulation parameter or aggregate of parameters;
  - an actuator to receive and act upon the controller output signal; and
  - a regulation law to relate the sensed condition to the actuated state.
- Control loops are used to regulate HVAC components and manage building-side entities, such as solar control devices.

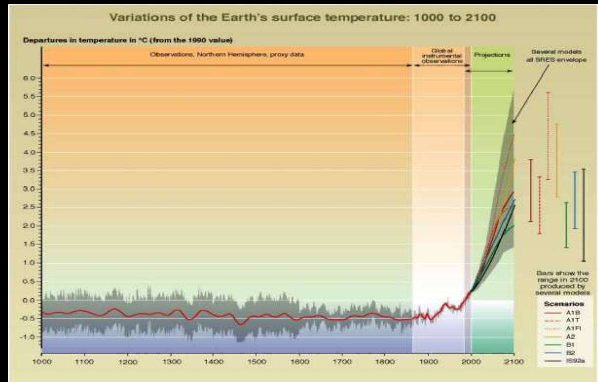
Passive solar features

a) non-diffusing direct gain
b) diffusing direct gain
c) earth banking
d) attached sunspaces
e) thermo-siphon
f) double envelope
g) mass Trombe-Michel walls
h) water Trombe-Michel walls
i) induced ventilation
j) phase change materials
k) transwalls
l) roof ponds
m) evaporative cooling
n) desiccant materials
o) movable shading
p) movable insulation
q) selective thin films



Environmental impact

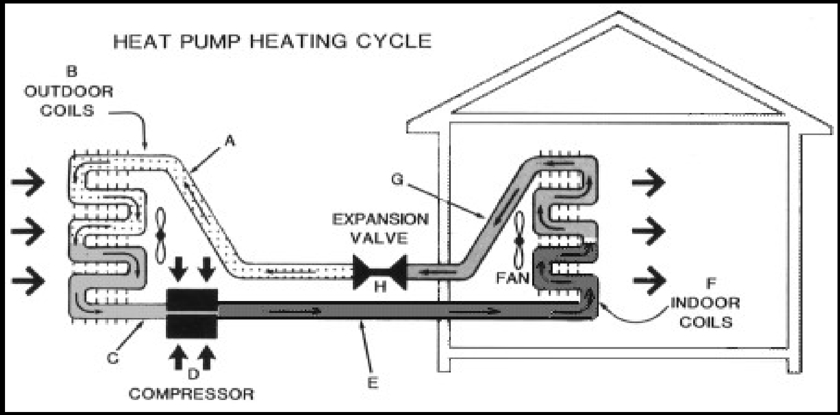
- Buildings typically account for around 50% of the total energy consumption in a developed country and a similar portion of the carbon dioxide emissions.
- Significant additional energy consumption is associated with the production and transportation of construction materials.
- Associated with energy consumption are gaseous emissions that can contribute to global warming (CO_2), acidification (SO_x) and ozone generation (NO_x).
- The integrated performance modelling approach is able to address all aspects of a building's life cycle and thereby help designers to strike a balance between energy use, indoor comfort and local/global impact.



Uncertainty

- All design parameters are subject to uncertainty.
- Programs need to be able to apply uncertainty bands to their input data and use these bands to determine the impact of uncertainty on likely performance.
- Programs so endowed are able to assess risk, rather than merely presenting performance data to users.

Mathematical modelling



- Underlying flow-paths is the concept of energy, mass and momentum conservation.

- Models of the heat, air, moisture, light and electricity flows are required.

- Computer tools have traditionally been constructed by simplifying system equations in order to lessen the computational load and user input burden:
  - aspects of the system may be neglected (e.g. longwave radiation exchange);
  - system parameters may be assumed time invariant (e.g. convection coefficients); or
  - steady state boundary conditions may be imposed.

- Within a simulation program such assumptions are heresy.

- A mathematical model is constructed to represent each energy flow-path and all possible interactions; in this sense simulation is an emulation of reality.

- The aim of integrative modelling is to preserve the integrity of the entire energy system by simultaneously processing all energy transport paths.

- The energy system is considered to be systemic (there are myriad inter-part interactions), dynamic (the parts evolve at different rates), non-linear (parameter values depend on the thermodynamic state) and stochastic (some events and influences are random).

Modelling methods

- Steady-state: not dynamic have and have no mechanism for the accurate inclusion of many flow-paths and systems (e.g. solar gain, longwave radiation exchanges, control systems etc.).

- Simple dynamic: these are mostly based on regression techniques applied to the results of multiple parametric runs of more powerful modelling systems. Useful at the early design stage.

- Electrical Analogue: exploiting the analogy that exists between electrical flow and heat flow. Has little application in a design context.

- Response Function: based on an analytical solution of the governing conservation equations under special boundary conditions and assuming that system parameters are linear and time invariant.

- Numerical: use numerical techniques to solve connected systems of equations that may be non-linear and time varying. Can therefore handle problems of arbitrary complexity.