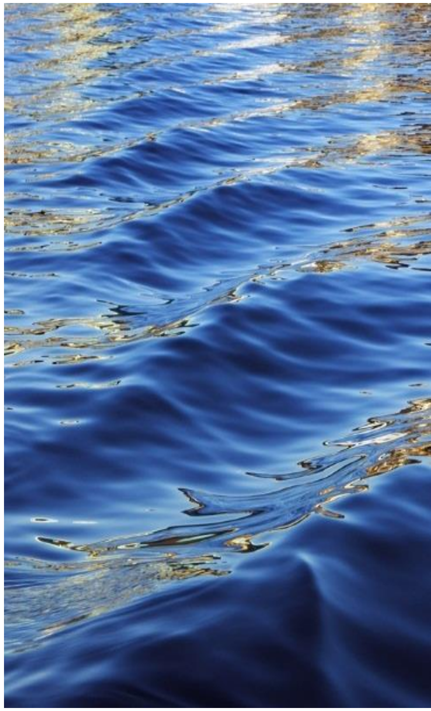
Environmental Thermal Engineering

Lecture Note #12

Professor Min Soo KIM

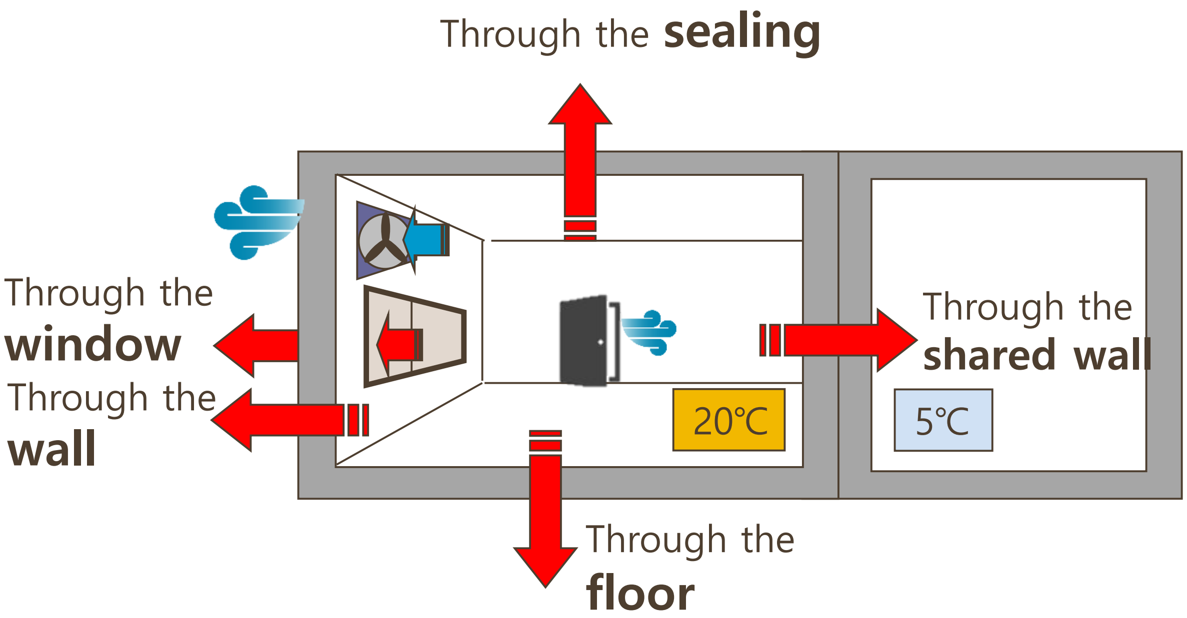


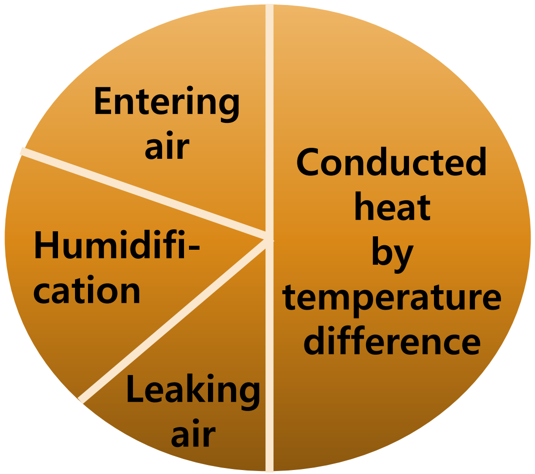
Space Heating Load

Space Heating Load

❑ Types of heat losses :

- Heat transmitted through the walls, ceiling, or other surface
- Heat required to warm outdoor air entering the space





① **Conducted heat** - by temp. difference

② **Leaking air** - by infiltration

③ **Entering air** - by ventilation

Design Criteria

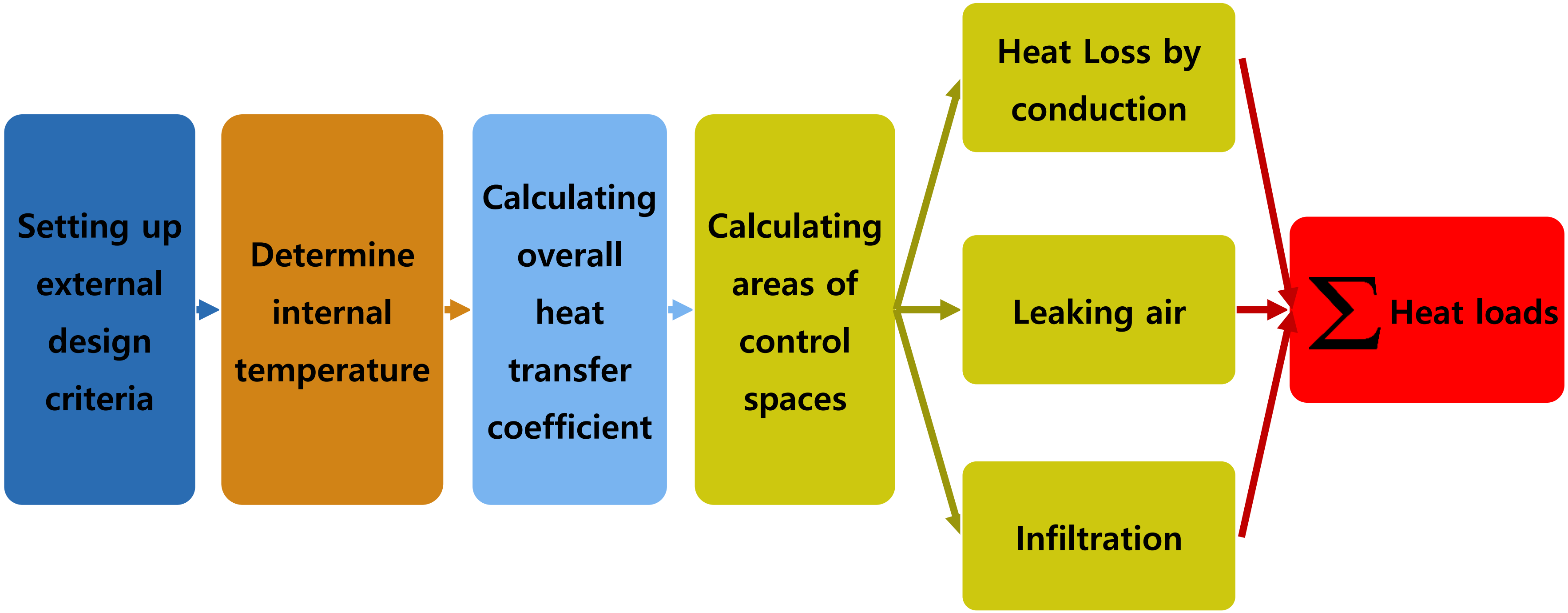
External condition

- Building structure / Insulation
- Degree of exposure / Air-tightness
- Area of Window
- House of use / Occupied room characteristics / Temperature drop condition
- Daily temperature range / Lowest temperature
- Auxiliary heating system
- Economic feasibility

Internal Condition

- Purpose of Building
- Occupied room characteristics
- Legal validity

Calculating Heating Loads



Categories of Heat Loss

1. Heat loss through external wall, roof, floor, and window

$$q = UA(t_i - t_o)$$

q : Heat loss through external wall, roof, floor, and window [W]

A : Area of wall, roof, floor, and window [m²]

U : Overall coefficient of heat transfer [W/m² K]

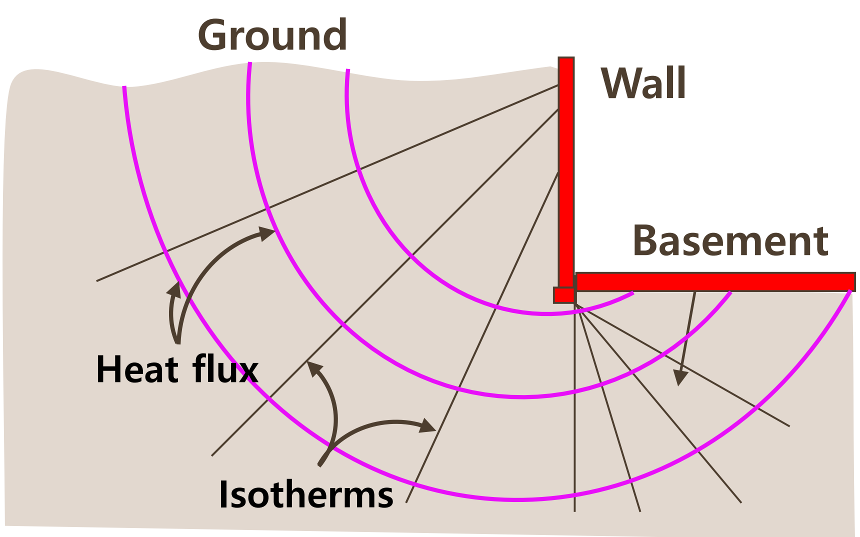
t_i : Indoor air temperature [K]

t_o : Outdoor air temperature [K]

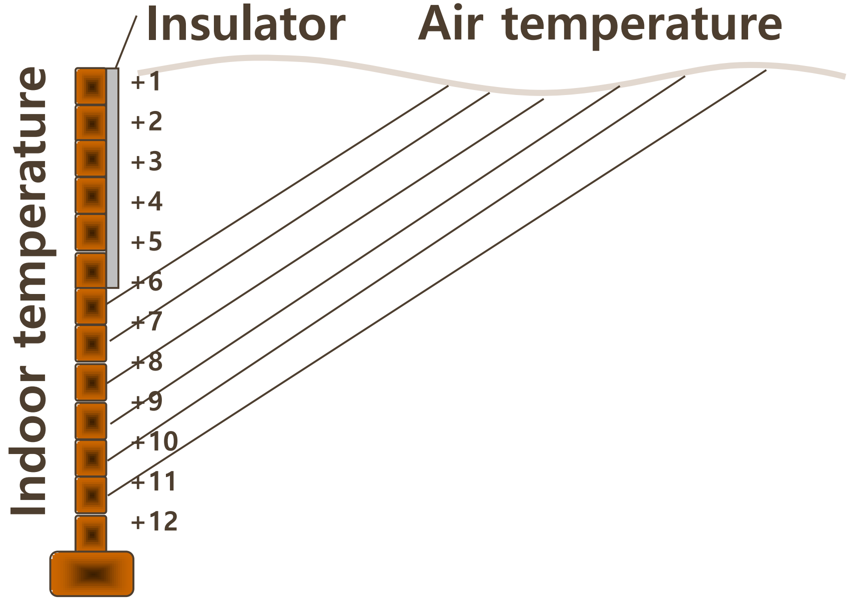
Categories of Heat Loss

2. Heat loss through underground wall and floor

- Heat loss through underground wall
- Heat loss through underground floor
- Heat loss through floor on the surface of the earth



(a) Without insulators



(b) With partial insulators

FIGURE Path of heat loss through underground

Categories of Heat Loss

2. Heat loss through underground wall and floor

- Heat loss through underground wall
- Heat loss through underground floor
- Heat loss through floor on the surface of the earth

TABLE Path of heat loss through underground

Underground wall height	Heat loss coefficient, W/(m^{2}K)			
	Minimum width of the building, m			
	6	7.3	8.5	9.7
1.5	0.18	0.16	0.15	0.13
1.8	0.17	0.15	0.14	0.12
2.1	0.16	0.15	0.13	0.12

Categories of Heat Loss

3. Heat loss due to outdoor air infiltration

- **Sensible heat loss**

$$q = m_o c_p (t_i - t_o)$$

$$q = \frac{Q c_p (t_i - t_o)}{v_o}$$

m_o : Mass flow rate of outdoor air
c_p : Specific heat of air
Q : Volume flow rate of outdoor air
v_o : Specific volume

- **Latent heat loss**

$$q_l = \frac{Q\rho(W_i - W_o) h_{fg}}{1000}$$

q_l : Required heat to increase humidity W_o from to W_i [W]
Q : Volume flow rate of outdoor air infiltration [L/s]
$W_{i,o}$: Absolute humidity of indoor or outdoor air
h_{fg} : Latent heat of vapor

seasonsviewwindowanddoor.com

Categories of Heat Loss

4. Outdoor air infiltration prediction

- **Air change Method – Empirical Prediction**

$$Q = ACH(V)$$

- ACH (Air change per hour) range : 0.5~2.0
- Modern office building : 0.1 ACH

- Outdoor air requirements per person = 36 CMH/person (ASHRAE)

