UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Tambahan
Sidang Akademik 1993/94

Jun 1994

EMK 404 - PENYEJUKAN DAN PENYAMANAN UDARA

Masa : [3 jam]

ARAHAN KEPADA CALON

Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM muka surat dan TUJUH soalan serta EMPAT BELAS lampiran yang bercetak sebelum anda memulakan peperiksaan ini.

Jawab LIMA soalan sahaja.

Semua soalan MESTILAH dijawab dalam bahasa Melayu.

Termasuk lampiran-lampiran:

1. Analisis Beban Penyamanan Udara
2. Jadual: "Recommended NC (Noise Criteria)"

...2/-

1. [a] Terangkan cara kerja kitar penyejukan penyerapan wap (vapour absorption).

(30 markah)

[b] Dalam sebuah loji penyejukan yang menggunakan refrigerant-12, wap meninggalkan penyejat dalam keadaan tepu kering. Ia kemudian dimampatkan secara adiabatik tak-boleh-balik (irreversible) di dalam pemampat empar. Tekanan penyejat adalah 1.826 bar dan tekanan pemeluwap adalah 7.449 bar. Suhu wap yang meninggalkan pemampat adalah 45°C. Cecair meninggalkan pemeluwap pada 25°C dan ia didikitkan (throttle) sehingga mencapai tekanan penyejat. Kirakan kesan penyejukan, kerja dilakukan per kg bahan penyejuk, dan C.O.P mesin ini. Apakah nilai C.O.P.nya jika pemampatan dijalankan secara boleh balik dan hampir adiabatik di dalam sebuah pemampat saling (reciprocating compressor)?

(70 markah)

2. [a] Terangkan pengubahsuaian (modification) yang boleh dibuat ke atas kitar penyejukan mampatan wap bagi membaiki prestasinya.

(30 markah)

[b] Rajah S2[b] menunjukkan suatu sistem penyejukan mampatan wap dua peringkat yang menggunakan Refrigerant-12 sebagai bahan penyejuk. Sistem tersebut menggunakan penukar haba sentuhan terus (direct contact heat exchanger) bagi menghasilkan pendinginan-antara. Penyejatnya mempunyai keupayaan penyejukan 30 ton dan menghasilkan wap tepu - 6°C pada salur keluarnya. Pada peringkat mampatan pertama, bahan penyejuk dimampat secara adiabatik sehingga mencapai 3 bar. Ini merupakan tekanan di dalam penukar haba sentuhan terus. Wap tepu pada 3 bar memasuki peringkat kedua pemampat pada 3 bar dan dimampat secara adiabatik sehingga mencapai 12 bar. Setiap pemampat mempunyai kecekapan seentropi 85%. Tidak terdapat sebarang kejatuhan tekanan yang ketara semasa bahan penyejuk melalui penukar haba. Cecair tepu memasuki setiap injap pengembang (expansion valve). Tentukan

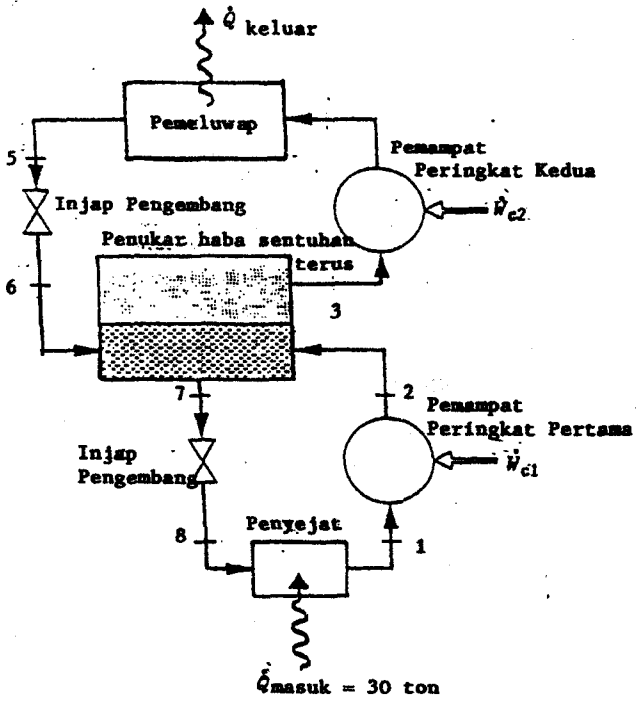
[i] Kadar alir jisim melalui penyejat

[ii] Kuasa masukan ke setiap peringkat pemampatan

[iii] C.O.P

(70 markah)

...3/-



Rajah S2[b]

3. [a] Terangkan cara kerja sistem penyejukan jet stim.

