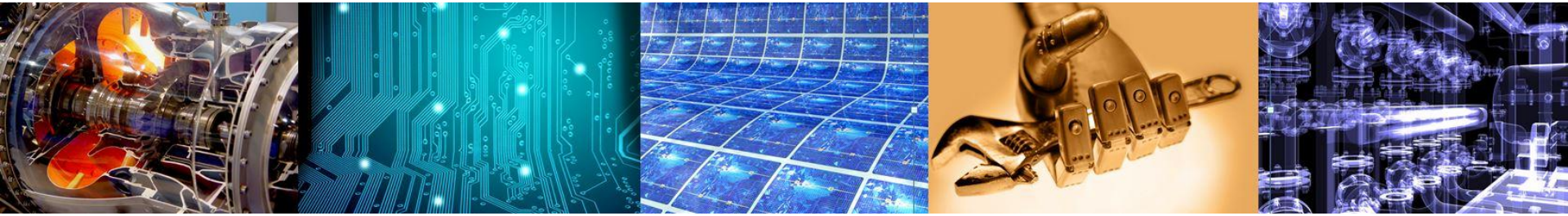
Faculty of Mechanical and Manufacturing Engineering

MECH4880 Refrigeration and air conditioning

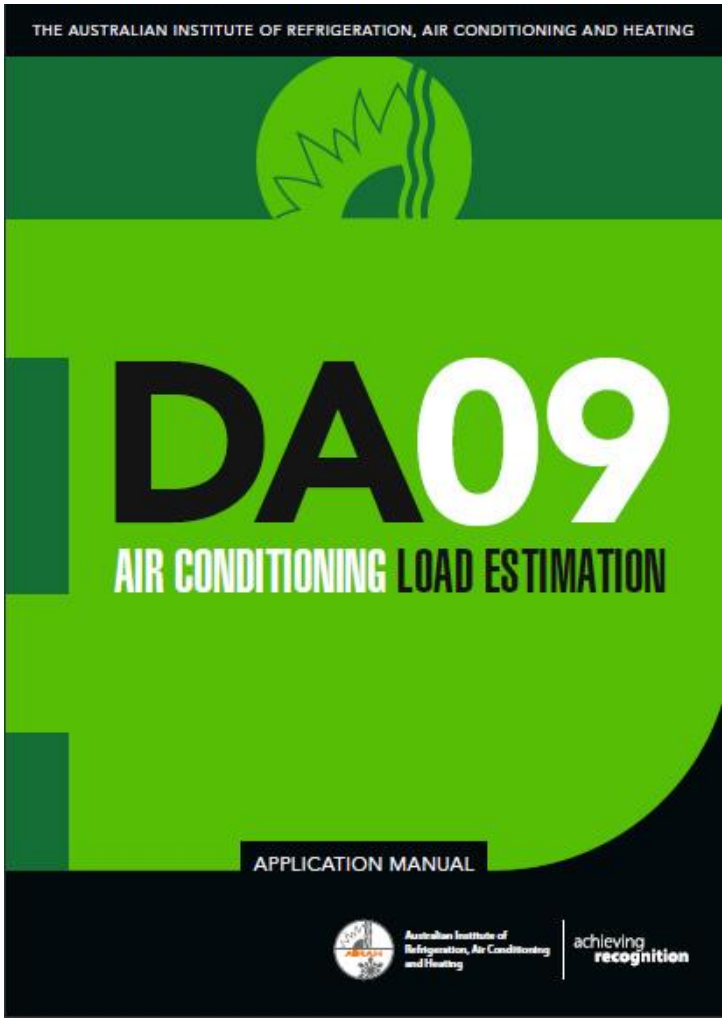
Semester 1 2017



DA09 calculation method for cooling and heating loads

Introduction