Categories of Heat Loss

4. Outdoor air infiltration prediction

- **Cracking Method**
  - Prediction using pressure difference between indoor & outdoor and characteristics of window, wall, and door

$$Q = AC\Delta P^{n}$$

Q : Volume flow rate of outdoor air infiltration

A : Valid leaking area of the crack

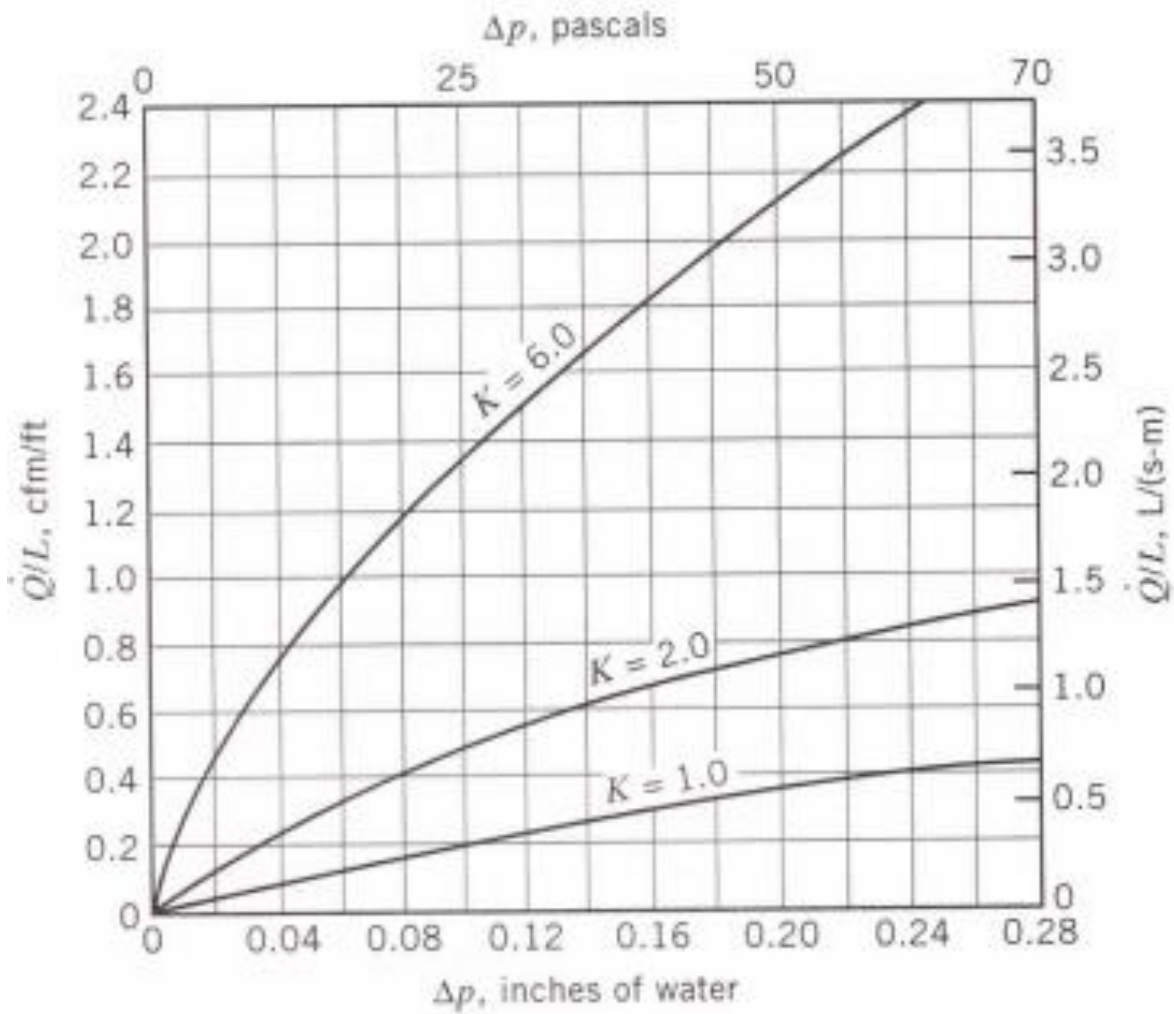
C : Flow factor depending on crack shape and flow characteristics

ΔP : Pressure difference between indoor and outdoor

n : Flow characteristic factor at the crack (0.4 ~ 1.0)

Categories of Heat Loss

- **Window and door infiltration characteristics**



Categories of Heat Loss

- **Window Classification**

	Wood Double-hung (Locked)	Other types
Tight-fitting window K = 1.0	Weatherstripped average gap (1/64". Crack)	Wood casement and awning windows, weatherstripped Metal casement windows, weatherstripped
Average-fitting window K = 2.0	Nonweatherstripped average gap (1/64". Crack)	All types of vertical and horizontal sliding windows, weatherstripped. Note: If average gap (1/64". Crack) this could be tight-fitting window
	Weatherstripped large gap (3/32". Crack)	Metal casement windows; Nonweatherstripped. Note: If large gap (3/32". Crack) this could be a loose-fitting window
Loose-fitting window K = 6.0	Nonweatherstripped large gap (3/32". Crack)	Vertical and horizontal sliding windows, nonweatherstripped

Ref., ASHRAE Cooling and Heating Load Calculation Manual, 2nd ed., 1992

Categories of Heat Loss

- **Door Classification**

Tight-fitting door **K = 1.0**	Very small perimeter gap and perfect fit weatherstripping - often characteristic of new doors
Average-fitting door **K = 2.0**	Small perimeter gap having stop trim fitting properly around door and weatherstripped
Loose-fitting door **K = 6.0**	Larger perimeter gap having poor fitting stop trim and weatherstripped or Small perimeter gap with no weatherstripping

Ref., ASHRAE Cooling and Heating Load Calculation Manual, 2nd ed., 1992

Categories of Heat Loss

$$\Delta P = \Delta P_w + \Delta P_s + \Delta P_p$$

ΔP_w: Pressure difference due to wind —— (a)

ΔP_s: Pressure difference due to chimney effects —— (b)

ΔP_p: Pressure difference due to pressurization —— (c)

*** Pressure differences are positive values when they make air flow into the building**

Categories of Heat Loss

(a) Pressure difference due to wind

$$\Delta P_w = \frac{\rho}{2}\left(V_w^2 - V_f^2\right)$$

$$\cong C_p \frac{\rho}{2} V_w^2$$

(pressure difference when V_f =0)

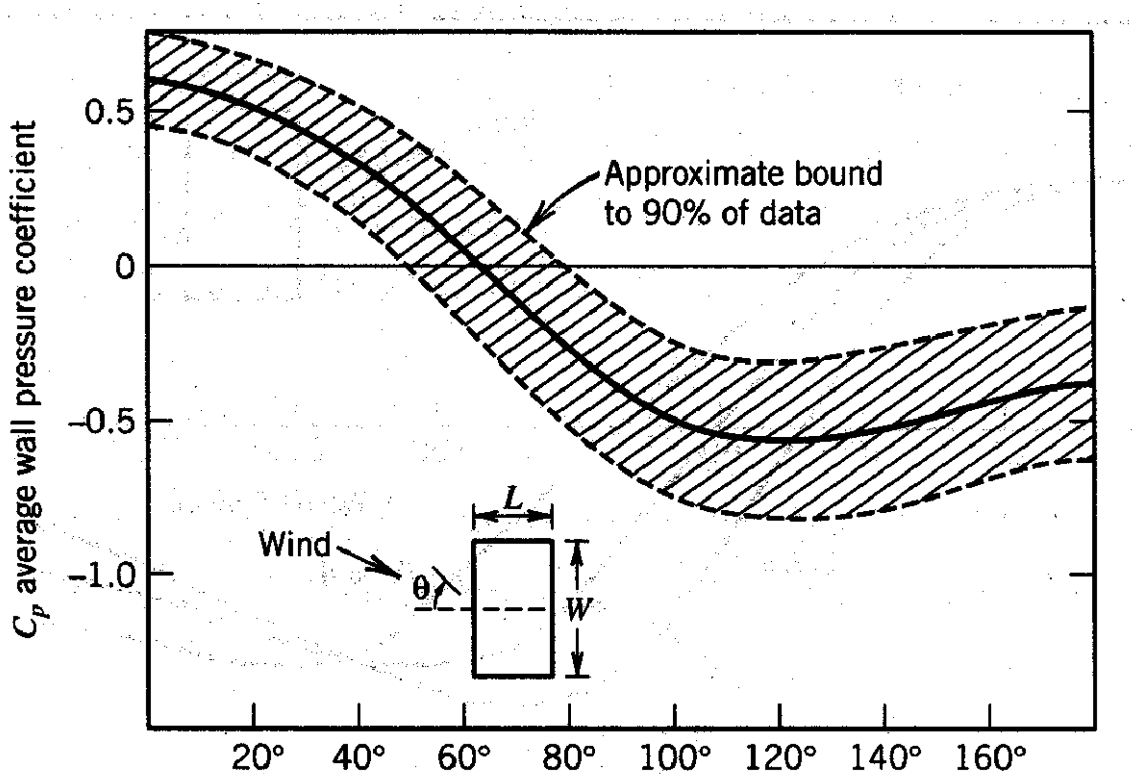
V_w: Speed of wind

V_f: Final speed of wind at the border of the building

C_p: Pressure coefficient

Categories of Heat Loss

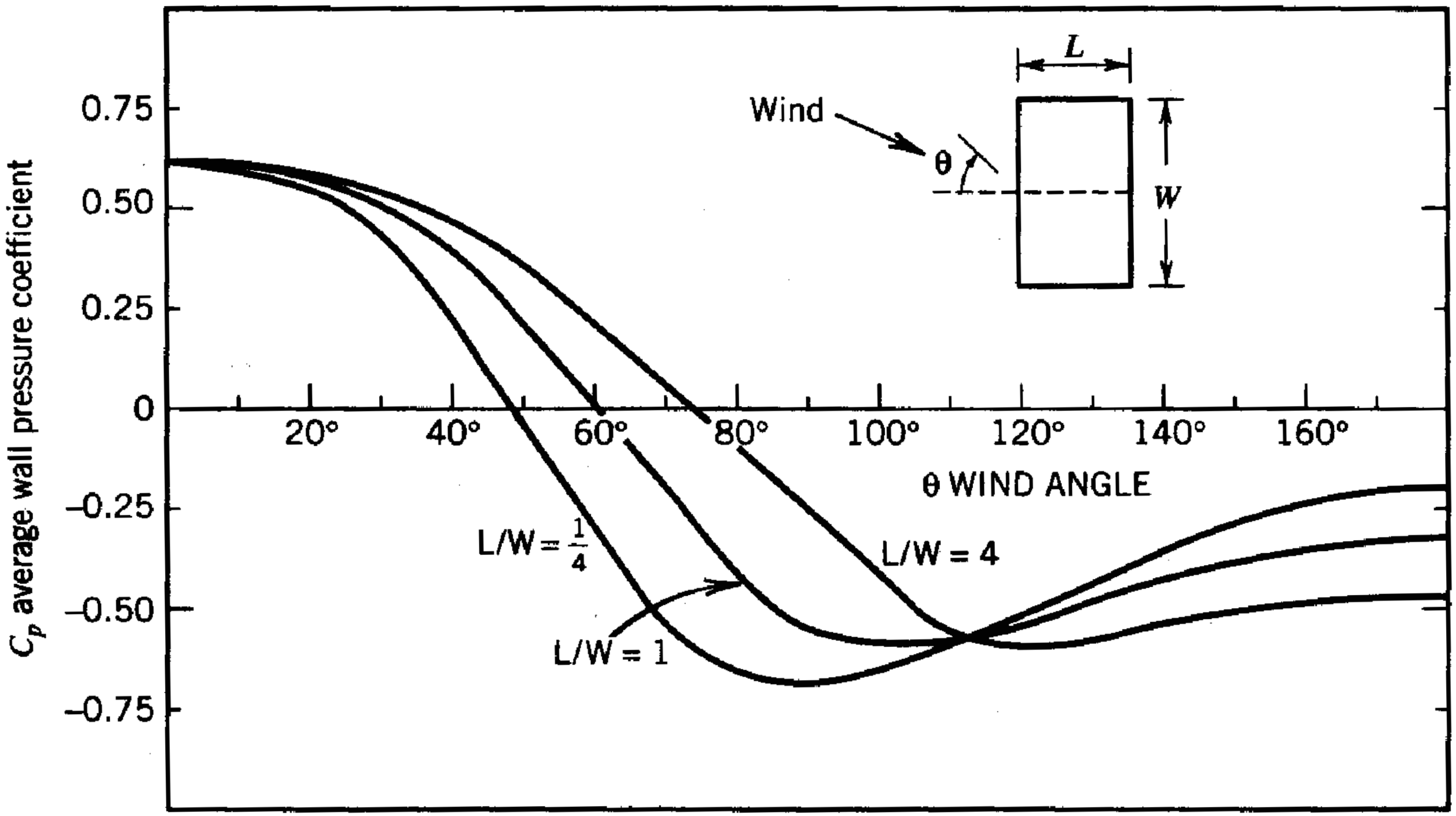
- **Pressure coefficient (C_p)**
  - Depend on direction and shape of the building



Ref., ASHRAE Handbook, Fundamentals Volume, 1989

FIGURE Variation of averaged pressure coefficients for a low-rise building

Categories of Heat Loss



Ref., ASHRAE Handbook, Fundamentals Volume, 1989

FIGURE Wall averaged pressure coefficients for a tall building

Categories of Heat Loss

(b) Pressure difference due to chimney effects

- Chimney effects : Occurs when indoor & outdoor air densities are different
- Neutral pressure height : Height where pressure difference is zero when only chimney effect is considered

Theoretical pressure difference without internal barriers

$$\Delta P_{st} = \frac{P_o h}{R_a} \frac{g}{g_c} \left(\frac{1}{T_o} - \frac{1}{T_i} \right)$$