(30 markah)

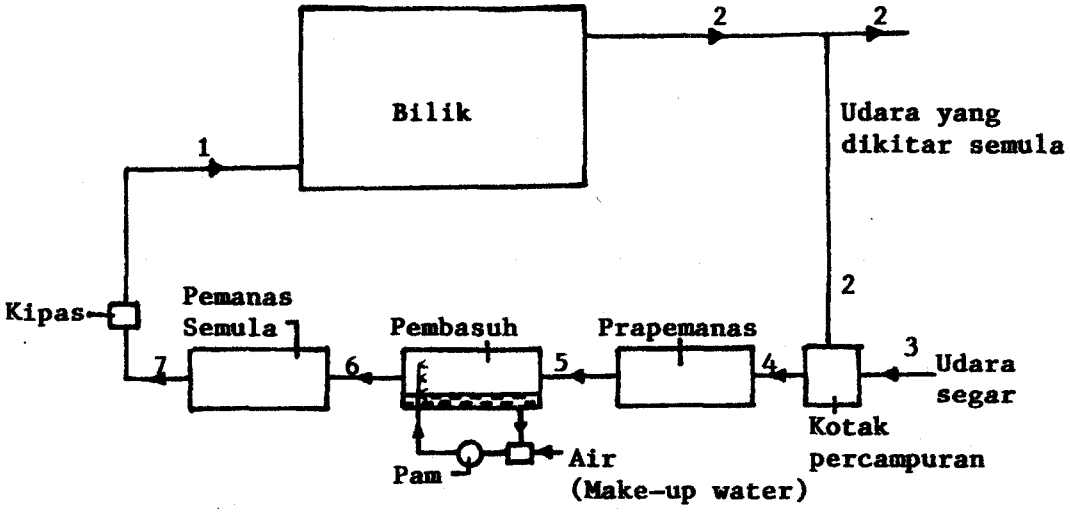
[b] Di dalam sistem penyejukan sebuah kapal terbang, udara yang keluar dari pemampat pada 4 bar dan 280°C didinginkan di dalam penukar haba sejukan udara (air cooled heat exchanger) udara tersebut meninggalkan penukar haba pada 4 bar dan 80°C. Seterusnya ia dikembangkan melalui turbin sehingga mencapai 0.75 bar. Kecekapan seentropi turbin udara tersebut adalah 88°C. Udara tersebut kemudian dibekalkan ke kabin. Selepas itu ia meninggalkan kapal terbang pada suhu 16°C. Kirakan kesan penyejukan per kg udara dan kuasa yang dihasilkan oleh turbin udara per kg udara per saat.

(70 markah)

4. [a] Rajah S4[a] menunjukkan sebuah sistem pendinginan udara yang biasa digunakan. Tunjukkan proses-proses sistem tersebut di atas suatu carta psikrometri.

(30 markah)

...4/-



Rajah S4[a]

[b] Udara luar yang dicampurkan dengan udara dalam bangunan digunakan dalam suatu sistem pendinginan udara yang dikendalikan pada tekanan 101 kPa. Kadar alir udara luar adalah 2 kg/s dan keadaannya adalah 35°C DBT dan 25°C WBT. Kadar alir udara dalam bangunan adalah 3 kg/s pada suhu 24°C dan 50 peratus tepuan (saturation). Tentukan

[i] entalpi campuran tersebut

[ii] nisbah kelembapan campuran tersebut

[iii] DBT campuran tersebut dikira menggunakan properti dari [i] dan [ii]

[iv] DBT campuran yang dikira dari purata berpemberat (weighted average) kedua-dua aliran.

(70 markah)

5. [a] Terbitkan persamaan peratusan ketepuan menggunakan ungkapan-ungkapan kelembapan relatif, tekanan keseluruhan dan tekanan tepu.

(30 markah)

[b] Sebuah restoran yang mengisi 100 orang pada keadaan paling sibuk mempunyai pintu berputar (revolving door) 72 in. Kipas ekzos mengeluarkan 500 cfm udara dari ruang restoran. Kawasan yang didinginkan berukuran 50 x 30 x 20 kaki dengan satu dari dindingnya terdedah.

...5/-

Keadaan rekabentuk : Di dalam 78°F, 50% RH
Di luar 90°F (DB), 70°F (WB)

Kirakan

[i] beban disebabkan pengudaraan (ventilation)

[ii] beban disebabkan infiltrasi

[iii] jumlah beban disebabkan udara luar

[iv] beban disebabkan penghuni

(70 markah)

6. [a] Terangkan faktor-faktor yang perlu dipertimbangkan bagi merekabentuk sistem pendinginan udara sebuah bangunan.

