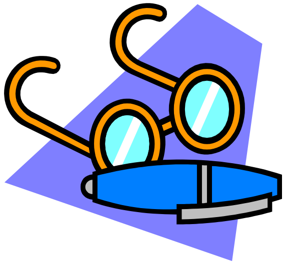
# Contents

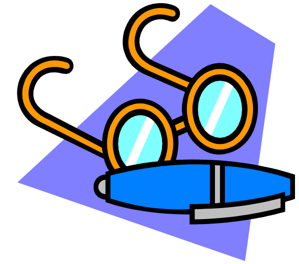
- Basic Concepts
- Outdoor Design Conditions
- Indoor Design Criteria
- Cooling Load Principles
- Cooling Load Components
- Heating Load

# Basic Concepts



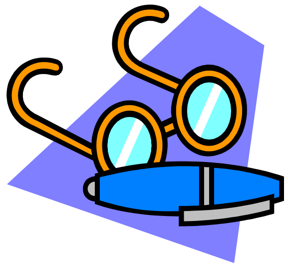
- Thermal load
  - The amount of heat that must be added or removed from the space to maintain the proper temperature in the space
- When thermal loads push conditions outsider of the comfort range, HVAC systems are used to bring the thermal conditions back to comfort conditions

# Basic Concepts



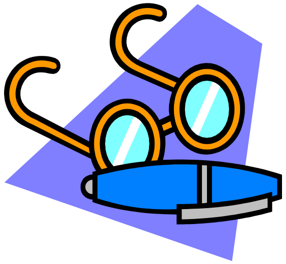
- Purpose of HVAC load estimation
  - Calculate peak design loads (cooling/heating)
  - Estimate likely plant/equipment capacity or size
  - Provide info for HVAC design e.g. load profiles
  - Form the basis for building energy analysis
- Cooling load is our main target
  - Important for warm climates & summer design
  - Affect building performance & its first cost

# Basic Concepts

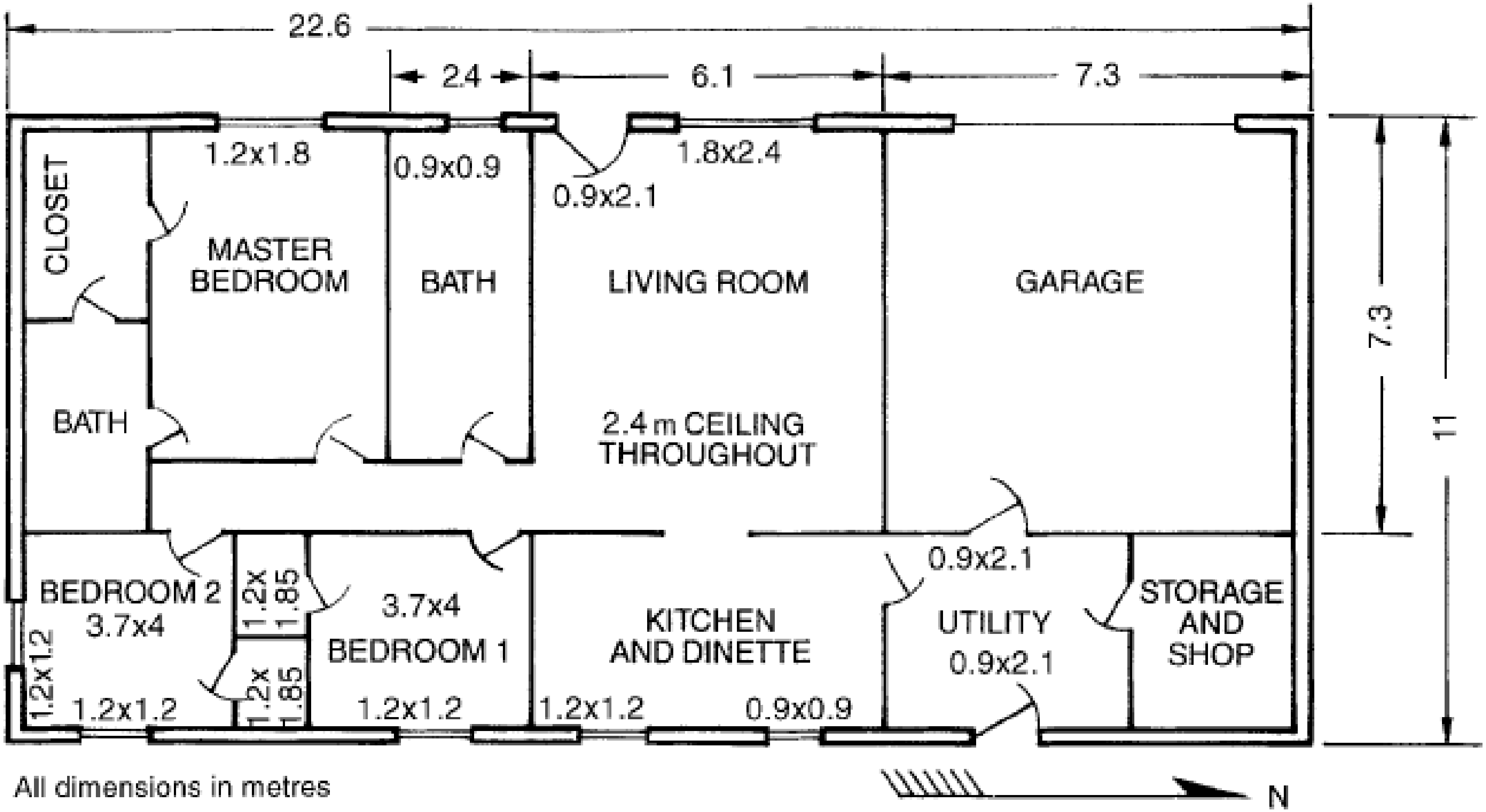


- Heat transfer mechanism
  - Conduction
  - Convection
  - Radiation
- Thermal properties of building materials
  - Overall thermal transmittance (U-value)
  - Thermal conductivity
  - Thermal capacity (specific heat)

# Basic Concepts



- A building survey will help us achieve a realistic estimate of thermal loads
  - Orientation of the building
  - Use of spaces
  - Physical dimensions of spaces
  - Ceiling height
  - Columns and beams
  - Construction materials
  - Surrounding conditions
  - Windows, doors, stairways




All dimensions in metres

# Basic Concepts

- Building survey (cont'd)
  - People (number or density, duration of occupancy, nature of activity)
  - Lighting ($W/m^2$, type)
  - Appliances (wattage, location, usage)
  - Ventilation (criteria, requirements)
  - Thermal storage (if any)
  - Continuous or intermittent operation

# Outdoor Design Conditions

- They are used to calculate design space loads
- Climatic design information
  - General info: e.g. latitude, longitude, altitude, atm. pressure
  - Outdoor design conditions
    - Derived from statistical analysis of weather data
    - Typical data can be found in handbooks/databooks, such as ASHRAE Fundamentals Handbooks

# Outdoor Design Conditions

- Climatic design conditions from ASHRAE
  - Previous data & method (before 1997)
    - For Summer (Jun. to Sep.) & Winter (Dec, Jan, Feb)
    - Based on 1%, 2.5% & 5% nos. hours of occurrence
  - New method (ASHRAE Fundamentals 2001):
    - Based on <u>annual</u> percentiles and cumulative frequency of occurrence, e.g. 0.4%, 1%, 2%
    - More info on coincident conditions
    - Findings obtained from ASHRAE research projects
      - Data can be found on a relevant CD-ROM

# Recommended Outdoor Design Conditions for Hong Kong

| | | | | |
|---|---|---|---|---|
| Location | Hong Kong (latitude 22° 18′ N, longitude 114° 10′ E, elevation 33 m) | | | |
| Weather station | Royal Observatory Hong Kong | | | |
| Summer months | June to September (four hottest months), total 2928 hours | | | |
| Winter months | December, January & February (three coldest months), total 2160 hours | | | |
| Design temperatures: | For comfort HVAC (based on summer 2.5% or annualised 1% and winter 97.5% or annualised 99.3%) | | For critical processes (based on summer 1% or annualised 0.4% and winter 99% or annualised 99.6%) | |
| | Summer | Winter | Summer | Winter |
| DDB / CWB | 32.0 °C / 26.9 °C | 9.5 °C / 6.7 °C | 32.6 °C / 27.0 °C | 8.2 °C / 6.0 °C |
| CDB / DWB | 31.0 °C / 27.5 °C | 10.4 °C / 6.2 °C | 31.3 °C / 27.8 °C | 9.1 °C / 5.0 °C |
| Extreme temperatures: | Hottest month: July<br>mean DBT = 28.6 °C<br>absolute max. DBT = 36.1 °C<br>mean daily max. DBT = 25.7 °C | | Coldest month: January<br>mean DBT = 15.7 °C<br>absolute min. DBT = 0.0 °C<br>mean daily min. DBT = 20.9 °C | |
| Diurnal range: | Summer | Winter | Whole year | |
| - Mean DBT | 28.2 | 16.4 | 22.8 | |
| - Daily range | 4.95 | 5.01 | 5.0 | |
| Wind data: | Summer | Winter | Whole year | |
| - Wind direction | 090 (East) | 070 (N 70° E) | 080 (N 80° E) | |
| Wind speed | 5.7 m/s | 6.8 m/s | 6.3 m/s | |

Note: 1. DDB is the design dry-bulb and CWB is the coincident wet-bulb temperature with it; DWB is the design wet-bulb and CDB is the coincident dry-bulb with it.

