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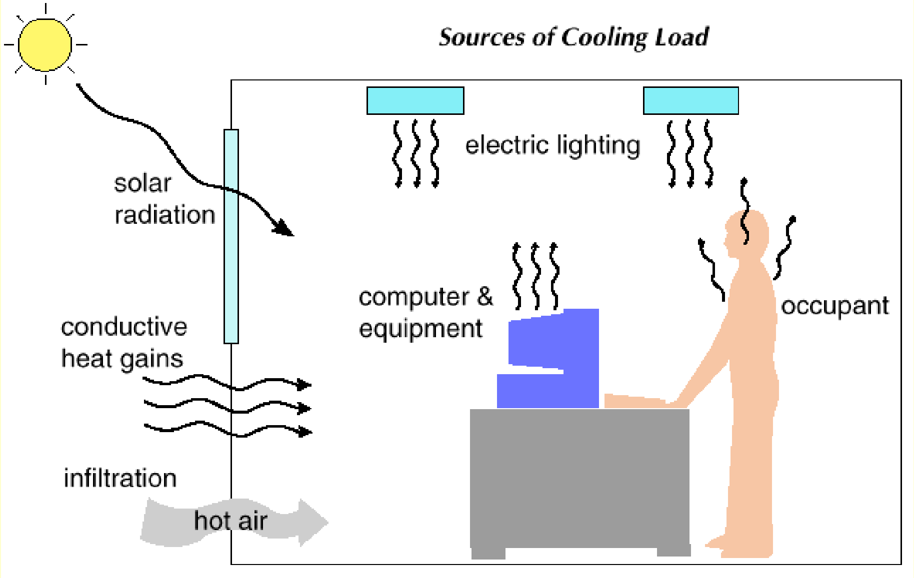

Energy Calculations

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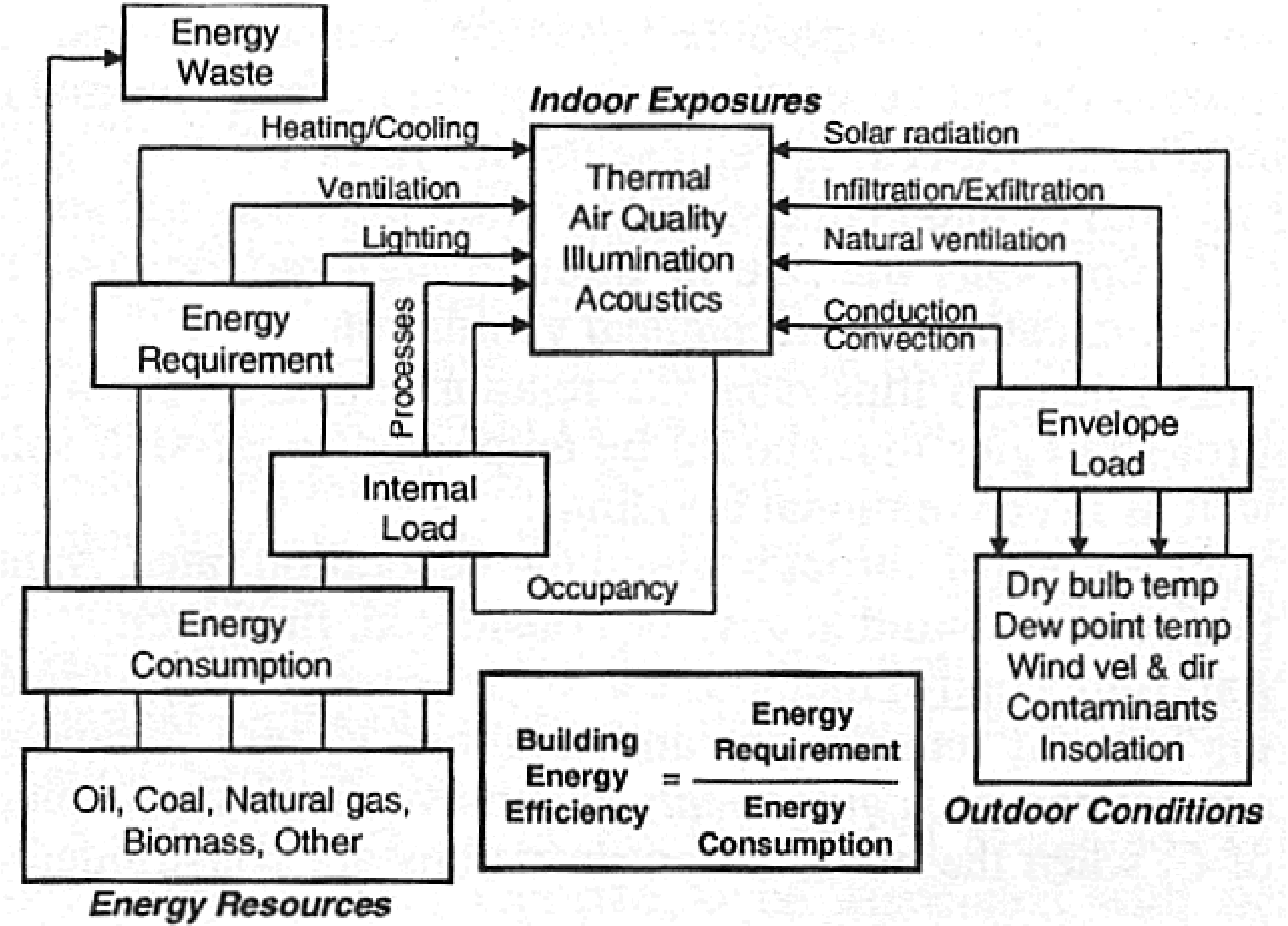
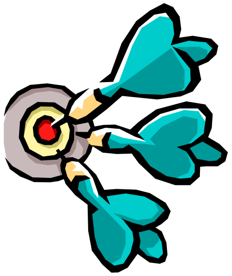
Contents

- Objectives between load calculation vs energy calculation
- Calculation Methodology
  - TFM/ CLTD/SCL/CLF/TETD/TA/HBM/RTSM
- Energy Calculation Methods
- Building Energy Simulation



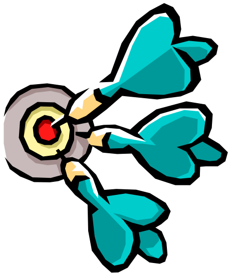
Energy flow and concept in buildings

Objectives



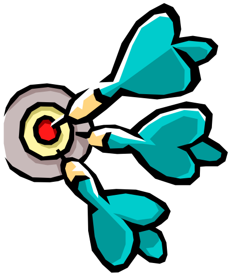
- From *load estimation* to *energy calculations*
  - Only determine peak design loads is NOT enough
  - Need to evaluate HVAC and building energy consumption
    - To support design decisions (e.g. evaluate design options)
    - To enhance system design and operation
    - To compile with building energy code
- Energy calculations
  - More complicated than design load estimation
  - Form the basis of building energy and economic analysis

Objectives



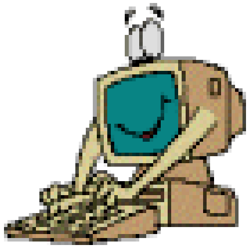
- Load estimation and energy calculations
  - They are based on the same principles
  - But with different purposes & approaches
- Design (peak) load estimation
  - Focus on maximum load or worst conditions
  - For a particular hour or period (e.g. peak summer)
  - For equipment sizing
- Energy calculations
  - Focus on average or typical conditions
  - On whole year (annual) performance or multiple years energy consumption
  - May involve analysis of energy costs & life cycle costs

Objectives



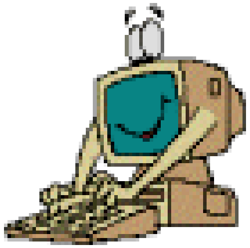
- Tasks at different building design stages
  - Conceptual design stage:
    - Rules of thumb + loading check figures (rough estimation)
  - Outline/Scheme design:
    - Load estimation (approximation)
    - Design evaluations (e.g. using simplified tools/models)
  - Detailed design:
    - Load calculations (complete)
    - Energy calculations + building energy simulation

Calculation Methodology

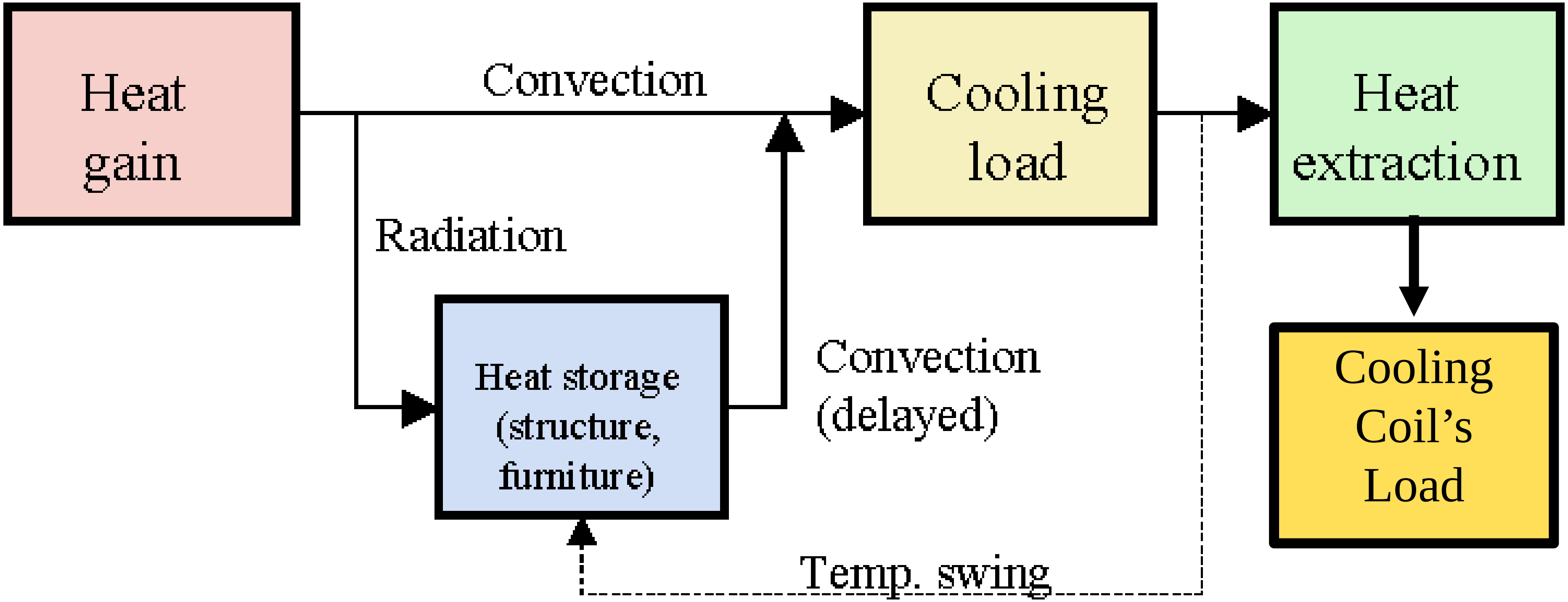


- Basic considerations
  - 1. Peak load calculations
    - Evaluate maximum load to size/select equipment
  - 2. Energy analysis
    - Calculate energy use and compare design options
  - 3. Space cooling load $Q = V \rho c_p (t_r - t_s)$
    - To calculate supply air volume flow rate (V) and size the air system, ducts, terminals
  - 4. Cooling coil's load
    - To size cooling coil and refrigeration system

Calculation Methodology



- Basic considerations (cont'd)
  - Assumptions:
    - Heat transfer equations are linear (even for radiant heat) within a time interval (superposition principle holds)
      - Total load = sum of individual ones
    - Convective heat, latent heat & sensible heat gains from infiltration are all converted to cooling load instantaneously
  - Main difference in various methods
    - How to convert space radiative heat gains into space cooling loads



Conversion of heat gain into cooling load

(Source: ASHRAE Handbook Fundamentals 2005)

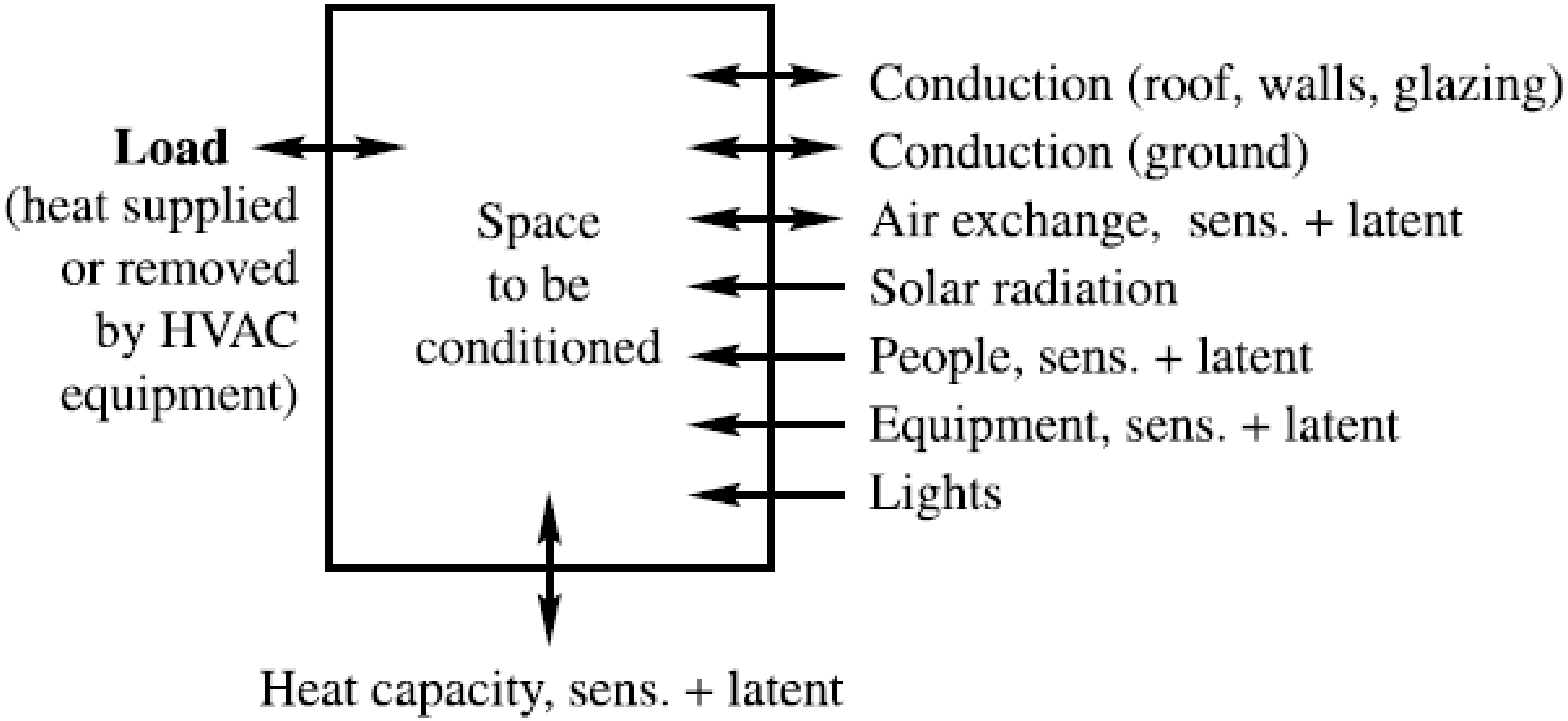
Cooling Load Principle

(pg.40 of last lecture notes)

- Definitions
  - Space heat gain: instantaneous rate of heat gain that enters into or is generated within a space
  - Space cooling load: the rate at which heat must be removed from the space to maintain a constant space air temperature
  - Space heat extraction rate: the actual rate of heat removal when the space air temperature may swing
  - Cooling coil load: the rate at which energy is removed at a cooling coil serving the space
    - space heat + external load

Thermal Load

Heat Gains/Losses



Load
(heat supplied
or removed
by HVAC
equipment)

Space
to be
conditioned

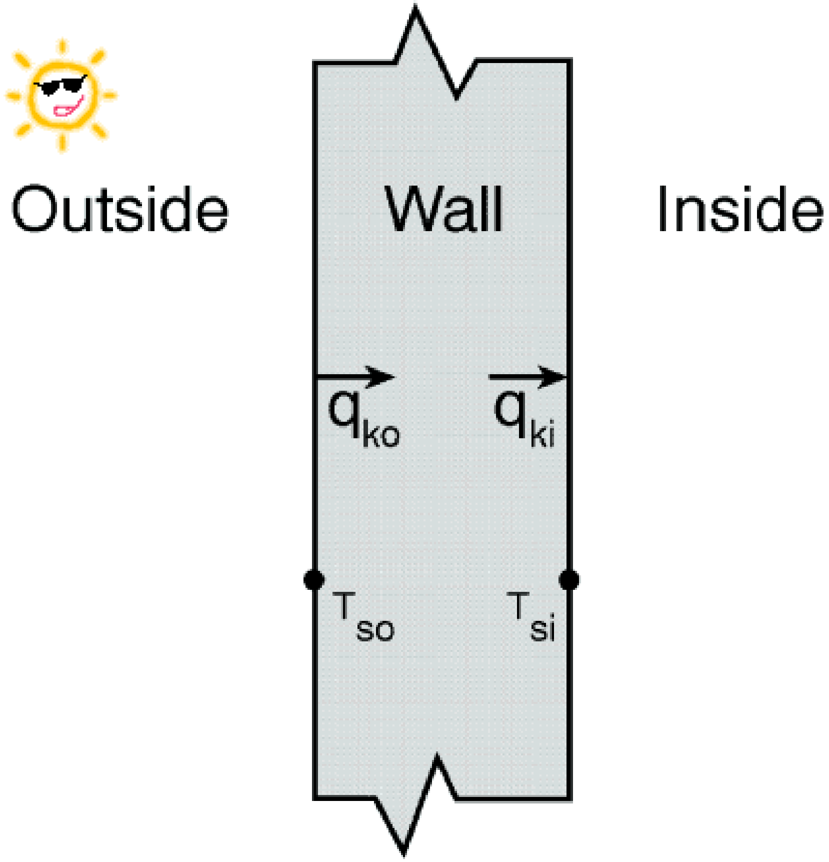
Conduction (roof, walls, glazing)
Conduction (ground)
Air exchange, sens. + latent
Solar radiation
People, sens. + latent
Equipment, sens. + latent
Lights

Heat capacity, sens. + latent

Heat Storage

(Source: ASHRAE Handbook Fundamentals 2005)

A basic example of modelling heat transfer through an external wall



q_{ko} = convective flux into the wall, W/m^2
q_{ki} = convective flux from the wall, W/m^2
T_{so} = wall surface temperature outside, ºC
T_{si} = wall surface temperature outside, ºC

Note that q_{ko} is not equal to q_{ki} !
Affected by the thermal capacity and the transmittance of the wall

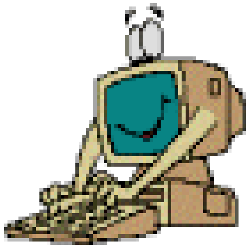
Possible ways to model this process:

1. Numerical finite difference
2. Numerical finite element
3. Transform methods
4. Time series methods

Wall conduction process

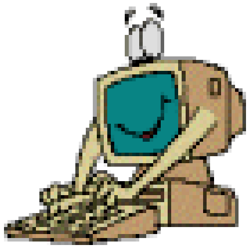
(Source: ASHRAE Handbook Fundamentals 2005)

Calculation Methodology



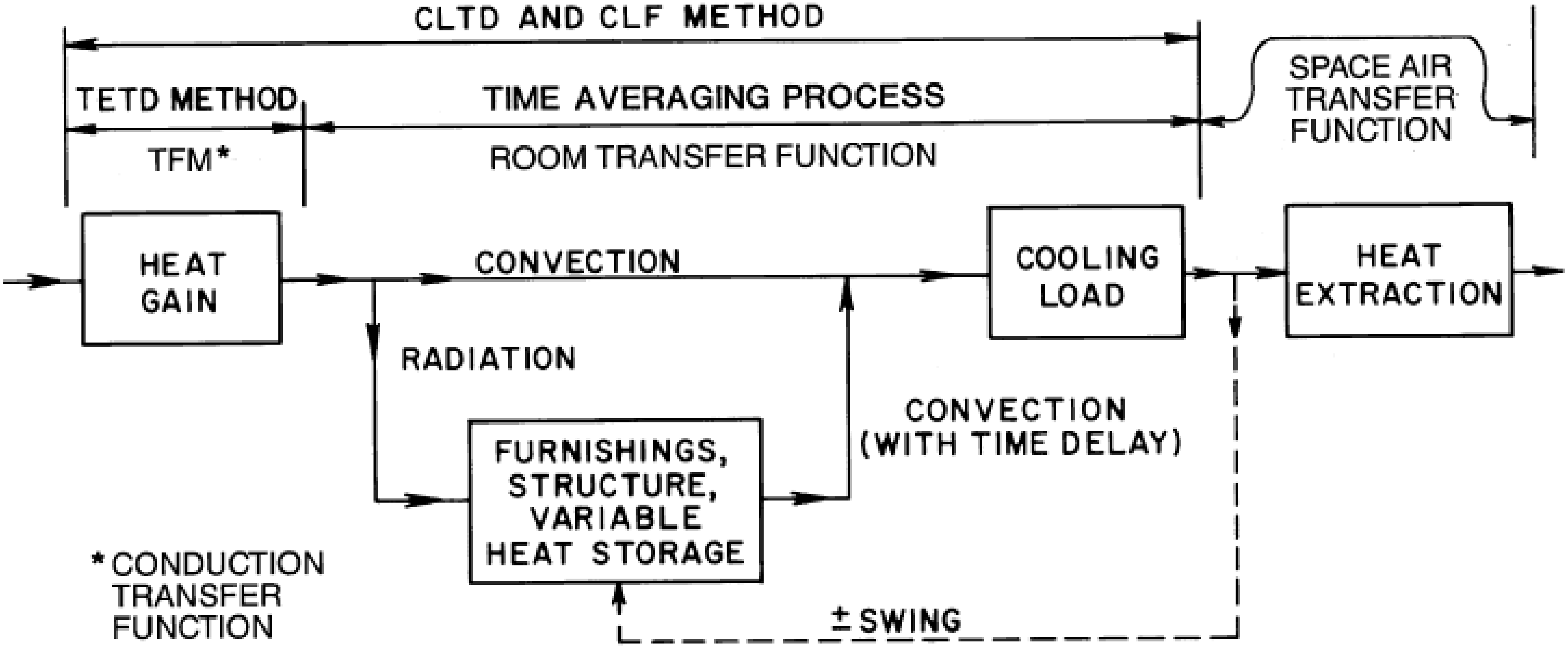
- Common methods:
    - Total Equivalent Temperature Differential / Time Averaging (**TETD/TA**) method
    - Transfer Function Method (**TFM**)
    - Cooling Load Temperature Difference / Solar Cooling Load Factors / Internal Cooling Load Factor (**CLTD/SCL/CLF**) method
- Present methods:
    - Heat Balance Method (**HBM**)
    - Radiant Time Series Method (**RTSM**)
- Other methods:
    - Finite Difference / Finite Element Method (**FDM/FEM**)
    - CIBSE method