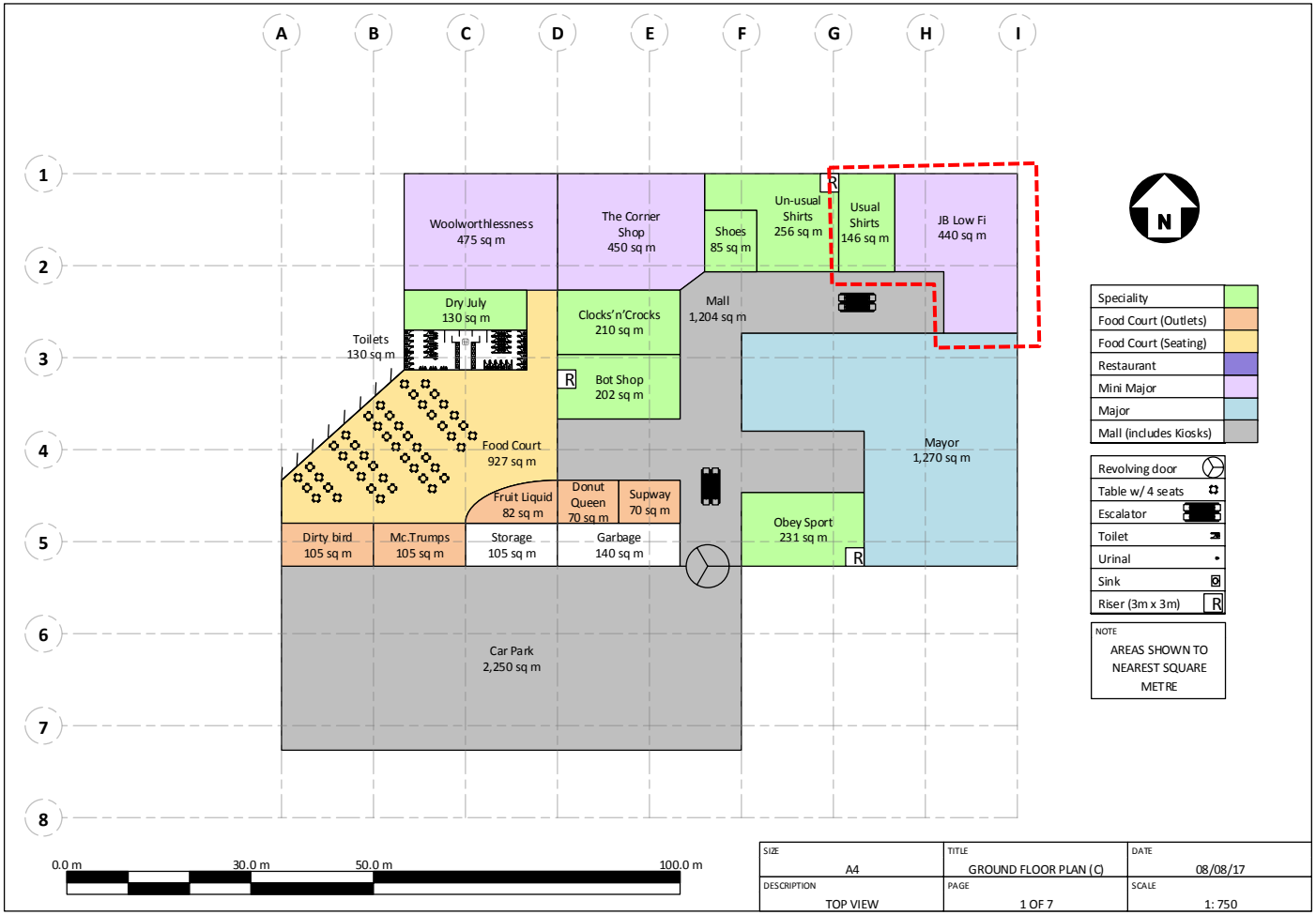
Brief overview of calculation method **comprehensively** outlined in DA09



Overview:

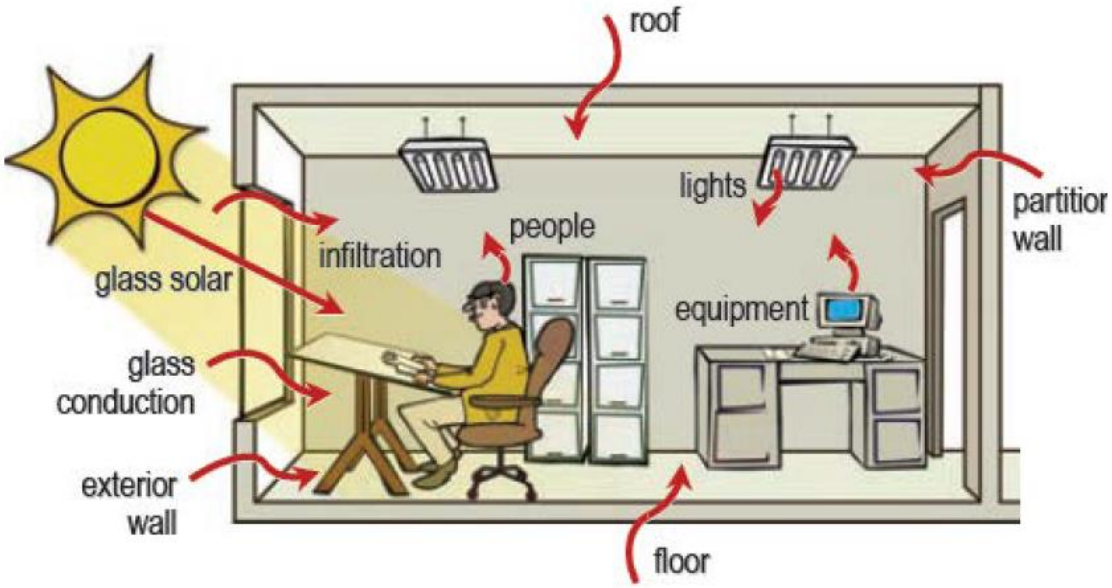
- Components of thermal loads
- Thermal load calculations
  - U-value
  - Combined conduction and radiation
  - Glass radiation