2. The design temperatures and daily ranges were determined based on hourly data for the 35-year period from 1960 to 1994; extreme temperatures were determined based on extreme values between 1884-1939 and 1947-1994.

4. Wind data are the prevailing wind data based on the weather summary for the 30-year period 1960-1990. Wind direction is the prevailing wind direction in degrees clockwise from north and the wind speed is the mean prevailing wind speed.

# Outdoor Design Conditions

- Climatic design conditions (ASHRAE 2001):
  - Heating and wind design conditions
    - Heating dry-bulb (DB) temp.
    - Extreme wind speed
    - Coldest month wind speed (WS) & mean coincident dry-bulb temp. (MDB)
    - Mean wind speed (MWS) & prevailing wind direction (PWD) to DB
    - Average of annual extreme max. & min. DB temp. & standard deviations

# Outdoor Design Conditions

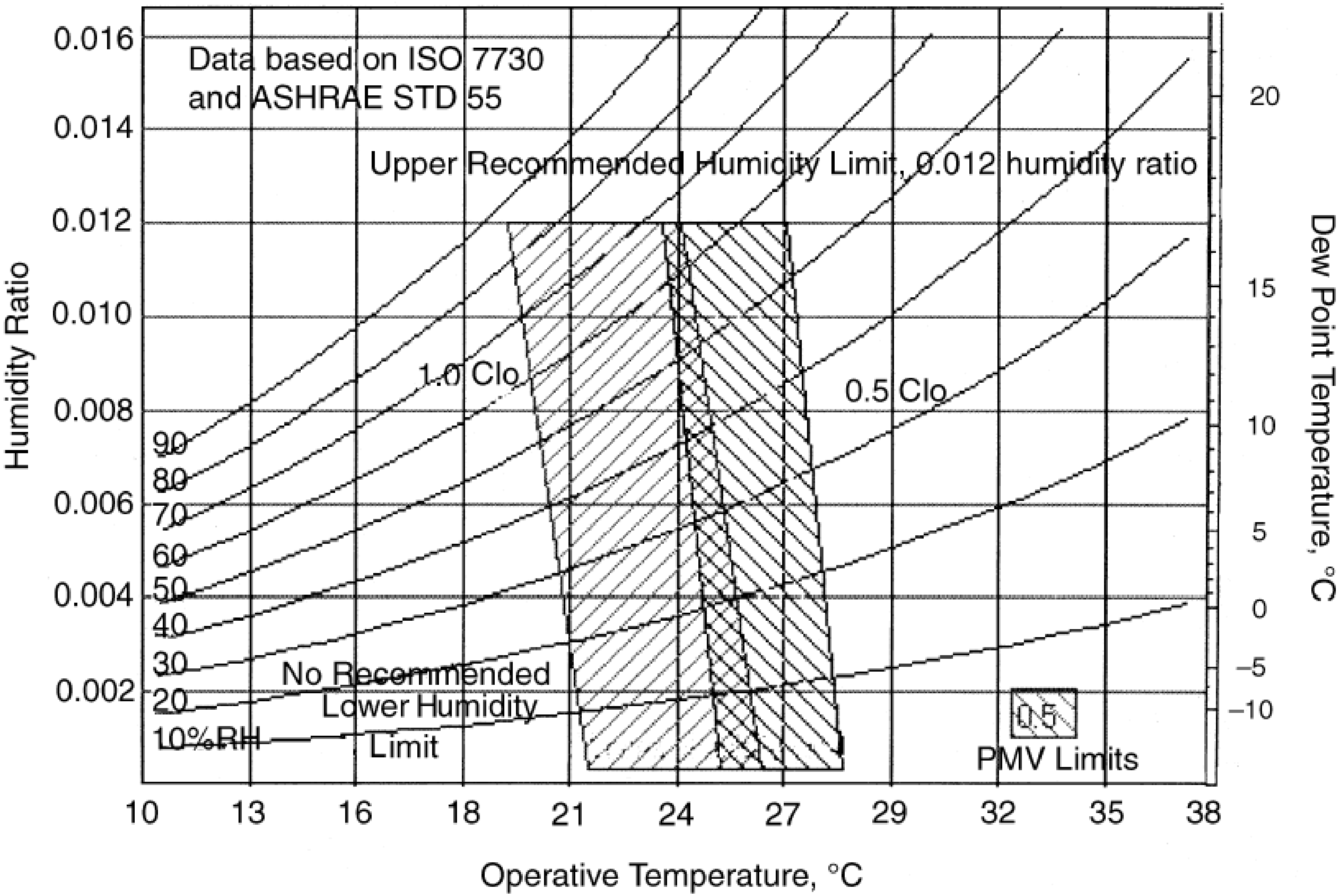
- Climatic design conditions (ASHRAE):
  - Cooling and dehumidification design conditions
    - Cooling DB/MWB: Dry-bulb temp. (DB) + Mean coincident wet-bulb temp. (MWB)
    - Evaporation WB/MDB: Web-bulb temp. (WB) + Mean coincident dry-bulb temp. (MDB)
    - Dehumidification DP/MDB and HR: Dew-point temp. (DP) + MDB + Humidity ratio (HR)
    - Mean daily (diurnal) range of dry-bulb temp.

# Outdoor Design Conditions

- Other climatic info:
  - Joint frequency of temp. and humidity
    - Annual, monthly and hourly data
  - Degree-days (cooling/heating) & climatic normals
    - To classify climate characteristics
  - Typical year data sets (1 year: 8,760 hours)
    - For energy calculations & analysis

# Indoor Design Criteria

- Basic design parameters: (for thermal comfort)
  - Air temp. & air movement
    - Typical: summer 24-26 $^{o}$C; winter 21-23 $^{o}$C
    - Air velocity: summer < 0.25 m/s; winter < 0.15 m/s
  - Relative humidity
    - Summer: 40-50% (preferred), 30-65 (tolerable)
    - Winter: 25-30% (with humidifier); not specified (w/o humidifier)
  - See also ASHRAE Standard 55-2004
    - ASHRAE comfort zone



Data based on ISO 7730
and ASHRAE STD 55
Upper Recommended Humidity Limit, 0.012 humidity ratio
1.0 Clo
0.5 Clo
90
80
70
60
50
40
30
20
10%RH
No Recommended
Lower Humidity
Limit
0.5
PMV Limits
Humidity Ratio
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
Dew Point Temperature, °C
20
15
10
5
0
−5
−10
10
13
16
18
21
24
27
29
32
35
38
Operative Temperature, °C

# Indoor Design Criteria

- Indoor air quality:
  - Air contaminants
    - e.g. particulates, VOC, radon, bioeffluents
  - Outdoor ventilation rate provided
    - ASHRAE Standard 62-2001
  - Air cleanliness (e.g. for processing)
- Other design parameters:
  - Sound level
  - Pressure differential between the space & surroundings (e.g. +ve to prevent infiltration)

| Type of area | Recommended NC or RC range (dB) |
|---|---|
| Hotel guest rooms | 30–35 |
| Office | |
| Private | 30–35 |
| Conference | 25–30 |
| Open | 30–35 |
| Computer equipment | 40–45 |
| Hospital, private | 25–30 |
| Churches | 25–30 |
| Movie theaters | 30–35 |