Calculation Methodology



- TETD/TA method
  - 1967 ASHRAE Fundamentals
  - Heat gains calculated from Fourier series solution of 1-dimensional transient heat conduction
  - Average heat gains to current and successive hours according to thermal mass & experience
- Transfer Function Method (TFM)
  - 1972 ASHRAE Fundamentals
  - Laplace transform and *z*-transform of time series
- CLTD/CLF method
  - 1977 ASHRAE Fundamentals
  - A one-step simplification of TFM

Basic concepts of TFM, CLTD/CLF and TETD/TA methods



(Source: ASHRAE Handbook Fundamentals 2005)

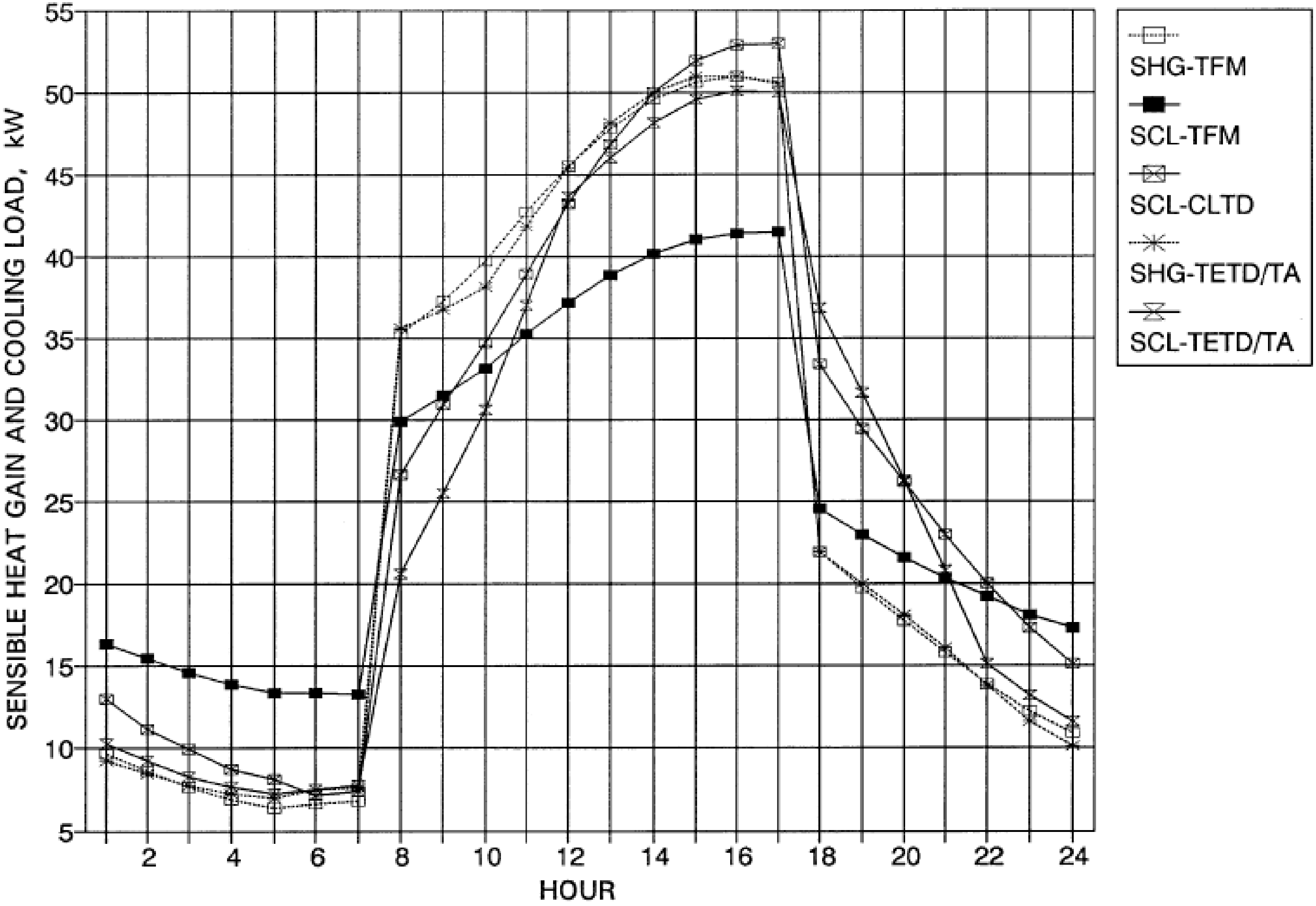
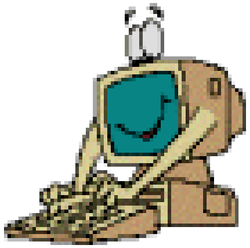


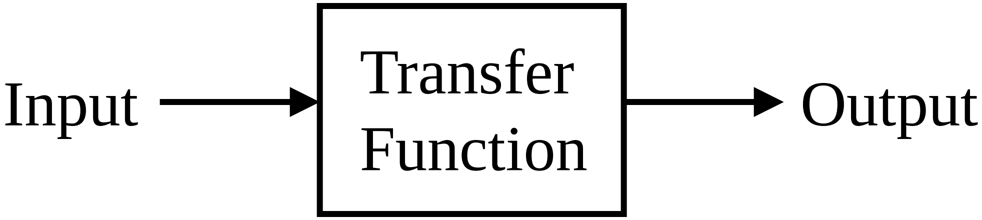
Fig. 5 TFM versus CLTD/SCF/CLF Versus TETD/TA Methods of Calculating Sensible Heat Gain and Cooling Load

(Source: ASHRAE Handbook Fundamentals 2005)

Transfer Function Method



- Transfer Function Method (TFM)
  - Most commonly adopted for energy calculations
  - Three components:
    - Conduction Transfer Function (CTF)
    - Room Transfer Function (RTF)
    - Space Air Transfer Function (SATF)
  - Implemented numerically using weighting factors
    - Transfer function coefficients, to weight the importance of current & historical values of heat gain & cooling load on currently calculated loads



Transfer function (K)

Polynominals of z-transform

$$K = Y/G = \left(v_o + v_1 z^{-1} + v_2 z^{-2} + \ldots\right) / \left(1 + w_1 z^{-1} + w_2 z^{-2} + \ldots\right)$$

Y = Laplace transform of the output
G = Laplace transform of the input or driving force

When a continuous function $f(t)$ is represented at regular intervals Δt and its magnitude are $f(0)$, $f(\Delta)$, $f(2\Delta)$,…, $f(n\Delta)$, the Laplace transform is given by a polynomial called "z-transform":

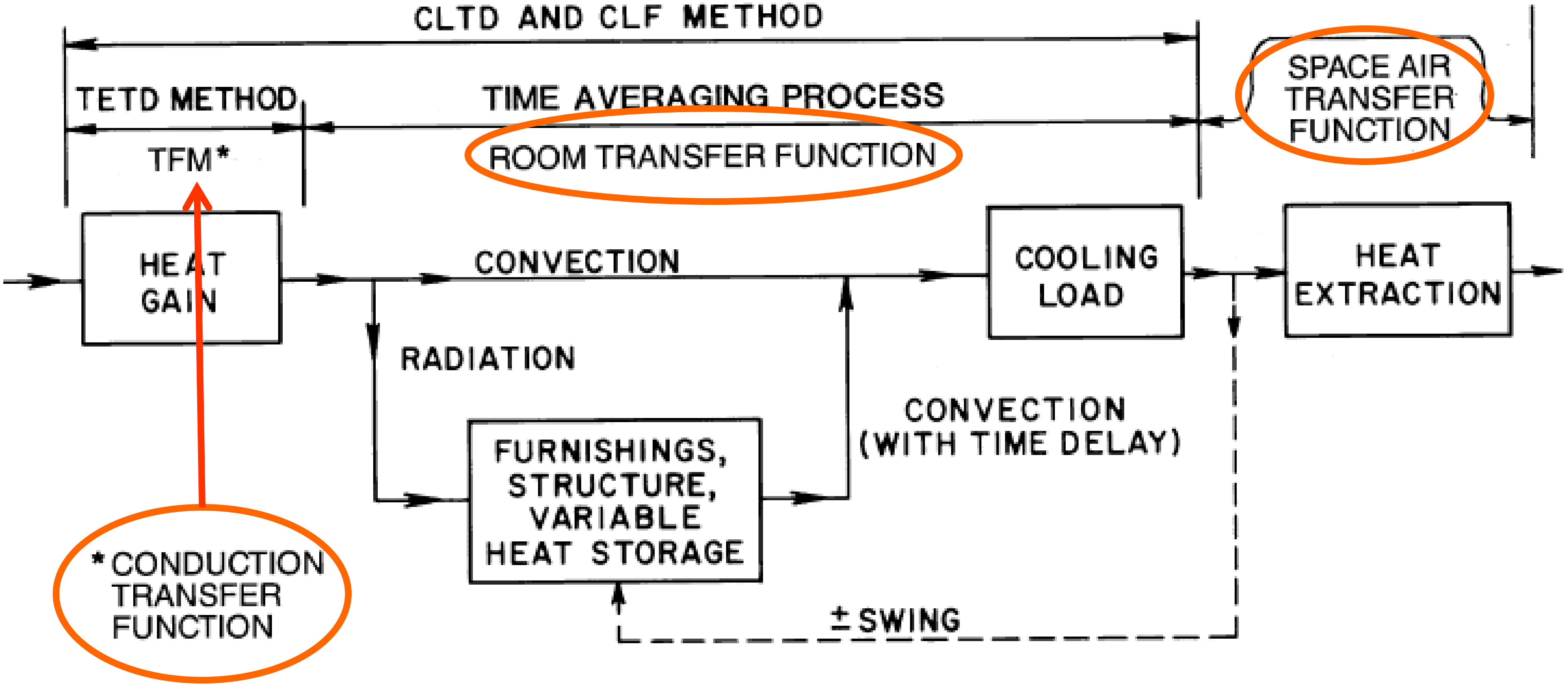
$$\varphi(z) = f(0) + f(\Delta)\, z^{-1} + f(2\Delta)\, z^{-2} + \ldots + f(n\Delta)\, z^{-n}$$

where Δ = time interval, hour

$$z = e^{t\Delta}$$

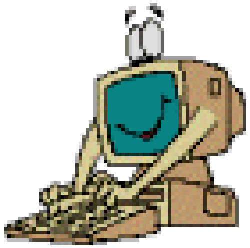
v_0, v_1, v_2, … & w_1, w_2, … are weighting factors for the calculations

Three components of transfer function method (TFM)



(Source: ASHRAE Handbook Fundamentals 2005)

Transfer Function Method



- Sol-air temperature (t_e)
  - A fictitious outdoor air temperature that gives the rate of heat entering the outer surface of walls and roofs due to the combined effect of incident solar radiation, radiative heat exchange with the sky vault and surroundings, and convective heat exchange with the outdoor air

$$t_e = t_o + \frac{\alpha E_t}{h_o} - \frac{\varepsilon \Delta R}{h_o}$$

Outdoor air temperature

Surface absorptance

Surface emittance

Heat balance at a sunlit surface, heat flux is equal to:

$$\frac{q}{A} = \alpha E_t + h_o(t_o - t_s) - \varepsilon \Delta R$$

where

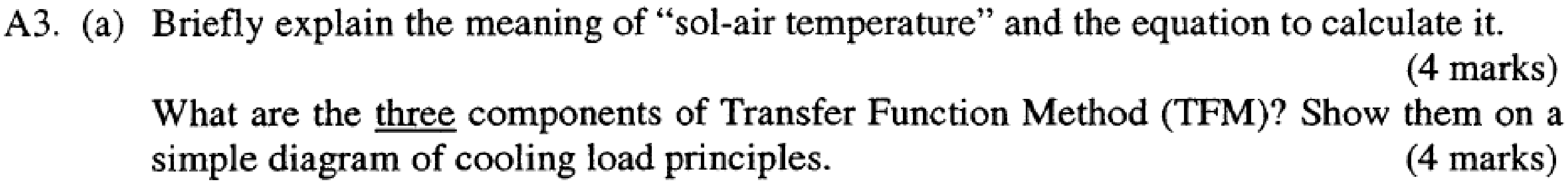
α = absorptance of surface for solar radiation
E_t = total solar radiation incident on surface, W/ m^2
h_o = coefficient of heat transfer by long-wave radiation and convection at outer surface, W/(m$^2 \cdot$K)
t_o = outdoor air temperature, °C
t_s = surface temperature, °C
ε = hemispherical emittance of surface
ΔR = difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature, W/m^2

Assume the heat flux can be expressed in terms of sol-air temp. (t_e)

$$\frac{q}{A} = h_o(t_e - t_s)$$

Thus, sol-air temperature is given by: $t_e = t_o + \frac{\alpha E_t}{h_o} - \frac{\varepsilon \Delta R}{h_o}$

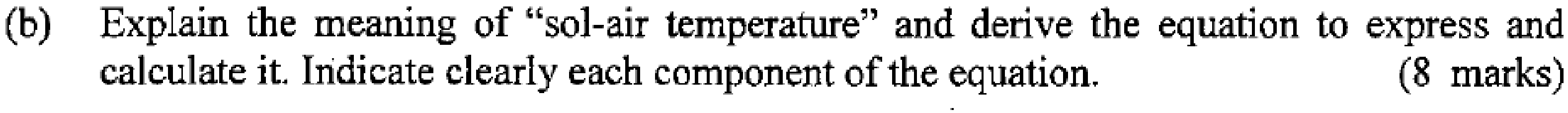
2007 Past Paper



A3. (a) Briefly explain the meaning of "sol-air temperature" and the equation to calculate it. (4 marks)

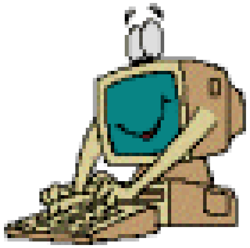
What are the <u>three</u> components of Transfer Function Method (TFM)? Show them on a simple diagram of cooling load principles. (4 marks)

2009 Past Paper



(b) Explain the meaning of "sol-air temperature" and derive the equation to express and calculate it. Indicate clearly each component of the equation. (8 marks)

Transfer Function Method



- Use of Conduction Transfer Function (CTF)
- External walls and roofs:

Sol-air temperature

$$q_{\mathrm{e},t} = A\left[\sum_{n=0} b_n T_{\mathrm{sol},t-n\delta} - \sum_{n=1} d_n \left(q_{\mathrm{e},t-n\delta}/A\right)\right] - T_{\mathrm{r}} \sum_{n=0} c_n$$

$q_{e,t}$ = heat gain through wall or roof, at hour t

A = indoor surface area of wall or roof

t = time

δ = time interval

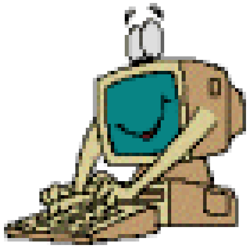
n = summation index

$t_{sol,t-n\delta}$ = sol-air temperature at time sol,$t-n\delta$

T_r = constant indoor room temperature

b_n, c_n, d_n = conduction transfer function (CTF) coefficients

Transfer Function Method

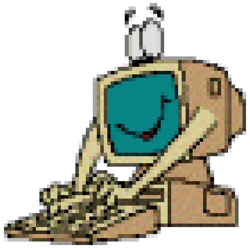


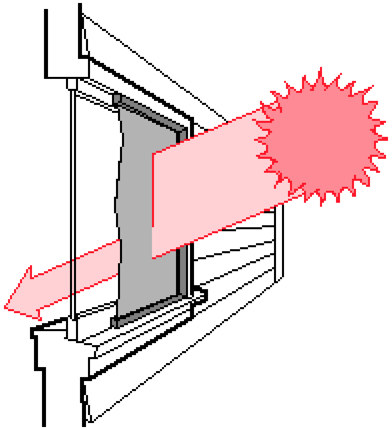
- Ceiling, floors & partition wall:

$$q_{\mathrm{aj},t} = UA\left(T_{\mathrm{aj}} - T_{\mathrm{r}}\right)$$

aj = adjacent space
r = room

Transfer Function Method





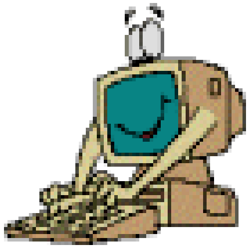
- Window glass
  - Solar heat gain:
    - Shading Coefficient (SC)
    - Solar Heat Gain Factor (SHGF)

$$q_{\mathrm{es},t} = \left(A_\mathrm{s} \times \underbrace{\mathrm{SHGF}}_{\text{Sunlit}} \times \mathrm{SC}\right) + \left(A_\mathrm{sh} \times \underbrace{\mathrm{SHGF}_\mathrm{sh}}_{\text{Shaded}} \times \mathrm{SC}\right)$$

  - Conduction heat gain: U-value

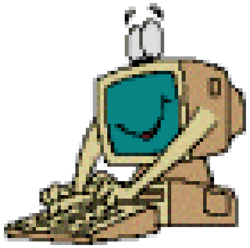
$$q_{\mathrm{ec},t} = U_\mathrm{g}\left(\underbrace{A_\mathrm{s}}_{\text{Sunlit}} + \underbrace{A_\mathrm{sh}}_{\text{Shaded}}\right)\left(T_{\mathrm{o},t} - T_\mathrm{r}\right)$$

Transfer Function Method



- Internal heat gains
  - People (sensible + latent)
  - Lights
  - Machine & appliances
- Infiltration (uncontrolled, via cracks/opening)
  - If positive pressure is maintained in conditioned space, infiltration is normally assumed zero

Transfer Function Method



- Convert heat gain into cooling load
  - Use of Room Transfer Function (RTF)
  - Depends on heat gain and heat storage

$$q_{\mathrm{s-e},t} = \sum_{i=1} \left(v_{\mathrm{o}} q_{\mathrm{e},t} + v_1 q_{\mathrm{e},t-\delta} + v_2 q_{\mathrm{e},t-2\delta} + \ldots \right) - \left(w_1 q_{\mathrm{r},t-\delta} + w_2 q_{\mathrm{r},t-2\delta} + \ldots \right)$$

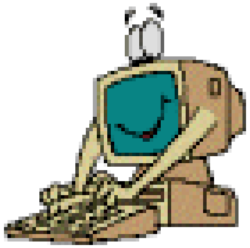
v_0, v_1, v_2, … & w_1, w_2, … are weighting factors

  - Space sensible cooling load (from convective):

$$q_{\mathrm{s-c},t} = \sum_{k=1} q_{\mathrm{ec},t}$$

  - Space latent cooling load: $q_{\mathrm{rl},t} = \sum_{m=1} q_{\mathrm{el},t}$

Transfer Function Method



- Convert heat gain into cooling load (cont’d)
  - Use of Space Air Transfer Function
  - Heat extraction rate & space air temperature

$$\sum_{i=0}^{1} p_i \left(q_{\mathrm{xs},t} - q_{\mathrm{rs},t-\mathrm{i}\delta} \right) = \sum_{i=0}^{2} g_i \left(T_{\mathrm{r}} - T_{\mathrm{r},t-\mathrm{i}\delta} \right)$$

  - Cooling coil load (sensible & latent)
    - Air mixture & air leaving the cooling coil
    - Ventilation load

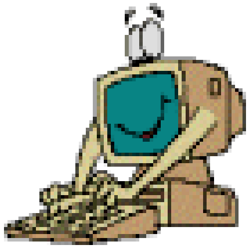
Prefer to Table 10 – Chapter 28 ASHRAE Fundamentals 1997

CLTD/SCL/CLF Procedure

- Same general procedures outlined for TFM relative to data apply
- Basic heat gain concepts of solar radiation, total heat gain through exterior walls and roofs, heat gain through interior surfaces, heat gain through infiltration and ventilations are handled identically
- One step hand calculation procedure
- Used to approximate the cooling load corresponding to
  - Conductive heat gain through surfaces like walls, roofs, windows
  - Solar heat gain through fenestrations
  - Internal heat gain from lights, people, equipment
  - Infiltration and ventilation

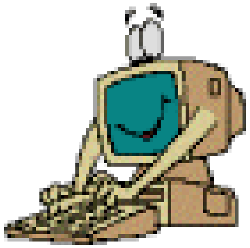
Prefer to Table 29 – Chapter 28 ASHRAE Fundamentals 1997

Calculation Methodology



- Recent methods:
  - Heat balance (HB) method
    - The rigorous approach (mainly for research use)
    - Requires solving of partial differential equations and often involves iteration
  - Radiant time series (RTS) method
    - A simplified method derived from HB procedure
- Differences from previous TFM
  - Periodic response factors and radiant time factors have clear physical meanings
  - Allow users to visually see the effects of damping and time delay on conduction heat gains

Calculation Methodology



- Heat Balance (HB) Method
  - Use heat balance equations to calculate:
    - Surface-by-surface conductive, convective & radiative heat balance for each room surface
    - Convective heat balance for the room air
  - Calculation process
    - Find the inside surface temperatures of building structures due to heat balance
    - Calculate the sum of heat transfer from these surfaces and from internal loads