P_{st} : Theoretical Pressure difference [Pa]
P_o : Outdoor pressure [Pa]
h : Vertical distance from neutral pressure height [m]
T_o : Outdoor temperature [K]
T_i : Indoor temperature [K]
R_a : Gas constant for air [J/(kg · K)]
g_c : Dimensional constant, 1 [(kg·m)/(N · s^2)]

Categories of Heat Loss

- **Ventilation coefficient**

  - $C_d = \frac{\Delta P_s}{\Delta P_{st}} (< 1)$

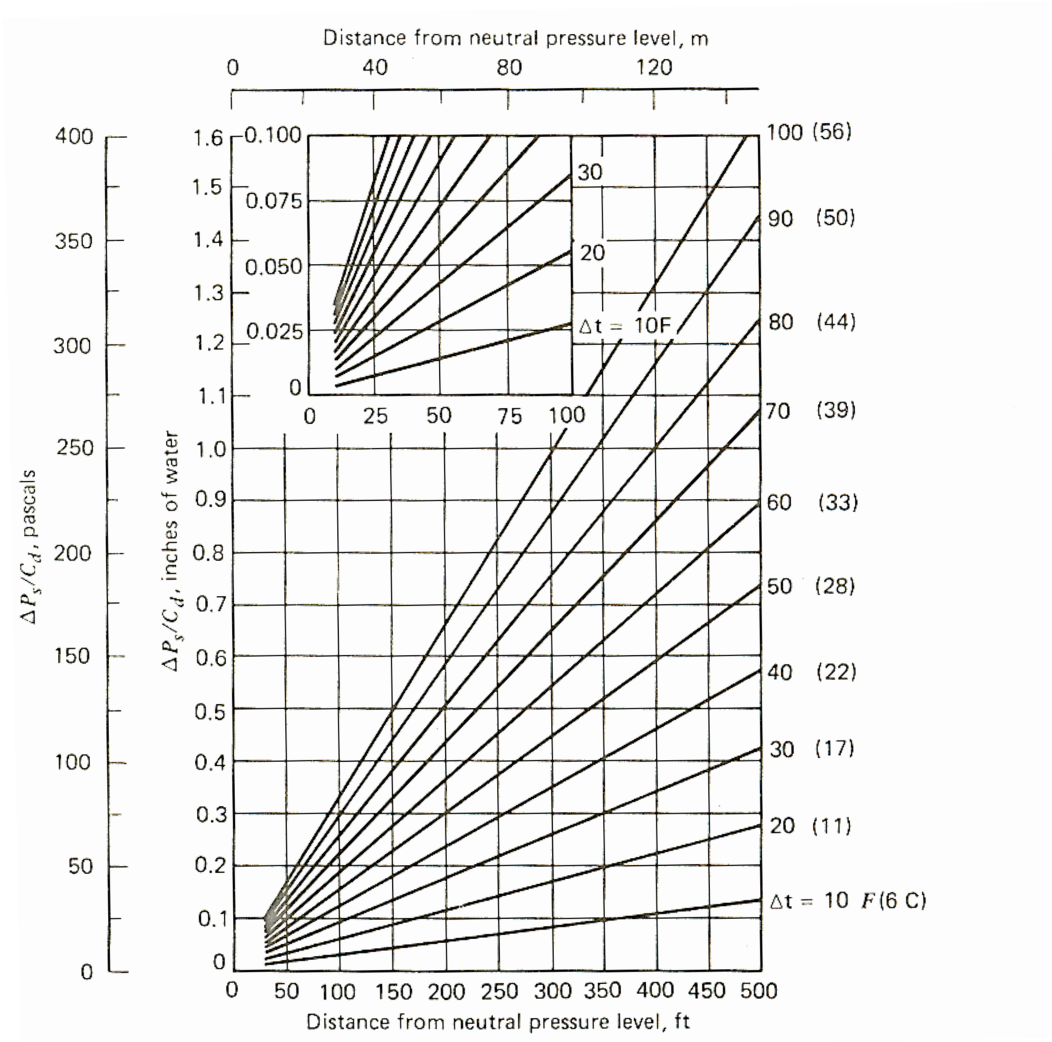
Actual pressure difference due to chimney effects

$$\Delta P_s = \frac{C_d P_o h g}{R_a g_c}\left(\frac{1}{T_o} - \frac{1}{T_i}\right)$$

P_s : Actual Pressure difference due to the stack effect [Pa]
P_o : Outdoor pressure [Pa]
C_d : Draft coefficient
h : Vertical distance from neutral pressure height [m]
T_o : Outdoor temperature [K]
T_i : Indoor temperature [K]
R_a : Gas constant for air [J/(kg · K)]
g_c : Dimensional constant, 1 [(kg·m)/(N · s^2)]

Space Heating Load

Categories of Heat Loss



Ref., ASHRAE GRP 158, *Cooling and heating Load Calculation Manual*, 2nd ed., 1992

FIGURE Pressure difference due to chimney effects

Categories of Heat Loss

5. Heat loss through the duct system

- **Heat loss through the duct system**

$$q = UA_s\Delta T_m$$

U : Overall heat transfer coefficient

A_s : Exterior surface area of duct

Δt_m : Mean temperature difference between air inside duct and surrounding

Categories of Heat Loss

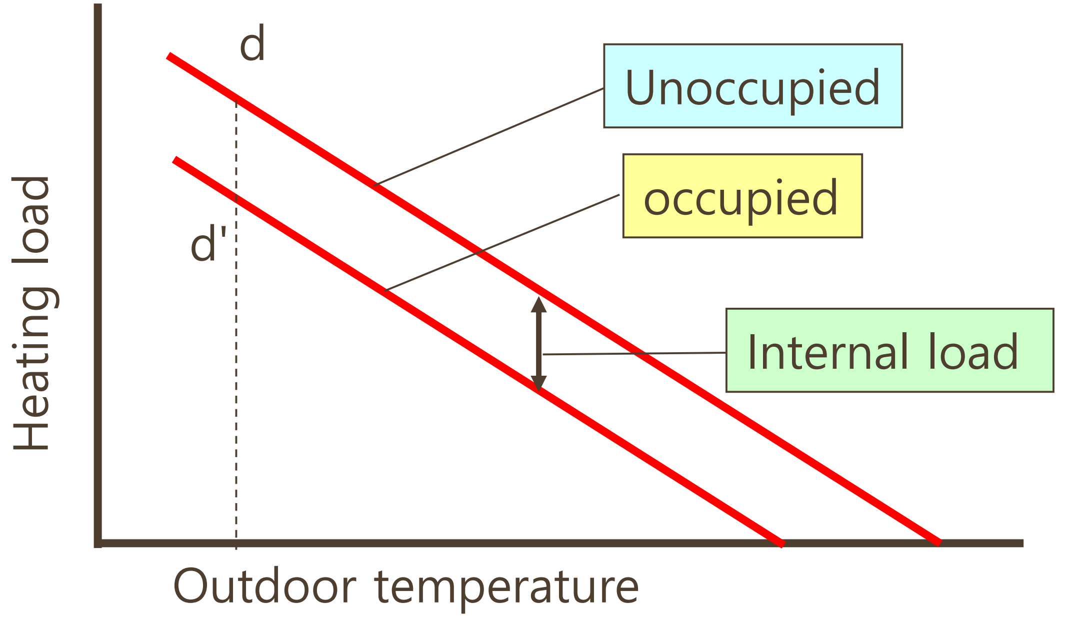
Example

- Calculate the heat loss for circular duct when air flows 93 ccm at 49 ℃. The length and diameter of duct are 7.62 m and 0.4 m in respectively. The insulator of duct is 2.5 cm in fiber glass and overall heat transfer coefficient is 0.0011 kW/m^2K). The outside temperature is -11 ℃.

$$q = UA_s\Delta T_m$$

Space Heating Load
Bin Method

- A hand-calculation procedure where energy requirements are determined at many outdoor temperature conditions.
- The "bin method" refers to a procedure where monthly weather data is sorted into discrete groups (bins) of weather conditions.
- Each bin contains the number of average hours of occurrence during a month or year of a particular range of weather condition.



Efficiency

❑ Partial load factor (PLF)

$$PLF = \frac{\text{Theoretical energy requried at port load}}{\text{Actual energy requried at part load}} = \frac{\text{Theoretical run time}}{\text{Actual run time}} \quad \textbf{Eq. (1)}$$

$$= 1 - D_C\left[1 - \frac{unoccupied\ load}{Equipment\ capacity}\right]$$

D_C : Performance degradation coefficient

❑ Occupied runtime [hr]

$$\frac{Q_{occupied} \times t_{occupied}}{C_{Equipment} \times PLF_{occupied}}$$

❑ Unoccupied runtime [hr]

$$\frac{Q_{unoccupied} \times t_{unoccupied}}{C_{Equipment} \times PLF_{unoccupied}}$$

❑ Occupied Electric resistance input [kW]

$$Q_{occupied} - C_{Equipment}$$

❑ Unoccupied Electric resistance input [kW]

$$Q_{unoccupied} - C_{Equipment}$$

❑ Total Energy [kWh]

$$t_{occupied}\left(P_{input} + R_{occupied}\right) + t_{unoccupied}\left(P_{input} + R_{unoccupied}\right)$$

Bin Data

❑ BIN data

- Indicators representing the annual distribution of ambient temperature in a specific area by time zone.
- The building cooling and heating load is calculated using the highest and lowest temperatures of BIN data.
- It is specified in KSC 9306 in Korea and is produced based on weather information of 10 years (1998-2007).
- Cooling hours: June 1st to Sept 30th, 11:00 to 23:00, 24°C to 38°C.
- Heating hours: Nov 1st to Feb 28th, 00:00 to 24:00, -15°C to 15°C

Table 1 BIN temperature data for cooling(KS C 9306)

BIN Temp.(j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Dry bulb Temp.(℃)	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
BIN hours(h)	152	146	140	130	112	89	69	47	29	14	6	4	2	1	0	941

Table 2 BIN temperature data for heating(KS C 9306)

BIN Temp.(j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Dry bulb Temp.(℃)	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
BIN hours(h)	2	3	5	6	6	9	14	21	30	43	59	77	89	114	136	317
BIN Temp.(j)	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
Dry bulb Temp.(℃)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
BIN hours(h)	182	187	191	192	184	173	140	138	124	106	88	74	58	45	36	2849

Space Heating Load

Bin Data

Area	Temp. / Total	BIN hours for heating season														
		-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
Gangneung	2,784	0	0	1	2	2	6	9	20	27	39	61	78	105	122	149
Gwangju	2,761	0	0	0	0	1	2	5	10	20	31	52	77	111	138	178
Gunsan	2,807	0	0	1	3	4	8	15	26	37	63	78	108	136	171	197
Daegu	2,767	0	0	0	1	1	3	6	11	18	33	51	76	100	118	152
Daejeon	2,808	2	2	6	8	12	21	37	49	66	84	101	124	146	172	186
Mokpo	2,771	0	0	0	0	0	0	1	3	7	17	29	51	82	118	171
Busan	2,684	0	0	0	1	0	1	1	2	7	14	24	33	51	75	90
Seoul	2,810	4	5	10	15	22	36	55	76	90	95	112	126	138	144	174
Andong	2,832	6	5	9	13	22	30	50	60	82	95	110	133	159	186	185
Yeongwol	2,845	39	22	30	42	47	59	71	83	96	113	136	145	153	174	187
Ulsan	2,738	0	0	0	1	1	1	3	6	12	20	38	56	74	94	133
Incheon	2,826	1	2	4	9	13	23	28	54	74	96	118	125	136	156	169
Jeonju	2,771	0	1	1	3	6	10	21	27	43	62	75	96	132	159	189
Jeju	2,616	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9
Jinju	2,770	0	1	2	3	5	10	24	35	52	70	87	102	130	157	161
Cheonan	2,817	10	9	14	18	30	35	51	63	76	98	118	151	159	182	184
Cheongju	2,809	1	4	5	8	16	23	36	52	72	85	109	131	139	162	179
Chundheon	2,850	50	29	38	51	53	63	72	88	97	116	131	152	165	175	178
Pohang	2,735	0	0	0	1	1	2	4	7	11	25	40	57	78	95	116

Bin Method Calculation

❑ Sequence of Bin method

1) Set building load using load curve
2) Set unit capacity
3) Calculate theoretical operating time as ratio of building load and unit capacity
4) Calculate partial load ratio
5) Calculate real operating time ratio
6) Calculate real operating time (Bin hour * Real operating time ratio)
7) Calculate power consumption of unit
8) Calculate energy required (Power consumption of unit * Real operating time)
9) Set the cost of unit energy
10) Calculate energy cost of a single bin (Cost of unit energy * Energy required)
11) Repeat 1~10 for all the other bins

Example

- Consider a building in Oklahoma City, Oklahoma, which is operated on two shifts as shown in Fig. 1. The load profiles are given by

Shift A, Occupied : $\dot{q}_o = 32.8 - 2.57t_o$ **[kW]** **Eq. (2)**

Shift B, Unoccupied : $\dot{q}_{uo} = 47.1 - 2.57t_o$ **[kW]** **Eq. (3)**

The heat pump performance is shown in Table 4 with a degradation coefficient of 0.25. Compute the energy required to heat the building assuming all the applicable bins in Table 2 and 3 occur during the heating season and the building is maintained at 21.1^{o}C during both shifts.