(30 markah)

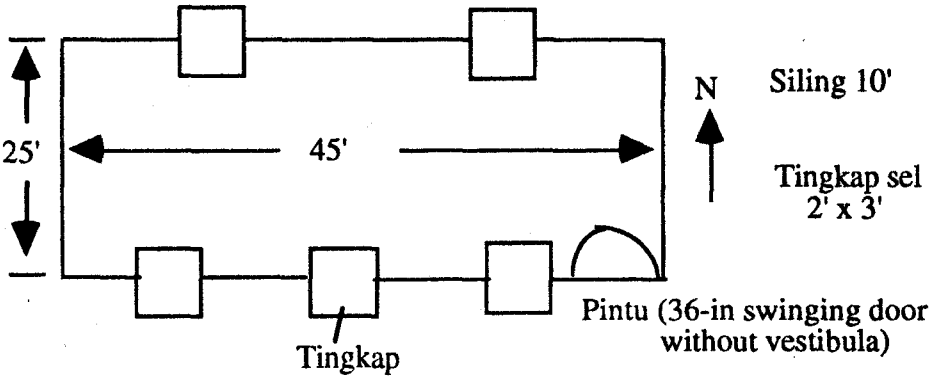
[b] Rajah S6[b] menunjukkan sebuah bangunan pejabat yang perlu dipasangkan pendingin hawa. Kirakan bilangan pendingin udara jenis tingkap (window type) 2 ton yang diperlukan bagi bangunan tersebut.

Keadaan rekabentuk:

Keadaan luar	:	90°F (DBT)	80°F (WBT)
Keadaan dalam:		78°F (DBT)	45% RH
Tingkap	:	'single strength glass having indoor shading with dark colour (roller shade, fully drawn)'	
Dinding	:	'12 in. hollow concrete wall without interior finish and external facing'	
Beban letrik	:	15 bulp lampu 100 W setiap satu dan 10 lampu fluorescent 40 W setiap satu	
Bilangan penghuni:		15	

(70 markah)

...6/-



Rajah S6[b]

7. [a] Takrifkan ungkapan-ungkapan berikut:

[i] resapan (diffussion),

[ii] kebezaan suhu (temperature differential),

[iii] induksi, iringan (entrainment),

[iv] jejari sebaran resapan (radius of diffusion spread) dan

[v] kriteria bunyi bersabit sistem pengagihan udara.

(20 markah)

[b] Apakah jenis bahan cemar yang perlu disingkirkan oleh alat pembersih udara (air cleaning device)? Terangkan jenis-jenis alat pembersih udara.

(20 markah)

[c] Ruang makan sebuah restoran berukuran 60 kaki x 80 kaki dan memerlukan keupayaan pendinginan 15 ton. Tentukan bilangan dan saiz peresap siling (ceiling diffuser) yang diperlukan jika siling bilik itu setinggi 12 kaki dan perbezaan suhu adalah 22°F.

(60 markah)

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LAMPIRAN 1

ANALISIS BEBAN PENYAMANAN UDARA
(ANALYSIS OF THE AIR CONDITIONING LOAD)