Refer to Ch.18 – ASHRAE Fundamentals 2009

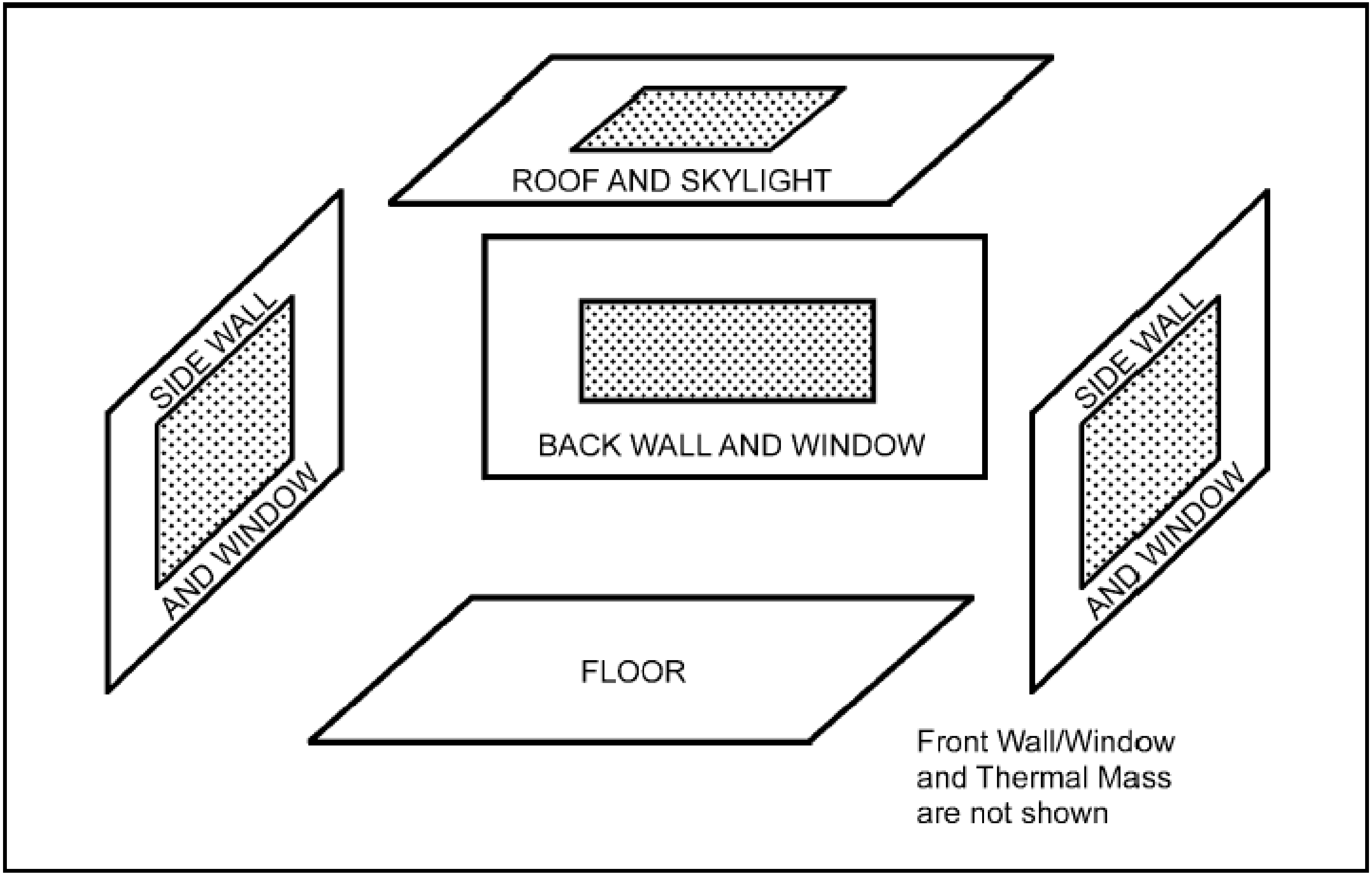
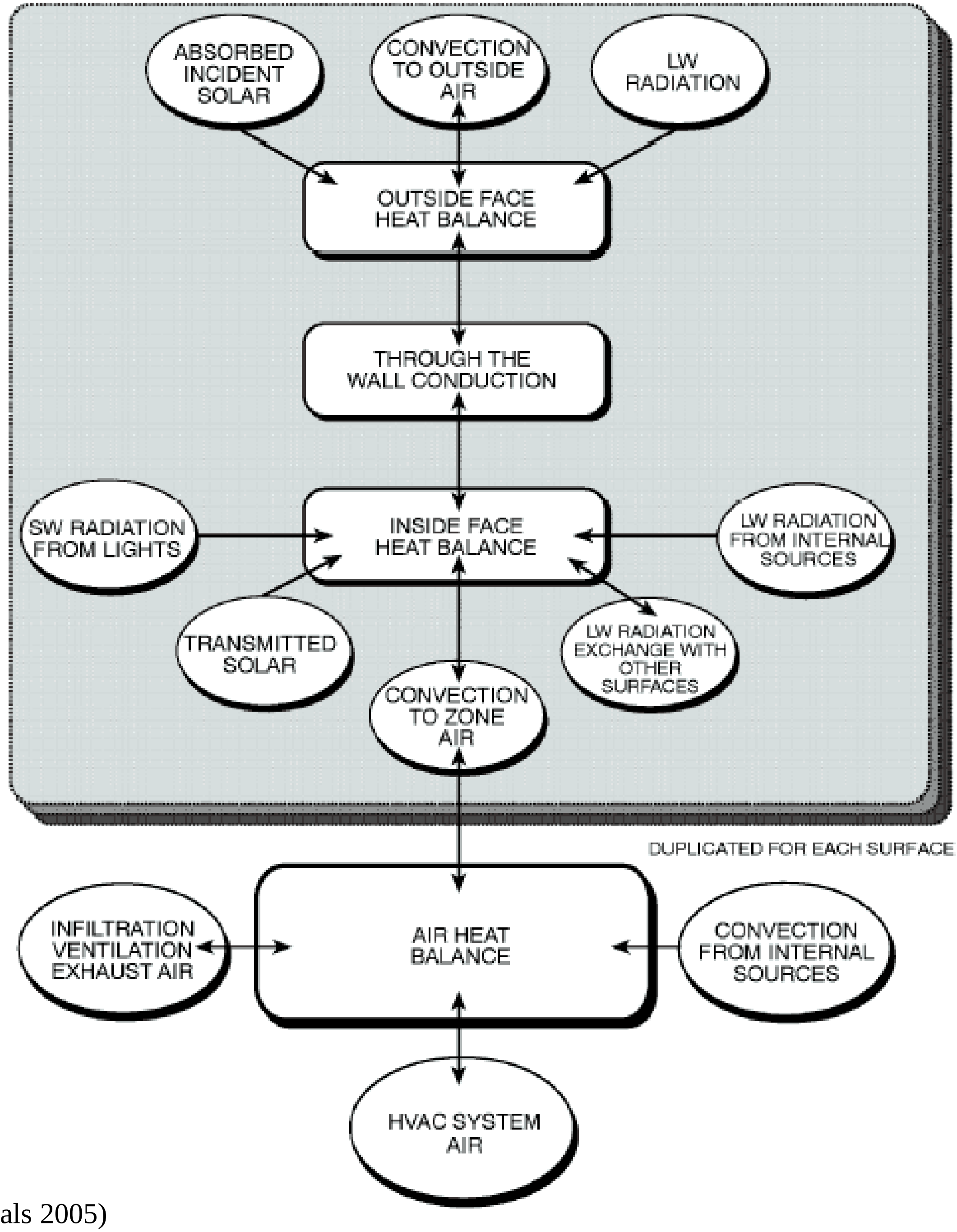


Fig. 7 Schematic View of General Heat Balance Zone

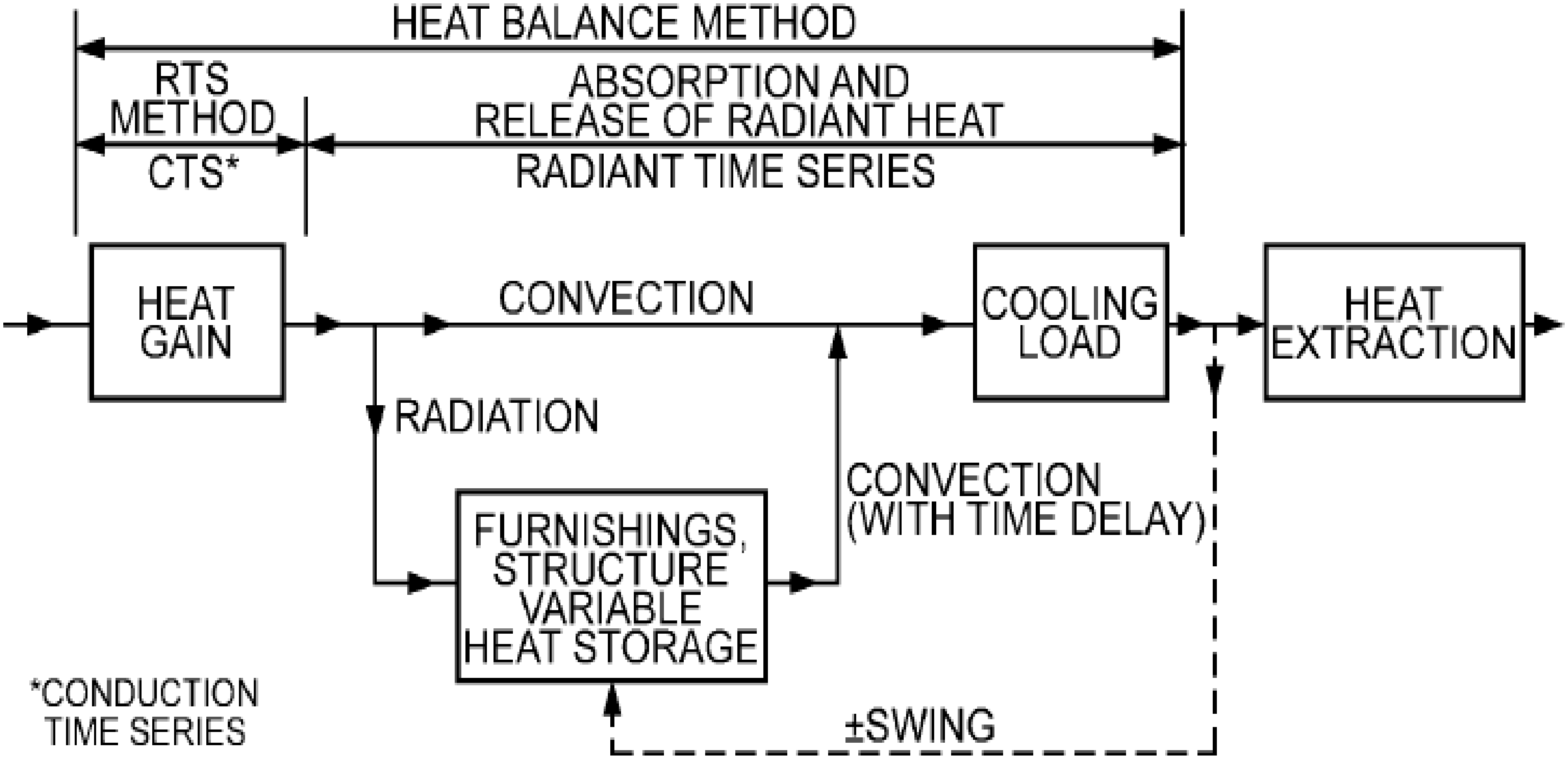
(Source: ASHRAE Handbook Fundamentals 2005)

Heat balance process in a zone



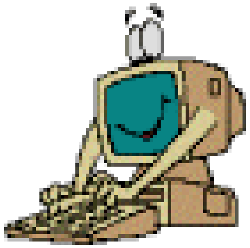
(Source: ASHRAE Handbook Fundamentals 2005)

Basic concepts of heat balance and radiant time series methods



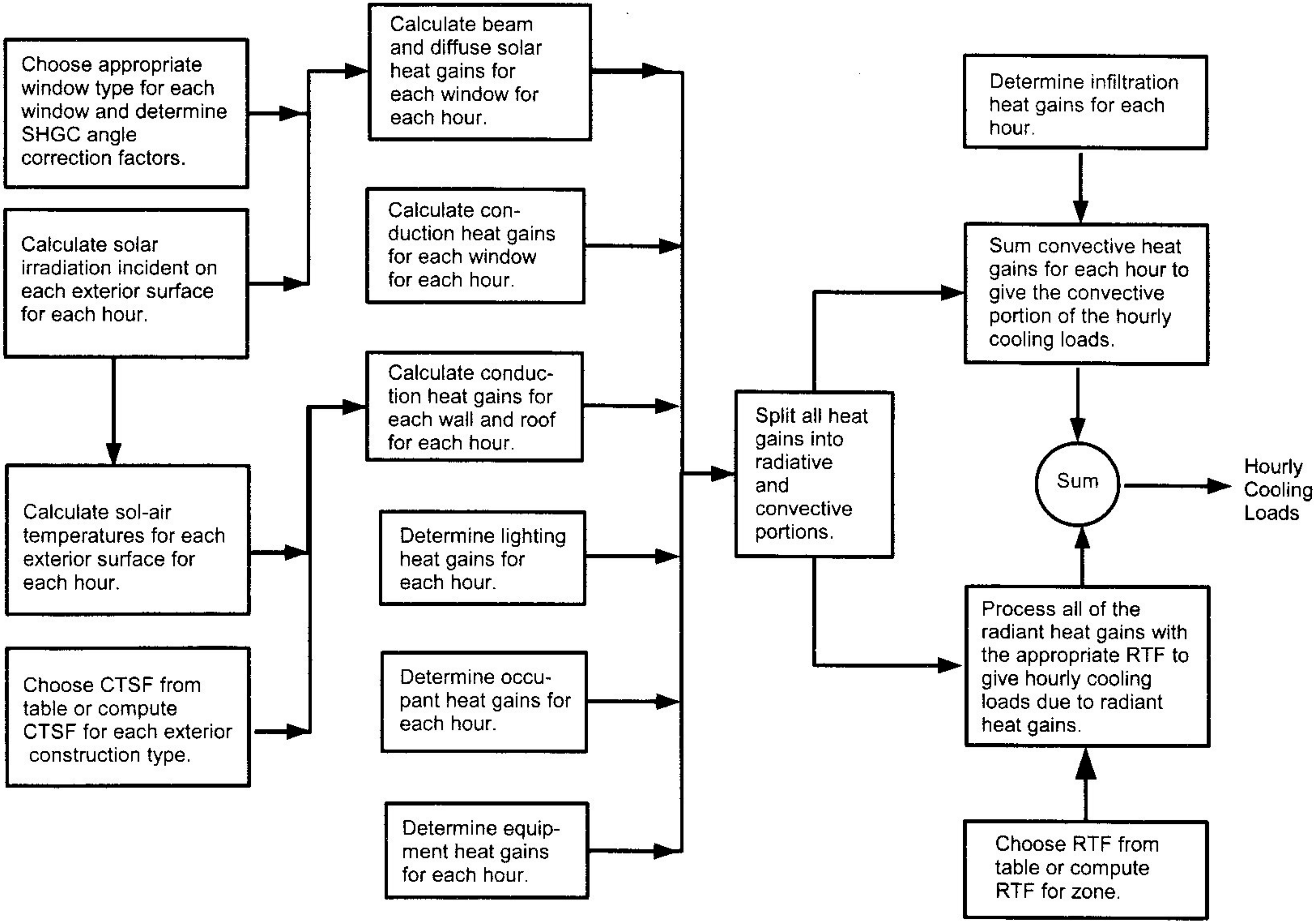
(Source: ASHRAE Handbook Fundamentals 2005)

Calculation Methodology



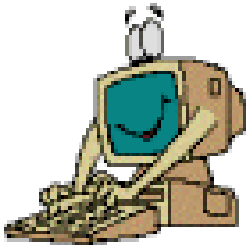
- Radiant time series (RTS) method
  - A simplified method directly related to and derived from the HB calculation procedure
  - Does not require iterative calculations
  - Can quantify each component contribution to the total cooling load
  - Assumes the design-day cooling load for a single day with previous days having the same condition
  - → Suitable for peak design load calculations, but <u>not for annual energy simulations</u>

RTS Method for a Single Zone



(Source: Load Calculation Applications Manual, ASHRAE, 2009)

RTS Method



- Conductive Heat Gain through external walls and roof (using <u>Conduction Time Series Factor</u>)

$$q_\theta = \sum_{j=0}^{23} c_j UA(t_{e,\theta-j\delta} - t_{rc})$$

$$q_\theta = c_0 UA(t_{e,\theta} - t_{rc}) + c_1 UA(t_{e,\theta-\delta} - t_{rc}) + c_2 UA(t_{e,\theta-2\delta} - t_{rc}) + \ldots + c_{23} UA(t_{e,\theta-23\delta} - t_{rc})$$

where

q_θ = hourly conductive heat gain, Btu/h (W), for the surface

U = overall heat transfer coefficient for the surface, Btu/h·ft^2·°F(W/m^2·K)

A = surface area, ft^2 (m^2)

c_j = j^{th} conduction time series factor

$t_{e,\theta-j\delta}$ = sol-air temperature, °F (°C), j hours ago

t_{rc} = presumed constant room air temperature, °F (°C)

θ = the current hour

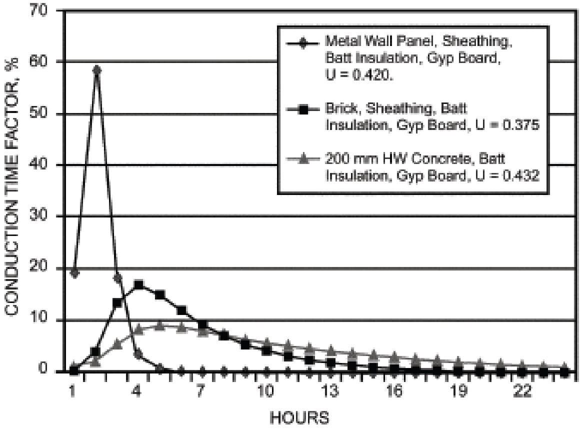
δ = the time step (one hour)

Table 16 Wall Conduction Time Series (CTS)

	CURTAIN WALLS			STUD WALLS				EIFS			BRICK WALLS									
Wall Number =	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
U-Factor, W/(m²·K)	0.428	0.429	0.428	0.419	0.417	0.406	0.413	0.668	0.305	0.524	0.571	0.377	0.283	0.581	0.348	0.628	0.702	0.514	0.581	0.389
Total *R*	2.3	2.3	2.3	2.4	2.4	2.5	2.4	1.5	3.3	1.9	1.7	2.7	3.5	1.7	2.9	1.6	1.4	1.9	1.7	2.6
Mass, kg/m²	31.0	20.9	80.0	25.5	84.6	25.6	66.7	36.6	38.3	130.9	214.1	214.7	215.8	290.6	304.0	371.7	391.5	469.3	892.2	665.1
Thermal Capacity, kJ/(m²·K)	30.7	20.4	67.5	24.5	73.6	32.7	61.3	36.7	38.8	120.6	177.8	177.8	177.8	239.1	253.5	320.9	312.7	388.4	784.9	580.5
Hour	**Conduction Time Factors, %**																			
0	18	25	8	19	6	7	5	11	2	1	0	0	0	1	2	2	1	3	4	3
1	58	57	45	59	42	44	41	50	25	2	5	4	1	1	2	2	1	3	4	3
2	20	15	32	18	33	32	34	26	31	6	14	13	7	2	2	2	3	3	4	3
3	4	3	11	3	13	12	13	9	20	9	17	17	12	5	3	4	6	3	4	4
4	0	0	3	1	4	4	4	3	11	9	15	15	13	8	5	5	7	3	4	4
5	0	0	1	0	1	1	2	1	5	9	12	12	13	9	6	6	8	4	4	4
6	0	0	0	0	1	0	1	0	3	8	9	9	11	9	7	6	8	4	4	5
7	0	0	0	0	0	0	0	0	2	7	7	7	9	9	7	7	8	5	4	5
8	0	0	0	0	0	0	0	0	1	6	5	5	7	8	7	7	8	5	4	5
9	0	0	0	0	0	0	0	0	0	6	4	4	6	7	7	6	7	5	4	5
10	0	0	0	0	0	0	0	0	0	5	3	3	5	7	6	6	6	5	4	5
11	0	0	0	0	0	0	0	0	0	5	2	2	4	6	6	6	6	5	5	5
12	0	0	0	0	0	0	0	0	0	4	2	2	3	5	5	5	5	5	5	5
13	0	0	0	0	0	0	0	0	0	4	1	2	2	4	5	5	4	5	5	5
14	0	0	0	0	0	0	0	0	0	3	1	2	2	4	5	5	4	5	5	5
15	0	0	0	0	0	0	0	0	0	3	1	1	1	3	4	4	3	5	4	4
16	0	0	0	0	0	0	0	0	0	3	1	1	1	3	4	4	3	5	4	4
17	0	0	0	0	0	0	0	0	0	2	1	1	1	2	3	4	3	4	4	4
18	0	0	0	0	0	0	0	0	0	2	0	0	1	2	3	3	2	4	4	4
19	0	0	0	0	0	0	0	0	0	2	0	0	1	2	3	3	2	4	4	4
20	0	0	0	0	0	0	0	0	0	2	0	0	0	1	3	3	2	4	4	4
21	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	2	1	4	4	4
22	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	2	1	4	4	3
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	4	3
Total Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Layer ID from outside to inside (see Table 19)	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01
	F09	F08	F10	F08	F10	F11	F07	F06	F06	F06	M01	M01	M01	M01	M01	M01	M01	M01	M01	M01
	F04	F04	F04	G03	G03	G02	G03	I01	I01	I01	F04	F04	F04	F04	F04	F04	F04	F04	F04	F04
	I02	I02	I02	I04	I04	I04	I04	G03	G03	G03	I01	G03	I01	I01	M03	I01	I01	I01	I01	M15
	F04	F04	F04	G01	G01	G04	G01	F04	I04	M03	G03	I04	G03	M03	I04	M05	M01	M13	M16	I04
	G01	G01	G01	F02	F02	F02	F02	G01	G01	F04	F04	G01	I04	F02	G01	G01	F02	F04	F04	G01
	F02	F02	F02	0	0	0	0	F02	F02	G01	G01	F02	G01	0	F02	F02	0	G01	G01	F02
	0	0	0	0	0	0	0	0	0	F02	F02	0	F02	0	0	0	0	F02	F02	0

Wall Number Descriptions

1. Spandrel glass, insulation board, gyp board
2. Metal wall panel, insulation board, gyp board
3. 25 mm stone, insulation board, gyp board
4. Metal wall panel, sheathing, batt insulation, gyp board
5. 25 mm stone, sheathing, batt insulation, gyp board
6. Wood siding, sheathing, batt insulation, 13 mm wood
7. 25 mm stucco, sheathing, batt insulation, gyp board
8. EIFS finish, insulation board, sheathing, gyp board
9. EIFS finish, insulation board, sheathing, batt insulation, gyp board
10. EIFS finish, insulation board, sheathing, 200 mm LW CMU, gyp board
11. Brick, insulation board, sheathing, gyp board
12. Brick, sheathing, batt insulation, gyp board
13. Brick, insulation board, sheathing, batt insulation, gyp board
14. Brick, insulation board, 200 mm LW CMU
15. Brick, 200 mm LW CMU, batt insulation, gyp board
16. Brick, insulation board, 200 mm HW CMU, gyp board
17. Brick, insulation board, brick
18. Brick, insulation board, 200 mm LW concrete, gyp board
19. Brick, insulation board, 300 mm HW concrete, gyp board
20. Brick, 200 mm HW concrete, batt insulation, gyp board



(Ref: Load Calculations Applications Manual, ASHRAE, 2008)