- **Fig. 1 Converting bin hours into shifts A and B**
- **Table 1 Computation of Fraction of Bin Hours in Each Shift**
- **Table 2 Annual Bin Weather Data for Oklahoma City, Oklahoma, 35° 24′ N 97° 36′ W, 390 m Elevation**
- **Table 3 Calculation of Bin Hours for Each Shift (from Table 1, 2)**
- **Table 4 Annual Bin Hours for Oklahoma City, Oklahoma**
- **Fig. 2 Heat-pump operating characteristics.**
- **Table 5 Heat Pump Heating Capacities at 6000 CFM**
- **Solution**

Space Heating Load

Example

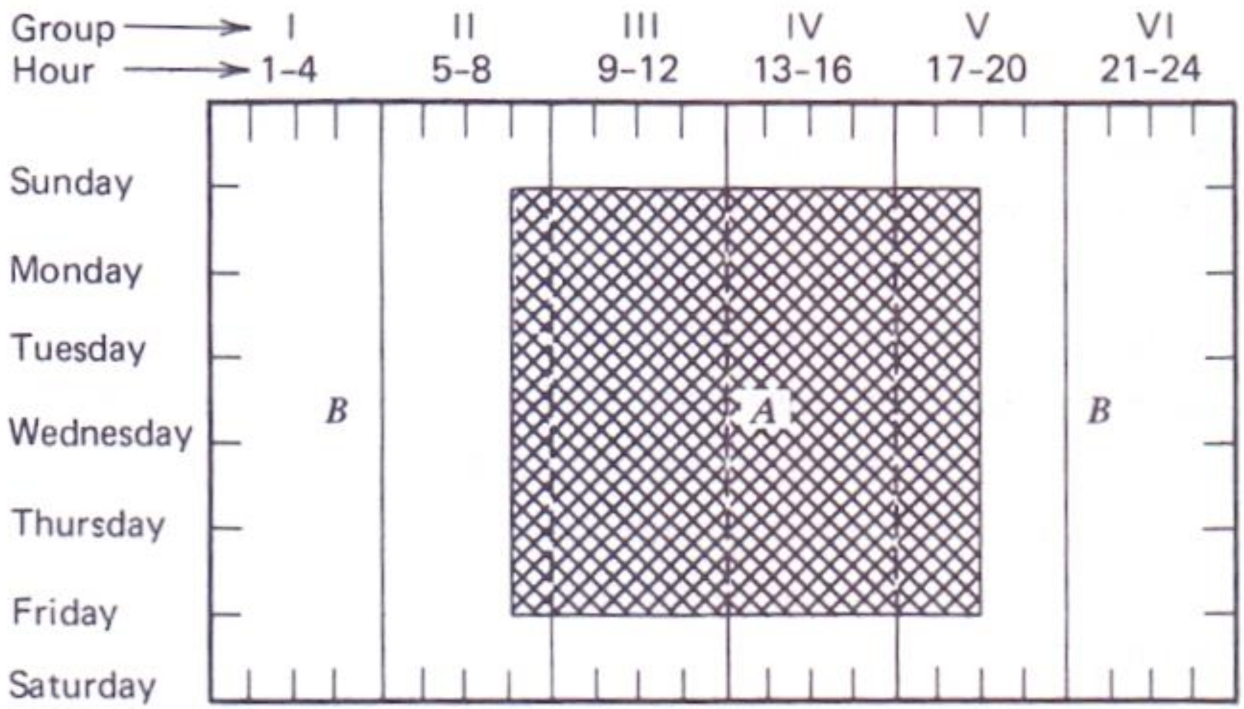


Fig. 1 Converting bin hours into shifts A and B

Example

Table 1 Computation of Fraction of Bin Hours in Each Shift

Time Group	Hour in Shift A in Each group	Days in Shift A in Each Group	Total Occupied Hours in Each Group	Total Hours in Each Group	Shift A fraction in Each Group	Shift B fraction in Each Group
I	0	0	0	28	0	1
II	1	5	5	28	0.18	0.82
III	4	5	20	28	0.71	0.29
IV	4	5	20	28	0.71	0.29
V	2	5	10	28	0.36	0.64
VI	0	0	0	28	0	1

Example

Table 2 Annual Bin Weather Data for Oklahoma City, Oklahoma, 35° 24′ N 97° 36′ W, 390 m Elevation

Bin Temperature °C	Time Group						
	1-4	5-8	9-12	13-16	17-20	21-24	Total
Hours of Dry-bulb Occurrence							
37.8 ~ 40.0	0	0	0	2	0	0	2
35.0 ~ 37.2	0	0	5	70	29	0	104
32.2 ~ 34.4	0	0	55	153	88	0	296
29.4 ~ 31.7	2	0	116	145	120	24	407
26.7 ~ 28.9	20	33	148	153	168	96	618
23.9 ~ 26.1	121	93	132	115	144	171	776
21.1 ~ 23.3	229	221	138	118	117	186	1009
18.3 ~ 20.6	161	161	98	98	93	136	747
15.6 ~ 17.8	120	99	95	135	96	97	642
12.8 ~ 15.0	87	104	105	108	116	81	601
10.0 ~ 12.2	96	103	137	94	133	121	684
7.2 ~ 9.4	98	96	100	66	87	122	569
4.4 ~ 6.7	150	121	98	67	91	140	667
1.7 ~ 3.9	144	153	89	54	76	105	621
-1.1 ~ 1.1	107	140	74	40	50	93	504
-3.9 ~ -1.7	63	51	27	24	24	40	229
-6.7 ~ -4.4	36	41	23	17	23	31	171
-9.4 ~ -7.2	19	37	17	1	5	16	95
-12.2 ~ -10.0	7	7	3	0	0	1	18

Space Heating Load

Example

Table 3 Calculation of BIN Hours for each shift (from Table 1, 2)

	Shift A hours Each Time Group						Shift A Hours	Shift B Hours
Bin Temperature °C	I	Ⅱ	Ⅲ	IV	V	VI		
	0.00[a]	0.18[a]	0.71[a]	0.71[a]	0.36[a]	0.00[a]		
38.9	0	0	0	1	0	0	1	1
36.1	0	0	4	50	10	0	64	40
33.3	0	0	39	109	32	0	180	117
30.6	0	0	82	103	43	0	228	178
27.8	0	6	105	109	60	0	280	338
25.0	0	17	94	82	52	0	245	532
22.2	0	40	98	84	42	0	264	745
19.4	0	29	70	70	33	0	202	545
16.7	0	18	67	96	35	0	216	426
13.9	0	19	75	77	42	0	213	389
11.1	0	19	97	67	48	0	231	454
8.3	0	17	71	47	31	0	166	403
5.6	0	22	70	48	33	0	173	495
2.8	0	28	63	38	27	0	156	465
0.0	0	25	53	28	18	0	124	380
-2.8	0	9	19	17	9	0	54	185
-5.6	0	7	16	12	8	0	43	127
-8.3	0	7	12	1	2	0	22	74
-11.1	0	1	2	0	0	0	3	15
						Total	2861	5899

[a] : Shift A fraction

Space Heating Load

Example

Table 3 Annual Bin Hours for Oklahoma City, Oklahoma

Bin Temperature °C	Time Group 1~4 I	5~8 II	9~12 III	13~16 IV	17~20 V	21~24 VI	Total Hours
38.9	0	0	0	2	0	0	2
36.1	0	0	5	70	29	0	104
33.3	0	0	55	153	88	0	296
30.6	2	0	116	145	120	24	407
27.8	20	33	148	153	168	96	618
25.0	12	93	132	115	144	171	667
22.2	229	221	138	118	117	186	1009
19.4	161	161	98	98	93	136	747
16.7	120	99	95	135	96	97	642
13.9	87	104	105	108	116	81	601
11.1	96	103	137	94	133	121	684
8.3	98	96	100	66	87	122	569
5.6	150	121	98	67	91	140	667
2.8	144	153	89	54	76	105	621
0.0	107	140	74	40	50	93	504
-2.8	63	51	27	24	24	40	229
-5.6	36	41	23	17	23	31	171
-8.3	19	37	17	1	5	16	95
-11.1	7	7	3	0	0	1	18

Space Heating Load

Example

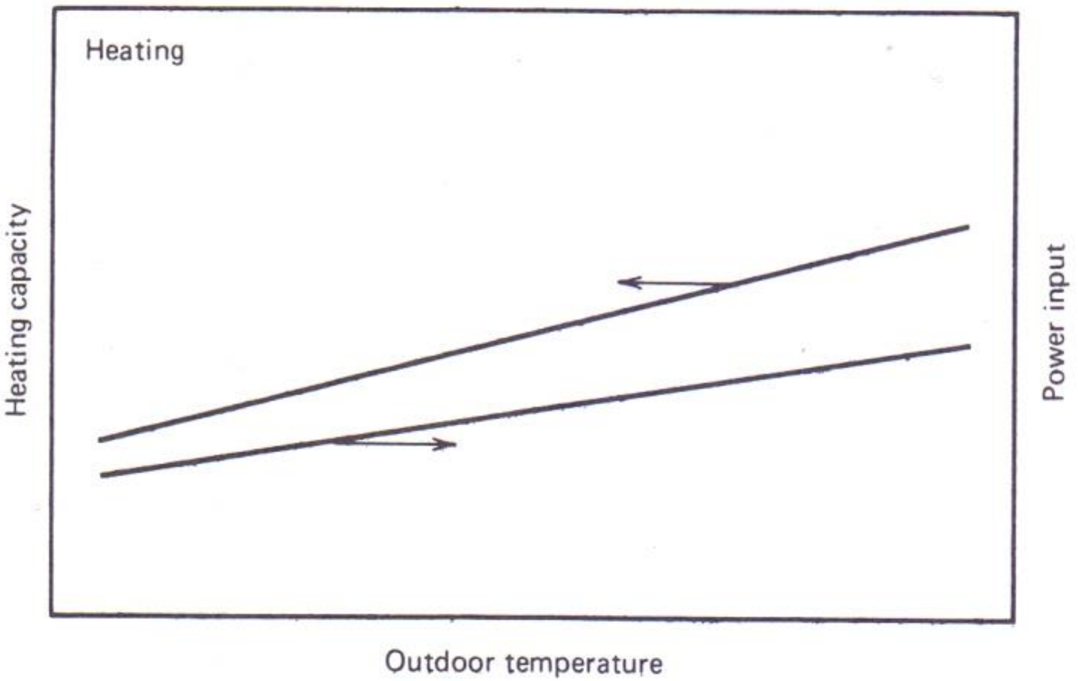


Fig. 2 Heat-pump operating characteristics.

Space Heating Load

Example

Table 5 Heat Pump Heating Capacities at 560 CMM

Outdoor Temperature, °C	Heating Capacity, kW at Indoor Dry Bulb Temperature, °C					Total Power Input, kW at Indoor Dry Bulb Temperature, °C			
	15.6	21.1	23.9	26.7		15.6	21.1	23.9	26.7
-19.4	20.7	20.2	20.0	19.8		12.9	13.3	13.5	13.7
-16.7	23.1	22.6	22.3	22.1		13.4	13.8	14.0	14.2
-13.9	25.6	25.0	24.7	24.4		13.8	14.2	14.5	14.7
-11.1	28.0	27.3	27.0	26.7		14.3	14.7	14.9	15.2
-8.3	30.3	29.7	29.3	29.0		14.7	15.2	15.4	15.7
-5.6	32.6	32.0	31.8	31.2		15.0	15.5	15.7	16.0
-2.8	35.3	34.4	33.8	33.5		15.3	15.8	16.0	16.3
0.0	37.6	36.8	36.2	35.6		15.5	16.0	16.3	16.6
2.8	41.2	40.0	39.7	39.1		16.0	16.6	16.8	17.1
5.6	46.5	45.3	44.7	44.1		16.9	17.4	17.7	18.0
8.3	51.7	50.6	50.0	49.4		17.7	18.3	18.6	18.9
11.1	55.3	54.1	53.5	52.6		18.2	18.8	19.1	19.4
13.9	59.1	57.6	56.7	56.2		18.7	19.3	19.7	20.0
16.7	62.6	61.2	60.3	59.4		19.2	19.9	20.2	20.5
19.4	66.2	64.4	63.8	62.9		19.7	20.4	20.7	21.0

Note: Correction factor – value at other air flow = (Value at 560 CMM X (Correction factor))

Air flow	490	630
Heating capacity	0.99	1.01
Power input	1.01	0.99

Example

Solution

The load profiles are given in a convenient form for use with the bin method. The balance temperature for each shift may be found by setting $\dot{q}_o$ and $\dot{q}_{uo}$ equal to zero.

Occupied:

$$\boldsymbol{t_o} = \mathbf{32.80}/\mathbf{2.57} = \mathbf{12.76}℃$$

and

Unoccupied:

$$\boldsymbol{t_{uo}} = \mathbf{47.10}/\mathbf{2.57} = \mathbf{18.30}℃$$

Therefore, bin temperatures greater than 18.3°C do not have to be considered.