Orientation



UNSW SYDNEY

Cooling load components



External	Heat transfer mechanism
Exposed walls	Combined conduction /radiation
Internal walls	Conduction
Glass conduction	Conduction
Glass radiation	Radiation
Infiltration	Convection

Internal	Sensible or latent
People	Sensible + latent
Lights	Sensible
Appliances	Sensible + latent

Equations summary

Conduction heat transfer $\boldsymbol{Q[W] = U.A.\Delta T}$

$\boldsymbol{Q[W] = 0.5.(U.A.\Delta T)}$ (if the zone is adjacent to the unconditioned space)

Combined conduction/radiation $Q[W] = U.A.\Delta t_e$

Glass radiation $Q[W] = Peaksolar\ heat\ gain\ \left[\frac{W}{m^2}\right](table\ 5{,}14).A\ [m^2].SF\ (tables6 - 10).k1.k2.k3.k4.k5\ (chapter\ 4)$

Infiltration

$$Q_{infiltration}\ [W] = Q_{latent} + Q_{sensible}$$

$$Q_{sensible} = 1.2\forall_{zone} AC_{hour} \Delta T$$

$$Q_{latent} = 2.9\forall_{zone} AC_{hour} \Delta\omega$$

Internal loads

$Q_{people\ or\ lights} = Heat\ gain\ [W](chapter\ 7).Storage\ factor\ (Table\ 11).Divrsity\ factor(Table\ 13)$

Load calculation summary

External	Heat transfer mechanism	Sensible or latent	DA09 Table	DA09 Chapter
Exposed walls	Combined conduction /radiation	Sensible	Table 21 to 23 Table 24 to 37	5
Internal walls	Conduction	Sensible	Table 24 to 37	5
Glass conduction	Conduction	Sensible	Table 37	5
Glass radiation	Radiation	Sensible	Table 5 to 19	3, 4
Infiltration	Convection	Sensible + latent	Table 44	6

External	Sensible or latent	Reference
People	Sensible + latent	DA09 Chapter 7 ASHRAE Handbook
Light	Sensible	
Appliances	Sensible + latent	

NOTE: References, chapters and tables are non-exhaustive. You may need to find additional sources.

U-value calculation: Layout

U-value: Measures a material thermal insulating properties. High values are insulating and low values are conducting.

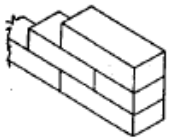
It is the inverse of the R-value or thermal resistance where low values are conducting and high vales are insulating.

Building section	Construction material	Area (m^2)	Density (kg/m^3)	Thickness (m)	Surface density (kg/m^2)	U-value (W/m^2K)	Reference
Roof							
External wall							
Window							
Floor							
Ceiling							
Floor							

U-value calculation: Direct method

- Example of the **direct method**
- Table 24-36
- Read thickness, mass per unit area and U-value from table.
- Careful to consider assumptions

TABLE 26—TRANSMISSION COEFFICIENT U—PARTITION SYSTEMS
Watts per square metre degree Celsius. Still air assumed on both sides of the partitions

CONSTRUCTION			INTERIOR FINISH				
Description	Thickness mm*	Mass per Unit Area* kg/m²	None	15 mm Gypsum Plaster (21)	12 mm Plaster Board (11)	6 mm Hard-Board (16)	12 mm Hard-Wood (11)
 100 mm air	100	11			1.78	1.51	1.70
50 mm air, 50 mm glass wool	100	14			0.560	0.530	0.550
100 mm glass wool	100	18			0.347	0.336	0.344
Aluminium Foil on one inner surface, and 100 mm of air	100	11			1.27	1.12	1.22
Terracotta Brick 	100	101	2.27	2.06			

*Values quoted are for the studs and for the terracotta bricks. The contribution of the finishes is given at the top of the appropriate column. The mass per unit area is in brackets.