- Fenestration Heat Gain

$$q_\theta = UA(t_{o,\theta} - t_{rc}),$$

where

q_θ = hourly conductive heat gain, Btu/h (W), for the window;
U = overall heat transfer coefficient for the window, Btu/h·ft²·°F (W/m²·K) as specified by the window manufacturer;
A = window area—including frame, ft² (m²);
$t_{o,}\theta$ = outdoor air temperature, °F (°C);
t_{rc} = presumed constant room air temperature, °F (°C); and
θ = the current hour.

$$q_{SHG,D} = E_D A_{sunlit} \mathrm{SHGC}(\theta) \tag{7.4a}$$

$$q_{SHG,d} = (E_d + E_r)A \cdot \mathrm{SHGC}_{diffuse} \tag{7.4b}$$

$$q_{SHG} = q_{SHG,D} + q_{SHG,d} \tag{7.4c}$$

where

$q_{SHG,D}$ = direct (beam) solar heat gain, Btu/h·ft² (W/m²)
$q_{SHG,d}$ = diffuse solar heat gain, Btu/h·ft² (W/m²)
q_{SHG} = total solar heat gain, Btu/h·ft² (W/m²)
E_D = incident direct (beam) irradiation, Btu/h·ft² (W/m²)
E_d = incident diffuse irradiation from sky, Btu/h·ft² (W/m²)
E_r = incident diffuse reflected irradiation, Btu/h·ft² (W/m²)
SHGC (θ) = angle-dependent SHGC determined from manufacturer's normal *SHGC* corrected by correction factors in Table 7.9 or 3.8
$\mathrm{SHGC}_{diffuse}$ = the SHGC for diffuse irradiation, determined by multiplying the manufacturer's normal SHGC by the diffuse correction factor in Table 7.9 or 3.8
A_{sunlit} = the unshaded area of the window, ft² (m²)
A = the total area of the window, including the frame, ft² (m²)

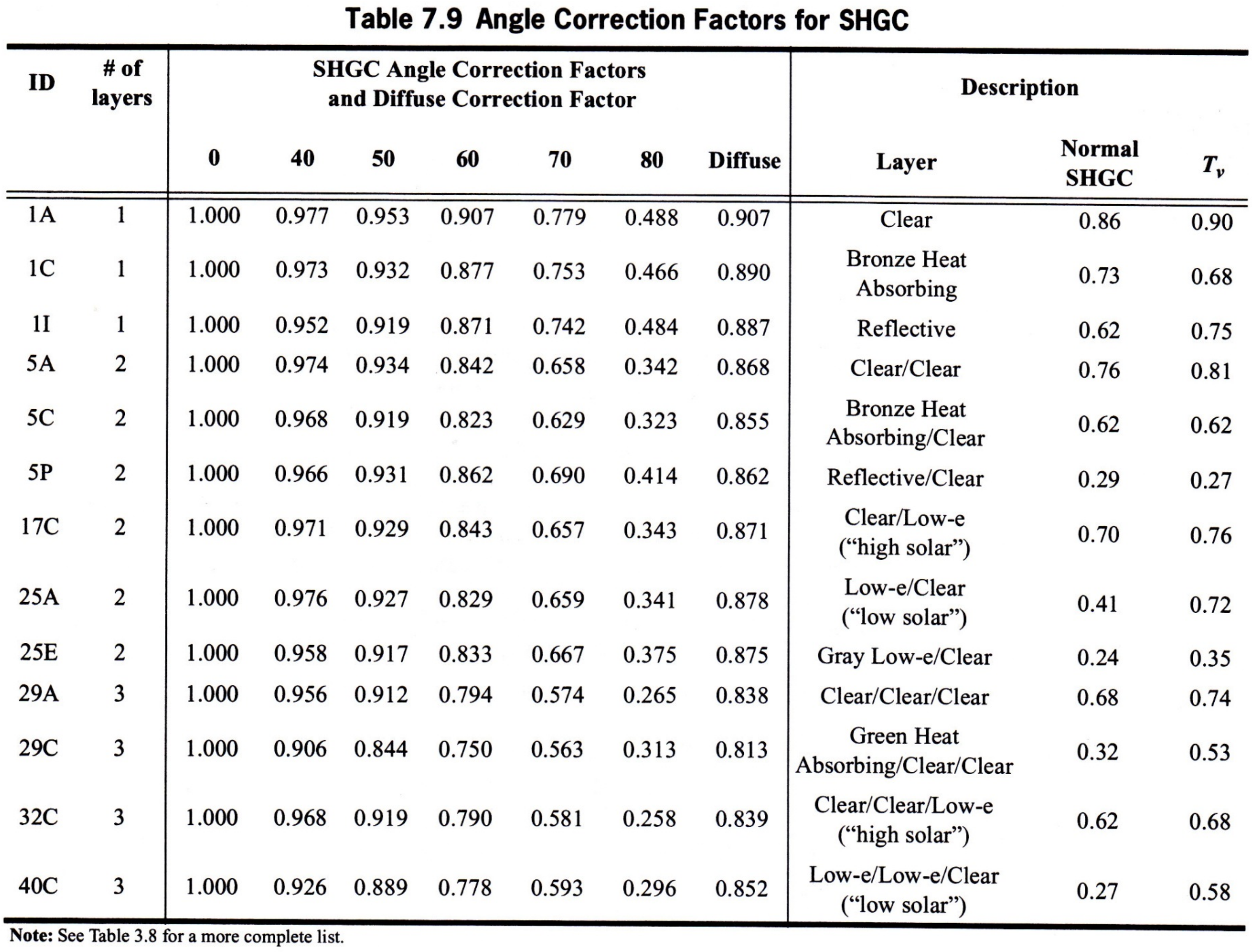


Table 7.9 Angle Correction Factors for SHGC

ID	# of layers	SHGC Angle Correction Factors and Diffuse Correction Factor							Description		
		0	40	50	60	70	80	Diffuse	Layer	Normal SHGC	T_v
1A	1	1.000	0.977	0.953	0.907	0.779	0.488	0.907	Clear	0.86	0.90
1C	1	1.000	0.973	0.932	0.877	0.753	0.466	0.890	Bronze Heat Absorbing	0.73	0.68
1I	1	1.000	0.952	0.919	0.871	0.742	0.484	0.887	Reflective	0.62	0.75
5A	2	1.000	0.974	0.934	0.842	0.658	0.342	0.868	Clear/Clear	0.76	0.81
5C	2	1.000	0.968	0.919	0.823	0.629	0.323	0.855	Bronze Heat Absorbing/Clear	0.62	0.62
5P	2	1.000	0.966	0.931	0.862	0.690	0.414	0.862	Reflective/Clear	0.29	0.27
17C	2	1.000	0.971	0.929	0.843	0.657	0.343	0.871	Clear/Low-e ("high solar")	0.70	0.76
25A	2	1.000	0.976	0.927	0.829	0.659	0.341	0.878	Low-e/Clear ("low solar")	0.41	0.72
25E	2	1.000	0.958	0.917	0.833	0.667	0.375	0.875	Gray Low-e/Clear	0.24	0.35
29A	3	1.000	0.956	0.912	0.794	0.574	0.265	0.838	Clear/Clear/Clear	0.68	0.74
29C	3	1.000	0.906	0.844	0.750	0.563	0.313	0.813	Green Heat Absorbing/Clear/Clear	0.32	0.53
32C	3	1.000	0.968	0.919	0.790	0.581	0.258	0.839	Clear/Clear/Low-e ("high solar")	0.62	0.68
40C	3	1.000	0.926	0.889	0.778	0.593	0.296	0.852	Low-e/Low-e/Clear ("low solar")	0.27	0.58

Note: See Table 3.8 for a more complete list.

- Splitting Heat Gains into Radiative and Convective Components

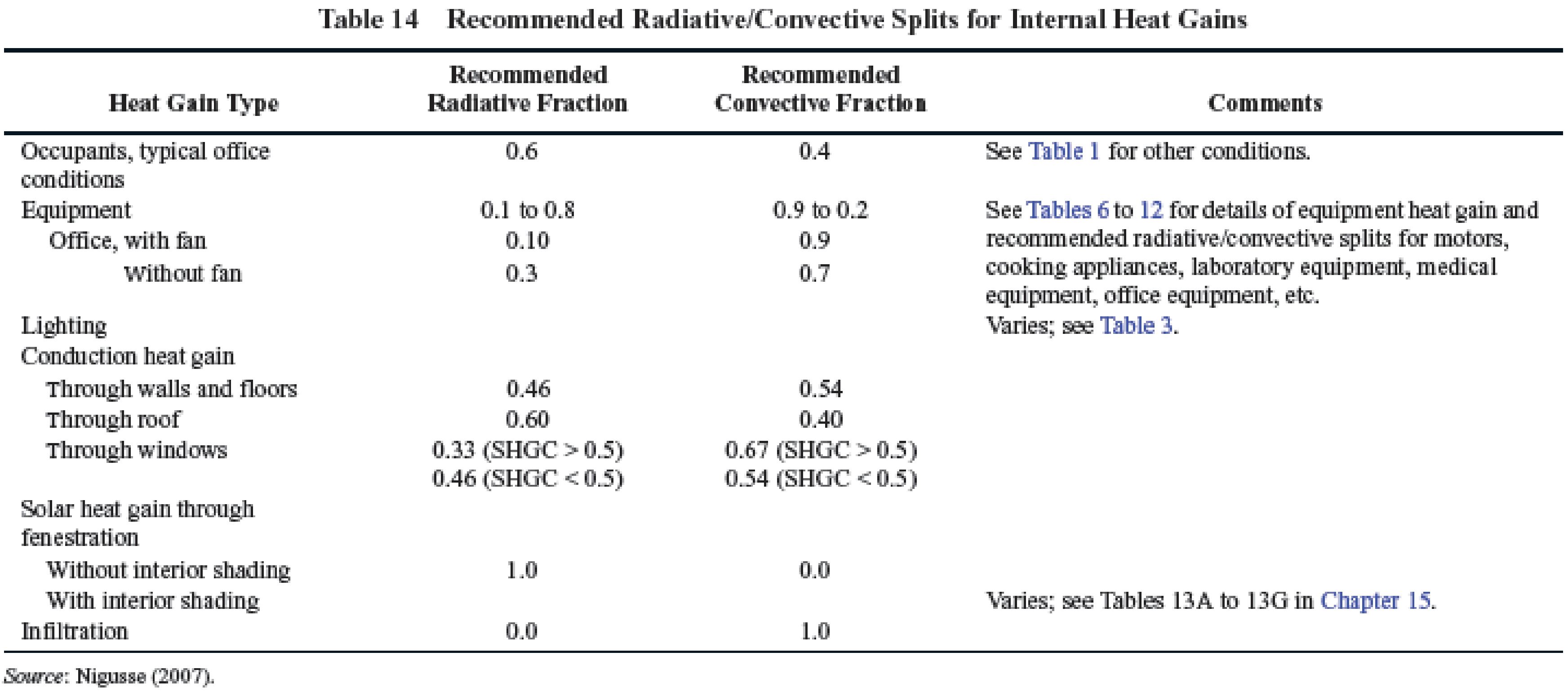


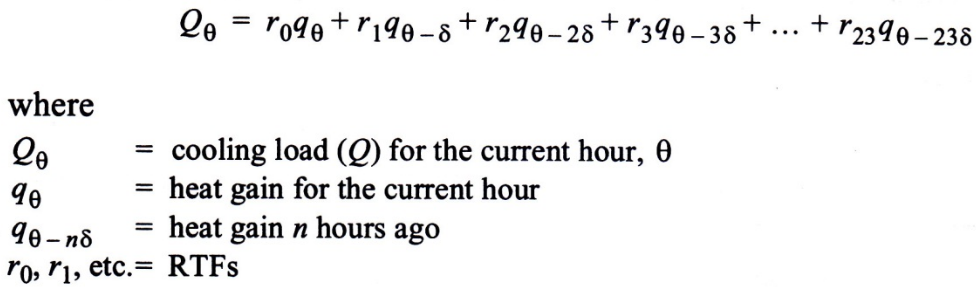
Table 14 Recommended Radiative/Convective Splits for Internal Heat Gains

Heat Gain Type	Recommended Radiative Fraction	Recommended Convective Fraction	Comments
Occupants, typical office conditions	0.6	0.4	See Table 1 for other conditions.
Equipment	0.1 to 0.8	0.9 to 0.2	See Tables 6 to 12 for details of equipment heat gain and recommended radiative/convective splits for motors, cooking appliances, laboratory equipment, medical equipment, office equipment, etc.
Office, with fan	0.10	0.9	
Without fan	0.3	0.7	
Lighting			Varies; see Table 3.
Conduction heat gain			
Through walls and floors	0.46	0.54	
Through roof	0.60	0.40	
Through windows	0.33 (SHGC > 0.5) 0.46 (SHGC < 0.5)	0.67 (SHGC > 0.5) 0.54 (SHGC < 0.5)	
Solar heat gain through fenestration			
Without interior shading	1.0	0.0	
With interior shading			Varies; see Tables 13A to 13G in Chapter 15.
Infiltration	0.0	1.0	

Source: Nigusse (2007).

(Ref: Ch.18 – ASHRAE Fundamentals 2009)

- # Conversion of Radiant Heat Gains into Cooling Loads



$$Q_\theta = r_0 q_\theta + r_1 q_{\theta-\delta} + r_2 q_{\theta-2\delta} + r_3 q_{\theta-3\delta} + \ldots + r_{23} q_{\theta-23\delta}$$

where

Q_θ = cooling load (Q) for the current hour, θ

q_θ = heat gain for the current hour

$q_{\theta-n\delta}$ = heat gain n hours ago

r_0, r_1, etc.= RTFs

Solar RTS = transmitted solar radiation
Non-solar RTS = radiation from internal gains and building envelope

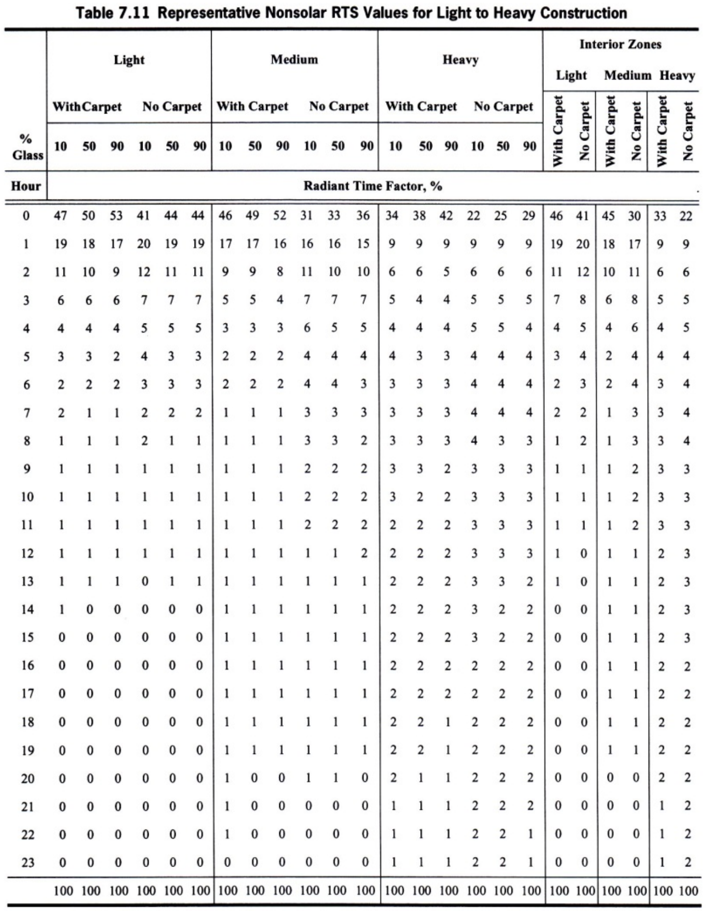


Table 7.11 Representative Nonsolar RTS Values for Light to Heavy Construction

	Light						Medium						Heavy						Interior Zones					
																			Light		Medium		Heavy	
	With Carpet			No Carpet			With Carpet			No Carpet			With Carpet			No Carpet			With Carpet	No Carpet	With Carpet	No Carpet	With Carpet	No Carpet
% Glass	10	50	90	10	50	90	10	50	90	10	50	90	10	50	90	10	50	90						
Hour	Radiant Time Factor, %																							
0	47	50	53	41	44	44	46	49	52	31	33	36	34	38	42	22	25	29	46	41	45	30	33	22
1	19	18	17	20	19	19	17	17	16	16	16	15	9	9	9	9	9	9	19	20	18	17	9	9
2	11	10	9	12	11	11	9	9	8	11	10	10	6	6	5	6	6	6	11	12	10	11	6	6
3	6	6	6	7	7	7	5	5	4	7	7	7	5	4	4	5	5	5	7	8	6	8	5	5
4	4	4	4	5	5	5	3	3	3	6	5	5	4	4	4	5	5	4	4	5	4	6	4	5
5	3	3	2	4	3	3	2	2	2	4	4	4	4	3	3	4	4	4	3	4	2	4	4	4
6	2	2	2	3	3	3	2	2	2	4	4	3	3	3	3	4	4	4	2	3	2	4	3	4
7	2	1	1	2	2	2	1	1	1	3	3	3	3	3	3	4	4	4	2	2	1	3	3	4
8	1	1	1	2	1	1	1	1	1	3	3	2	3	3	3	4	3	3	1	2	1	3	3	4
9	1	1	1	1	1	1	1	1	1	2	2	2	3	3	2	3	3	3	1	1	1	2	3	3
10	1	1	1	1	1	1	1	1	1	2	2	2	3	2	2	3	3	3	1	1	1	2	3	3
11	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	1	1	1	2	3	3
12	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	1	0	1	1	2	3
13	1	1	1	0	1	1	1	1	1	1	1	1	2	2	2	3	3	2	1	0	1	1	2	3
14	1	0	0	0	0	0	1	1	1	1	1	1	2	2	2	3	2	2	0	0	1	1	2	3
15	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	3	2	2	0	0	1	1	2	3
16	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	2
17	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	2
18	0	0	0	0	0	0	1	1	1	1	1	1	2	2	1	2	2	2	0	0	1	1	2	2
19	0	0	0	0	0	0	1	1	1	1	1	1	2	2	1	2	2	2	0	0	1	1	2	2
20	0	0	0	0	0	0	1	0	0	1	1	0	2	1	1	2	2	2	0	0	0	0	2	2
21	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	2	2	2	0	0	0	0	1	2
22	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	2	2	1	0	0	0	0	1	2
23	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	1	0	0	0	0	1	2
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

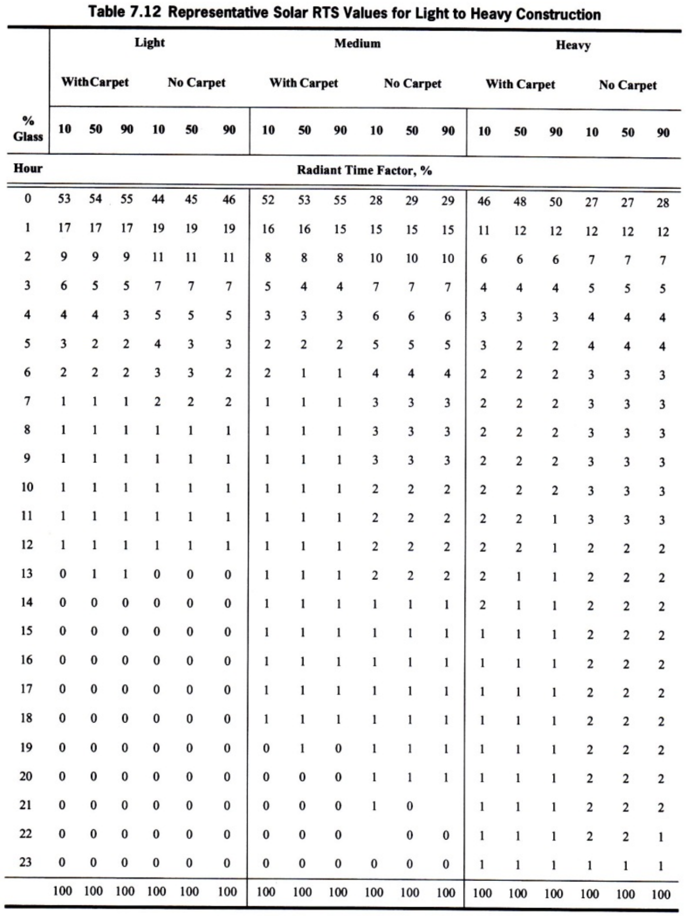


Table 7.12 Representative Solar RTS Values for Light to Heavy Construction

	Light						Medium						Heavy					
	With Carpet			No Carpet			With Carpet			No Carpet			With Carpet			No Carpet		
% Glass	10	50	90	10	50	90	10	50	90	10	50	90	10	50	90	10	50	90
Hour	Radiant Time Factor, %																	
0	53	54	55	44	45	46	52	53	55	28	29	29	46	48	50	27	27	28
1	17	17	17	19	19	19	16	16	15	15	15	15	11	12	12	12	12	12
2	9	9	9	11	11	11	8	8	8	10	10	10	6	6	6	7	7	7
3	6	5	5	7	7	7	5	4	4	7	7	7	4	4	4	5	5	5
4	4	4	3	5	5	5	3	3	3	6	6	6	3	3	3	4	4	4
5	3	2	2	4	3	3	2	2	2	5	5	5	3	2	2	4	4	4
6	2	2	2	3	3	2	2	1	1	4	4	4	2	2	2	3	3	3
7	1	1	1	2	2	2	1	1	1	3	3	3	2	2	2	3	3	3
8	1	1	1	1	1	1	1	1	1	3	3	3	2	2	2	3	3	3
9	1	1	1	1	1	1	1	1	1	3	3	3	2	2	2	3	3	3
10	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3
11	1	1	1	1	1	1	1	1	1	2	2	2	2	2	1	3	3	3
12	1	1	1	1	1	1	1	1	1	2	2	2	2	2	1	2	2	2
13	0	1	1	0	0	0	1	1	1	2	2	2	2	1	1	2	2	2
14	0	0	0	0	0	0	1	1	1	1	1	1	2	1	1	2	2	2
15	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2
16	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2
17	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2
18	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2
19	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	2	2	2
20	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
21	0	0	0	0	0	0	0	0	0	1	0		1	1	1	2	2	2
22	0	0	0	0	0	0	0	0	0		0	0	1	1	1	2	2	1
23	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

(Ref: Load Calculations Applications Manual, ASHRAE, 2008)

Energy Calculation Methods

- Two categories
  - Steady-state methods
    - Degree-day method
    - Variable base degree-day method
    - Bin and modified bin methods
  - Dynamic methods
    - Using computer-based building energy simulation
    - Try to capture dynamic response of the building
    - Can be developed based on transfer function, heat balance or other methods

Energy Calculation Methods

- Degree-day method
  - A degree-day is the sum of the number of degrees that the average daily temperature (technically the average of the daily maximum and minimum) is above (for cooling) or below (for heating) a base temperature times the duration in days
    - Heating degree-days (HDD)
    - Cooling degree-days (CDD)
  - Summed over a period or a year for indicating climate severity (effect of outdoor air on a building)

Heating degree-day:

$$DD_h(t_{bal}) = (1\text{ day}) \sum_{\text{days}} (t_{bal} - t_o)^+$$

$^+$ Only take the positive values

Cooling degree-day:

$$DD_c(t_{bal}) = (1\text{ day}) \sum_{\text{days}} (t_o - t_{bal})^+$$

t_{bal} = base temperature (or balance point temperature)
(e.g. 18.3 ^{o}C or 65 ^{o}F); $Q_{load} = Q_{gain} + Q_{loss} = 0$
t_o = outdoor temperature (e.g. average daily max./min.)