Equations to express the steady-state heat pump performance can be derived from Table 5 as follows. Assuming linear dependence on the outdoor temperature, select two operating capacities and temperatures such as 29.7 kW at -8.3°C and 50.6 kW at 8.3°C and fit the points to a linear equation of the form Y = ax + b. For this case the heating capacity is

$$\boldsymbol{C} = \mathbf{1.26}\boldsymbol{t_o} + \mathbf{40.15}\ [\mathbf{kW}] \qquad \textbf{Eq. (4)}$$

Using the same approach for the power input

$$\boldsymbol{P} = \mathbf{0.187}\boldsymbol{t_o} + \mathbf{16.75}\ [\mathbf{kW}] \qquad \textbf{Eq. (5)}$$

Example

Bin Energy Calculation for Example

Bin Temperature °C	Occupied Hours	Unoccupied Hours	Occupied Load kW	Unoccupied Load kW	Equipment Capacity kW	Occupied PLF
1 Table 1, 3	2 Table 1, 3	3 Table 1, 3	4 Given Eq. (2)	5 Given Eq. (3)	6 Given Eq. (4)	7 Eq. (1) D_c = 0.25
16.7	216	426	0.0	4.3	61.0	0.75
13.9	212	389	0.0	11.5	57.5	0.75
11.1	230	454	4.2	18.6	54.1	0.77
8.3	166	403	11.3	25.7	50.6	0.81
5.6	172	495	18.5	32.9	47.1	0.85
2.8	156	465	25.6	40.0	43.6	0.9
0.0	124	380	32.8	47.2	40.1	0.95
-2.8	54	175	39.9	54.3	36.7	1
-5.6	54	127	47.1	61.5	33.2	1
-8.3	21	74	54.2	68.6	29.7	1
-11.1	3	15	61.4	75.8	26.2	1

Space Heating Load

Example

Bin Energy Calculation for Example (Continued)

Unoccupied PLF	Occupied Run Time Hr	Unoccupied Run Time Hr	Power Input kW	Occupied Electrical Resistance Input kW	Unoccupied Electrical Resistance Input kW	Total Energy kWh
8 Eq. (1) D_c = 0.29	9 4 x 2/(6 x 7)	10 5 x 3/(6 x 8)	11 Given Eq. (5)	12 4 - 6	13 5 - 6	14 9 x (11 + 12) + 10 x (11 + 13)
0.77	0.0	39.3	19.8			776.7
0.80	0.0	96.9	19.3			1,867.0
0.84	23.2	186.9	18.8			3,941.1
0.88	46.2	233.9	18.2			5,108.8
0.92	79.6	373.9	17.7			8,039.4
0.98	102.2	435.8	17.2			9,259.8
1.00	106.1	446.7	16.7		7.0	12,368.6
1.00	58.8	259.4	16.2	3.3	17.6	9,908.6
1.00	62.4	235.3	15.7	13.8	28.2	12,165.8
1.00	38.3	171.0	15.2	24.4	38.8	10,741.5
1.00	7.0	43.3	14.6	35.0	49.4	3,123.8
					TOTAL	77,301.1

Cooling Load

Cooling Load

- The amount of energy to be removed from space to maintain constant temperature and humidity.
- It is different to heat acquisition because solar heat coming through the open space and radiation by the inner surface of wall and object do not heat indoor air directly.
- Decrease of maximum cooling load by thermal delay decide size of air conditioner.

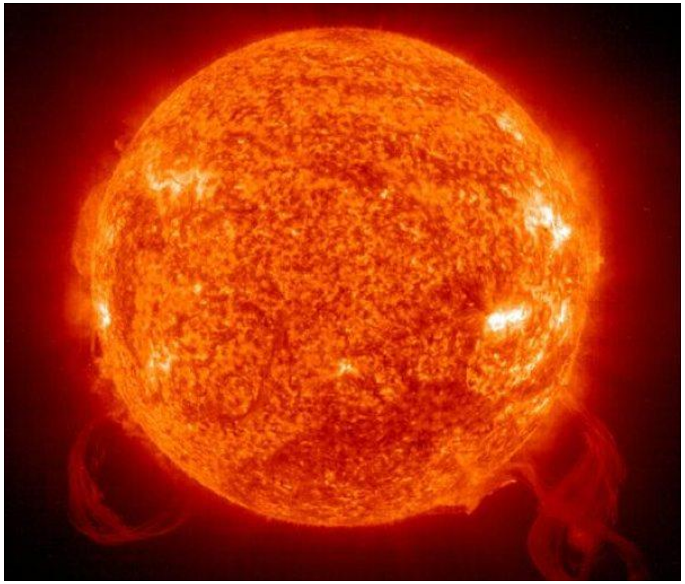
Types of Cooling Load

Division		Contents	Type of heat
Indoor load	Solar radiation heat	• through the glass	Sensible Heat
		• through the wall & roof	Sensible Heat
	Conduction by thermal difference	• through the glass	Sensible Heat
		• through the wall & roof	Sensible Heat
		• through the mid-wall, floor and ceiling	Sensible Heat
	Internally generated heat	• by lighting	Sensible Heat
		• by human body	Sensible + Latent
		• by indoor facilities	Sensible + Latent
	Intrusion of outside air	• Air leakage of the window chassis and door crevice	Sensible + Latent
	Others	• Heat loss at supply duct	Sensible + Latent
		• Heat generation at ventilator	Sensible + Latent
Outdoor load	Introduction of outside air	• cool or humidify the outdoor air to indoor air	Sensible + Latent
Others	Others	• Heat loss at supply duct, pipe	Sensible + Latent
		• Heat generation at pump	Sensible + Latent

Solar Radiation Heat

❑ Heat gain and lose of building

They are affected by location of sun, cleanliness of air, characteristic and direction of building.



❑ Amount of solar radiation

$$\alpha + \rho + \tau = 1$$

α : Absorptance
The fraction of the total incident thermal radiation absorbed

ρ : Reflectance
The fraction of the total incident thermal radiation reflected

τ : Transmittance
The fraction of the total incident radiation transmitted through the body

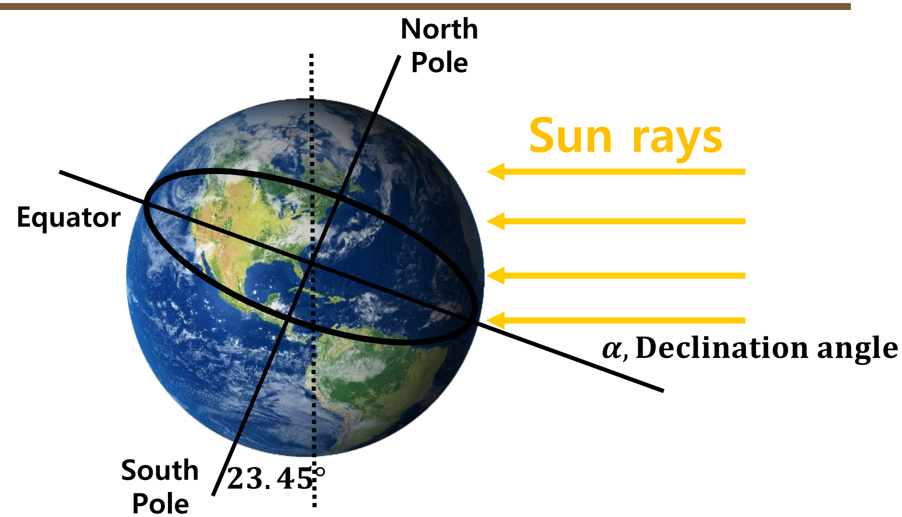
Cooling Load

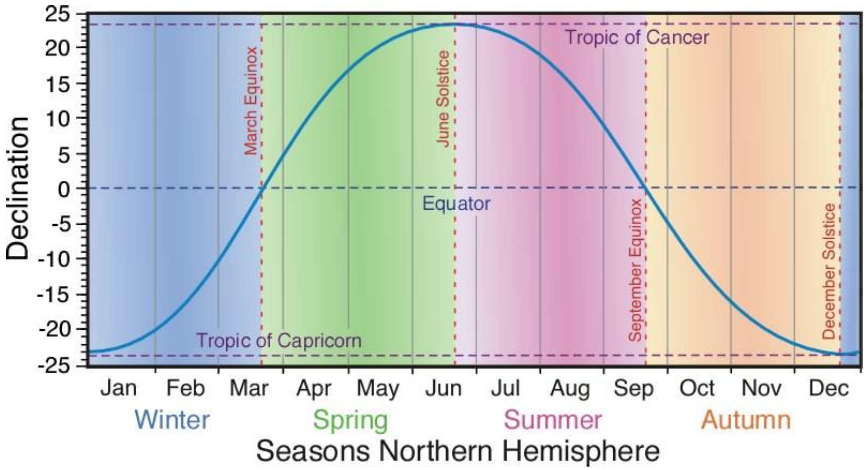
Solar Data

※ Solar data for 21st day of each month

Month	Equation of Time (min)	Declination (degree)
January	11.2	-20.0
February	-13.9	-10.8
March	-7.5	0.0
April	1.1	11.6
May	3.3	20.0
June	-1.4	23.45
July	-6.2	20.6
August	-2.4	12.3
September	7.5	0.0
October	15.4	-10.5
November	13.8	-19.8
December	1.6	-23.45

Ref., ASHRAE Cooling and Heating Load Calculation Manual, 2nd ed., 1992.





Ref., www.atmo.arizona.edu

Local solar time(LST) = Local civil time(LCT) + Equation of time(EOT)

Heat Gain through Fenestrations

❑ Fenestrations :

- Any glazed aperture in a building envelope

- Glazing materials, either glass or plastic
- Framing, mullions, muntin, and dividers
- External shading devices
- Internal shading devices
- Integral (between-glass) shading systems

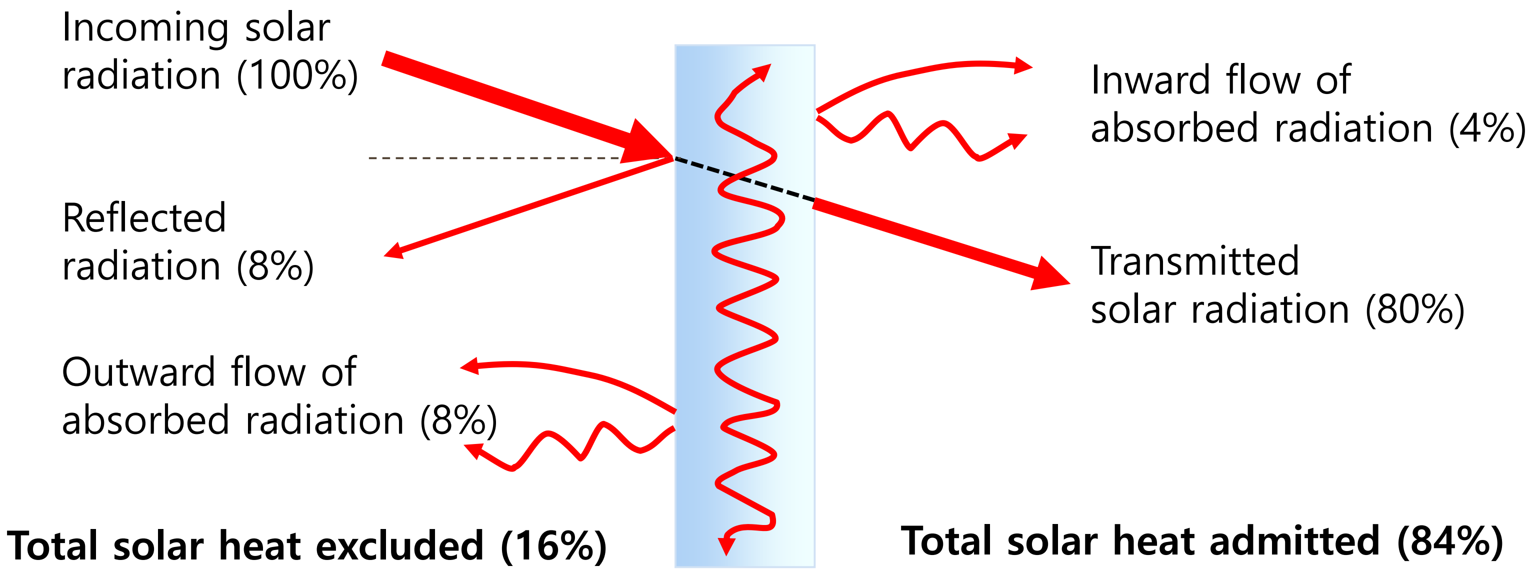
Total heat gain = Sunlight gain + Conduction gain

Conduction heat gain

= Overall heat transfer coefficient X outdoor-indoor temperature difference

Heat Gain through Fenestrations

❑ Solar radiation projected on clear plate glass



Total heat admission through glass = Radiation transmitted through glass
+ Inward flow of absorbed solar radiation
+ Conduction heat gain

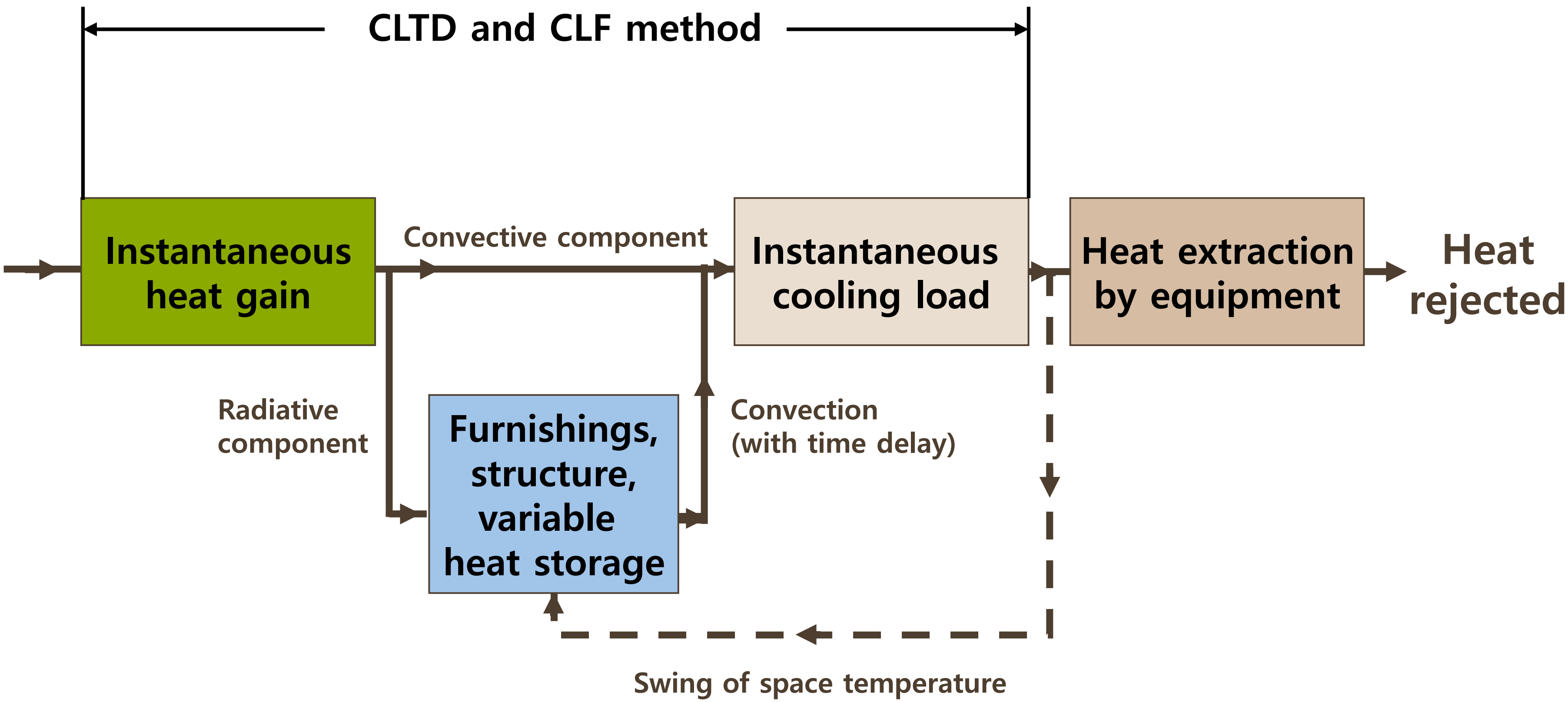
Solar heat gain factor (SHGF)