Equations: Heat gain W = (Area m²) × (U-Value) × 0.5 (Outdoor temperature − indoor temperature) ‡
Heat loss W = (Area m²) × (U-Value) × 0.5 (Indoor temperature − outdoor temperature) ‡

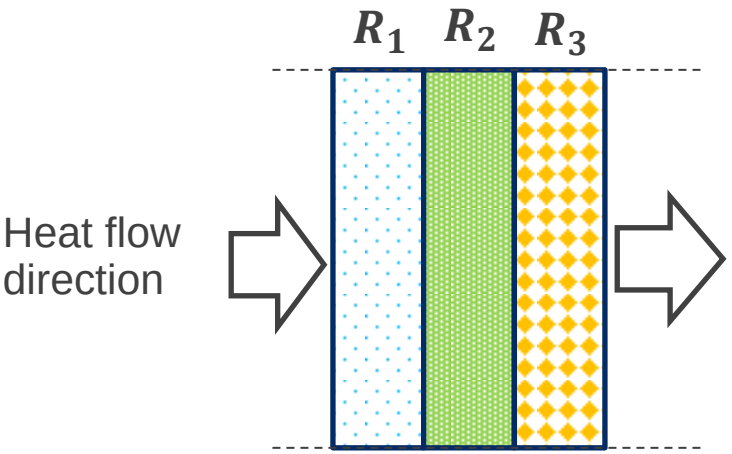
‡It is assumed that the temperature of the unconditioned space adjacent to the partition is midway between the outside temperature and the temperature inside the conditioned space.

It is assumed that the temperature of the unconditioned space adjacent to the partition is midway between the outside temperature and the temperature inside the conditioned space

U-value calculation: Thermal resistance network

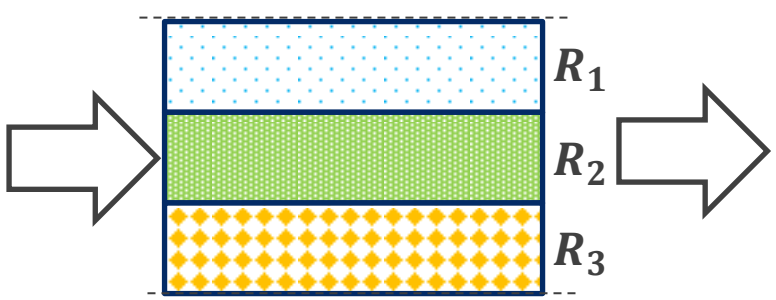
- When construction material NOT directly available