$$1 \text{ Btu/hr} = 0.293 \text{ W}$$

$$= 2.93 \times 10^{-4} \text{ kW}$$

$$= 7 \times 10^{-5} \text{ kcal/sec}$$

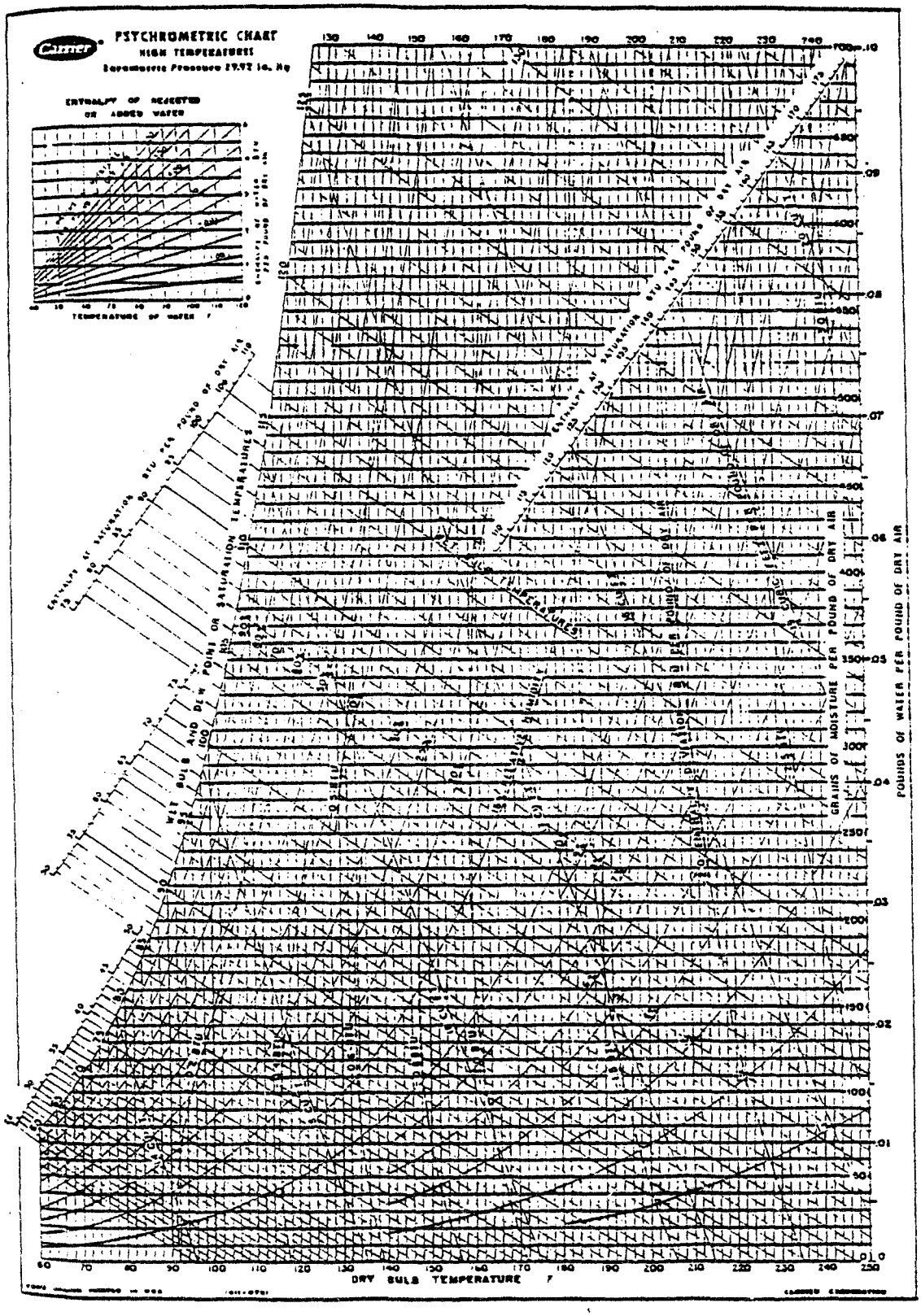


FIG. 7-20 Psychrometric chart for high temperatures—USCS units.

TABLE 8-1 Recommended Inside Design Conditions,* Summer and Winter—Present Practice and Possible Future Trends

Type of Application	Summer: Present Practice Dry Bulb, °F	Summer: Present Practice Rel. Hum., %	Summer: Future Trends (Energy-Dictated) Dry Bulb, °F	Summer: Future Trends (Energy-Dictated) Rel. Hum., %	Summer: Future Trends (Energy-Dictated) Temp. Swing,† °F	Winter: Present Practice Dry Bulb, °F	Winter: Present Practice Rel. Hum., %	Winter: Present Practice Temp. Swing,‡ °F	Winter: Future Trends (Energy-Dictated) Dry Bulb, °F	Winter: Future Trends (Energy-Dictated) Temp. Swing,‡ °F
General comfort										
Apartment, house, hotel, office, hospital, school, etc.	78–80	50	80–82	50	2 to 4	72–74	40–30	−3 to −4	68–70	−4
Retail shops (short-term customer occupancy)										
Bank, barber or beauty shop, department store, supermarket, etc.	78	50	78–80	50	2 to 4	70–72	40–30§	−3 to −4	68–70	−4
Low sensible-heat-factor (SHF) applications (high latent load)										
Auditorium, church, bar, restaurant, kitchen, etc.	78	60–50	78–80	60–50	1 to 2	70–72	40–35	−2 to −3	68–70	−4
Factory comfort										
Assembly areas, machining rooms, etc.	78–80	60–50	80–85	60–50	2 to 4	68–72	35–30	−3 to −5	66–68	−4

* The room design dry-bulb temperature should be reduced when hot, radiant panels are adjacent to the occupant and increased when cold panels are adjacent, to compensate for the increase or decrease in radiant heat exchange from the body. A hot or cold panel may be unshaded glass or glass block windows (hot in summer, cold in winter) and thin partitions with hot or cold spaces adjacent. An unheated slab floor on the ground or walls below the ground level are cold panels during the winter and frequently during the summer also. Hot tanks, furnaces, or machines are hot panels.

† Temperature swing is above the thermostat setting at peak summer load conditions.

‡ Temperature swing is below the thermostat setting at peak winter load conditions (no lights, people, or solar heat gain).

§ Winter humidification in retail clothing shops is recommended to maintain the quality texture of goods.

Source: Carrier Air Conditioning Co., *Handbook of Air Conditioning System Design*, McGraw-Hill Book Company, New York, 1966; and current federal, state, and local standards.