- **On a given time and direction, solar heat gain per unit area and unit time through the double reinforced glass**

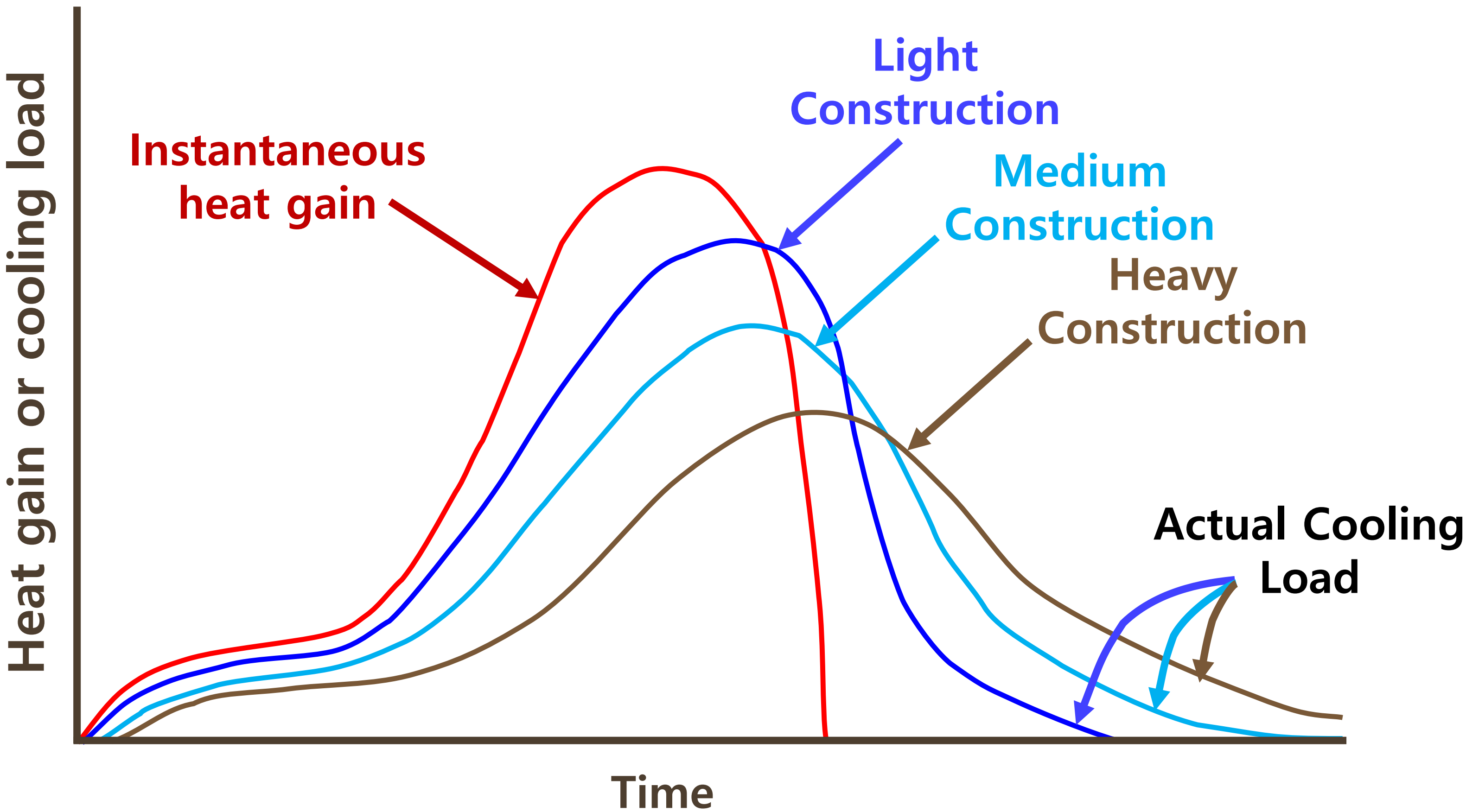
  - **Transmitted solar heat gain factor (TSHGF)**

  - **Absorbed solar heat gain factors (ASHGF)**

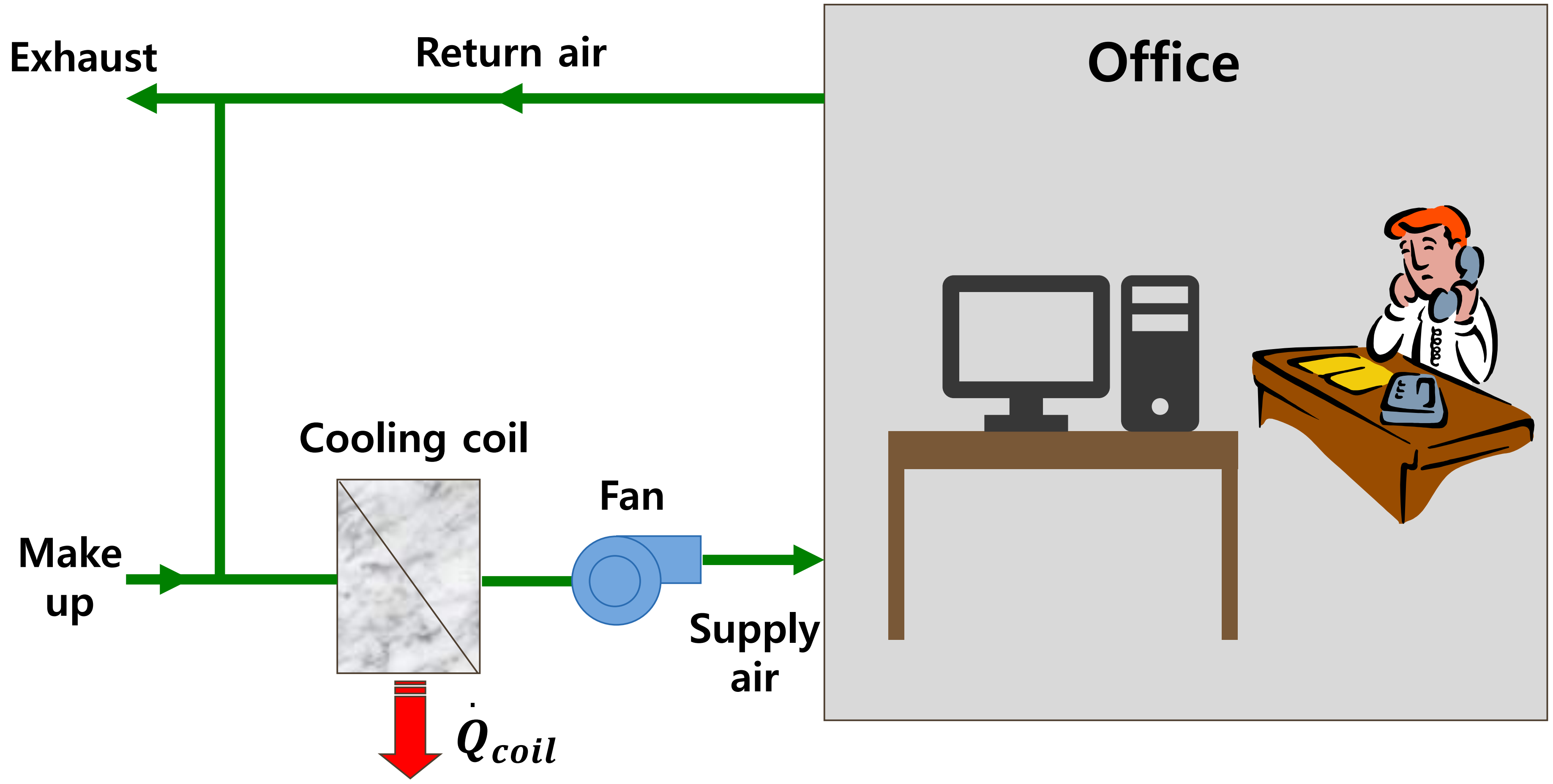
Relationship of Heat Gain to Cooling Load



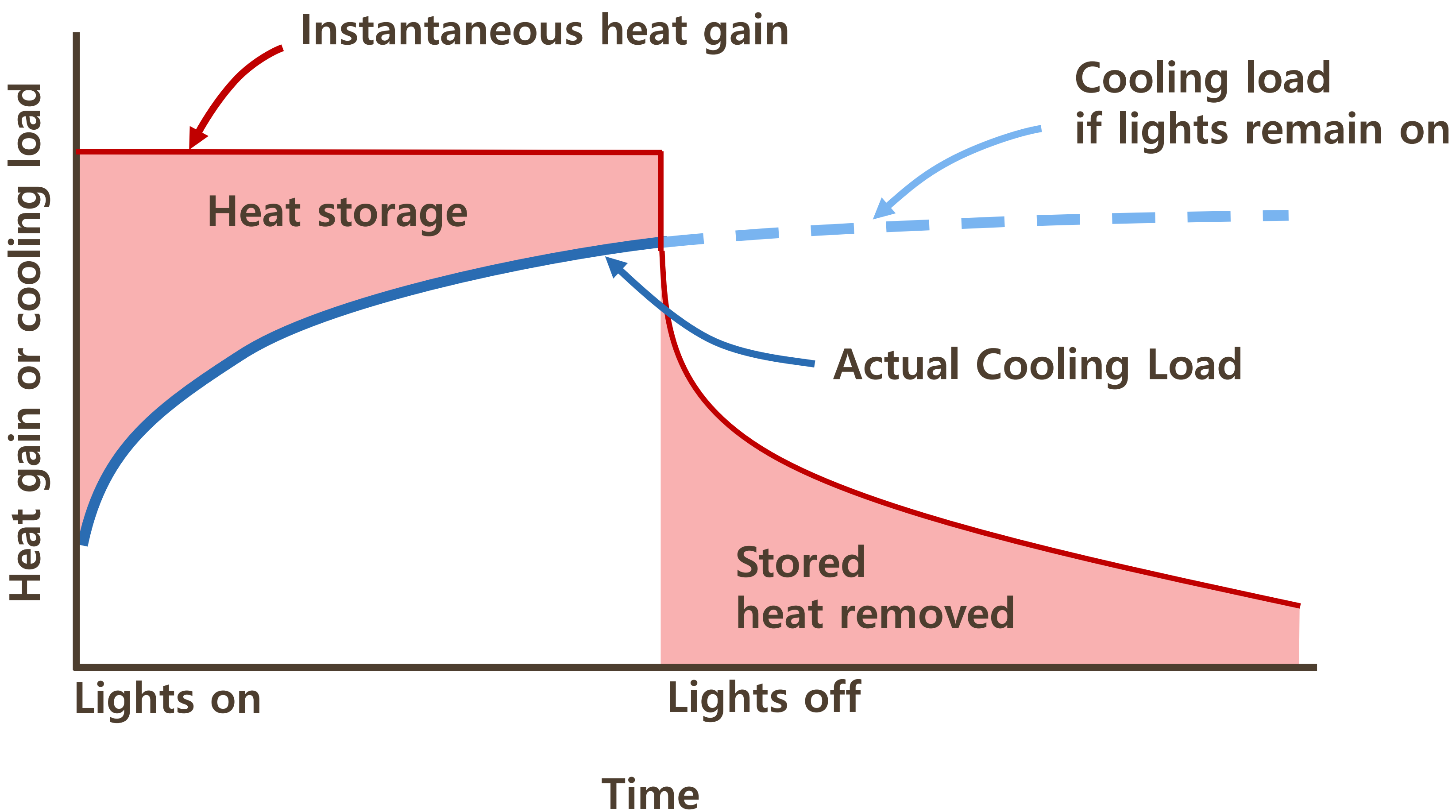
Cooling load with various constructions



Cooling Load of Forced Air Cooling



Cooling Load from Fluorescent Lights



Cooling Load Calculation

- Heat balance method

- Transfer function method

- CLTD/SCL/CLF method

  (Cooling Load Temperature difference / Shading Cooling Load / Cooling Load Factor)

Cooling Load

Heat Balance Method

- The energy flow in each section is equilibrium
- Get a solution by energy equilibrium of each space's air separating by each wall, roof and ceiling.

$$\dot{q}_{\theta} = [\sum_{i=1}^{6} h_{ci}(t_{i,\theta} - t_{a,\theta})]A_i + \rho c_p \dot{Q}_{i,\theta}(t_{o,\theta} - t_{a,\theta}) + \rho c_p \dot{Q}_{v,\theta}(t_{v,\theta} - t_{a,\theta}) + \dot{q}_{s,\theta} + \dot{q}_{l,\theta} + \dot{q}_{e,\theta}$$