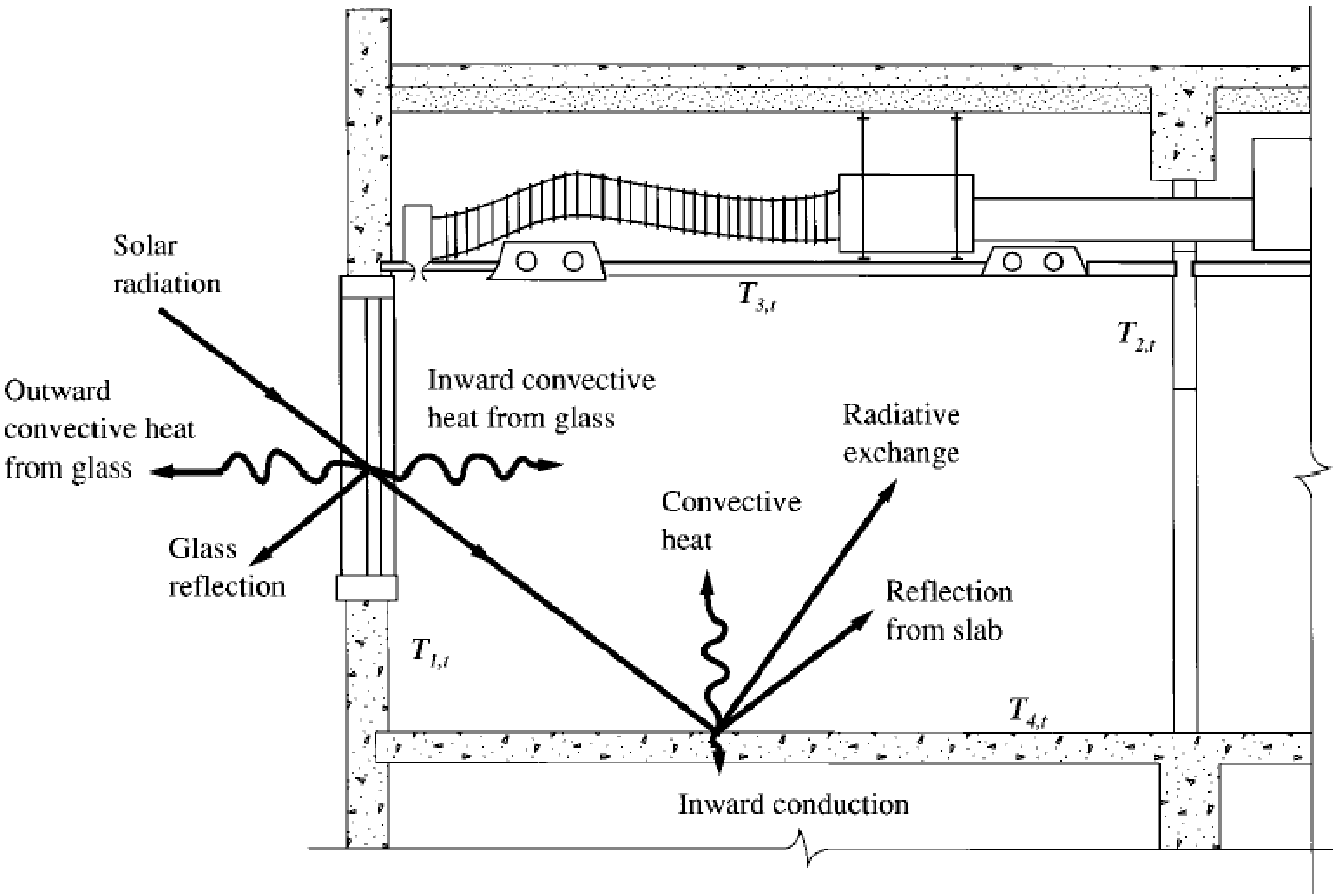
# Cooling Load Principles

# Cooling Load Principles

- Terminology:
  - Space – a volume w/o a partition, or a partitioned room, or group of rooms
  - Room – an enclosed space (a single load)
  - Zone – a space, or several rooms, or units of space having some sort of coincident loads or similar operating characteristics
    - Thermal zoning

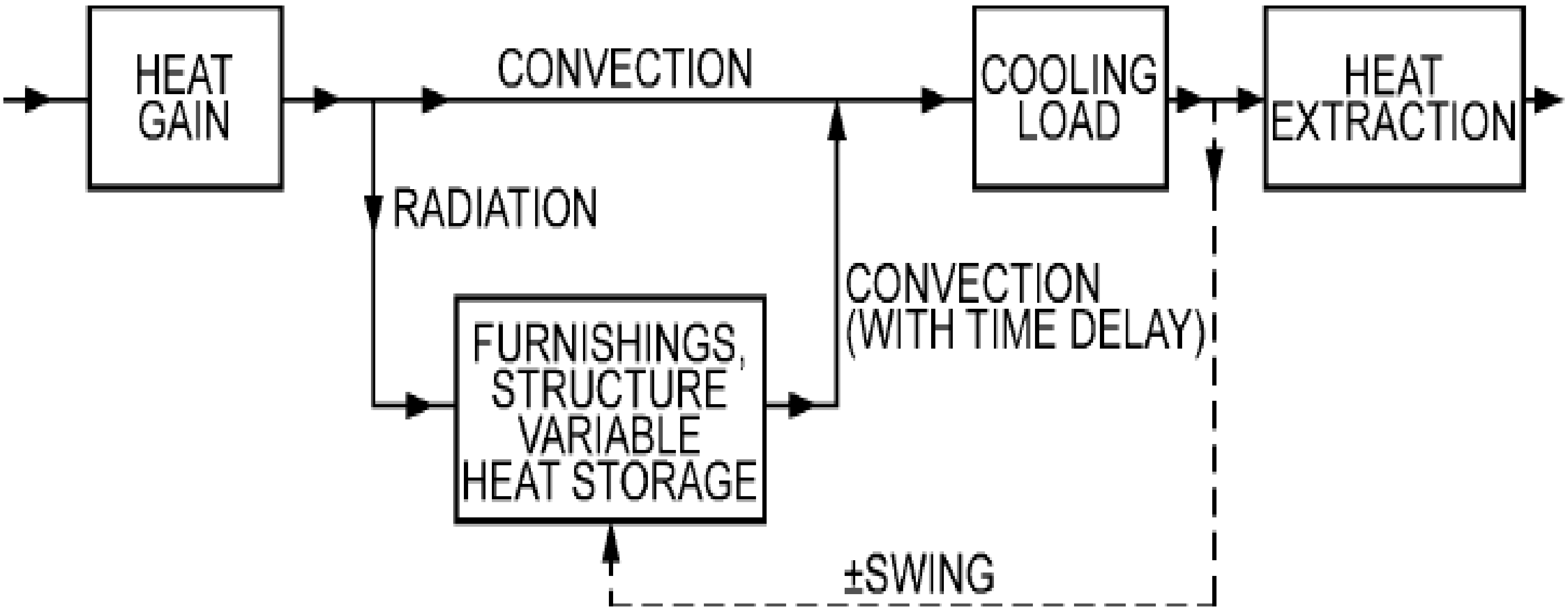
# Cooling Load Principles

- Space and equipment loads
  - Space heat gain (sensible, latent, total)
  - Space cooling load / space heating load
  - Space heat extraction rate
  - Cooling coil load / heating coil load
  - Refrigeration load
- Instantaneous heat gain
  - Convective heat
  - Radiative heat (heat absorption)