TABLE 8-3 Suggested Outside Design Conditions for Selected Localities throughout the World

Place	Winter, Dry Bulb, °C	Summer Dry Bulb, °C	Summer Wet Bulb, °C	Place	Winter, Dry Bulb, °C	Summer Dry Bulb, °C	Summer Wet Bulb, °C
Athens, Greece	31	34	22	Panama City, Panama	22	33	27
Bogota, Columbia	7	21	16	Paris, France	−6	30	20
Bombay, India	18	34	28	Rio de Janeiro, Brazil	14	33	26
Buenos Aires, Argentina	0	32	24	Riyadh, Saudia Arabia	3	42	25
Cairo, Egypt	7	38	24	Rome, Italy	−1	33	23
Capetown, South Africa	4	32	22	Shanghai, China	5	32	28
Caracas, Venezuela	11	28	21	Singapore	22	33	27
Kuala Lumpur, Malaysia	21	34	28	Stockholm, Sweden	−15	24	17
London, England	−4	27	19	Sydney, Australia	4	29	23
Madrid, Spain	−4	33	21	Tel Aviv, Israel	4	34	23
Manila, Philippines	20	33	27	Tokyo, Japan	−3	32	27
Melbourne, Australia	2	33	21	Vienna, Austria	−14	30	21
Mexico City, Mexico	2	27	16				

ASHRAE Handbook, 1977 Fundamentals.

[3/12]

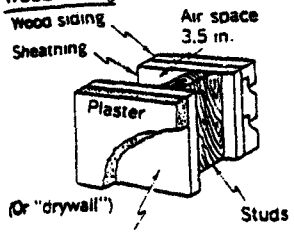
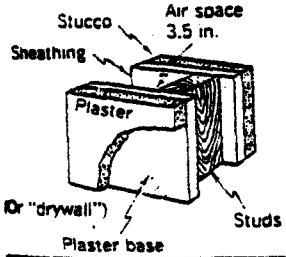
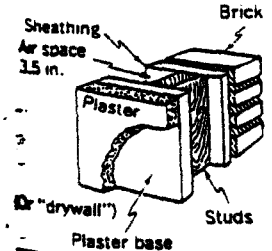
TABLE 8-4 Conductivities *K*, Conductances *C*, and Resistances *R* of Common Building Materials [Units of *K*, Btu/(hr)(ft²)(F°/in.); Units of *C*, Btu/(hr)(ft²)(F°) for Thickness Stated, Not per Inch Thick; Units of *R*, (hr)(ft²)(F°)/ Btu]

Material	*Description*	*Conductivity K*	*Conductance C*	*Resistance R*
Building boards	Gypsum board,	1.41		
	0.5 in.		2.22	0.45
	0.625 in.		1.78	0.56
	Plywood:	0.81		
	0.5 in.		1.60	0.62
	0.75 in.		1.07	0.93
	Wood:			
	Fir or pine sheathing, $^{25}/_{32}$ in.		1.02	0.98
Flooring materials	Asphalt tile, vinyl tile		20.0	0.05
	Carpet with fiber pad		0.48	2.08
	Ceramic tile, 1 in.		12.5	0.08
	Cork tile	0.45		
	Linoleum, ⅛ in.		12.0	0.083
	Plywood subfloor, 0.75 in.		1.07	0.93
	Terrazzo, 1 in.		12.5	0.08
	Wood, hardwood, ¾ in.		1.47	0.68
Glass		5.5		
Insulating materials:				
Blanket and batt	Mineral wool, fiberglass	0.25–0.27		
	3.5 in.		0.091	11
	6 in.		0.045	22
	8–10 in.		0.033	30
Board	Cork	0.34		
	Polyurethane	0.16		
	Wood or cane fiber	0.35		
	Polystyrene	0.20		
	Acoustical tile:			
	0.5 in.		0.80	1.25
	0.75 in.		0.53	1.9
	Interior finish boards:	0.35		
	0.5 in.		0.70	1.43
Loose fill	Mineral wool	0.27		
	4 in.			11
	6 in.			20
	10 in.			28
	Wood pulp	0.30		
Masonry materials	Cement mortar	5.0		
	Stucco	5.0	6.6 for ¾ in. thick	0.15
Masonry units	Brick, common, low-density	5.0		
	Brick, high-density (face brick)	9.0		
	Concrete blocks:			
	Sand and gravel aggregate:			
	8 in.		0.90	1.11
	12 in.		0.78	1.3
	Cinder aggregate:			
	8 in.		0.58	1.7
	12 in.		0.53	1.9
	Stone	12.5		
Plastering materials	Gypsum plaster, sand aggregate	5.6		
	Gypsum lath ("button board," 0.5 in.) and plaster, plaster thickness 0.625 in.		1.52	0.66
	Metal lath and plaster, plaster thickness 0.75 in.		2.13	0.47

Material	*Description*	*Conductivity K*	*Conductance C*	*Resistance R*
Roofing materials	Asphalt roll roofing, 70 lb		6.50	0.15
	Asphalt shingles, 70 lb		2.27	0.44
	Built-up roofing, 0.375 in.		3.00	0.33
	Slate, 0.5 in.		20.00	0.05
	Wood shingles, cedar		1.06	0.94
Siding materials	Shingles, wood, 16 in, 7.5 in. to the weather		1.15	0.87
	Siding, redwood, or cedar, lap, average		1.20	0.83
	Board and batt, cedar, 1 in.		0.95	1.05
	Aluminum, applied on 0.375 insulating board		0.55	1.82
Woods	Maple, oak, and similar hardwoods	1.20		
	Fir, pine, and similar softwoods	0.84		
	Plywood, 0.625 in.		1.29	0.77
	California redwood	0.74		

American Society of Heating, Refrigerating, and Air Conditioning Engineers, *ASHRAE Handbook, 1977 Fundamentals*, and various industry sources.