ρ = Density of air

c_p = Specific heat of air

$\dot{Q}_{i,\theta}$ = Volumetric flow rate of outdoor air entering into the room at time Θ

$t_{o,\theta}$ = Outdoor air temperature at time Θ

$\dot{Q}_{v,\theta}$ = Ventilating air volume flow rate at time Θ

$t_{v,\theta}$ = Ventilating temperature at time Θ

$\dot{q}_{s,\theta}$ = Solar heat radiation amount into the room at time Θ

$\dot{q}_{l,\theta}$ = Lighting heat radiation into the room at time Θ

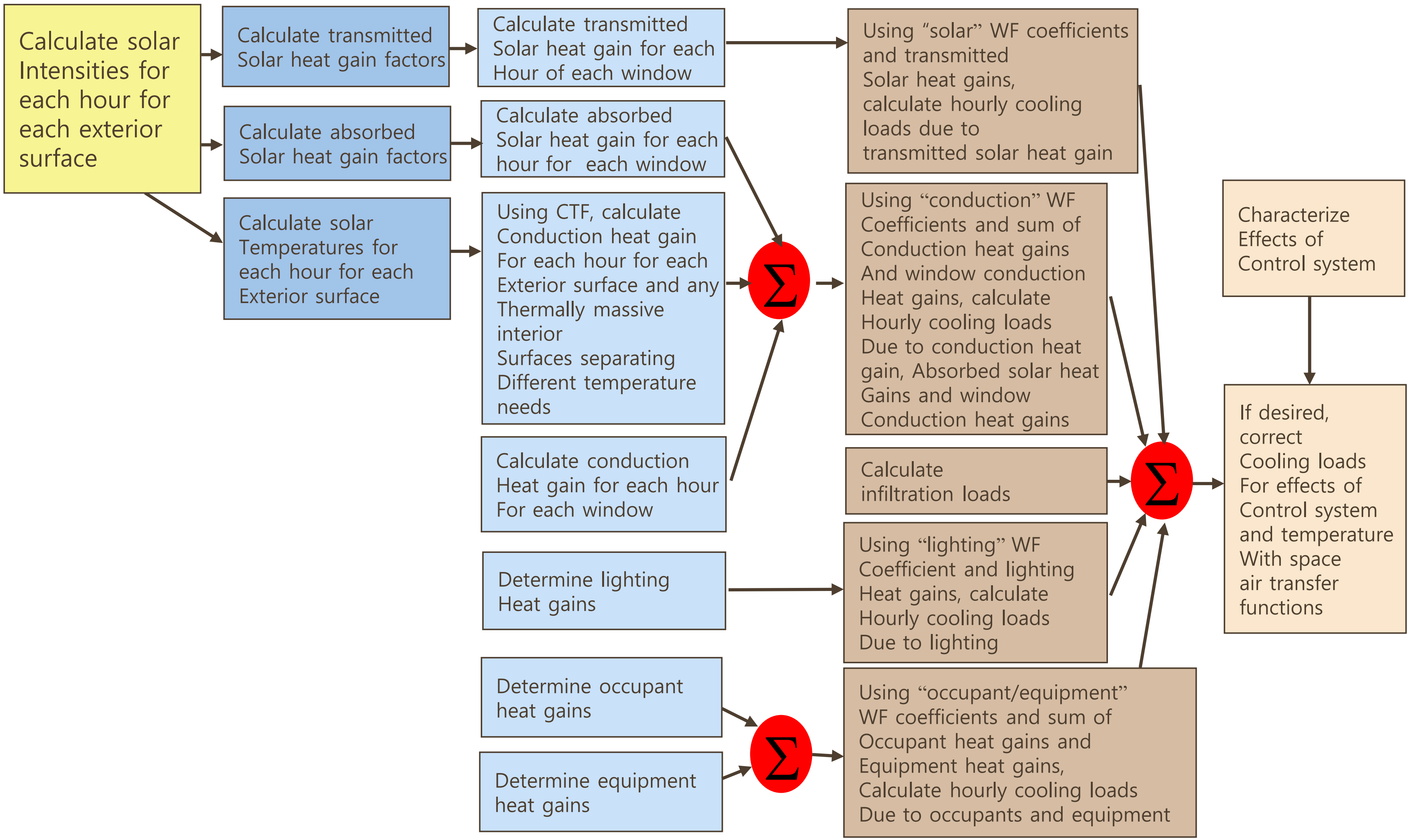
$\dot{q}_{e,\theta}$ = Facility heat radiation into the room at time Θ

The Transfer Function Method

- **Specification**
  - Time rating that relates variables of past values and others at discontinuous time interval
  - Derived from response coefficient

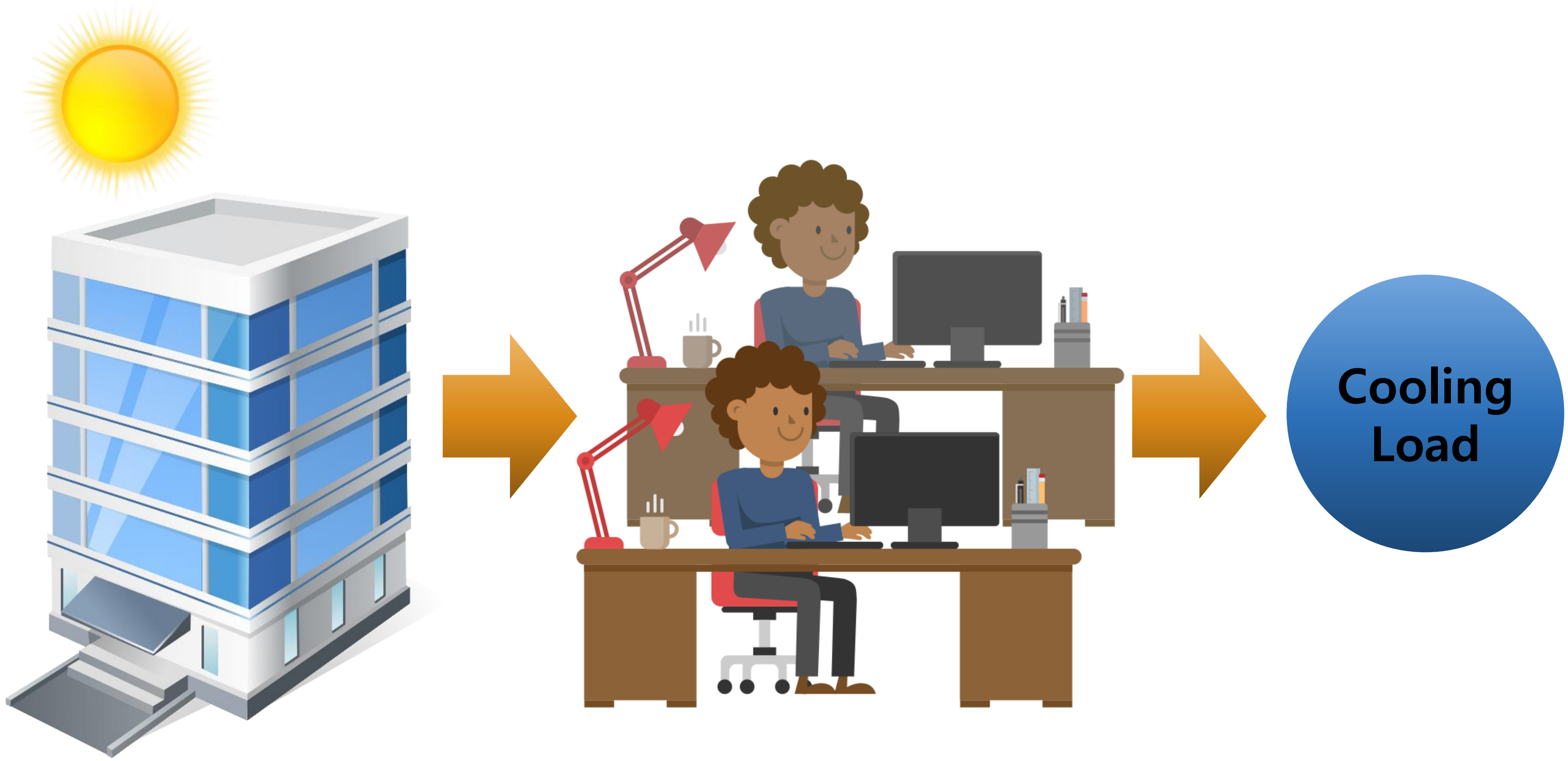
- **Type**
  - Conduction transfer function
  - Room transfer function

Overview of Transfer Function



Cooling Load

Order Of Transfer Function Calculation



Exterior heat gain **Interior heat gain**

CLTD Method

❑ Cooling Load Temperature Difference (CLTD)

Temperature difference of cooling load of the ceiling, wall and glass (exterior cooling load)

$$q = UA(CLTD)$$

A : Area of the ceiling, wall and glass calculated by floor plan drawing (m^2)

U : Total heat transfer coefficient of the ceiling, wall and glass

CLTD Method

- Following CLTD example's conditions are given below.
  - All conditions are steady-state.
  - Indoor / Outdoor temperature : 26 ℃ / 35 ℃
  - Maximum temperature range 12 ℃

Structure	Structure's characteristic and material	CLTD value per time at July				
		6 AM	12 PM	15 PM	18 PM	0 AM
Ceiling	25mm Wood	-3	42	50	33	1
	50mm high-density concrete	2	17	34	39	15
	Steel sliding	8	9	21	31	23
Wall (South direction)	25mm wood	0	12	21	18	6
	100mm insulator	4	8	13	14	9
	300mm high-density concrete	7	4	7	12	13

Modified CLTD Method

- Use the Modified CLTD if the above criteria does not fit.

Modified CLTD = CLTD + (78 – Indoor temperature)
+ (Modified outdoor temperature – 85)

※ Modified outdoor temperature in Fahrenheit
= Designed outdoor temperature – (Daily temperature range / 2)

CLTD Method Example

Question

One-story building located in Las Vegas, Nevada has 50mm high-density concrete ceiling. Find the value of cooling load of 100 m^2 at solar time 6 AM and 6 PM by CLTD method. Designed outdoor temperature is 41℃, daily temperature range is 1.11℃, designed indoor temperature is 23℃ and U = 0.07.

Solution

1) Modified outdoor temperature = 41 – (1.11/2) = 40.445 ℃
2) 6 AM CLTD = 7 + (26 – 23) + (40.445 – 29.44) = 21.005 ℃
3) 6 PM CLTD = 78 + (26 - 23) + (40.445 - 29.44) = 92.005 ℃
4) 6 AM cooling load

   q = UA(CLTD) = 0.07(100)21.005 = 147.035 W
5) 6 PM cooling load

   q = UA(CLTD) = 0.07(100)92.005 = 644.035 W

SCL Method

❑ Shading Cooling Load (SCL)

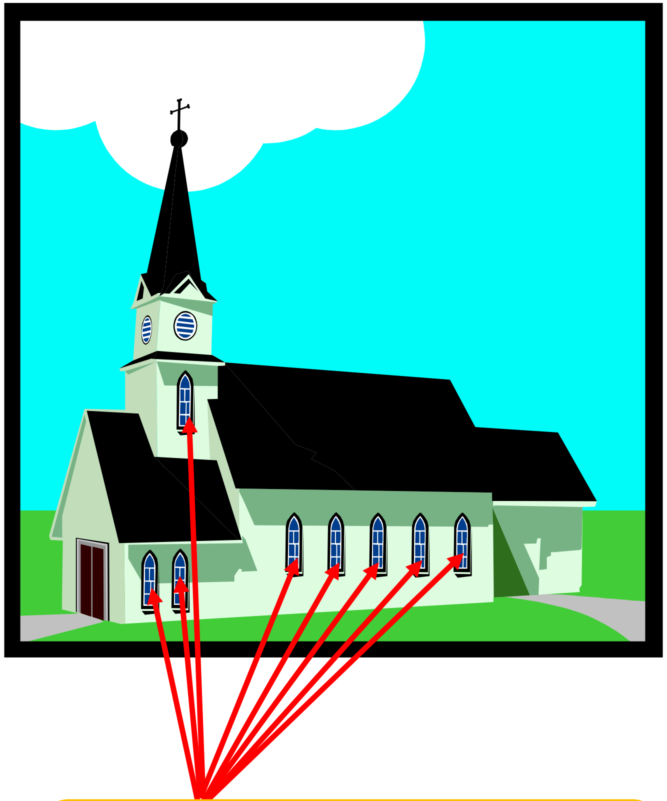
Solar cooling load factor for the presence or absence of internal shading

❑ Shading Coefficient (SC)

$$SC = \frac{\text{Solar heat gain of fenestration}}{\text{Solar heat gain of DSA}}$$

❑ Shading Coefficient (SC)

$$q = A(SC)(SCL)$$



Solar load through glass

SCL Method

- **Shielding coefficient(SC) of insulating / insulation glass**

Type of Glass	Nominal Thickness		Solar Trans.[a]	Shading Coefficient	
				h_0 = 4.0	h_0 = 3.0
	In.	mm		BTU/(hr-ft²-F)	BTU/(hr-ft²-F)
A. Single Glass					
Clear	1/8	3.2	0.86	1.00	1.00
	1/4	6.4	0.78	0.94	0.95
	3/8	9.5	0.72	0.90	0.92
	1/2	12.7	0.67	0.87	0.88
Heat absorbing	1/8	3.2	0.64	0.83	0.85
	1/4	6.4	0.46	0.69	0.73
	3/8	9.5	0.33	0.60	0.64
	1/2	12.7	0.24	0.53	0.58
B. Insulating Glass[b]					
Clear out. Clear in	1/8[c]	3.2	0.71[e]	0.88	0.88
Clear out, clear in	1/4	6.4	0.61	0.81	0.82
Heat absorbing[d], clear in	1/4	6.4	0.36	0.55	0.58