* Degree-hours if summing over 24-hourly intervals
Degree-day = $\Sigma(\text{degree-hours})^+ / 24$

To determine the heating degree-day:

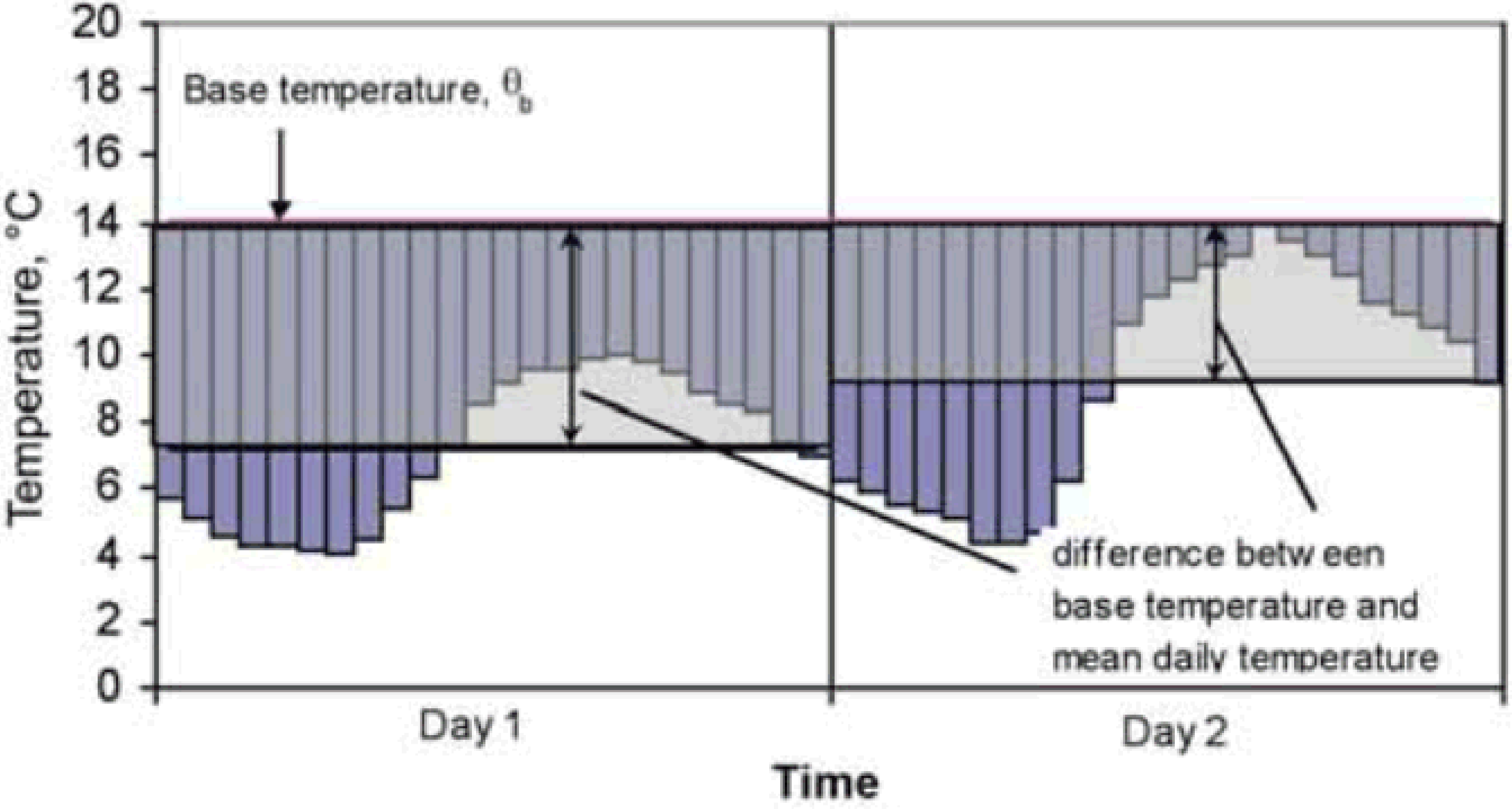


Figure 1.1 The basic definition of degree-days as the difference between the base temperature and the mean daily outdoor temperature

To determine the heating degree-day (cont’d):

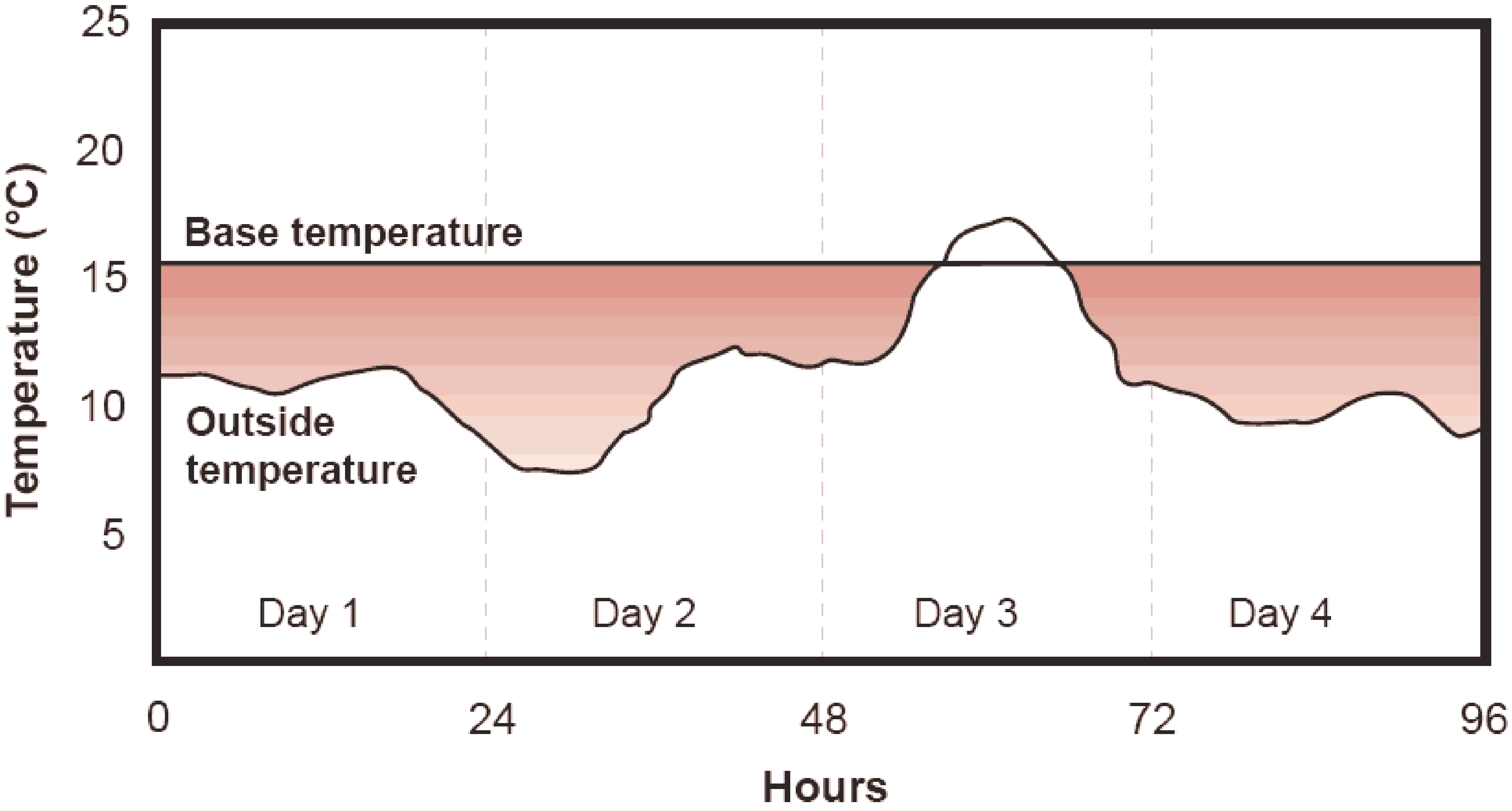
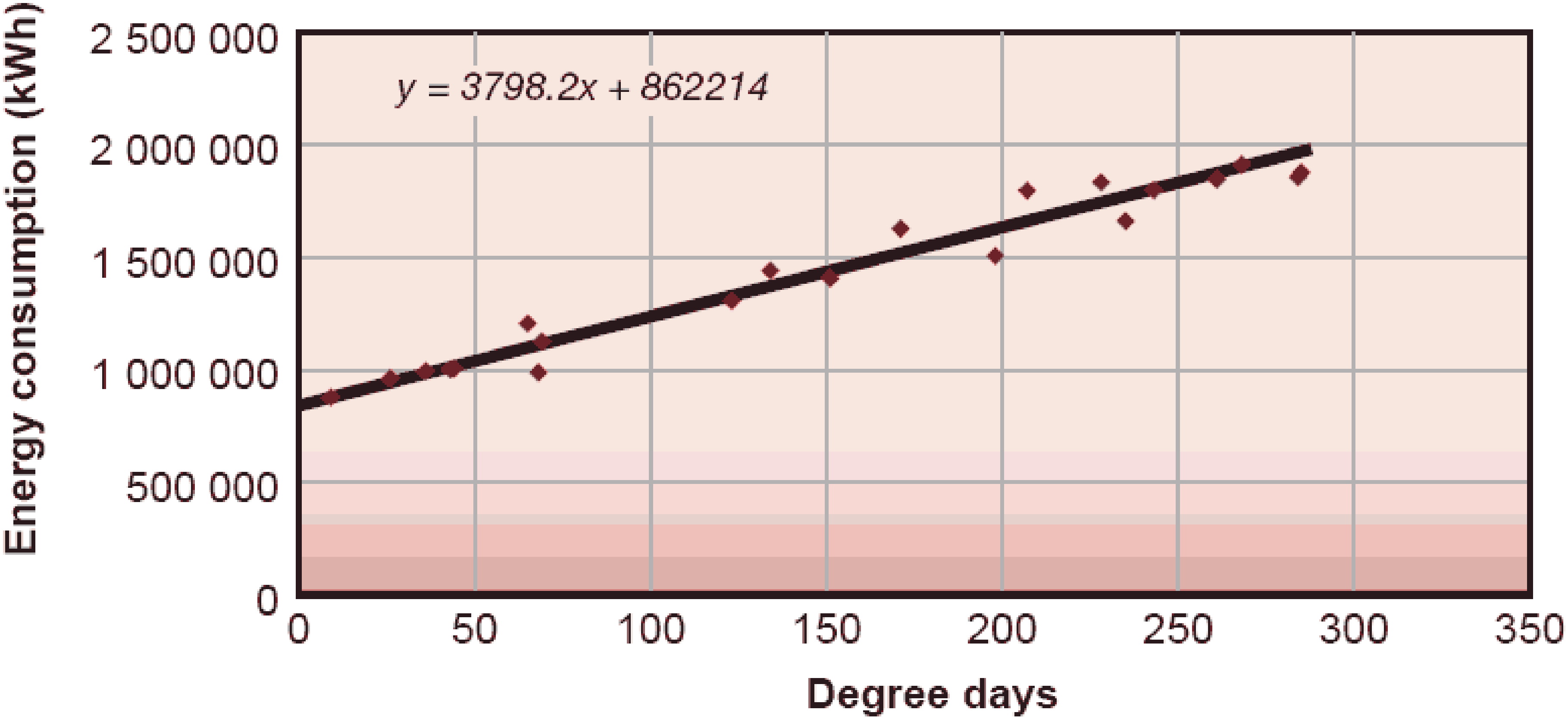


Figure 1 The shaded area is the degree-day value for the period



Correlation between energy consumption and degree days

Energy Calculation Methods

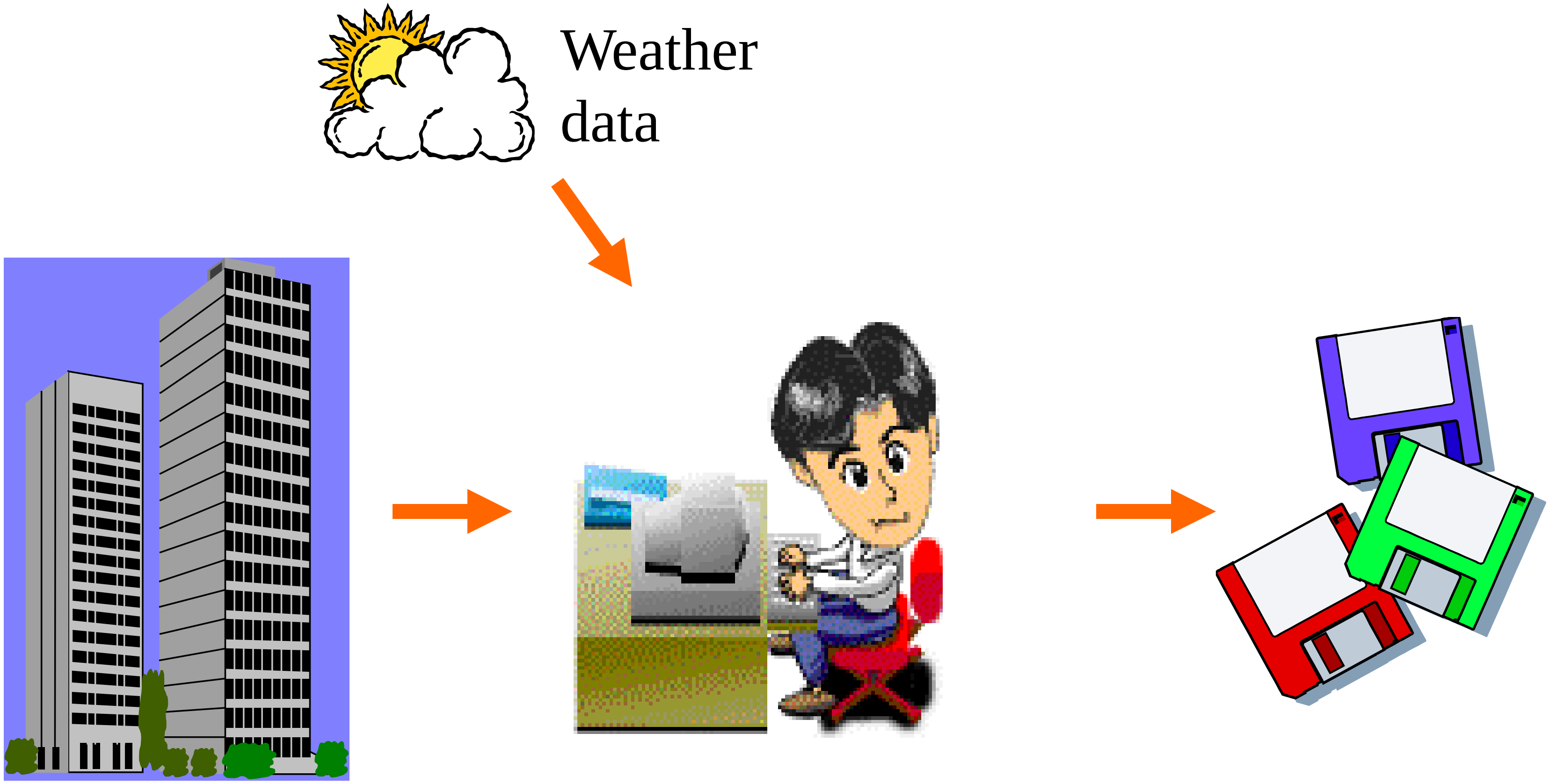
- Variable base degree-day (VBDD) method
  - Degree-day with variable reference temperatures
    - To account for different building conditions and variation between daytime and nighttime
    - First calculate the balance point temperature of a building and then the heating and cooling degree hours at that base temperature
    - Require tedious calculations and detailed processing of hourly weather data at a complexity similar to hourly simulations. Therefore, does not seem warranted nowadays (why not just go for hourly simulation)

Energy Calculation Methods

- Bin and modified bin methods
  - Evolve from VBDD method
  - Derive building annual heating/cooling loads by calculating its loads for a set of temperature “bins”
  - Multiplying the calculated loads by nos. of hours represented by each bin (e.g. 18-20, 20-22, 22-24 ^{o}C)
  - Totaling the sums to obtain the loads (cooling/heating energy)
  - Original bin method: not account of solar/wind effects
  - Modified bin method: account for solar/wind effects

Energy Calculation Methods

- Dynamic simulation methods
  - Usually hour-by-hour, for 8,760 hours (24 x 365)
  - Energy calculation sequence:
    - Space or building load [LOAD]
    - Secondary equipment load (airside system) [SYSTEMS]
    - Primary equipment energy requirement (e.g. chiller) [PLANT]
  - Computer software
    - Building energy simulation programs, e.g. Energy-10, DOE-2, TRACE 700, Carrier HAP



Weather
data

Building description

Simulation tool (computer program)

Simulation outputs

- physical data
- design parameters

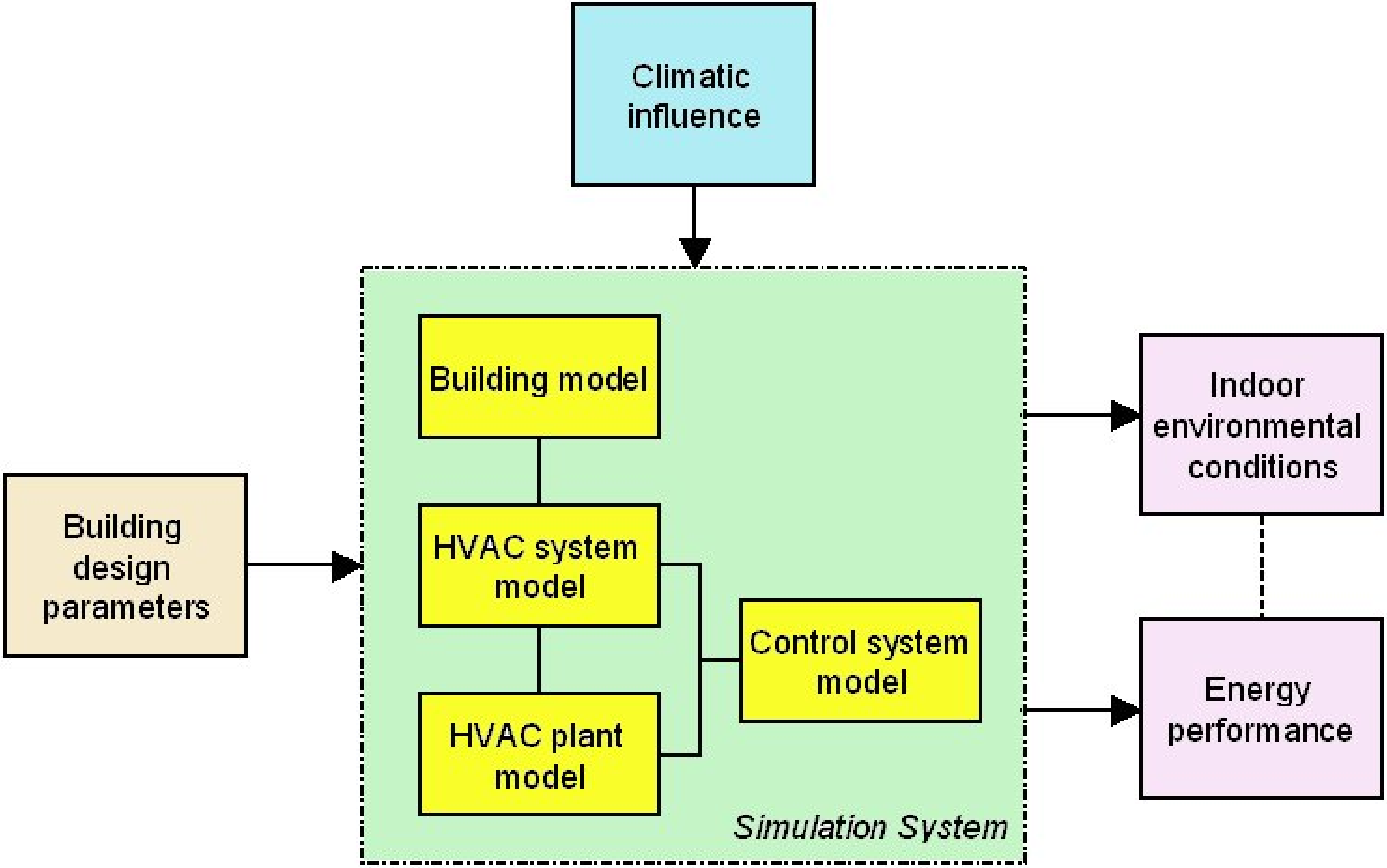
- energy consumption (MWh)
- energy demands (kW)
- environmental conditions