Convective and radiative heat in a conditioned space

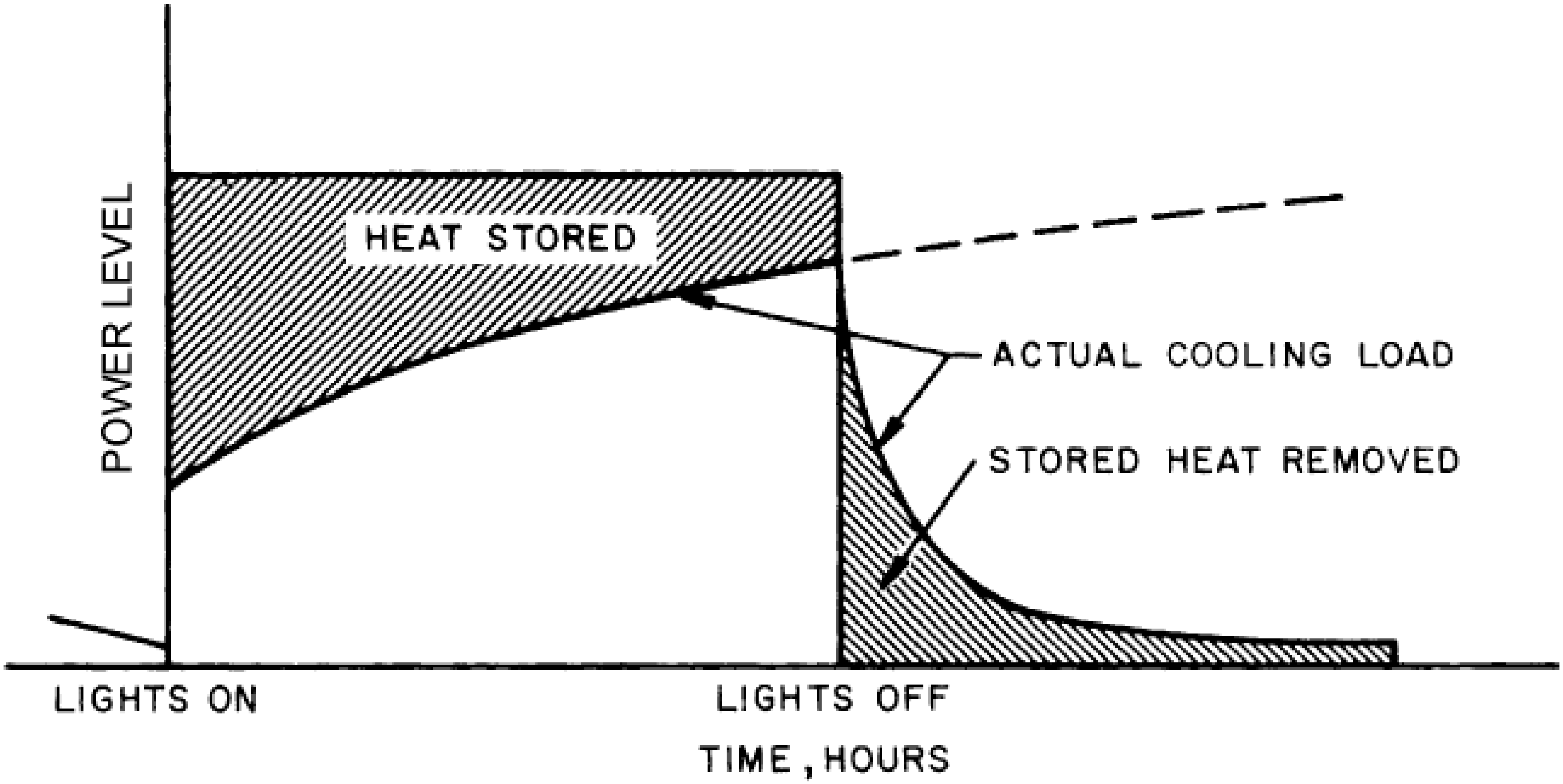
| Sensible heat gains | Convective (%) | Radiative (%) |
|---|---|---|
| Solar radiation with internal shading | 42 | 58 |
| Fluorescent lights | 50 | 50 |
| Occupants | 67 | 33 |
| External wall, inner surface | 40 | 60 |