Series



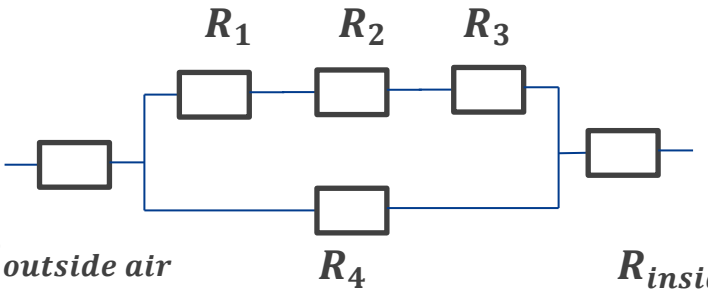
$$R_{total} = R_1 + R_2 + R_3$$

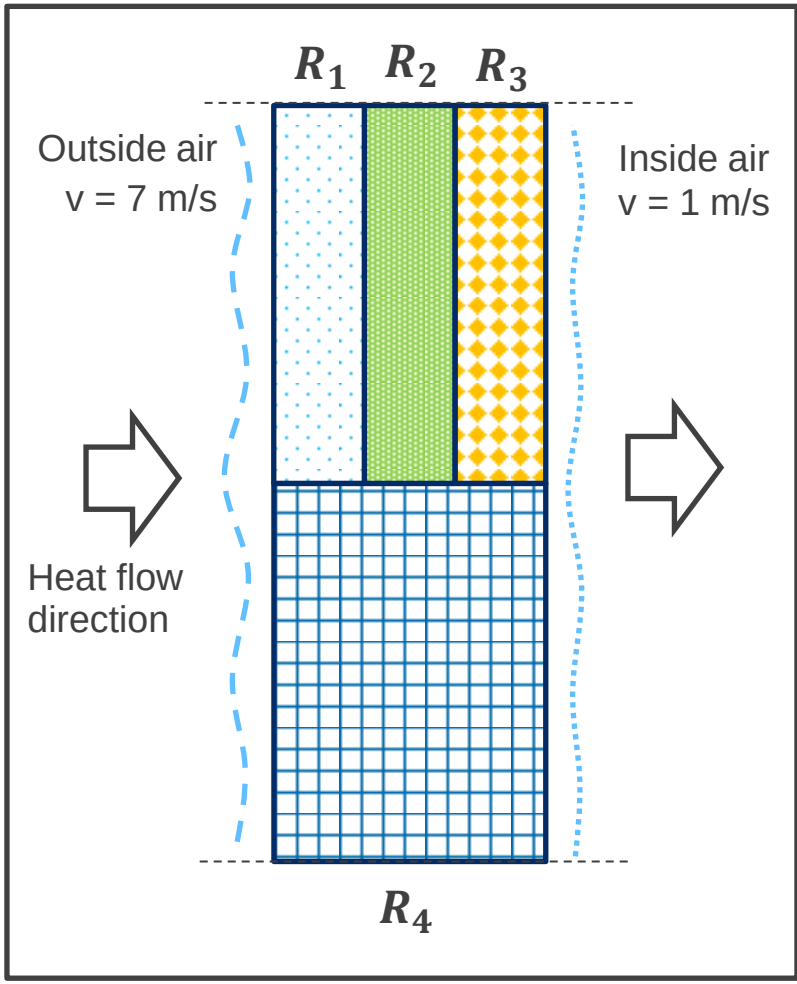
Parallel



$$R_{total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{3_1}}}$$

U-value calculation: Thermal resistance network





$$R_{total} = R_{outside\ air} + \left[\frac{1}{R_1 + R_2 + R_3} + \frac{1}{R_4}\right] + R_{inside\ air}$$

U-value calculation: Thermal resistance network

TABLE 37—THERMAL RESISTANCE R—BUILDING AND INSULATING MATERIALS (Cont.)

Note: An asterisk appearing in the density column signifies that the specimens have been conditioned in an atmopshere at 18°C and 65% relative humidity. Where two values are given in the temperature column, separated by a comma, the first refers to the hot face and the second to the cold face temperature.

Material	Moisture Content %	Density kg/m³	Temp. °C	Thickness mm	Resistivity (1/k) m.°C/W	Resistance for listed thickness m².°C/W	Source of Info.
pitch mastic, 4.5% sawdust, coloured				—	1.28	—	24
Brick (see also **Silica Brick**)							
common	0	1762		90	1.24	0.111	4
common	6	1874		90	0.83	0.074	4
common	9	1922		90	0.70	0.063	4
common	12	1970		90	0.68	0.061	4
common	16	2034		90	0.60	0.054	4
diatomaceous (see also		714	18	—	7.00	—	7

U-value calculation: Thermal resistance network

- **Ceiling** example of U-value data presentation
- Make sure to include reference for each value
- Show calculations once to demonstrate method

Component	Summer / Winter	R-Value (m^2C/W)	Reference
Air film	Summer	0.044	
	Winter	0.030	
Carpet		0.1	
Carpet underlay		0.4	
Concrete slab 150mm		0.25	
Air space 400mmm	Summer	0.6	
	Winter	0.868	
Air film	Summer	0.044	
	Winter	0.03	
Suspended grid ceiling tiles		2.84×10^{-5}	
Total R-value	Summer	1.44	
	Winter	1.68	
Total U-value	Summer	0.7	
	Winter	0.6	

Conduction / radiation: External walls

$$\boldsymbol{Q = U \times A \times \Delta t_e}$$

where:

$\boldsymbol{\Delta t_e}$ = equivalent temperature difference for latitude, month and time of day desired.

Tables 21-22 for dark coloured walls based on 35°C outdoor design temperature in January and 40° South latitude.

Corrections to these values on page 62 of DA09. Shaded walls, different latitudes, lighter wall colours etc.

Conduction / radiation: External walls

- Exposure: North, South etc
- Mass of wall per unit area
- Sun Time

TABLE 21—EQUIVALENT TEMPERATURE DIFFERENCE (°C)
FOR DARK COLOURED†, SUNLIT AND SHADED WALLS*
Based on Dark Coloured Walls, 35°C DB Outdoor Design Temp.; Constant 25°C DB Room Temp.; 10°C, Daily Range; 24-Hour Operation; January and 40° South Latitude†