Ref., ASHRAE Handbook, Fundamentals Volume, 1992

[a] Refer to manufacturer's literature
[b] Refer to factory-assembled units or windshield chassis on basic glass by using 3/16, 1/4 or 1/2 air space
[c] Window thickness (Not assembled unit's thickness)
[d] Refer to ray, bronze and green colored heat-absorption glass
[e] Transmissivity of assembled unit

CLF Method

Human body

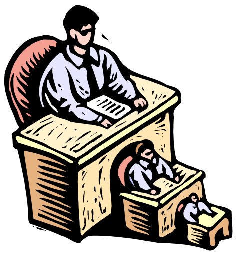
Cooling Load Factor(CLF)

- Coefficient related to the time in the room

$$q = N(SHG_p)(CLF)$$

SHG_p : Sensible heat generated by human

N : The number of people in the room



Lighting

Cooling Load Factor(CLF)

- Coefficient by lighting per unit time

$$q = WF_{ul}F_{sa}(CLF)$$

F_{ul} : Lighting Ratio

F_{sa} : Special allowable factor

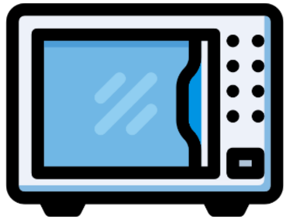
Power Requirement

Cooling Load Factor(CLF)

- Coefficient by continuous operation time & hood processing

$$q_{sensible} = q_{input}F_L\,(CLF)$$

F_l : Load ratio



CLF Method

- **Example of CLF values in no heat generation by human or facility case**

Type	Continuously spending time in the room	The elapsed time after someone comes into the room or facility operates				
		4	8	12	18	20
65mm concrete floor / ceiling	2	0.08	0.01	0	0	0
Carpet floor	8	0.95	0.98	0.04	0.01	0.01
Plaster wall	10	0.95	0.98	0.12	0.01	0.01
Shield room	16	0.96	0.99	0.99	0.12	0.05
65mm concrete floor / ceiling	2	0.11	0.04	0.01	0	0
Vinyl floor	8	0.85	0.95	0.13	0.03	0.02
Plaster wall	10	0.85	0.95	0.24	0.05	0.03
Shield room	16	0.87	0.95	0.98	0.25	0.15

Cooling Load

CLF Method

- **Example of CLF value by lighting**

Type	Continuously lighting time	The elapsed time after lighting				
		4	8	12	18	20
65mm concrete floor / ceiling	8	0.96	0.98	0.03	0.01	0.01
Carpet floor	10	0.97	0.98	0.07	0.02	0.02
Plaster wall	12	0.97	0.98	0.98	0.02	0.02
Shield room	14	0.97	0.98	0.99	0.03	0.03
65mm concrete floor / ceiling	8	0.93	0.96	0.05	0.02	0.02
Vinyl floor	10	0.93	0.96	0.13	0.03	0.03
Plaster wall	12	0.93	0.96	0.97	0.05	0.04
Shield room	14	0.94	0.97	0.98	0.07	0.05

CLF Method

- Example of CLF value by machine having a hood

Type	Continuously operating time	The elapsed time after operation				
		4	8	12	18	20
65mm concrete floor / ceiling	8	0.93	0.97	0.06	0.01	0.01
Carpet floor	10	0.93	0.97	0.17	0.01	0.01
Plaster wall	12	0.94	0.97	0.99	0.03	0.03
Shield room	14	0.94	0.99	0.99	0.07	0.04
65mm concrete floor / ceiling	8	0.79	0.93	0.19	0.04	0.03
Vinyl floor	10	0.79	0.93	0.34	0.07	0.04
Plaster wall	12	0.8	0.93	0.97	0.11	0.07
Shield room	14	0.8	0.93	0.97	0.21	0.13

CLF Method

- **Various load ratio of cook tools**

Heat Source	Cook tools	Load ratio
Electricity	Frying pot	0.03
	Oven	0.07
	Steam equipment	0.04
Gas	Frying pot	0.02
	Oven	0.08
	Gas stove	0.06

CLF Method Example

Question

There is big office having 10 personal office. There are four people in secretary room. There are drawing room, waiting room, secretary office and executive office. Find cooling load when solar time is 3 PM.

(1) Assume the number of people, the room having people, time.
(2) Assume a floating population
(3) Decide the number of people to calculate total heat gain by consider (1) & (2)
(4) Get sensible / latent heat amount by data in the table below.
(5) Calculate cooling load by sum of sensible and latent heat load.

TABLE Heat gain by people

Place	Activity	Sensible Heat [Btu/hr]	Sensible Heat [W]	Latent Heat [Btu/hr]	Latent Heat [W]
Theater	Sitting	225	66	105	31
Office, Home	Light working	245	72	155	45
Department store, Market	Working with standing	250	73	200	59
Dance Hall	Light dancing	305	89	545	160
Factory	Machine work	635	186	965	283
Gym	Exercising	710	208	1090	320

CLF Method Example

Solution

- **Following assumption would be reasonable**
  - 7 people are in personal office between 8 AM to 5 PM.
  - 3 secretaries and 1 guide are keeping the seat and always be there.
  - 2 people are in waiting room because waiting room is very flexible.
  - 1 person each in the executive office and secretary office
  - Total people is 15 and every people do light work in sitting.
  - One male and one female as a group.
  - (Light work) Sensible heat is 245Btu/hr and latent heat is 155Btu/hr

- **In this case, sensible heat load by people is following below.**

$$q_1 = 15 \times 155 = 2325\ Btu/hr$$

- **Assume everyone eat lunch in this place. Then their whole staying time is 9 hours and 3 PM is 7th time to starting time. In this case, CLF is 0.93. Latent cooling load is following below.**

$$q_2 = 15 \times 245 \times 0.93 = 3418\ Btu/hr$$

- **Then, total cooling load at 3 PM is following below.**

$$q_1 + q_2 = 2325 + 3418 = 5743\ Btu/hr$$

- **Resident could go in and out by various schedule.**
  In this case, we should calculate by each person.

Load Calculation of Cooling Warehouse

1. Heat intrusion through heat-resistant wall

$$Q = UA\Delta T$$

Q : Heat intrusion [kcal/h]
U : Total heat transfer coefficient [kcal/m^{2}h℃]
A : Wall area [m^2]
ΔT : Temperature difference between outdoor and indoor air [℃]

2. Heat intrusion by ventilation

$$Q = EVn/24$$

Q : Calories intrude by ventilation [kcal/h]
E : Ventilation calories per unit volume
n : Number of ventilation per 24 hour
V : Effective volume [m^3]

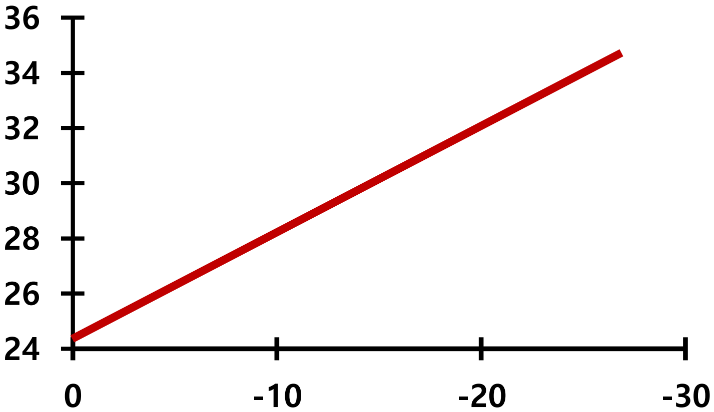


FIGURE Ventilation calories conversing graph

Load Calculation of Cooling Warehouse

- The number of ventilation by refrigerator volume

Volume [m^3]	Number of ventilation [number/h]	Volume [m^3]	Number of ventilation [number/h]
5	1.9(46)	160	0.27(6.5)
10	1.3(31)	200	0.24(5.8)
15	1.05(25)	250	0.22(5.2)
20	0.9(21.5)	300	0.2(4.7)
30	0.7(16.5)	400	0.18(4.2)
40	0.6(14)	500	0.16(3.7)
50	0.52(12.5)	700	0.13(3.0)
60	0.46(11)	900	0.11(2.7)
80	0.38(9.2)	1100	0.1(2.3)
100	0.35(8.5)	1400	0.09(2.0)
120	0.33(7.8)	1700	0.08(1.8)
140	0.3(7.2)	2000	0.07(1.6)

※ ( ) is per 24 hour

Load Calculation of Cooling Warehouse

3. Cooling calories of goods

$$Q = Gc\Delta T/24$$

G : Incoming amount per 1 day [kg/24h]
c : Specific heat of goods
ΔT : Maximum temperature difference between input goods and indoor air [℃]

$$QL = Gr/24$$

QL : Cooling calories of goods (Latent heat) [kcal/h]
G : Incoming amount per 1 day
r : latent heat of goods [kcal/kg]

4. Heat generation by worker

$$Q = No.Worker \times Heat\ Gen. \times \frac{Working\ hour}{24}$$

Load Calculation of Cooling Warehouse

- **Human body heat generation by refrigerator's temperature**

Refrigerator temperature [℃]	A human body heat generation [kcal/h num]	Refrigerator temperature [℃]	A human body heat generation [kcal/h num]
10	180	-15	315
5	205	-20	340
0	235	-25	370
-5	200	-30	390
-10	290	-45	470

- **The number of workers by refrigerator's size**

Area of refrigerator [㎥]	The number of workers
Below 250 ㎥	1
250 ~ 500 ㎥	2
500 ~ 750 ㎥	3
750 ~ 1000 ㎥	4

Calculating load of freezer

1. Design Criteria

Object item

↓

Freezing criteria

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Cooling system

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Insulation

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Equipment capacity

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Building construction

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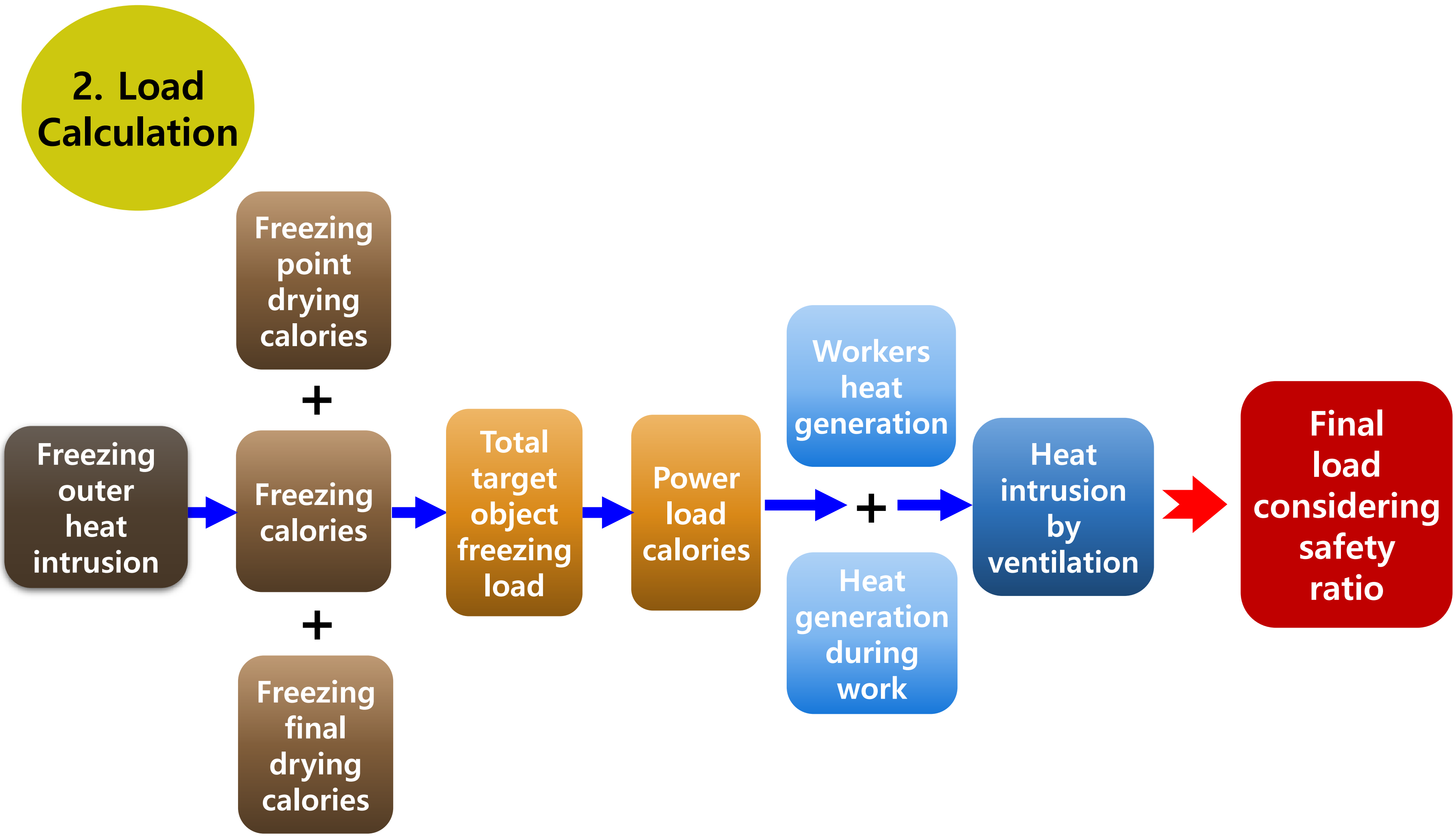
Cooling method

Calculating Load of Freezer



Question and Answer Session