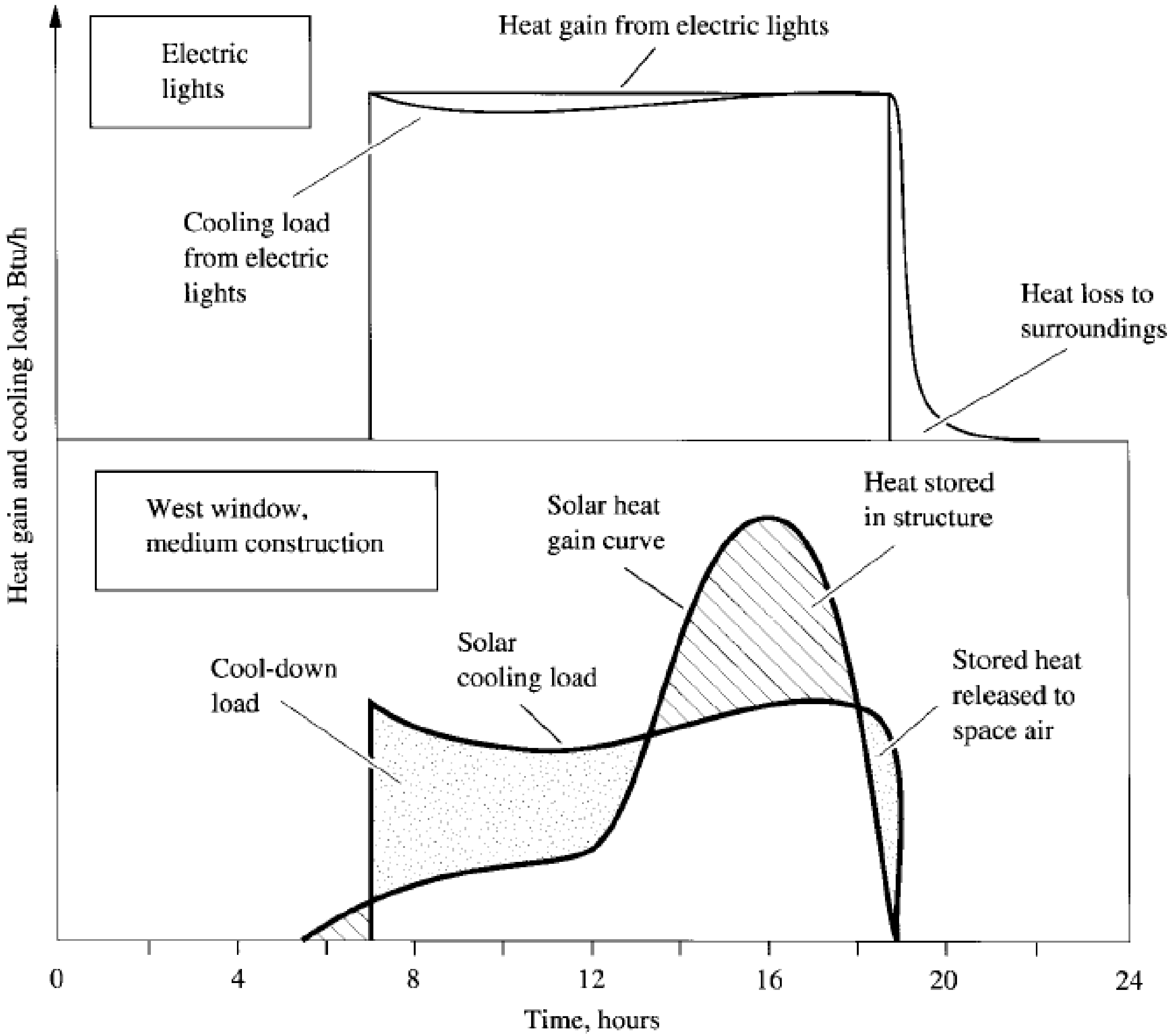

Conversion of heat gain into cooling load

# Cooling Load Principles

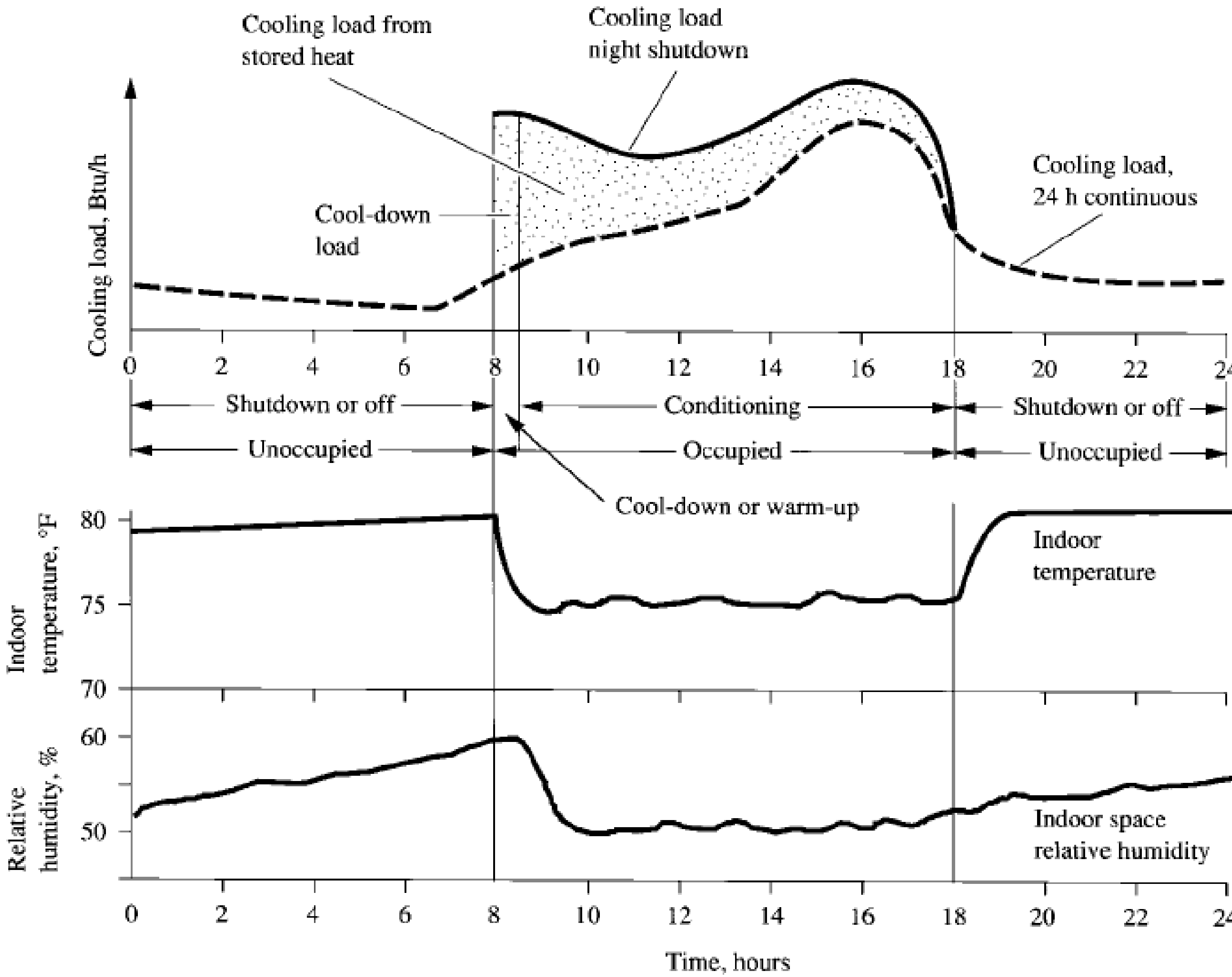
- Instantaneous heat gain vs space cooling loads
  - They are NOT the same
- Effect of heat storage
  - Night shutdown period
    - HVAC is switched off. What happens to the space?
  - Cool-down or warm-up period
    - When HVAC system begins to operate
  - Conditioning period
    - Space air temperature within the limits



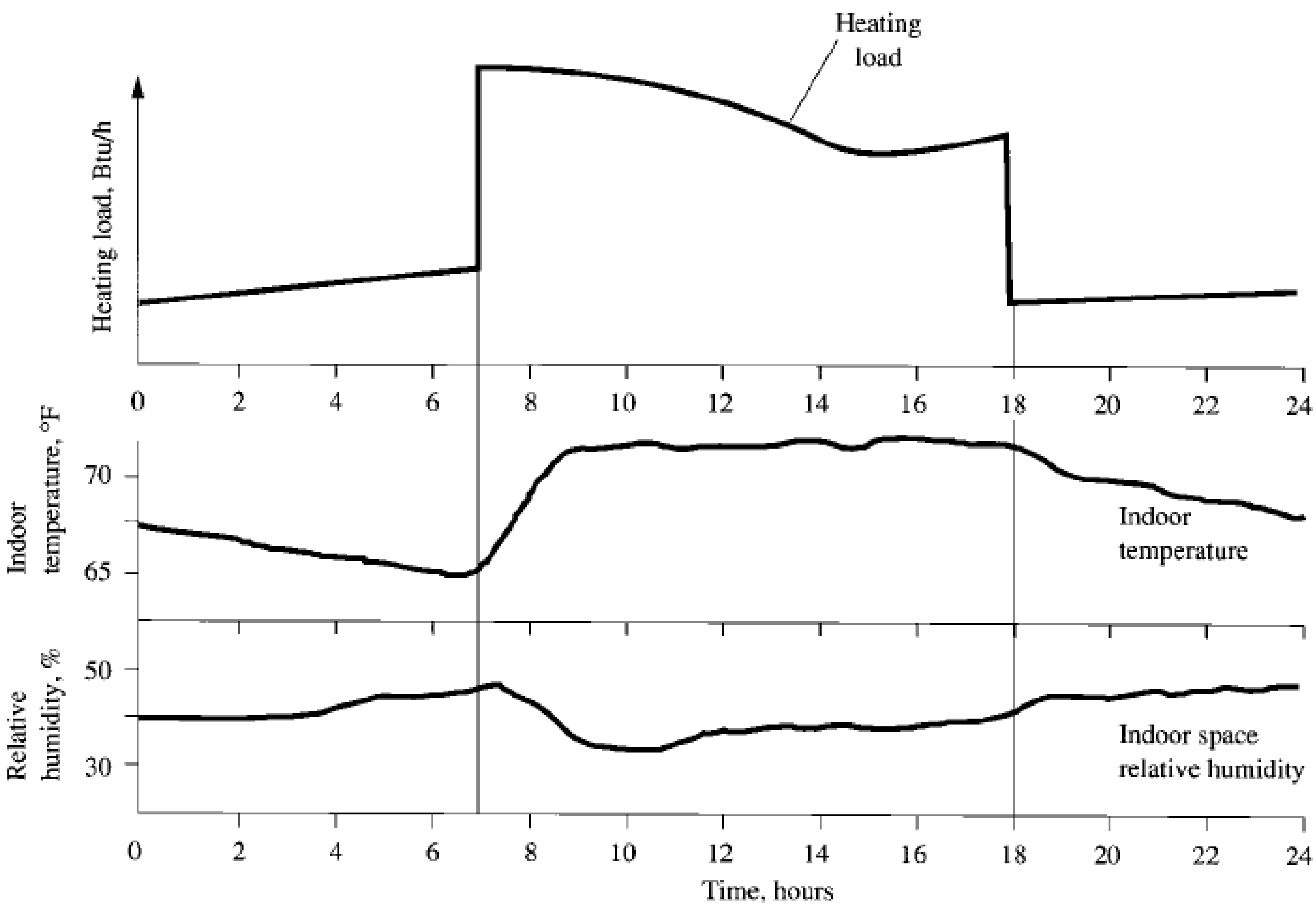

Thermal Storage Effect in Cooling Load from Lights



Electric
lights
Heat gain from electric lights
Cooling load
from electric
lights
Heat loss to
surroundings
West window,
medium construction
Solar heat
gain curve
Heat stored
in structure
Solar
cooling load
Cool-down
load
Stored heat
released to
space air
Heat gain and cooling load, Btu/h
0
4
8
12
16
20
24
Time, hours