Exposure	Mass of wall per unit area ‡ kg/m²	SUN TIME																							
		AM							PM												AM				
		6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
North	100	1.7	1.1	0.0	2.8	4.4	10.0	14.4	17.2	18.9	17.8	16.7	13.3	11.1	8.9	7.8	6.1	5.6	3.9	3.3	2.8	2.8	2.2	2.2	1.7
	300	1.7	0.6	0.0	0.6	1.1	6.1	8.9	13.3	15.6	16.1	16.7	15.0	13.3	10.6	8.9	7.8	6.7	5.6	4.4	3.3	2.8	2.8	2.2	1.7
	500	4.4	4.4	3.3	3.3	3.3	3.9	4.4	6.7	8.9	10.6	11.1	12.2	12.2	10.6	10.0	8.3	7.8	7.2	6.7	6.7	6.1	5.6	5.6	5.0
	700	6.1	5.6	5.6	5.0	4.4	4.4	4.4	4.4	4.4	6.1	7.8	9.4	10.0	10.6	11.1	11.1	10.0	8.9	7.8	7.8	7.2	7.2	6.7	6.1
Northeast	100	7.8	5.6	9.4	12.8	16.7	17.2	17.8	16.7	15.6	12.8	11.1	10.6	10.0	8.9	7.8	6.7	5.6	4.4	3.3	2.2	1.7	1.7	1.1	1.1
	300	2.8	2.8	2.2	9.4	13.3	15.6	17.8	16.7	16.1	13.9	12.2	10.6	10.0	9.4	8.9	8.3	7.8	6.7	5.6	5.0	4.4	3.9	3.9	3.3
	500	6.1	6.1	5.6	5.6	5.6	8.3	11.1	11.7	12.2	12.8	12.2	11.1	10.0	9.4	8.9	8.3	7.8	7.8	7.8	7.2	7.2	6.7	6.7	6.1
	700	7.2	6.7	6.7	6.7	6.7	6.1	5.6	8.3	10.0	10.6	11.1	12.2	11.1	10.6	10.0	9.4	8.9	8.9	8.9	8.3	8.3	7.8	7.8	7.2
East	100	2.8	11.7	18.9	20.6	22.2	21.7	20.0	13.3	8.9	9.4	10.0	10.0	10.0	8.9	7.8	6.7	5.6	4.4	3.3	2.2	1.7	1.1	0.6	0.6
	300	1.7	1.7	2.2	13.9	18.9	19.4	19.4	12.8	10.0	9.4	8.9	9.4	10.0	9.4	8.9	8.3	7.8	6.7	5.0	4.4	3.9	2.8	2.8	2.2
	500	5.0	5.0	5.6	6.7	10.0	13.3	15.6	16.1	15.6	13.3	12.2	11.1	10.0	10.0	10.0	9.4	8.9	8.3	7.8	7.2	6.7	6.1	6.1	5.6
	700	8.3	7.8	7.8	7.2	6.7	7.2	7.8	10.6	12.2	12.8	12.2	11.7	11.1	10.0	8.9	9.4	10.0	10.0	10.0	9.4	9.4	8.9	8.9	8.9
Southeast	100	5.0	10.6	14.4	15.0	15.6	12.8	10.0	9.4	8.9	9.4	10.0	10.0	10.0	8.9	7.8	6.7	5.6	4.4	3.3	2.2	1.1	0.6	0.0	1.1
	300	1.7	1.1	1.1	5.0	15.6	14.4	13.3	10.6	7.8	8.3	8.9	9.4	10.0	9.4	8.9	8.3	7.8	6.7	5.6	4.4	3.3	2.8	2.2	1.7
	500	4.4	3.9	4.4	4.4	4.4	7.8	11.1	10.6	10.0	8.9	7.8	8.3	8.9	8.9	8.9	8.3	7.8	7.2	6.7	6.1	5.6	5.6	5.0	5.0
	700	5.0	5.0	5.6	5.6	5.6	5.6	5.6	7.8	10.0	11.1	10.0	8.9	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.2	7.2	6.7	6.1	6.1
Southwest	100	0.6	0.0	0.0	1.1	2.2	3.9	5.6	7.8	8.9	12.8	15.6	20.6	24.4	22.8	21.1	12.2	5.6	4.4	3.3	2.2	1.7	1.7	1.1	1.1
	300	1.1	0.6	0.0	0.6	1.1	2.2	3.3	5.6	6.7	7.8	8.9	13.9	18.9	19.4	20.0	13.9	8.9	6.7	5.6	4.4	3.9	2.8	2.2	1.7
	500	5.0	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	5.0	5.6	7.2	8.9	11.7	13.3	13.9	14.4	10.0	6.7	6.1	6.1	5.6	5.6	5.0
	700	6.7	6.1	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	6.1	6.7	7.2	7.8	10.0	12.2	12.8	13.3	11.1	9.4	8.3	7.8	7.2
West	100	1.1	0.6	0.0	1.1	2.2	3.9	5.6	10.0	13.3	20.0	24.4	27.2	28.9	21.1	14.4	10.0	6.7	5.0	3.3	2.8	2.2	2.2	1.7	1.7
	300	3.3	2.8	2.2	2.2	2.2	3.3	4.4	6.1	7.8	12.8	16.7	21.1	24.4	25.0	22.2	17.8	11.1	7.8	5.6	5.0	4.4	3.9	3.9	3.3
	500	6.1	6.1	5.6	5.6	5.6	5.6	5.6	6.1	6.7	7.8	8.9	11.7	13.3	16.1	17.8	17.2	16.7	12.8	10.0	8.9	8.3	7.8	7.2	6.7
	700	8.9	8.3	7.8	7.2	6.7	6.7	6.7	7.2	7.8	7.8	7.8	8.3	8.9	10.0	11.1	13.9	14.4	15.0	14.4	13.3	12.2	11.1	10.6	9.4
Northwest	100	1.1	0.0	0.0	1.1	2.2	4.4	5.6	12.8	16.7	21.1	24.4	25.0	25.6	18.9	15.6	8.9	5.6	4.4	3.3	2.8	2.8	2.2	1.7	1.7
	300	3.3	2.8	2.2	2.2	2.2	2.8	3.3	6.7	8.9	15.6	20.0	21.7	22.2	21.7	21.1	13.3	7.8	6.1	5.6	5.0	4.4	4.4	3.9	3.9
	500	6.1	5.0	5.6	5.0	4.4	5.0	5.6	6.1	6.7	8.9	10.0	12.8	14.4	15.0	15.6	15.0	14.4	10.6	7.8	7.8	7.2	7.2	6.7	6.1
	700	6.7	6.7	6.7	6.7	6.7	6.1	5.6	5.6	5.6	6.1	6.7	7.2	7.8	10.6	12.2	12.8	13.3	9.4	6.7	6.7	6.7	6.7	6.7	6.7
South (Shade)	100	0.6	0.6	0.0	0.6	1.1	2.8	4.4	6.7	7.8	8.9	10.0	9.4	8.9	7.8	6.7	5.6	4.4	3.3	2.2	2.2	1.7	1.7	1.1	1.1
	300	0.6	0.6	0.0	0.6	1.1	1.7	2.2	3.9	5.6	6.7	7.8	8.3	8.9	8.9	8.9	7.8	6.7	5.6	4.4	3.3	2.8	2.2	1.7	1.1
	500	2.8	2.8	2.2	2.2	2.2	2.2	2.2	2.8	3.3	3.9	4.4	5.0	5.0	5.0	6.7	6.1	5.6	5.0	4.4	3.9	3.9	3.3	3.3	2.8
	700	2.8	2.8	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.8	3.3	3.9	4.4	5.0	5.6	6.1	6.7	6.1	5.6	4.4	3.9	3.3	3.3	2.8