TABLE 8-5 Coefficients of Heat Transmission U of Selected Frame Walls [in Btu/(hr)(ft²)(F°) Difference between the Air on the Two Sides, Effect of Studding Neglected; Effect of Air Films Included]

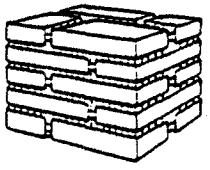
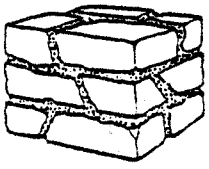
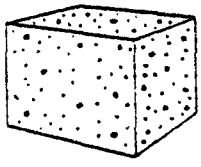
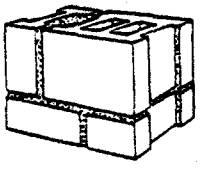
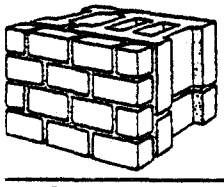
Diagram of Wall and Exterior Finish	Interior Finish	Type of Exterior Sheathing and Wall Insulation: Plywood 0.5 in. and Building Paper — No Insulation	Plywood 0.5 in. and Building Paper — 3.5 in. Insulation (R-11) in air space	Insulating Board 25/32 in. — No Insulation	Insulating Board 25/32 in. — 3.5 in. Insulation (R-11) in air space
Wood siding  Also applicable to: Wood shingles 7-in. exposure Board and batt siding ¾ in. thick	Gypsum board (dry wall)	0.25	0.069	0.20	0.062
	Gypsum lath and plaster	0.24	0.067	0.19	0.06
	Metal lath and plaster	0.28	0.075	0.24	0.07
	Plywood or wood paneling, 0.5 in.	0.35	0.082	0.26	0.075
	Insul. board 0.5 in.	0.22	0.064	0.16	0.057
Stucco  	Gypsum board (drywall)	0.32	0.072	0.22	0.071
	Gypsum lath and plaster	0.30	0.070	0.21	0.067
	Metal lath and plaster	0.36	0.080	0.25	0.075
	Plywood or wood paneling, 0.5 in.	0.38	0.083	0.22	0.076
Brick veneer  	Gypsum board (drywall)	0.30	0.071	0.21	0.068
	Gypsum lath and plaster	0.28	0.070	0.20	0.065
	Metal lath and plaster	0.34	0.078	0.22	0.072
	Plywood or wood paneling, 0.5 in.	0.34	0.083	0.24	0.07
	Wood lath and plaster	0.33	0.083	0.21	0.07

Source: *ASHRAE Handbook, 1977 Fundamentals*, and manufacturers' data.

Lights

For incandescent lamps the value 3.4 Btu/(hr)(W) of installed lamps should be used.

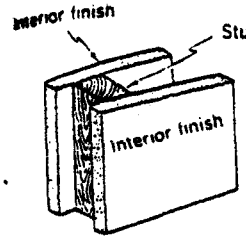
TABLE 8-6 Coefficients of Heat Transmission U of Masonry Walls [in Btu/(hr)(ft²)(F°) Difference between the Air on the Two Sides; Effects of Air Films Included]

Diagram of Wall and Type of Masonry	Thickness of Masonry, in.	Interior Finish and Insulation (If Indicated): Plain Wall, No Interior Finish	Metal Lath and Plaster, Furred	Gypsum Lath and Plaster, Furred	Gypsum Drywall on 1 x 3 Furring Strips with 0.75-in Rigid Board Insulation
Solid brick 	8	0.50	0.32	0.30	0.15
	12	0.35	0.25	0.24	0.14
	16	0.28	0.21	0.20	0.13
Stone 	8	0.70	0.39	0.36	0.16
	12	0.57	0.35	0.33	0.15
	16	0.49	0.32	0.30	0.14
Poured concrete 	6	0.79	0.42	0.39	0.16
	8	0.70	0.39	0.36	0.15
	12	0.58	0.35	0.33	0.14
		Sand and Gravel Aggregate			
Hollow concrete blocks (no exterior facing) 	8	0.56	0.34	0.32	0.14
	12	0.50	0.32	0.30	0.13
(with 4-in. face brick exterior or stone facing) 	8	0.33	0.26	0.24	0.13
	12	0.31	0.24	0.23	0.12

ASHRAE Handbook, 1977 Fundamentals, and manufacturers' data.