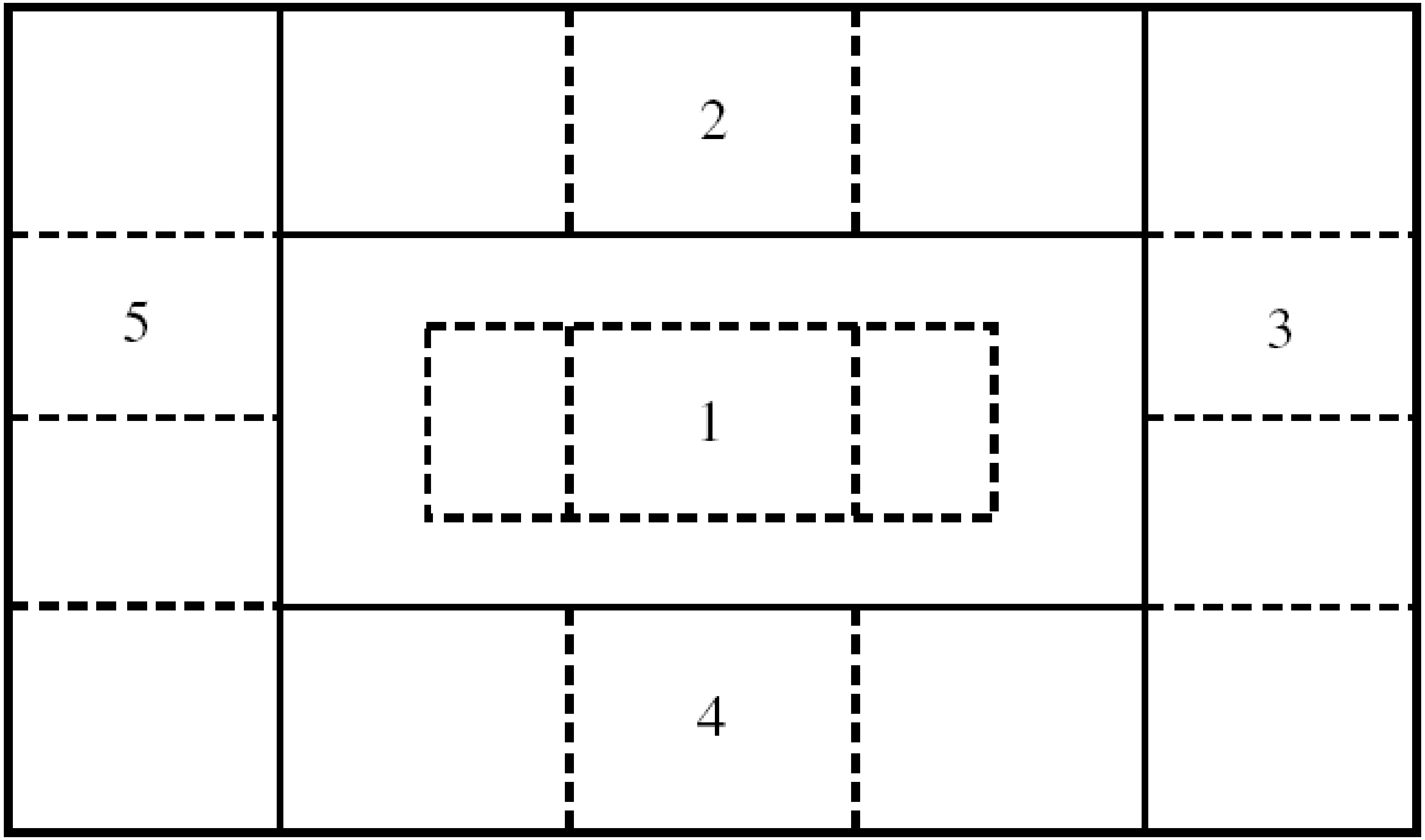
Cooling load from stored heat
Cooling load night shutdown
Cooling load, Btu/h
Cool-down load
Cooling load, 24 h continuous
0
2
4
6
8
10
12
14
16
18
20
22
24
Shutdown or off
Conditioning
Shutdown or off
Unoccupied
Occupied
Unoccupied
Cool-down or warm-up
80
75
70
Indoor temperature, °F
Indoor temperature
60
50
Relative humidity, %
Indoor space relative humidity
Time, hours



Heating load
Heating load, Btu/h
0
2
4
6
8
10
12
14
16
18
20
22
24
Indoor temperature, °F
70
65
Indoor temperature
Relative humidity, %
50
30
Indoor space relative humidity
Time, hours

# Cooling Load Principles

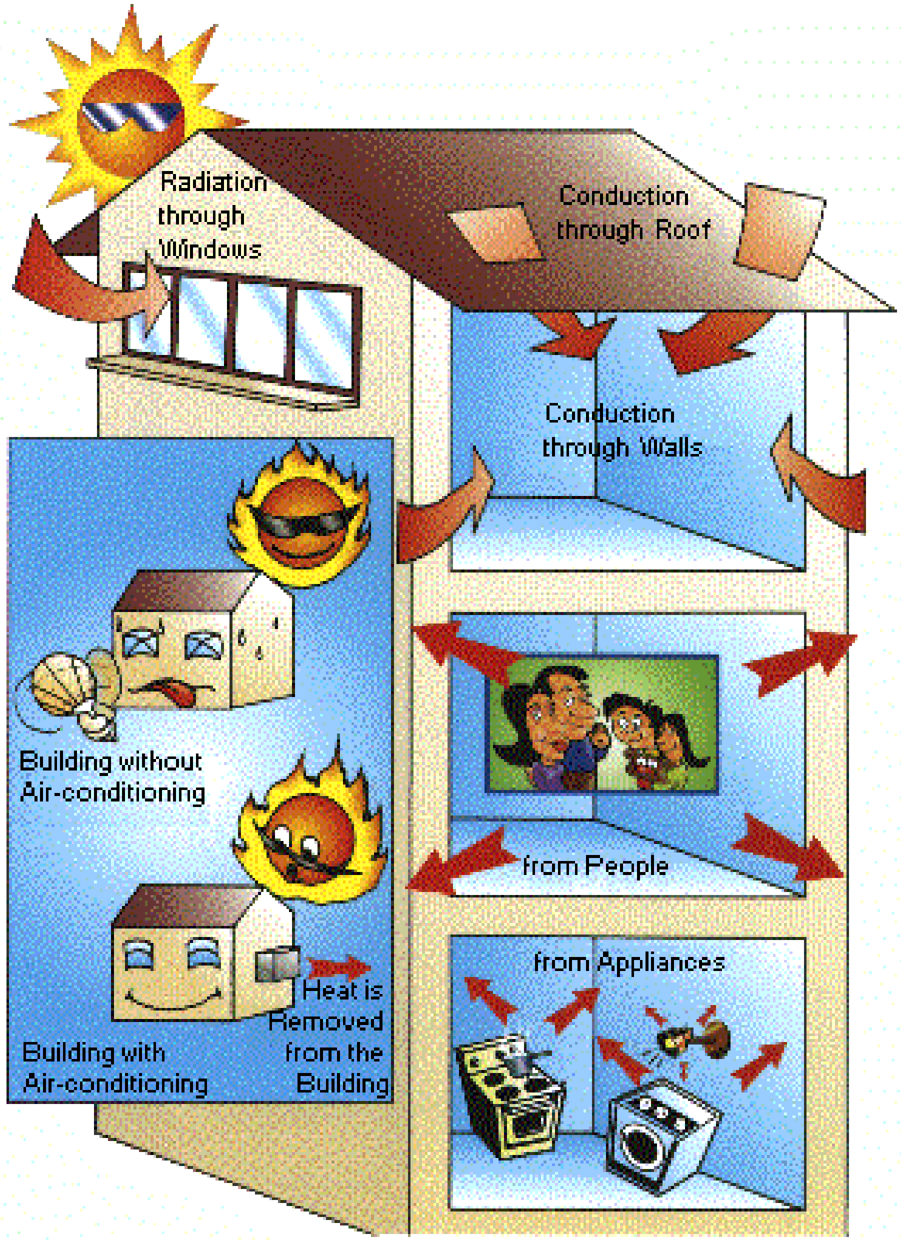
- Load profile
  - Shows the variation of space load
  - Such as 24-hr cycle
  - What factors will affect load profile?
  - Useful for operation & energy analysis
- Peak load and block load
  - Peak load = max. cooling load
  - Block load = sum of zone loads at a specific time