Equation: Heat Gain through Walls, W = (Area, m²) × (Equivalent temperature difference) × (Transmission coefficient U, *Tables 24* and *25*).
*All values are for both insulated and uninsulated walls.
†For other conditions refer to corrections listed after *Table 23*.
‡'Mass per unit area' values for common types of construction are listed in *Tables 24* and *25*.
For wall constructions less than 100 kg/m², use listed values of 100 kg/m², for wall constructions more than 700 kg/m², use listed values of 700 kg/m².

Glass radiation

$$Q[W] = Peaksolar\ heat\ gain\ \left[\frac{W}{m^2}\right](table\ 5{,}14).A\ [m^2].SF\ (tables6 - 10).k1.k2.k3.k4.k5\ (chapter\ 4)$$

$SF = storage\ load\ factor\ (tables6 - 10)$

$k1 = sash\ correction\ factor, table\ 5{,}14$

$k2 = haze\ correction\ factor, table\ 5{,}14$

$k3 = Altitude\ correction\ factor, table\ 5{,}14$

$k4 = dewpoint\ correction\ factor, table\ 5{,}14$

$k5 = glass\ factor, table\ 15$

$k6 = SOLAR\ factor, table\ 16\text{-}18$

$k5, k6 = OVERALL\ FACOTRS = T15 - T18$

Glass radiation: Peak solar heat gain

TABLE 14—SOLAR HEAT GAIN THROUGH REFERENCE GLASS

Watts per square metre sash area (W/m²)