Building Energy Simulation

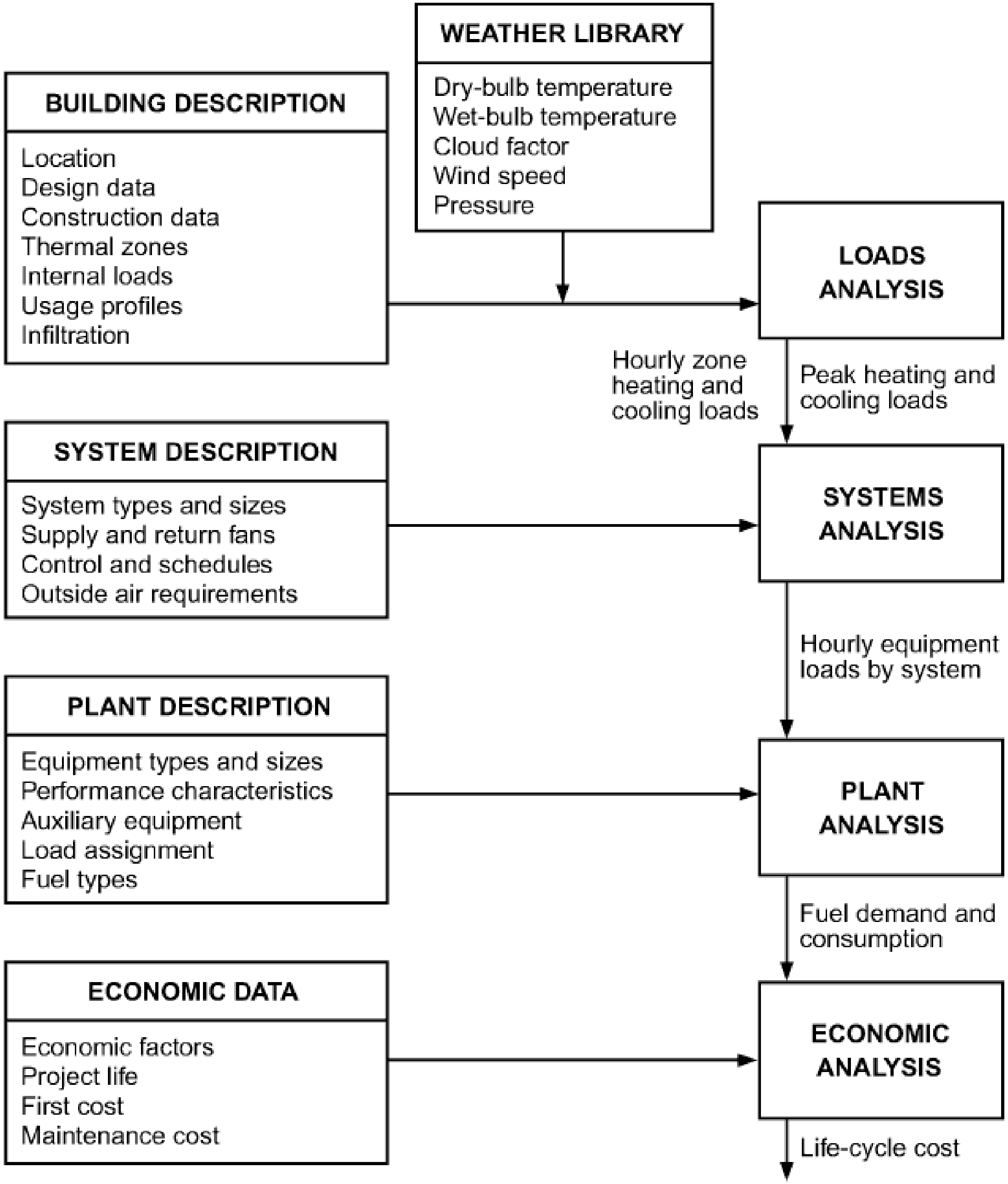
- Building energy simulation
  - Analysis of energy performance of building using computer modelling and simulation techniques
- Many issues can be studied, such as:
  - Thermal performance (e.g. bldg. fabric, glazing)
  - Comfort and indoor environment
  - Ventilation and infiltration
  - Daylighting and overshadowing
  - Energy consumption of building systems

Building Energy Simulation

- Four major elements
  - Building model
  - HVAC system model
  - HVAC plant model
  - Control system model
- An economic model may be added for life cycle costing



Major elements of building energy simulation



WEATHER LIBRARY

Dry-bulb temperature
Wet-bulb temperature
Cloud factor
Wind speed
Pressure

BUILDING DESCRIPTION

Location
Design data
Construction data
Thermal zones
Internal loads
Usage profiles
Infiltration

LOADS ANALYSIS

Hourly zone heating and cooling loads

Peak heating and cooling loads

SYSTEM DESCRIPTION

System types and sizes
Supply and return fans
Control and schedules
Outside air requirements

SYSTEMS ANALYSIS

Hourly equipment loads by system

PLANT DESCRIPTION

Equipment types and sizes
Performance characteristics
Auxiliary equipment
Load assignment
Fuel types

PLANT ANALYSIS

Fuel demand and consumption

ECONOMIC DATA

Economic factors
Project life
First cost
Maintenance cost

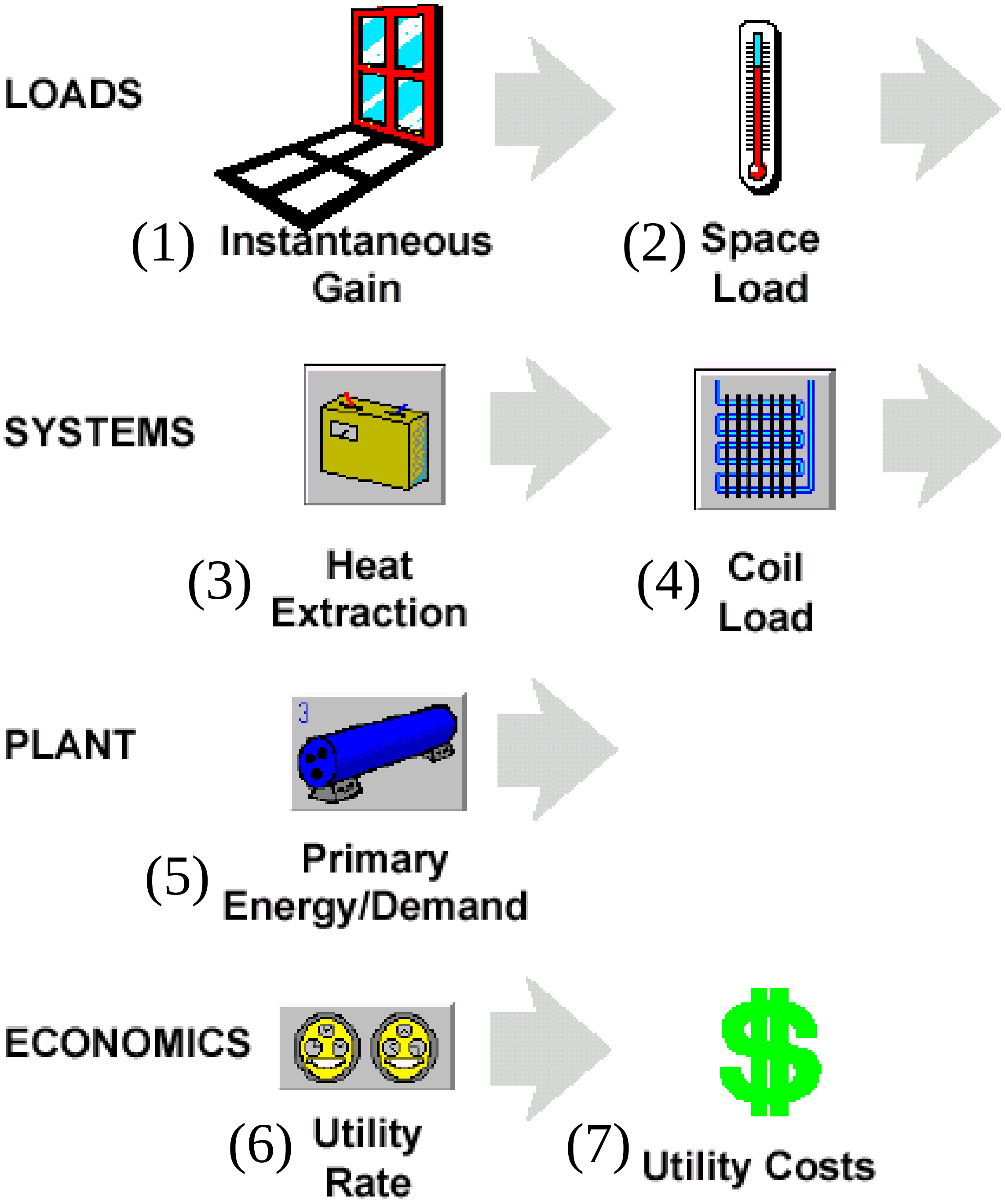
ECONOMIC ANALYSIS

Life-cycle cost

Fig. 1 Flow Chart for Building Energy Simulation Program

(Source: ASHRAE Handbook Fundamentals 2005)

“Seven steps” of simulation output



LOADS

(1) Instantaneous Gain

(2) Space Load

SYSTEMS

(3) Heat Extraction

(4) Coil Load

PLANT

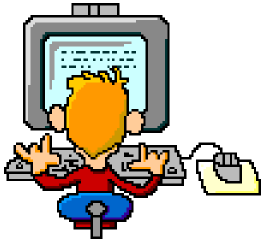
(5) Primary Energy/Demand

ECONOMICS

(6) Utility Rate

(7) Utility Costs

Building Energy Simulation



- Examples of building energy simulation tools
  - Simplified
    - Energy-10, ENER-WIN, Solar-5, Energy Scheming
  - Detailed
    - DOE-2, BLAST, ESP-r, TRNSYS, EnergyPlus
  - Commercial (proprietary)
    - Carrier HAP, TRACE 700

ENERGY - 10

blast

EnergyPlus

DOE-2

Solar-5

ESP-r

ENER-WIN©
Hourly Energy Simulation Program for Buildings

Building Energy Simulation Software

TRNSYS

Carrier

E-20-II & HAP

HOT2000

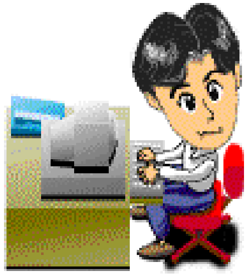
TRANE

TRACE 700

IEA ADELINE

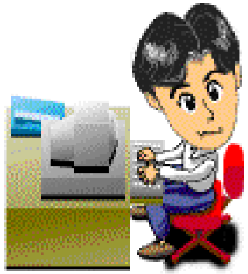
Tas

Building Energy Simulation



- Software examples:
  - Energy-10
    - http://www.nrel.gov/buildings/energy10.html
    - http://www.energy-10.com/
  - DOE-2 (VisualDOE 4.1)
    - http://gundog.lbl.gov/dirsoft/d2whatis.html
    - http://www.archenergy.com/products/visualdoe/

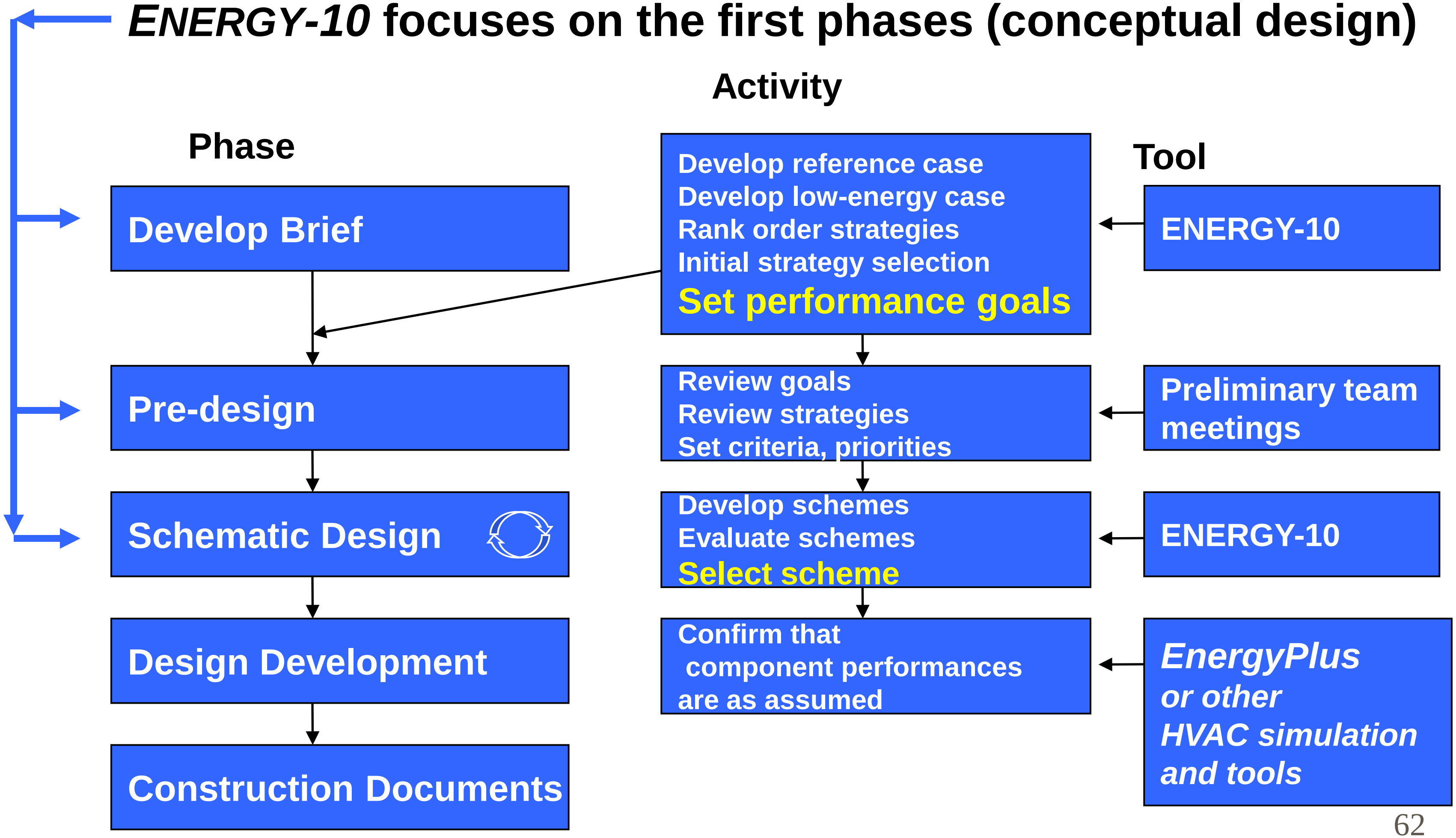
Building Energy Simulation



- Energy software example:
  - Energy-10
    - A software tool that helps architects and engineers quickly identify the most cost-effective, energy-saving measures to take in designing a low-energy building
    - Suitable for small commercial and residential buildings that are characterized by one, or two thermal zones (less than 10,000 ft^2 or 1,000 m^2)
    - http://www.nrel.gov/buildings/energy10.html
    - http://www.energy-10.com/

Example: Energy-10

ENERGY-10 focuses on the first phases (conceptual design)



Phase	Activity	Tool
Develop Brief	Develop reference case Develop low-energy case Rank order strategies Initial strategy selection Set performance goals	ENERGY-10
Pre-design	Review goals Review strategies Set criteria, priorities	Preliminary team meetings
Schematic Design	Develop schemes Evaluate schemes Select scheme	ENERGY-10
Design Development	Confirm that component performances are as assumed	*EnergyPlus or other HVAC simulation and tools*
Construction Documents		

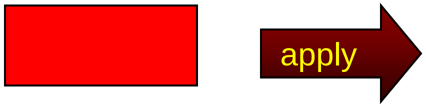
Example: Energy-10

- Creates two building descriptions based on five inputs and user-defined defaults.

- **Location**
- **Building Use**
- **Floor area**
- **Number of stories**
- **HVAC system**

Gets you started quickly.

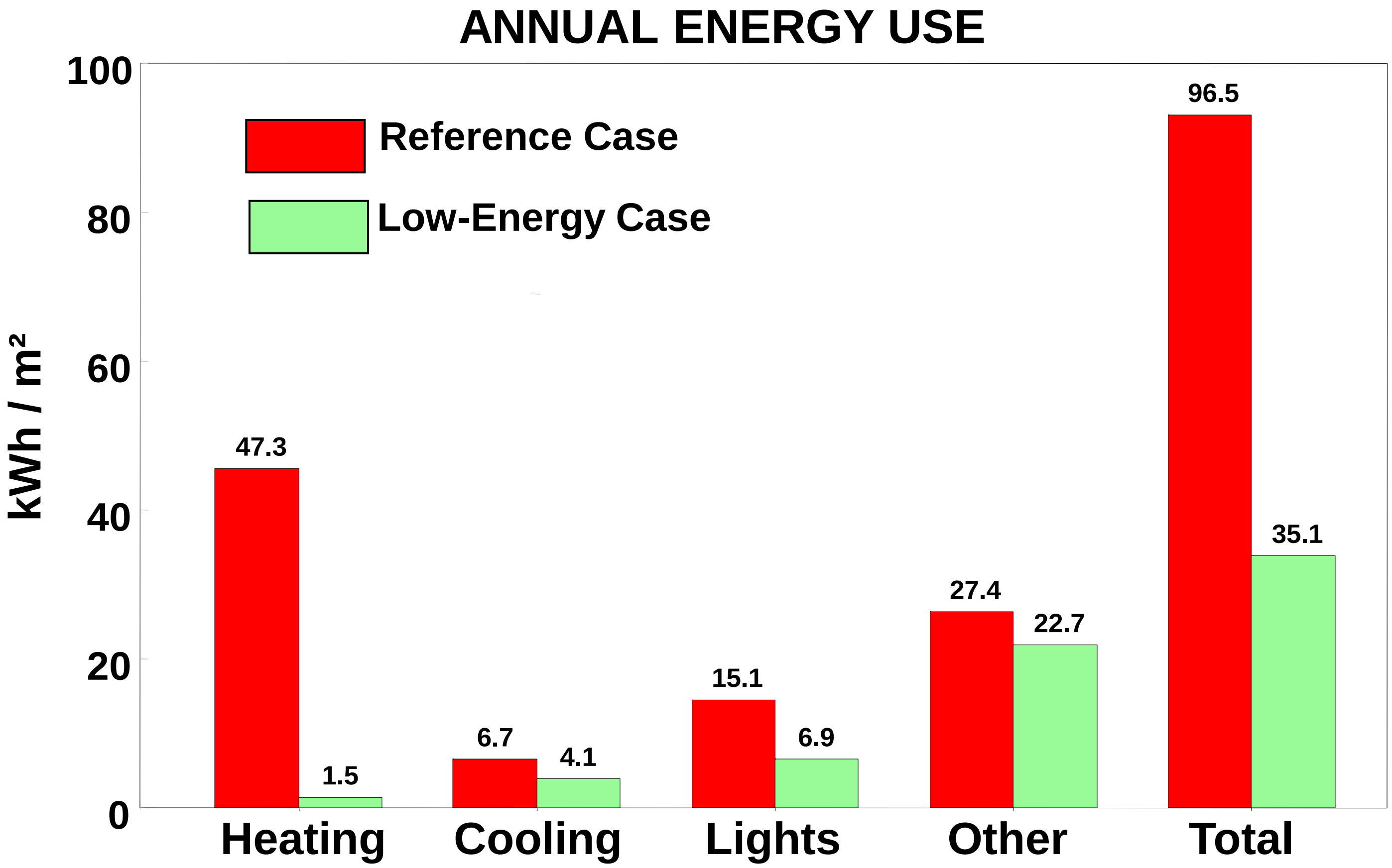
For example:



Reference Case	Low Energy Case
R-8.9 walls (4" steel stud)	R-19.6 Walls (6" steel stud with 2" foam)
R-19 roof	R-38 roof
No perimeter insulation	R-10 perimeter insulation
Conventional double windows	Best low-e double windows
Conventional lighting	Efficient lights with daylight dimming
Conventional HVAC	High efficiency HVAC
Conventional air-tightness	Leakage reduced 75%
Uniform window orientation	Passive solar orientation
Conventional HVAC controls	Improved HVAC controls
Conventional duct placement	Ducts located inside, tightened