TABLE 8-7 Coefficients of Heat Transmission U of Frame Partitions and Interior Walls [in Btu/(hr)(ft²)(F°) Difference between the Air on the Two Sides]

Diagram of Wall

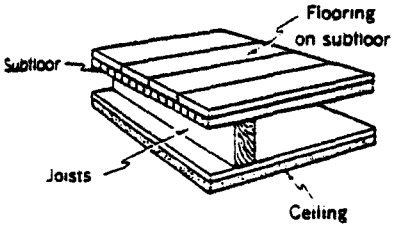


	Double Partition (Finish Both Sides)	
	No Insulation between Studs	*3.5 in. Blanket Insulation between Studs (R-11)*
Type of interior finish		
Gypsum lath and plaster	0.27	0.082
Metal lath and plaster	0.31	0.095
Plywood or wood paneling (⅜ in.)	0.33	0.105
Gypsum board (drywall), decorated	0.29	0.085

Source: ASHRAE Handbook, 1977 Fundamentals, and manufacturers' data.

TABLE 8-8 Coefficients of Heat Transmission U of Frame Construction Ceilings and Floors [in Btu/(hr)(ft²)(F°) Difference between the Air on the Two Sides]

Type of Ceiling or Floor

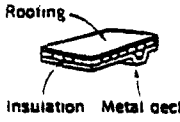
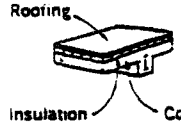
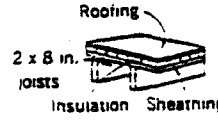


	No insulation	*6-in mineral wool blanket between joists (R-19)*	*8–10 in. Blown mineral wool (R-30)*
Ceilings (unheated attic space above)			
Plaster on gypsum board, on wood joists	0.63	0.055	0.045
Plaster on metal lath on wood joists	0.74	0.057	0.05
Gypsum board (drywall) decorated	0.75	0.057	0.05
Floors (over crawl space or basement)			
Hardwood on $^{25}/_{32}$-in. subfloor on wood joists	0.37		
Carpet on fiber pad on ¾-in. plywood subfloor on wood joists	0.24		
Linoleum or asphalt tile on 1-in. plywood subfloor on wood joists	0.57		

Floor-ceiling combinations	*Type of Floor*			
	Hardwood on $^{25}/_{32}$-in. Subfloor	*Carpet on Fiber Pad on ¾-in. Plywood Subfloor*	*Linoleum or Asphalt Tile on ¼-in. Plywood Subfloor*	*Linoleum or Asphalt Tile on 4-in. Concrete*
Type of ceiling				
Plaster on gypsum board on wood joists	0.22	0.17	0.28	
Plaster on metal lath on wood joists	0.25	0.20	0.26	
Gypsum (drywall)	0.23	0.19	0.25	
Plaster on metal lath on furring strips				0.33

ASHRAE Handbook, 1977 Fundamentals, and manufacturers' data.

TABLE 8-9 Coefficients of Heat Transmission U of Typical Flat Roofs Covered with Built-up Roofing [in Btu/(hr)(ft²)(F° Difference between the Air on the Two Sides]

Type of Roof Deck (Ceiling Not Shown)	*Thickness of Roof Deck, in.*	*Type of Suspended Ceiling*	*Insulation on Top of Deck (Covered with Built-up Roofing), in.* None	1	2
Flat metal roof deck		None	0.67	0.23	0.13
		Gypsum bd. and plaster (½ in.)	0.32	0.17	0.12
		Acoustical tile (¾ in.)	0.23	0.14	0.11
Concrete slab (light-weight aggregate)	2	None	0.30	0.18	0.11
		Gypsum bd. and plaster (½ in.)	0.18	0.12	0.09
		Acoustical tile (¾ in.)	0.15	0.11	0.08
	4	None	0.24	0.11	0.09
		Gypsum bd. and plaster (½ in.)	0.13	0.10	0.08
		Acoustical tile (¾ in.)	0.12	0.09	0.07
Wood, on 2 x 8 joists	1	None	0.40	0.19	0.13
		Gypsum bd. and plaster (½ in.)	0.24	0.15	0.11
		Acoustical tile (¾ in.)	0.19	0.13	0.10
	2	None	0.28	0.16	0.11
		Gypsum bd. and plaster (½ in.)	0.19	0.13	0.10
		Acoustical tile (¾ in.)	0.16	0.11	0.09

ASHRAE Handbook, 1977 Fundamentals, and manufacturers' data.

TABLE 8-11 Effect of Various Shading Conditions on Solar-Radiation Heat Gain (Multiply the SCs by Solar-Heat-Gain Factors from Table 15)

Type of Shading Device	*Shade Coefficients (SC)*
Canvas awning	0.25
Inside venetian blinds, set at 45°, light color	0.55
Inside venetian blinds, set at 45°, dark color	0.64
Roller shades, fully drawn, light color	0.25
Roller shades, fully drawn, dark color	0.59
Single glass: regular sheet	1.00
¼-in. plate glass	0.95
⅜-in. plate glass	0.91
½-in. plate glass	0.88
Roof overhang or marquee, full shading	0.25
Windows shaded by normal setback from external building surface	0.90
Outside shading screen	0.30
Wood sash (85% gross area equals net glass area)	0.85

ASHRAE handbooks and manufacturers' data.