0° South Latitude		AM						Sun Time						PM
Time of Year	Exposure	6	7	8	9	10	11	Noon	1	2	3	4	5	6
Jan 21	North	0	20	37	44	47	47	47	47	47	44	37	20	0
	Northeast	0	155	*175*	120	60	47	47	47	47	44	37	20	0
	East	0	410	*510*	470	320	145	47	47	47	44	37	20	0
	Southeast	0	400	*520*	510	420	290	145	55	47	44	37	20	0
	South	0	125	180	210	220	220	*230*	220	220	210	180	125	0
	Southwest	0	20	37	44	47	55	145	290	420	510	*520*	400	0
	West	0	20	37	44	47	47	47	145	320	470	*510*	410	0
	Northwest	0	20	37	44	47	47	47	47	60	120	*175*	155	0
	Horizontal	0	100	310	510	660	750	*790*	750	660	510	310	100	0
Feb 20 & Oct 23	North	0	19	38	40	45	45	*45*	45	45	40	38	19	0
	Northeast	0	210	*250*	210	110	47	45	45	45	40	38	19	0
	East	0	410	*510*	470	320	145	45	45	45	40	38	19	0
	Southeast	0	350	*440*	420	320	190	75	45	45	40	38	19	0
	South	0	54	90	100	105	105	*105*	105	105	100	90	54	0
	Southwest	0	19	38	40	45	45	75	190	320	420	*440*	350	0
	West	0	19	38	40	45	45	45	145	320	470	*510*	410	0
	Northwest	0	19	38	40	45	45	45	47	110	210	*250*	210	0
	Horizontal	0	100	310	470	650	740	*770*	740	650	470	310	100	0

Glass radiation: Storage load factor

TABLE 6—STORAGE LOAD FACTORS, SOLAR HEAT GAIN THROUGH GLASS
WITH INTERNAL SHADE*
24 Hour Operation, Constant Space Temperature†

Exposure	Mass per unit area of floor kg/m² ‡	SUN TIME																							
		AM							PM												AM				
		6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
North	700 & Over	0.06	0.06	0.23	0.38	0.51	0.60	0.66	0.67	0.64	0.59	0.42	0.24	0.22	0.19	0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.07	0.07
	500	0.04	0.04	0.22	0.38	0.52	0.63	0.70	0.71	0.69	0.59	0.45	0.26	0.22	0.18	0.16	0.13	0.12	0.10	0.09	0.08	0.07	0.06	0.06	0.05
	150	0.10	0.21	0.43	0.63	0.77	0.86	0.88	0.82	0.56	0.50	0.24	0.16	0.11	0.08	0.05	0.04	0.02	0.02	0.01	0.01	0	0	0	0
Northeast	700 & Over	0.04	0.28	0.47	0.59	0.64	0.62	0.53	0.41	0.27	0.24	0.21	0.19	0.16	0.14	0.12	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.05
	500	0.03	0.28	0.47	0.61	0.67	0.65	0.57	0.44	0.29	0.24	0.21	0.18	0.15	0.12	0.10	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.03
	150	0	0.30	0.57	0.75	0.84	0.81	0.69	0.50	0.30	0.20	0.17	0.13	0.09	0.05	0.04	0.03	0.02	0.01	0	0	0	0	0	0

Equation: Cooling Load, W = [Peak solar heat gain, W/m². (*Table 5*)]
× [Window area, m²]
× [Overall solar factor, Haze factor, etc. (*Chapter 4*)]
× [Storage factor, (above Table at desired time)]

*Internal shading device is any type of shade located on the inside of the glass.

†These factors apply when maintaining a CONSTANT TEMPERATURE in the space during the operating period. Where the temperature is allowed to swing, additional storage will result during peak load periods. Refer to *Table 12* for applicable storage factors.

‡Mass per unit area of floor—

$$\text{Room on Building Exterior (one or more outside walls)} = \frac{\text{(Mass of outside walls, kg)} + 0.5\ \text{(Mass of partitions, floor and ceiling, kg)}}{\text{Floor area in room, m}^2}$$

$$\text{Room in Building Interior (no outside walls)} = \frac{0.5\ \text{(Mass of Partitions, Floor and ceiling, kg)}}{\text{Floor area in room, m}^2}$$

$$\text{Basement Room (floor on ground)} = \frac{\text{(Mass of outside walls, kg)} + \text{(Mass of floor, kg)} + 0.5\text{(Mass of partitions and ceilings, kg)}}{\text{Floor area in room, m}^2}$$

$$\text{Entire Building or Zone} = \frac{\text{(Mass of outside wall, partitions, floors, ceilings, structural members and supports, kg)}}{\text{Air conditioned floor area m}^2}$$

With rug on floor—Mass of floor should be multiplied by 0.50 to compensate for insulating effect of rug.
Mass per unit area of common types of construction are contained in *Tables 24* to *36*.

Summary of loads

Description	Total sensible load (W)	Total Latent load (W)
Infiltration		
Internals		
Conductions		
Radiations		
	Total:	Total:

$$SHF = \frac{Q_{S,total}}{Q_{S,total} + Q_{L,total}}$$