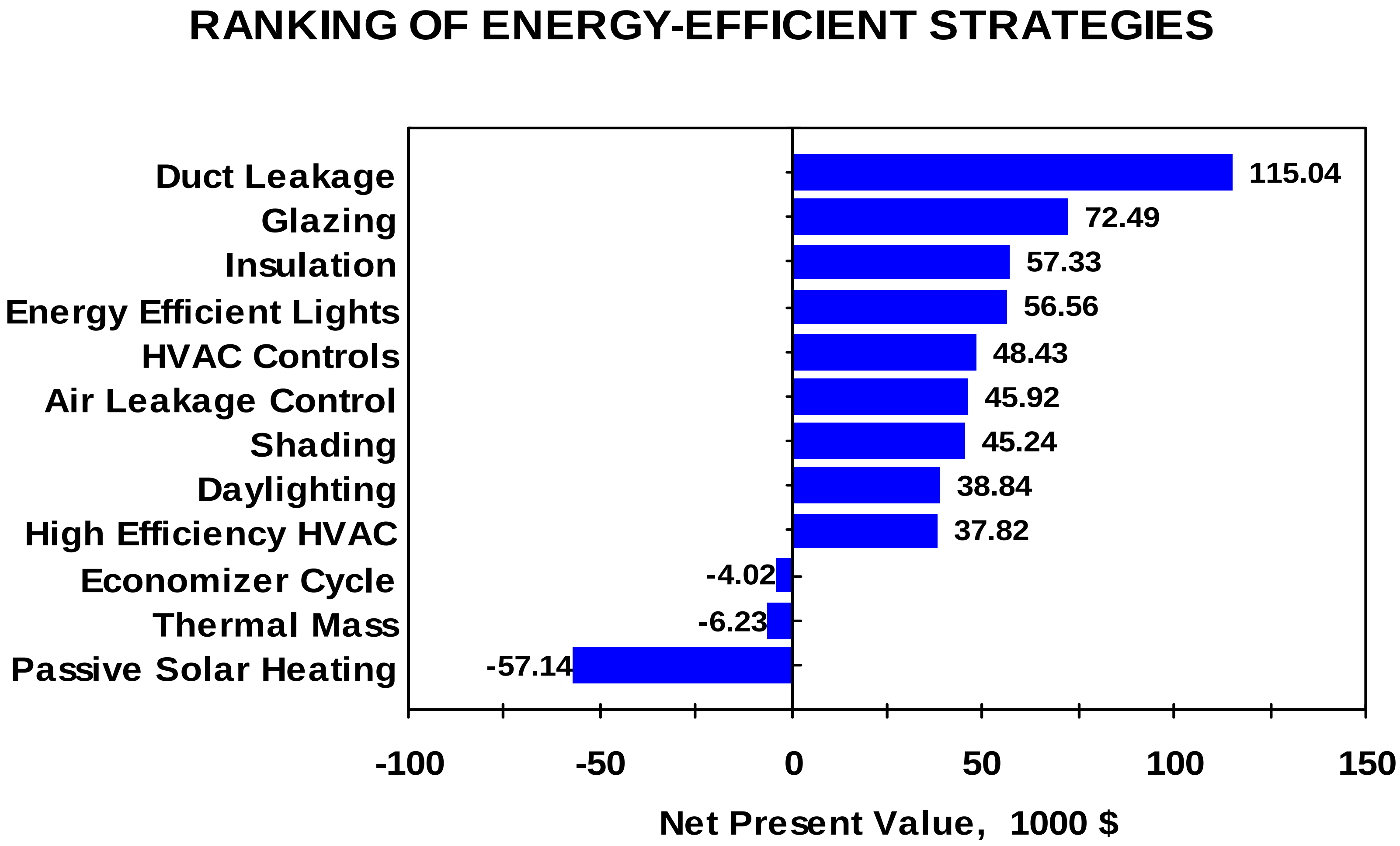
Example: Energy-10

2,000 m^2 office building

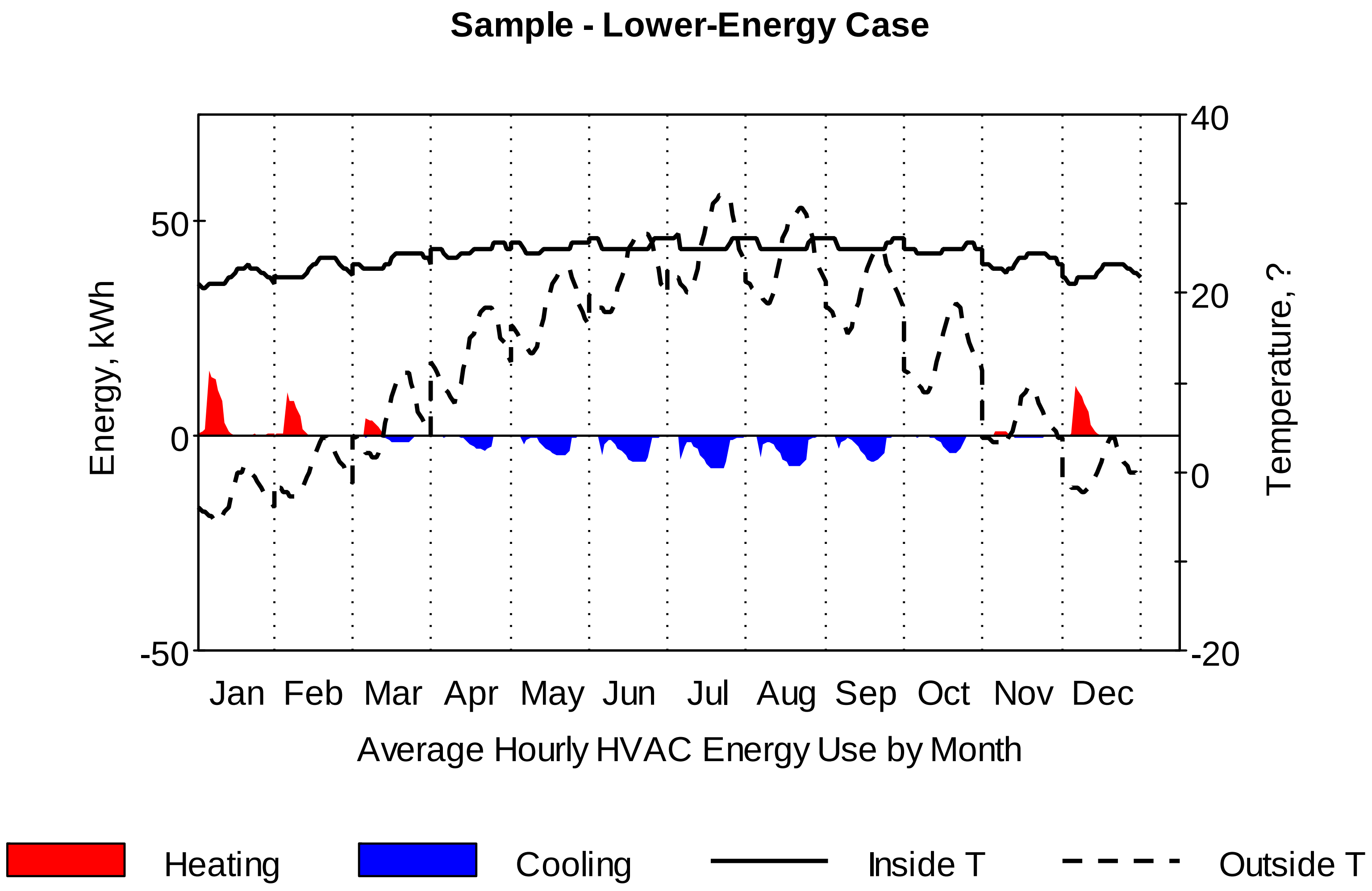


Example: Energy-10

ENERGY-10

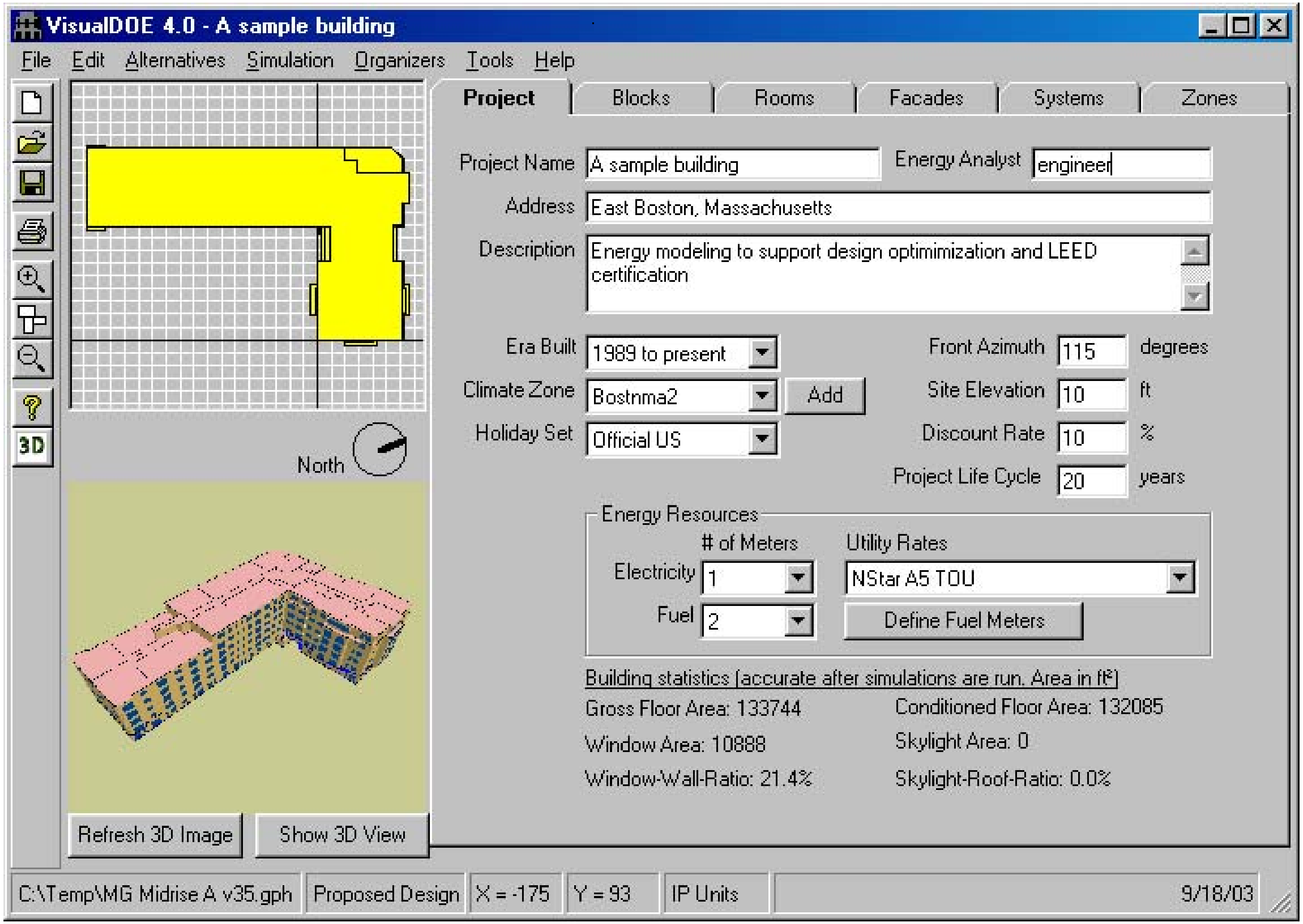


Example: Energy-10



DOE-2

Example: VisualDOE



Project Name: A sample building

Energy Analyst: engineer

Address: East Boston, Massachusetts

Description: Energy modeling to support design optimimization and LEED certification

Era Built: 1989 to present

Climate Zone: Bostnma2

Holiday Set: Official US

Front Azimuth: 115 degrees

Site Elevation: 10 ft

Discount Rate: 10 %

Project Life Cycle: 20 years

Energy Resources

	# of Meters	Utility Rates
Electricity	1	NStar A5 TOU
Fuel	2	

Building statistics (accurate after simulations are run. Area in ft²)

Gross Floor Area: 133744

Conditioned Floor Area: 132085

Window Area: 10888

Skylight Area: 0

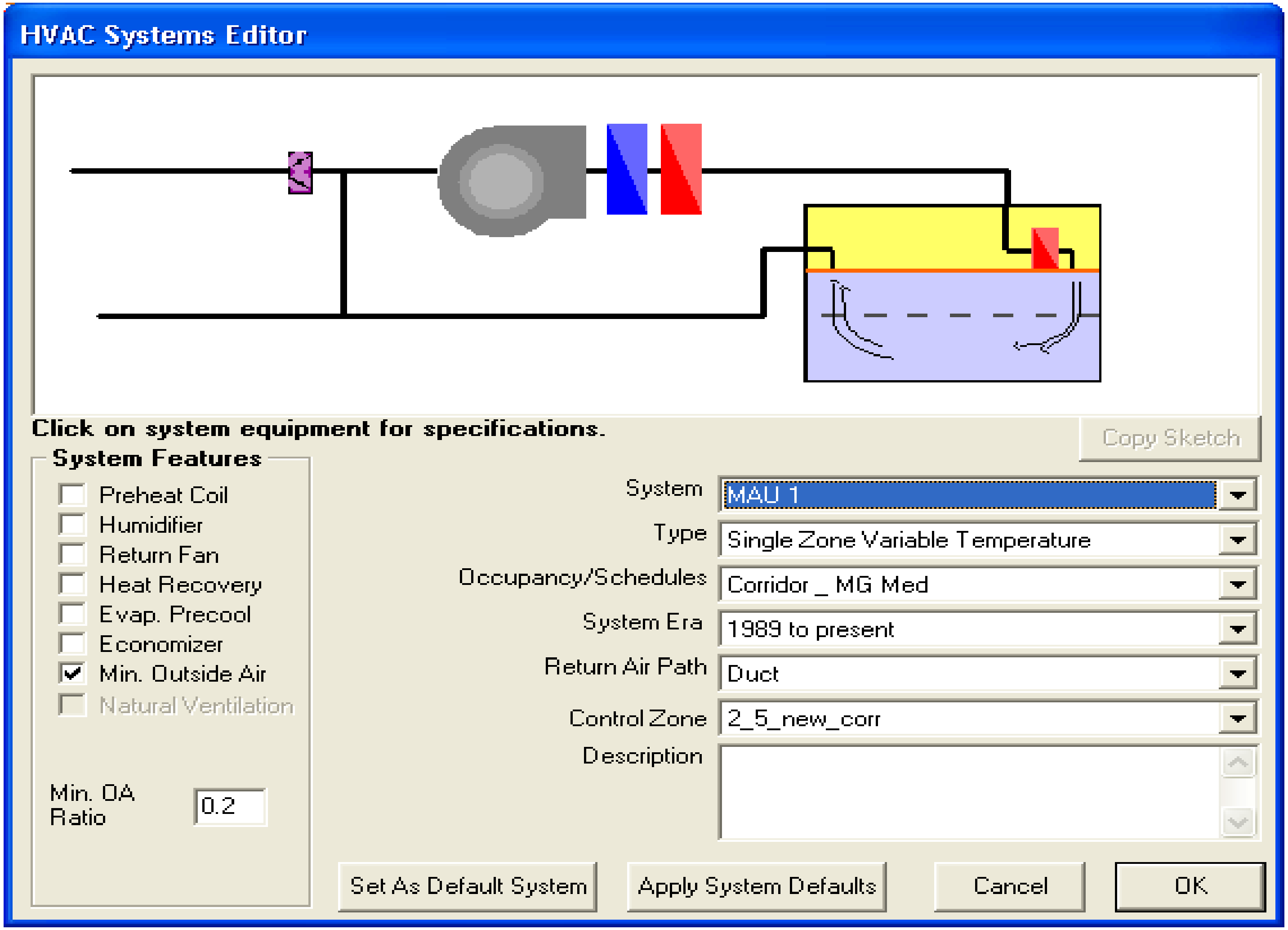
Window-Wall-Ratio: 21.4%

Skylight-Roof-Ratio: 0.0%

C:\Temp\MG Midrise A v35.gph | Proposed Design | X = -175 | Y = 93 | IP Units | 9/18/03

DOE-2

Example: VisualDOE



Click on system equipment for specifications.

System Features

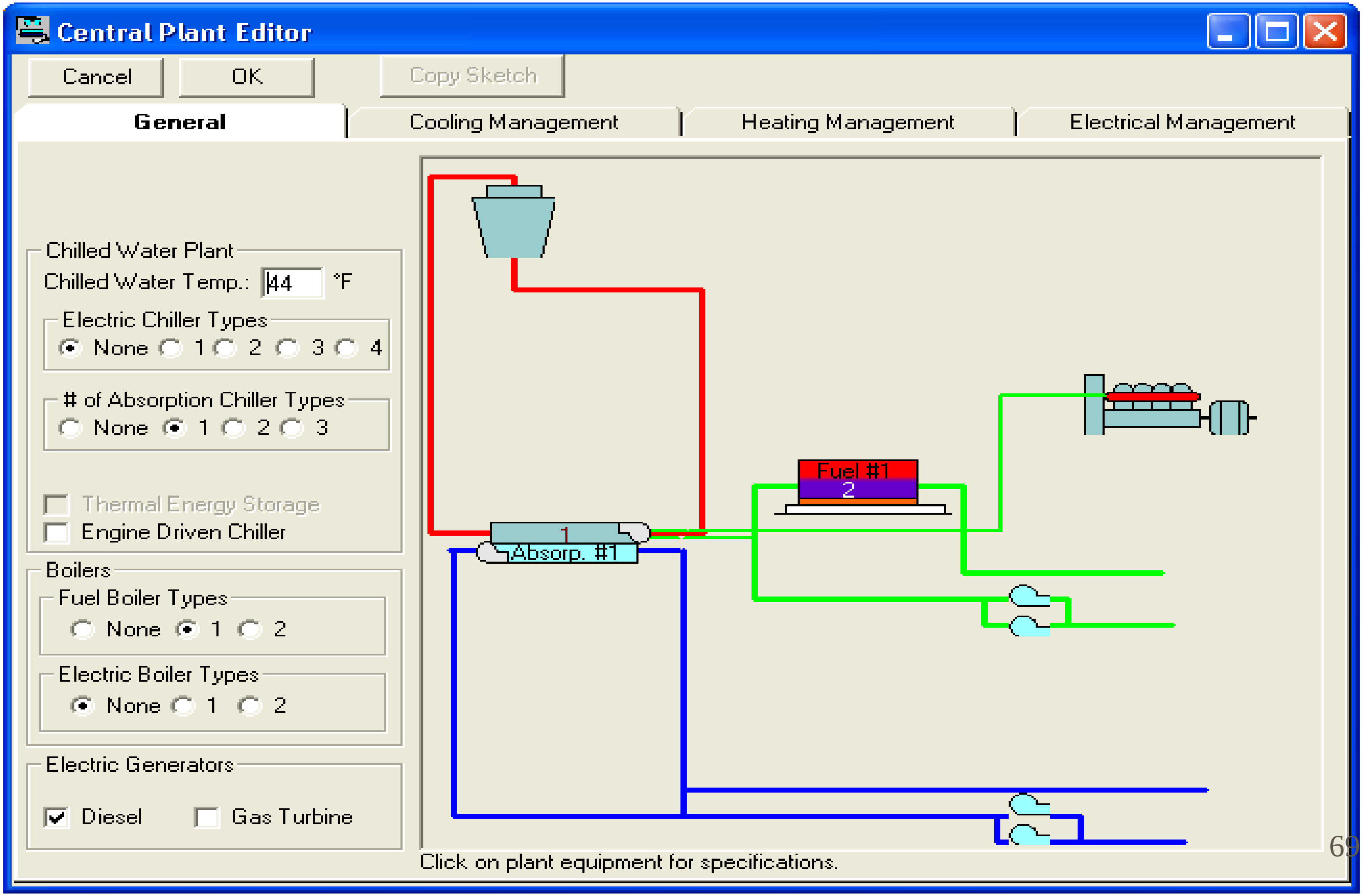
- ☐ Preheat Coil
- ☐ Humidifier
- ☐ Return Fan
- ☐ Heat Recovery
- ☐ Evap. Precool
- ☐ Economizer
- ☑ Min. Outside Air
- ☐ Natural Ventilation

Min. OA Ratio: 0.2

System: MAU 1
Type: Single Zone Variable Temperature
Occupancy/Schedules: Corridor _ MG Med
System Era: 1989 to present
Return Air Path: Duct
Control Zone: 2_5_new_corr
Description:

Example: VisualDOE

DOE-2



Chilled Water Plant

Chilled Water Temp.: 44 °F

Electric Chiller Types: ● None ○ 1 ○ 2 ○ 3 ○ 4

# of Absorption Chiller Types: ○ None ● 1 ○ 2 ○ 3

☐ Thermal Energy Storage

☐ Engine Driven Chiller

Boilers

Fuel Boiler Types: ○ None ● 1 ○ 2

Electric Boiler Types: ● None ○ 1 ○ 2

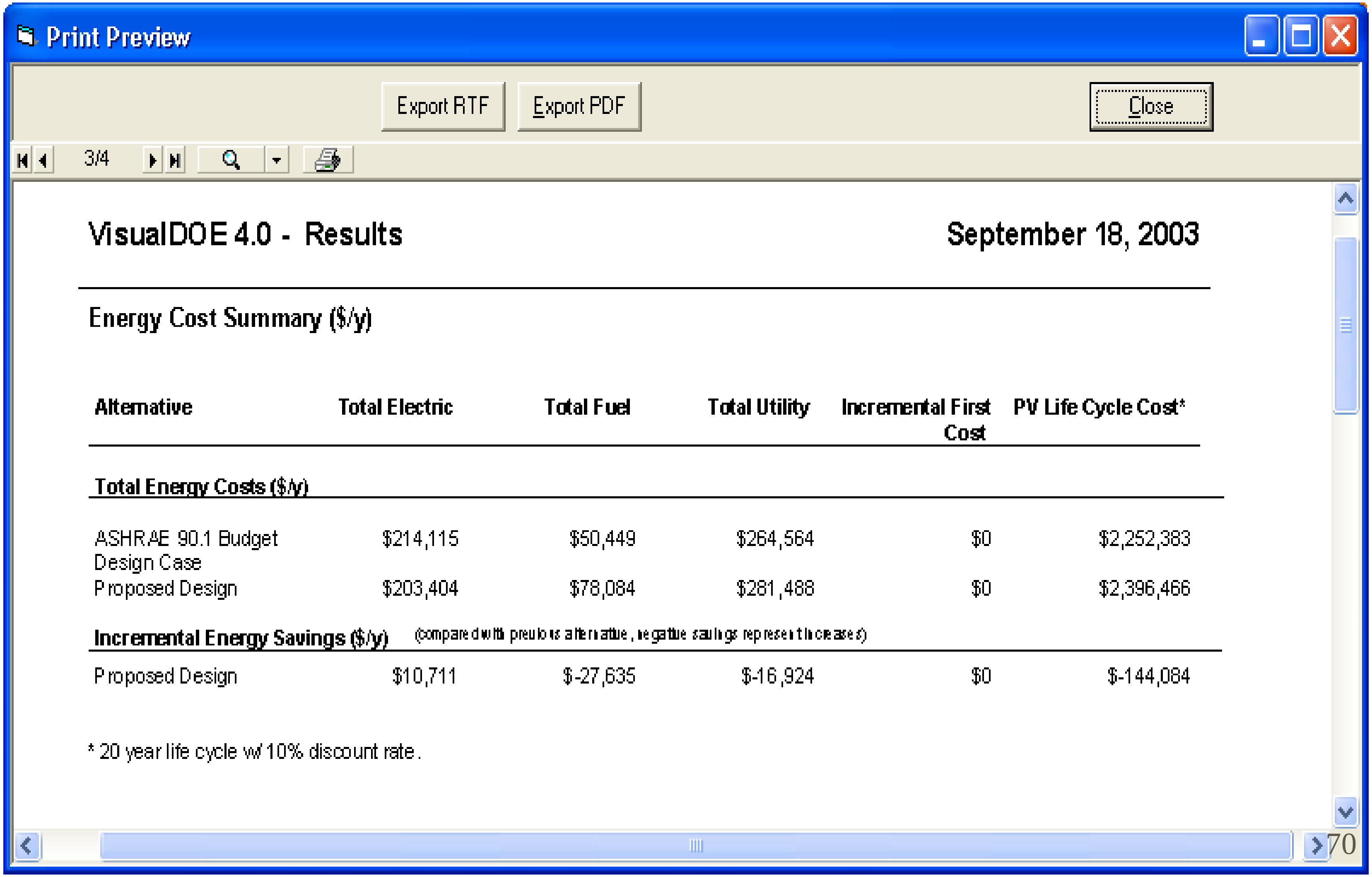
Electric Generators

☑ Diesel ☐ Gas Turbine

Click on plant equipment for specifications.