Block load and thermal zoning

# Cooling Load Principles

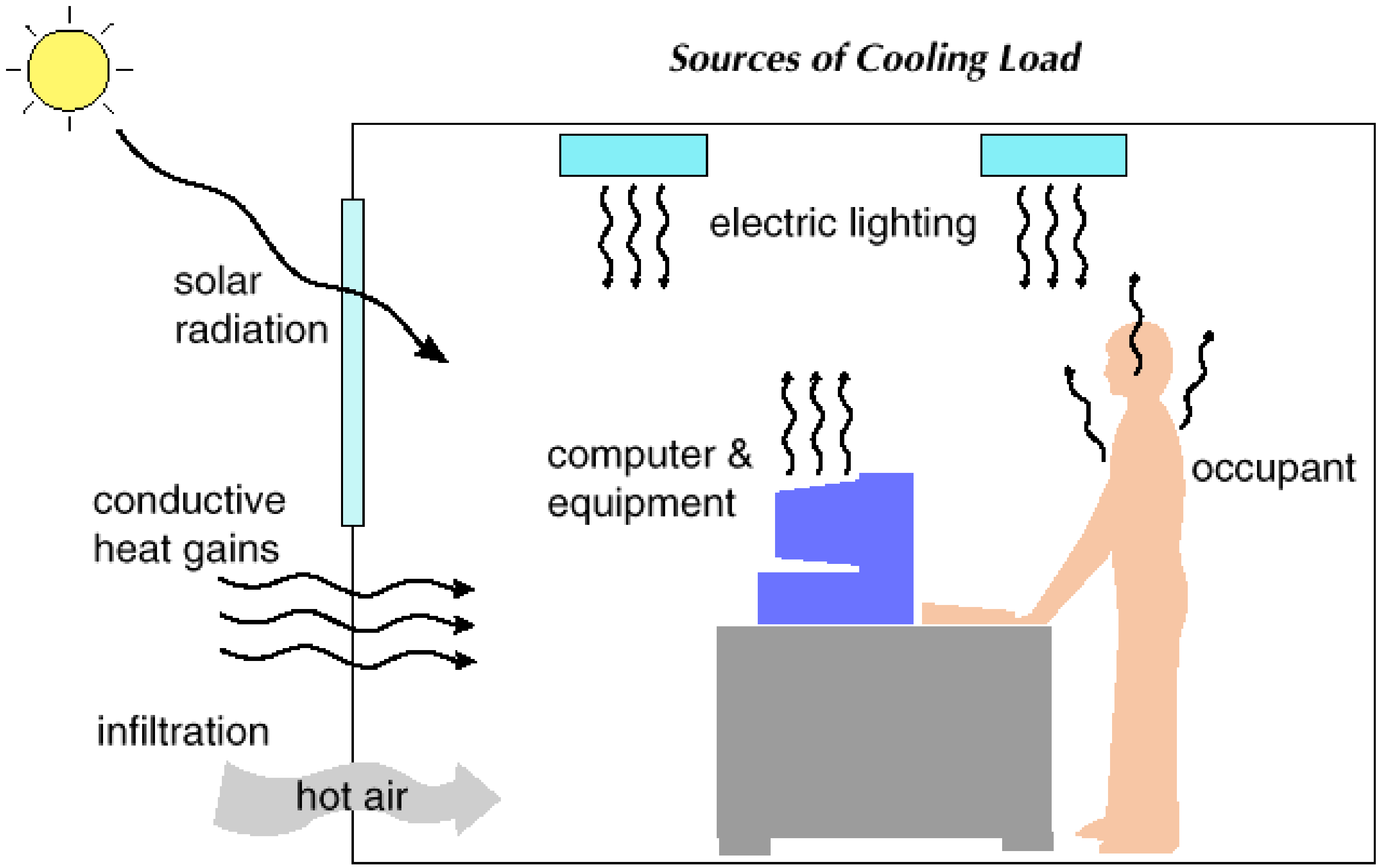
- Moisture transfer
  - Two paths:
    - Moisture migrates in building envelope
    - Air leakage (infiltration or exfiltration)
  - If slight RH variation is acceptable, then storage effect of moisture can be ignored
    - Latent heat gain = latent cooling load (instantaneously)
- What if both temp. & RH need to be controlled?


Radiation through Windows
Conduction through Roof
Conduction through Walls
Building without Air-conditioning
from People
Heat is Removed from the Building
Building with Air-conditioning
from Appliances

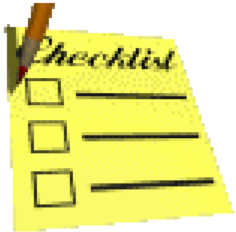
# Cooling Load Components

- Cooling load calculations
  - To determine volume flow rate of air system
  - To size the coil and HVAC&R equipment
  - To provide info for energy calculations/analysis
- Two categories:
  - External loads
  - Internal loads

Sources of Cooling Load

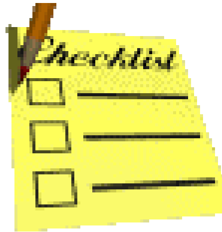


# Cooling Load Components




- External loads
  - Heat gain through exterior walls and roofs
  - Solar heat gain through fenestrations (windows)
  - Conductive heat gain through fenestrations
  - Heat gain through partitions & interior doors
  - Infiltration of outdoor air

# Cooling Load Components




- Internal loads
  - People
  - Electric lights
  - Equipment and appliances
- Sensible & latent cooling loads
  - Convert instantaneous heat gain into cooling load
  - Which components have only sensible loads?

**Table 1 Representative Rates at Which Heat and Moisture Are Given Off by Human Beings in Different States of Activity**

| | | Total Heat, W | | Sensible Heat, W | Latent Heat, W | % Sensible Heat that is Radiant[b] | |
|---|---|---|---|---|---|---|---|
| Degree of Activity | | Adult Male | Adjusted, M/F[a] | | | Low *V* | High *V* |
| Seated at theater | Theater, matinee | 115 | 95 | 65 | 30 | | |
| Seated at theater, night | Theater, night | 115 | 105 | 70 | 35 | 60 | 27 |
| Seated, very light work | Offices, hotels, apartments | 130 | 115 | 70 | 45 | | |
| Moderately active office work | Offices, hotels, apartments | 140 | 130 | 75 | 55 | | |
| Standing, light work; walking | Department store; retail store | 160 | 130 | 75 | 55 | 58 | 38 |
| Walking, standing | Drug store, bank | 160 | 145 | 75 | 70 | | |
| Sedentary work | Restaurant[c] | 145 | 160 | 80 | 80 | | |
| Light bench work | Factory | 235 | 220 | 80 | 140 | | |
| Moderate dancing | Dance hall | 265 | 250 | 90 | 160 | 49 | 35 |
| Walking 4.8 km/h; light machine work | Factory | 295 | 295 | 110 | 185 | | |
| Bowling[d] | Bowling alley | 440 | 425 | 170 | 255 | | |
| Heavy work | Factory | 440 | 425 | 170 | 255 | 54 | 19 |
| Heavy machine work; lifting | Factory | 470 | 470 | 185 | 285 | | |
| Athletics | Gymnasium | 585 | 525 | 210 | 315 | | |

*Notes*:

1. Tabulated values are based on 24°C room dry-bulb temperature. For 27°C room dry bulb, the total heat remains the same, but the sensible heat values should be decreased by approximately 20%, and the latent heat values increased accordingly.
2. Also refer to Table 4, Chapter 8, for additional rates of metabolic heat generation.
3. All values are rounded to nearest 5 W.

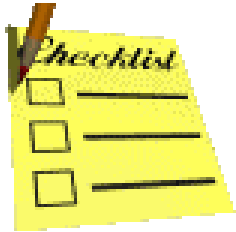
[a] Adjusted heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85% of that for an adult male, and that the gain from a child is 75% of that for an adult male.

[b] Values approximated from data in Table 6, Chapter 8, where  is air velocity with limits shown in that table.

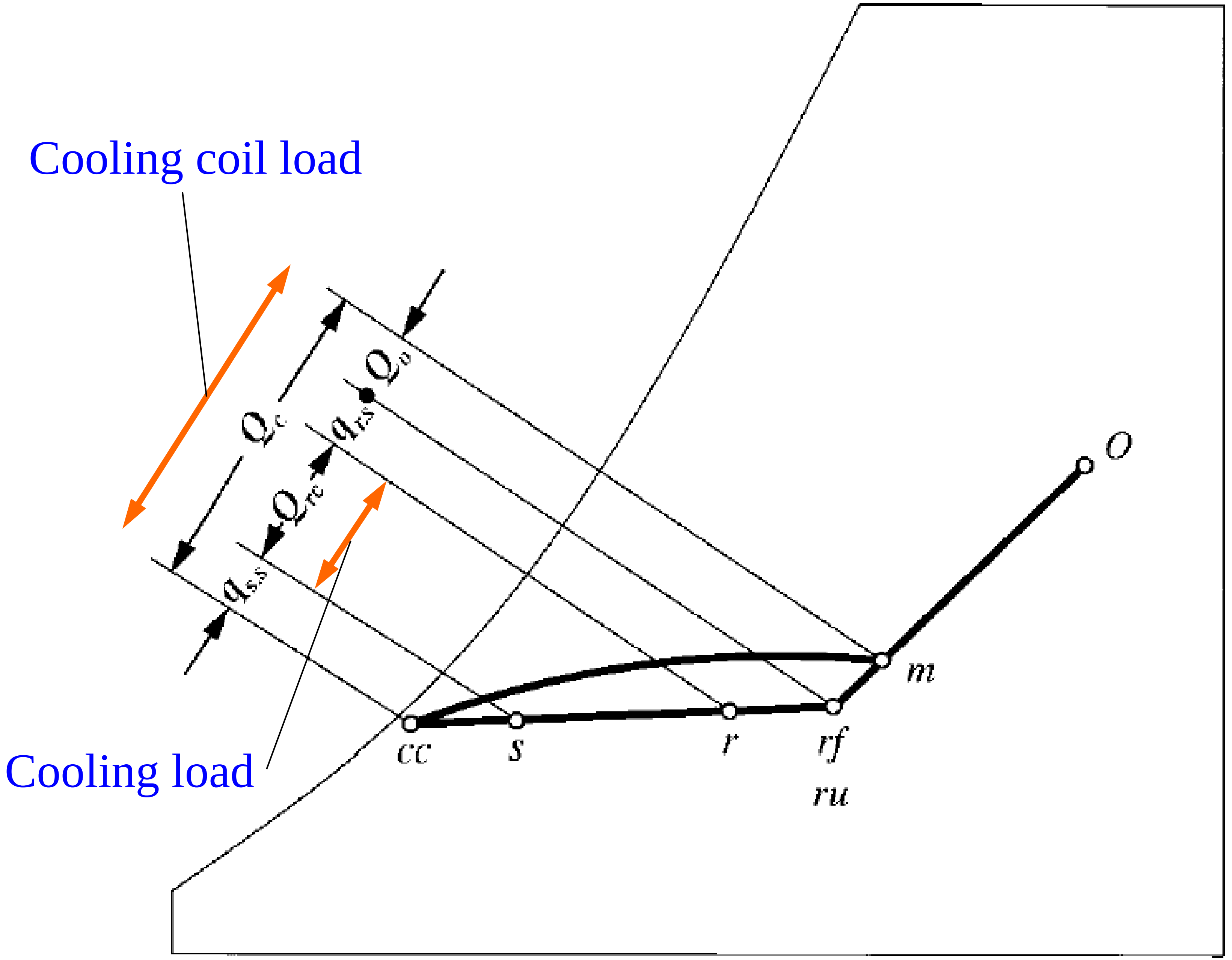
[c] Adjusted heat gain includes 18 W for food per individual (9 W sensible and 9 W latent).