Example: VisualDOE

DOE-2



VisualDOE 4.0 - Results

September 18, 2003

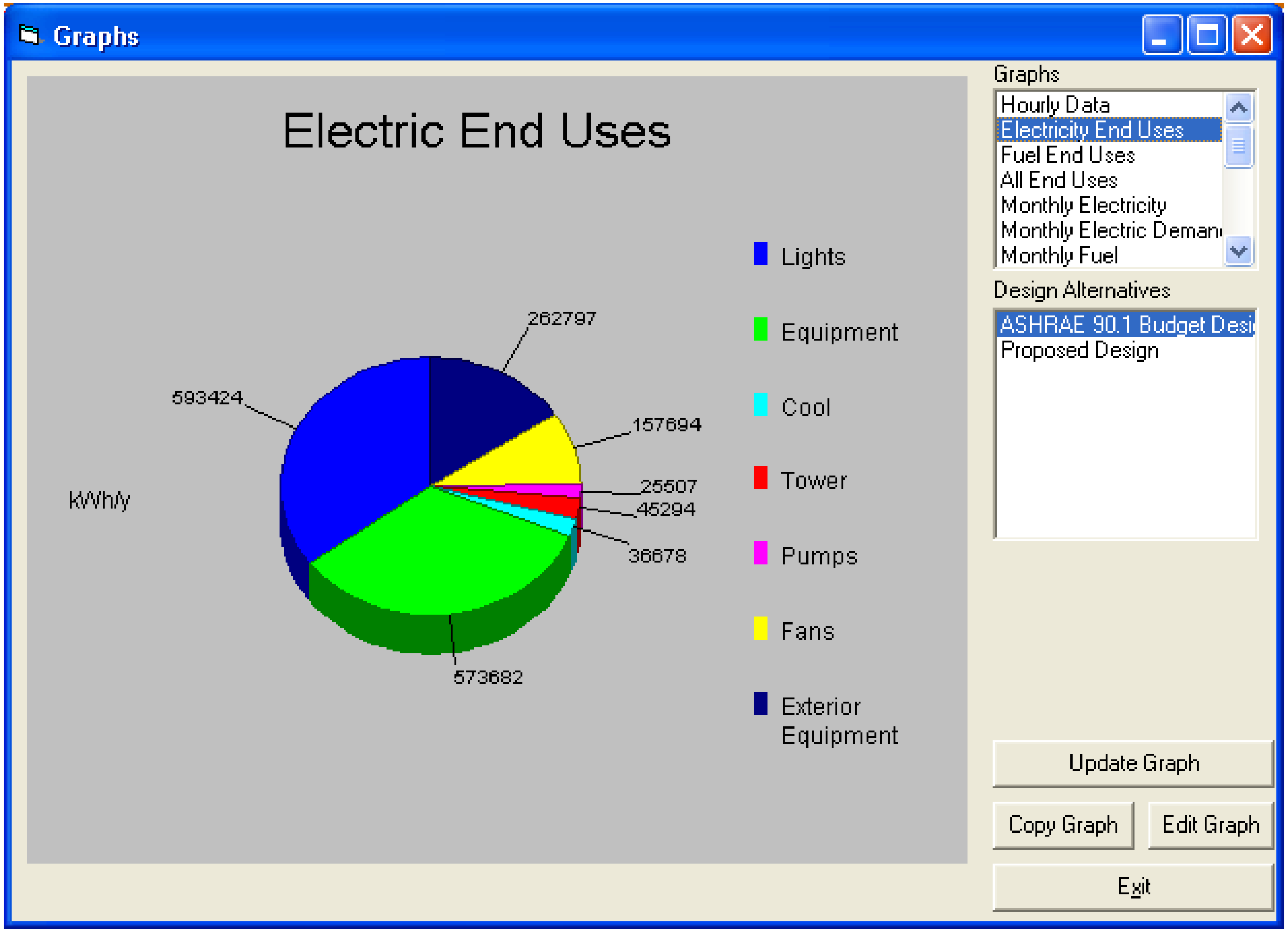
Energy Cost Summary ($/y)

Alternative	Total Electric	Total Fuel	Total Utility	Incremental First Cost	PV Life Cycle Cost*
Total Energy Costs ($/y)					
ASHRAE 90.1 Budget Design Case	$214,115	$50,449	$264,564	$0	$2,252,383
Proposed Design	$203,404	$78,084	$281,488	$0	$2,396,466
Incremental Energy Savings ($/y) (compared with previous alternative, negative savings represent increases)					
Proposed Design	$10,711	$-27,635	$-16,924	$0	$-144,084

* 20 year life cycle w/ 10% discount rate.

Example: VisualDOE

DOE-2



Example: VisualDOE

DOE-2

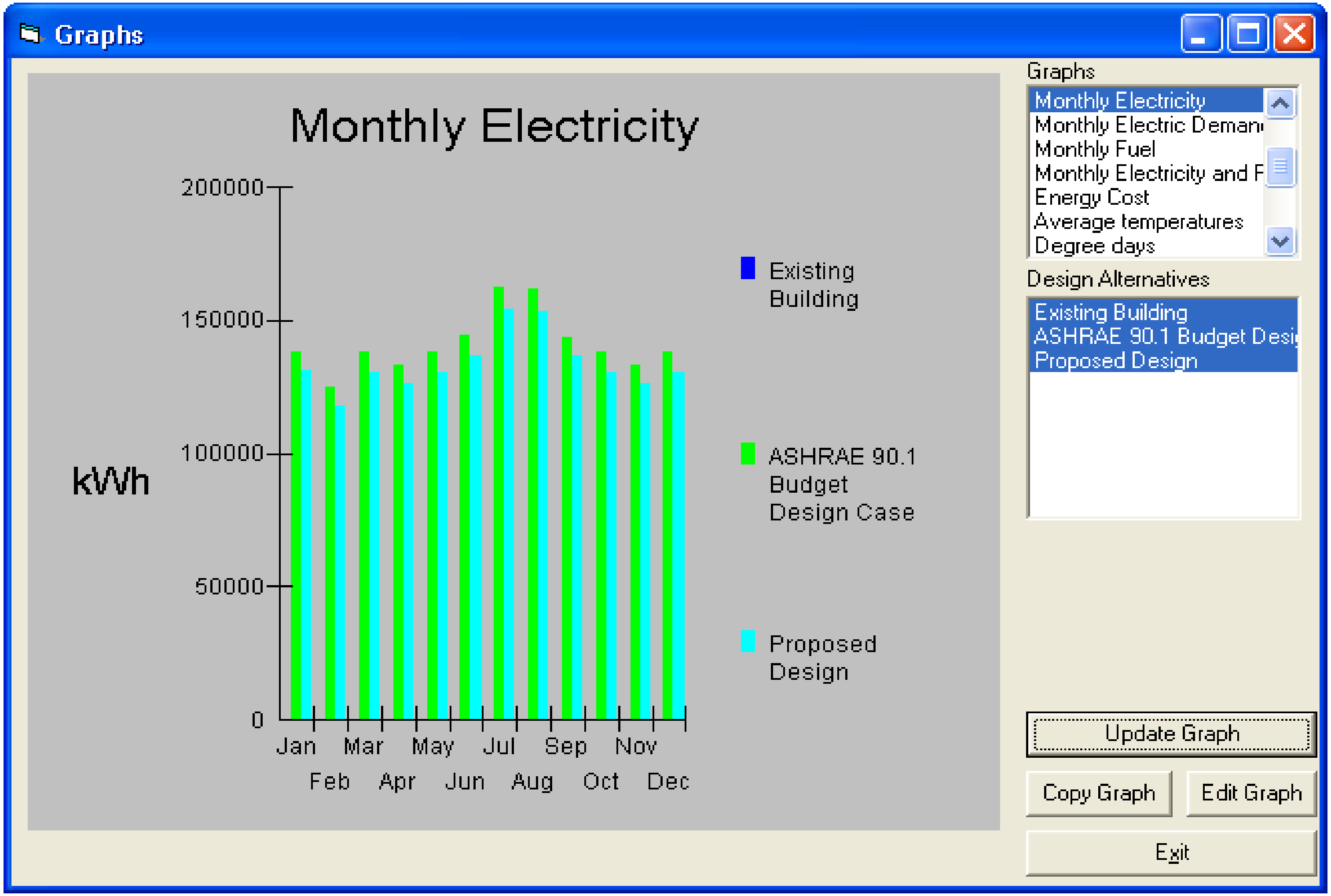


Table 43 Summary of TETD/TA Load Calculation Procedures

External Heat Gain

$$t_e = t_o + \alpha I_t / h_o - \varepsilon \Delta R / h_o \quad (6)$$

$$t_{ea} = t_{oa} + \alpha / h_o (I_{DT}/24) - \varepsilon \Delta R / h_o \quad (10)$$

t_e = sol-air temperature
t_o = current hour dry-bulb temperature, from design db (Chapter 26, Table 1) adjusted by Table 2, percentage at daily range values
α = absorptance of surface for solar radiation
α/h_o = surface color factor = 0.15 for light colors, 0.30 for dark
I_t = total incident solar load = 1.15 (SHGF), with SHGF per Chapter 29, Tables 15 through 21
$\varepsilon \Delta R/h_o$ = long-wave radiation factor = −3.9°C for horizontal surfaces, 0°C for vertical
t_e = 24-h average sol-air temperature
t_{oa} = 24-h average dry-bulb temperature
I_{DT} = total daily solar heat gain (Chapter 29, Tables 15 through 21)

Roofs and Walls

$$q = UA\ (\text{TETD}) \quad (48)$$

$$\text{TETD} = t_{ea} - t_i + 1(t_{e\delta} - t_{ea}) \quad (49)$$

U = design heat transfer coefficient for roof or wall, from Chapter 24, Table 4
A = area of roof or wall, calculated from building plans
TETD = total equivalent temperature difference, roof or wall
t_i = interior design dry-bulb temperature
λ = decrement factor, from Table 14 or 19
$t_{e\delta}$ = sol-air temperature at time lag δ hours (Table 14 or 19) previous to calculation hour

Roofs

Identify layers of roof construction from Table 11. With R-value of dominant layer, identify R-value Range number R and Roof Group number from Table 12. From Table 14 obtain decrement factor and time lag data with which to calculate TETD values for each sol-air temperature value by Equation (52). Calculate hourly heat gain with Equation (48).

Walls

Identify layers of wall construction from Table 11. With R-value of dominant layer, identify R-value Range number and Wall Group number from Table 15, 16, or 17.

Glass

Convective $q = UA(t_o - t_i)$
Solar $q = A(\text{SC})(\text{SHGF})$

U = design heat transfer coefficients, glass—Chapter 29
SC = shading coefficient—Chapter 29
SHGF = solar heat gain factor by orientation, north latitude, hour, and month—Chapter 29, Tables 15 to 21.

Partitions, Ceilings, Floors

$$q = UA\ (t_b - t_i) \quad (8)$$

t_b = temperature in adjacent space
t_i = inside design temperature in conditioned space

Internal Heat Gain

People

$q_{sensible} = N \times$ Sensible heat gain

$q_{latent} = N \times$ Latent heat gain

N = number of people in space, from best available source. Sensible and latent heat gain from occupancy—Table 3, or Chapter 8; adjust as required.

Lights

$$q_{el} = W F_{ul} F_{sa} \quad (9)$$

W = watts input from electrical plans or lighting fixture data
F_{ul} = lighting use factor, from the first section, as appropriate
F_{sa} = special allowance factor, from from section, as approp.

Power

$$q_p = P E_F \quad (15)(16)(17)$$

P = horsepower rating from electrical plans or manufacturer's data
E_F = efficiency factors and arrangements to suit circumstances

Appliances

$$q_{sensible} = q_{input} F_U F_R \quad (18)$$

or

$$q_{sensible} = q_{input} F_L \quad (19)$$

q_{input} = rated energy input from appliances from Tables 5 to 9 or manufacturer's data (Set latent heat = 0, if appliance is under exhaust hood.)
F_U, F_R, F_L = usage factors, radiation factors, flue loss factors

Ventilation and Infiltration Air

$$q_{sensible} = 1.23 Q(t_o - t_i) \quad (22)$$

$$q_{latent} = 3010 Q(W_o - W_i) \quad (23)$$

$$q_{total} = 1.20 Q(H_o - H_i) \quad (20)$$

Q = ventilation airflow—ASHRAE *Standard* 62; infiltration cfm—Chapter 25
t_o, t_i = outside, inside air temperature, °C
W_o, W_i = outside, inside air humidity ratio, kg (water)/kg (da)
H_o, H_i = outside, inside air enthalpy, kJ/kg (dry air)

Cooling Load

Sensible

$$q_{sensible} = q_{cf} + q_{arf} + q_c$$

$$q_{cf} = q_{s,1}(1 - rf_1) + q_{s,2}(1 - rf_2) + \ldots + rf_n$$

$$q_{arf} = \sum_{\gamma = h_{a+1-\theta}}^{\theta} \frac{(q_{s,1} \times rf_1 + q_{s,2} \times rf_2 + \ldots + rf_n)_\gamma}{\theta}$$

$$q_c = (q_{sc,1} + q_{sc,2} + q_{sc,\beta})$$

$q_{sensible}$ = sensible cooling load
q_{cf} = convective fraction of hourly sensible heat gain (current hour) for n load elements
$q_{s,1}$ = sensible hourly heat gain for load element 1, … n
rf_1 = radiation fraction (Table 44) of sensible hourly heat gain for load element 1, … n
q_{arf} = average of radiant fractions of hourly sensible heat gain for n load element 1, … n
θ = number of hour over which to average radiant fractions of sensible heat gain
h_a = current hour, 1 to 24, for which cooling load is to be calculated
γ = one of calculations hours, from $h_{a+1-\theta}$ to h_a, for which the radiant fraction of sensible heat gain is to be averaged for each of n load elements
q_c = convective hourly sensible heat gain (current hour) for β load elements having no radiant component

Latent

$$q_{latent} = (q_{l,1} + q_{l,2} + q_{l,\beta})$$

q_{latent} = latent cooling load
q_l = hourly latent heat gain (current hour) for β load elements

Table 10 Summary of TFM Load Calculation Procedures

External Heat Gain

$$t_e = t_o + \alpha I_t / h_o - \varepsilon \Delta R / h_o \qquad (6)$$

$$t_{ea} = t_{oa} + \alpha / h_o (I_{DT} / 24) - \varepsilon \Delta R / h_o \qquad (7)$$

where

t_e = sol-air temperature
t_o = current hour dry-bulb temperature, from design db (Chapter 26) adjusted by Table 2 daily range % values
α = absorptance of surface for solar radiation
α / h_o = surface color factor = 0.026 for light colors, 0.052 for dark
I_t = total incident solar load = 1.15 (SHGF), with SHGF per Chapter 29, Tables 15 through 21
$\varepsilon \Delta R / h_o$ = long-wave radiation factor = −3.9°C for horizontal surfaces, 0°C for vertical
t_e = 24-h average sol-air temperature
t_{oa} = 24-h average dry-bulb temperature
I_{DT} = total daily solar heat gain (Chapter 29, Tables 15 through 21)

Roofs and Walls

$$q_{e,\theta} = A\left[\sum_{n=0} b_n (t_{e,\theta-n\delta}) - \sum_{n=1} d_n [(q_{e,\theta-n\delta})/A] - t_{rc} - \sum_{n=0} c_n\right] \qquad (28)$$

where

b and d = conduction transfer coefficients—roof, Table 13; wall, Table 18
c and U_{table} = conduction transfer coefficients—roof, Table 14; wall, Table 19
U_{actual} = design heat transfer coefficient for roof or wall, from Chapter 24, Table 4

Adjust b and c coefficients by ratio U_{actual}/U_{table}.

Roofs

Identify layers of roof construction from Table 11. With R-value of dominant layer, identify R-value Range number R and Roof Group number from Table 12. Proceed to Table 13.

Walls

Identify layers of wall construction from Table 11. With R-value of dominant layer, identify R-value Range number and Wall Group number from Table 15, 16, or 17. Proceed to Table 14.

θ = hour for which calculation is made
δ = time interval (1 h)
n = number of hours for which and values are significant
e = element under analysis, roof or wall assembly
A = area of element under analysis

Glass

Convective $q = UA(t_o - t_i)$
Solar $q = A$(SC)(SHGF)

U = design heat transfer coefficients, glass—Chapter 29
SC = shading coefficient—Chapter 29
SHGF = solar heat gain factor by orientation, north latitude, hour, and month—Chapter 29, Tables 15 to 21.

Partitions, Ceilings, Floors

$$q = UA\,(t_b - t_i) \qquad (8)$$

t_b = temperature in adjacent space
t_i = inside design temperature in conditioned space

Internal Heat Gain

People

$q_{sensible} = N$(Sensible heat gain)
$q_{latent} = N$(Latent heat gain)

N = number of people in space, from best available source. Sensible and latent heat gain from occupancy—Table 3, or Chapter 8; adjust as required.

Lights

$$q_{el} = W F_{ul} F_{sa} \qquad (9)$$

where

W = watts input from electrical plans or lighting fixture data
F_{ul} = lighting use factor, from the first section, as appropriate
F_{sa} = special allowance factor, from first section, as approp.

Power

$$q_p = P E_F \qquad (15), (16), (17)$$

where

P = power rating from electrical plans or manufacturer's data
E_F = efficiency factors and arrangements to suit circumstances

Appliances

where $$q_{sensible} = q_{input} F_U F_R \qquad (18)$$

or $$q_{sensible} = q_{input} F_L \qquad (19)$$

q_{input} = rated energy input from appliances—Tables 5 to 9, or manufacturer's data (set latent heat = 0, if appliance is under exhaust hood)
F_U, F_R, F_L = usage factors, radiation factors, and load factors

Ventilation and Infiltration Air

$$q_{sensible} = 1.23 Q (t_o - t_i) \qquad (22)$$

$$q_{latent} = 3010 Q (W_o - W_i) \qquad (23)$$

$$q_{total} = 1.20 Q (h_o - h_i) \qquad (20)$$

Q = ventilation airflow—ASHRAE *Standard* 62; infiltration cfm—Chapter 25
t_o, t_i = outside, inside air temperature, °C
W_o, W_i = outside, inside air humidity ratio, kg (water)/kg (da)
H_o, H_i = outside, inside air enthalpy, kJ/kg (dry air)

Cooling Load

Sensible $Q\theta = Q_{rf} + Q_{sc}$

$$Q_{tf} = \sum_{i=1} (v_0 q_{\theta,i} + v_1 q_{\theta,i-\delta} + v_2 q_{\theta,i-2\delta} + \ldots) - (w_1 Q_{\theta-\delta} + w_2 Q_{\theta-2\delta} + \ldots) \qquad (28)$$

$$Q_{sc} = \sum_{j=1} (q_{c,j}) \qquad (30)$$

Q_{tf} = sensible cooling load from heat gain elements having convective and radiant components
v and w = room transfer function coefficients, Tables 24 and 25; select per element type, circulation rate, mass, and/or fixture type
q_θ = each of i heat gain elements having a radiant component; select appropriate fractions for processing, per Tables 24, 25, and 42
δ = time interval (1 h)
Q_{sc} = sensible cooling load from heat gain elements having only convective components
q_c = each of j heat gain elements having only convective component

Latent $Q_l = \sum_{n=1} (q_{c,n})$

q_c = each of n latent heat gain elements

The CLTD/SCL/CLF method is a one-step, hand calculation procedure, based on the transfer function method (TFM). It may be used to approximate the cooling load corresponding to the first three modes of heat gain (conductive heat gain through surfaces such as windows, walls, and roofs; solar heat gain through fenestrations; and internal heat gain from lights, people, and equipment) and the cooling load from infiltration and ventilation. The acronyms are defined as follows:

CLTD—Cooling Load Temperature Difference
SCL—Solar Cooling Load
CLF—Cooling Load Factor

The following sections give details of how the CLTD/SCL/CLF technique relates to and differs from the TFM. The sources of the space cooling load, forms of equations to use in the calculations, appropriate references, tables, are summarized in Table 29.

SYNTHESIS OF HEAT GAIN AND COOLING LOAD CONVERSION PROCEDURES

Exterior Roofs and Walls

This method was developed by using the TFM to compute one-dimensional transient heat flow through various sunlit roofs and walls. Heat gain was converted to cooling load using the room transfer functions for rooms with light, medium, and heavy thermal characteristics. Variations in the results due to such varying room constructions and other influencing parameters discussed in the TFM description are so large that only one set of factors is presented here for illustration. All calculations for data tabulated were based on the sol-air temperatures in Table 1. The inside air temperature was assumed to be constant at 25°C (cooling system in operation 24 h/day, seven days a week). The mass of building and contents was "light to medium." For application of CLTD/SCL/CLF techniques, refer to McQuiston and Spitler (1992).

Table 29 Procedure for Calculating Space Design Cooling Load by CLTD/SCL/CLF Method

External Cooling Load

Roofs, walls, and conduction through glass

$$q = UA(\text{CLTD}) \qquad (41)$$

U = design heat transfer coefficient for roof or wall from Chapter 24, Table 4; or for glass, Table 5, Chapter 29
A = area of roof, wall, or glass, calculated from building plans
CLTD = cooling load temperature difference, roof, wall, or glass

Solar load through glass

$$q = A(\text{SC})(\text{SCL}) \qquad (43)$$

SC = shading coefficient: Chapter 29
SCL = solar cooling load factor with no interior shade or with shade, Table 36.

Cooling load from partitions, ceilings, floors

$$q = UA(t_o - t_{rc}) \qquad (8)$$

U = design heat transfer coefficient for partition, ceiling, or floor, from Chapter 24, Table 4
A = area of partition, ceiling, or floor, calculated from building plans
t_b = temperature in adjacent space
t_{rc} = inside design temperature (constant) in conditioned space

Internal Cooling Load

People

$$q_{sensible} = N(\text{Sensible heat gain})\text{CLF} \qquad (44)$$

$$q_{latent} = N(\text{Latent heat gain}) \qquad (45)$$

N = number of people in space, from best available source. Sensible and latent heat gain from occupancy—Table 3, or Chapter 8; adjust as required
CLF = cooling load factor, by hour of occupancy, Table 37

Note: CLF 1.0 with high density or 24-h occupancy and/or if cooling off at night or during weekends.

Lights

$$q_{el} = WF_{ul}F_{sa}\,(\text{CLF}) \qquad (9)(46)$$

W = watts input from electrical plans or lighting fixture data
F_{ul} = lighting use factor, as appropriate
F_{sa} = special allowance factor, as appropriate
CLF = cooling load factor, by hour of occupancy, Table 38

Note: CLF = 1.0 with 24-h light usage and/or if cooling off at night or during weekends.

Power

$$q_p = PE_F\,\text{CLF} \qquad (15)(16)(17)(50)$$

P = horsepower rating from electrical plans or manufacturer's data
E_F = efficiency factors and arrangements to suit circumstances

CLF = cooling load factor, by hour of occupancy, Table 37

Note: CLF = 1.0 with 24-h power operation and/or if cooling off at night or during weekends.

Appliances

$$q_{sensible} = q_{input}F_U F_R(\text{CLF}) \qquad (18)(46)$$

or

$$q_{sensible} = q_{input}F_L(\text{CLF}) \qquad (19)(46)$$

q_{input} = rated energy input from appliances—Tables 5 through 9, or manufacturer's data
F_U, F_R, F_L = usage factors, radiation factors,and load factors from the General Principles section
CLF = cooling load factor, by scheduled hours and hooded or not; Tables 37 and 39

Note 1: CLF = 1.0 with 24-h appliance operation and/or if cooling off at night or during weekends.
Note 2: Set latent load = 0 if appliance under exhaust hood.

Ventilation and Infiltration Air

$$q_{sensible} = 1.23Q\,(t_o - t_i) \qquad (25)$$

$$q_{latent} = 3010Q\,(W_o - W_i) \qquad (23)$$

$$q_{total} = 1.20Q\,(h_o - h_i) \qquad (20)$$

Q = ventilation from ASHRAE *Standard* 62; infiltration from Chapter 25, L/s
t_o, t_i = outside, inside air temperature, °C
W_o, W_i = outside, inside air humidity ratio, kg (water)/kg (dry air)
H_o, H_i = outside, inside air enthalpy, kJ/kg (dry air)