[d] Figure one person per alley actually bowling, and all others as sitting (117 W) or standing or walking slowly (231 W).

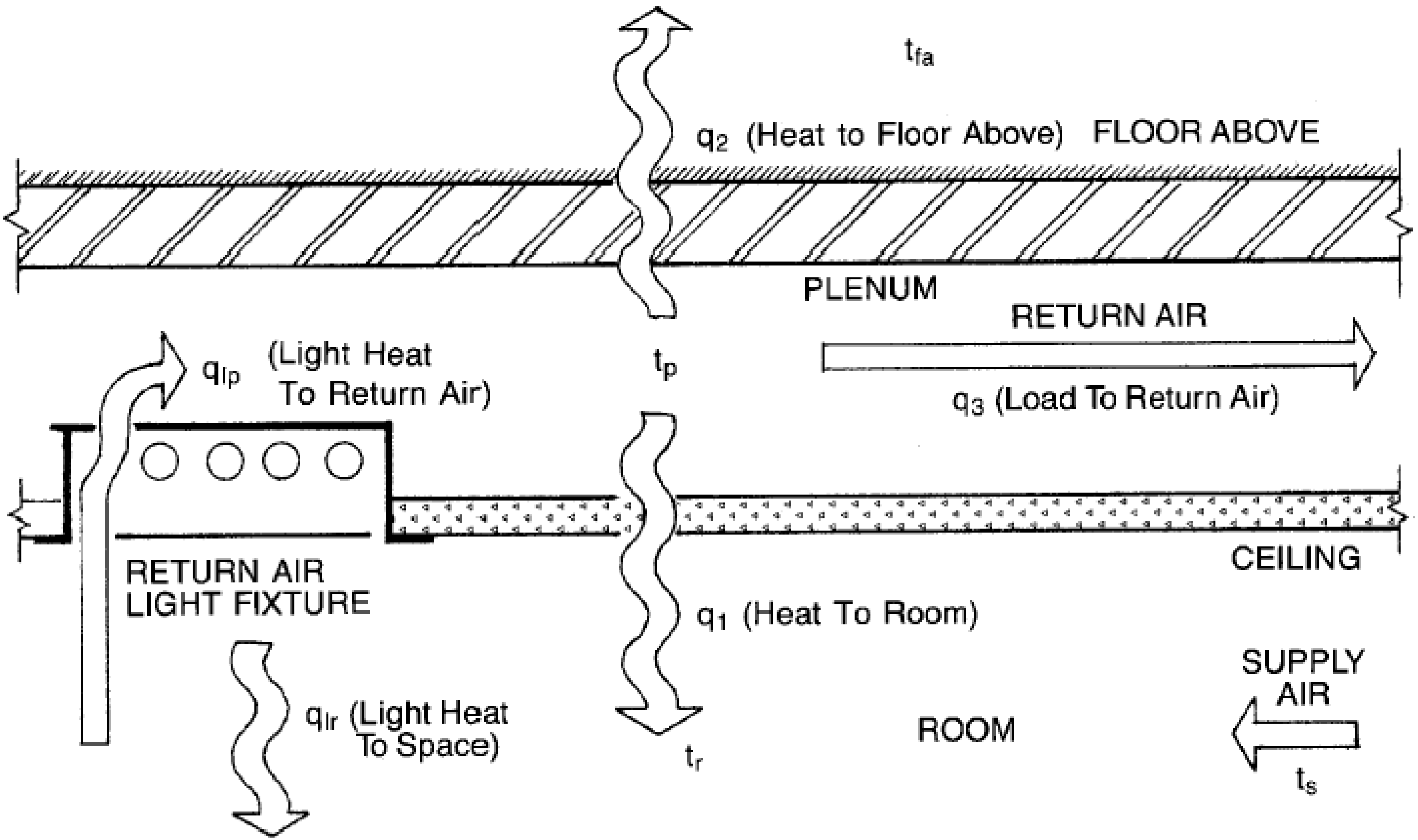
# Cooling Load Components




- Cooling coil load consists of:
  - Space cooling load (sensible & latent)
  - Supply system heat gain (fan + air duct)
  - Return system heat gain (plenum + fan + air duct)
  - Load due to outdoor ventilation rates (or ventilation load)
- How to construct a summer air conditioning cycle on a psychrometric chart?

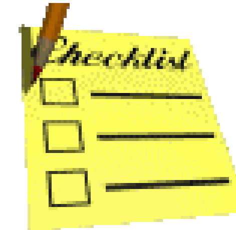


Cooling coil load
Cooling load
$Q_c$
$Q_o$
$q_{rs}$
$Q_{rc}$
$q_{s.s}$
O
m
cc
s
r
rf
ru



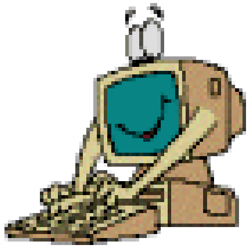

Schematic diagram of typical return air plenum

# Cooling Load Components




- Space cooling load
  - To determine supply air flow rate & size of air system, ducts, terminals, diffusers
  - It is a component of cooling coil load
  - Infiltration heat gain is an instant. cooling load
- Cooling coil load
  - To determine the size of cooling coil & refrigeration system
  - Ventilation load is a coil load

# Heating Load



- Design heating load
  - Max. heat energy required to maintain winter indoor design temp.
    - Usually occurs before sunrise on the coldest days
    - Include transmission losses & infiltration/ventilation
  - Assumptions:
    - All heating losses are instantaneous heating loads
    - Solar heat gains & internal loads usually not considered
    - Latent heat often not considered (unless w/ humidifier)

**Table 12 Summary of Loads, Equations, and References for Calculating Design Heating Loads**

| Heating Load | Equation | Reference, Table, Description |
|---|---|---|
| Roofs, ceilings, walls, glass | $q = U\ A\ \Delta t$ | $U$: Chapter 24, Tables 1, 2, and 4 |
| | | $\Delta t$: Temperature difference between inside and outside design dry bulbs, Chapter 26. For temperatures in unheated spaces, see Equation (2); for attic temperatures, see Equation (3). |
| | | $A$: Area calculated from plans |
| Walls below grade | $q = U\ A\ \Delta t$ | $U$: See Table 14. |
| | | $\Delta t$: Use Figure 6 to assist in determining $\Delta t$. |
| Floors | | |
| Above grade | $q = U\ A\ \Delta t$ | $\Delta t$: For crawl space temperatures, see Equation (4). |
| On grade | $q = F_2\ P\ \Delta t$ | $F_2$: See Table 16. |
| | | $\Delta t$: See Equation (6). |
| | | $P$: Perimeter of slab |
| Below grade | $q = U\ A\ \Delta t$ | $\Delta t$: Use Figure 6 to assist in determining $\Delta t$. |
| | | $U$: See Table 15. |
| Infiltration and ventilation air | | |
| Sensible | $q_s = 0.018\ Q\ \Delta t$ | $Q$: Volume of outdoor air entering building. See Chapter 25 for estimating methods for infiltration. |
| Latent | $q_l = 80.7\ Q\ \Delta W$ | $\Delta W$: Humidity ratio difference, if humidification is to be added |