TABLE 8-12 Coefficients of Heat Transmission U of Vertical Windows (Exterior)

Type of Glass	*U, Btu per (hr)(ft²)(F°)* No Indoor Shade	Indoor Shade
Single-strength glass	1.04	0.81
Double-strength (single-pane) glass	0.85	0.70
Extra-heavy plate glass	0.78	0.55
Double glass, insulating, ¼-in. air space	0.61	0.54
Triple glass, insulating, ¼-in. air spaces	0.44	0.40
Storm windows, 1 to 4 in. air space	0.50	0.48

ASHRAE handbooks and manufacturers' data.

TABLE 8-13 Calculation of Outside-Air Infiltration—Air-Change Method

H = room height L = length
W = width G = wall factor

Room with:
One outside wall, $G = 1$
Two outside walls, $G = 1.5$
Three outside walls, $G = 2$

$$\text{cfm} = \frac{W \times H \times L \times G}{60}$$

Notes:
1. For rooms with good weatherstripping on windows and doors, use 50 percent of the value calculated.
2. For commercial establishments where doors are opened frequently, add 100 ft³ per person per passage for each 36-in. swinging door.
3. Vestibules—reduce by 25 percent, revolving doors by 75 percent.
4. Residences—three-quarters air change per hour.

Source: Reprinted by permission of the Air Conditioning and Refrigeration Institute, Arlington, Va.

Infiltration

$$H_s = \text{cfm} \times 1.08 \times (t_o - t)$$

(sensible heat gain from outside air)

$$H_L = \text{cfm} \times 0.68 \times (W_o - W)$$

(latent heat gain from outside air)

TABLE 8-14 Infiltration through Cracks (Cubic Feet per Minute per Lineal Foot of Crack)

Type of Window or Door	Remarks	Wind Velocity, mi/hr 5	10	30
Double-hung wood sash	Average window in wood frame, non-weatherstripped	0.12	0.65	1.73
	Same, weatherstripped	0.07	0.40	1.05
	Poorly fitted window in wood frame, non-weatherstripped	0.45	1.85	4.20
	Same, weatherstripped	0.10	1.57	1.53
Steel sash, rolled section	Architectural, projected	0.25	1.03	2.30
	Industrial, pivoted	0.87	2.90	6.20
	Residential casement	0.25	0.87	2.10
	Heavy casement section, projected	0.13	0.63	1.53
	Hollow metal, vertically pivoted	0.50	2.40	4.00
Ordinary wood or metal door	Well fitted, non-weatherstripped	0.90	1.80	4.20
	Same, weatherstripped	0.45	0.90	2.10
	Poorly fitted, non-weatherstripped	0.90	3.70	8.40
	Same, weatherstripped	0.45	1.85	4.20
Glass door	Good installation	3.20	9.60	19.0
Factory door	⅛-in. crack	3.20	9.60	19.0
Metal-sash windows	Aluminum, double-hung or sliding, weatherstripped	0.10	0.53	1.27

Abstracted from Carrier Air Conditioning Co., *Handbook of Air Conditioning System Design*, McGraw-Hill Book Company, New York, 1966.

TABLE 8-15 Infiltration Due to Door Openings

Application	Cfm per Person entering Room per Door: 72-in. Revolving Door	36-in. Sunroom Door: No Vestibule	36-in. Sunroom Door: With Vestibule
Bank	6.5	8.0	6.0
Barber shop	4.0	5.0	3.8
Candy and ice cream	5.5	7.0	5.3
Cigar store	20.0	30.0	22.5
Department store (small)	6.5	8.0	6.0
Dress shop	2.0	2.5	1.9
Drug store	5.5	7.0	5.3
Hospital room		3.5	2.6
Lunch room	4.0	5.0	3.8
Men's shop	2.7	3.7	2.8
Restaurant	2.0	2.5	1.9
Shore store	2.7	3.5	2.6

Abstracted from Carrier Air Conditioning Co., *Handbook of Air Conditioning System Design*, McGraw-Hill Book Company, New York, 1966.

TABLE 8-16 Rates of Heat Gain from Occupants of Conditioned Spaces: Based on 78°F Room DB Temperature

Degree of Activity	Typical Application	Total Heat Adults, Male, Btu/hr	Total Heat, Adjusted, Btu/hr	Sensible Heat, Btu/hr	Latent Heat, Btu/hr
Seated, at rest	Theater	400	350	210	140
Seated, very light work	Offices, hotels, apartments	480	420	230	190
Moderately active office work	Offices, hotels, apartments	640	510	255	255
Standing, light work or walking slowly	Department store, retail store, dime store	800	640	315	325
Light bench work	Factory	880	780	345	435
Moderate dancing	Dance hall	1360	1280	405	875
Walking 3 mi/hr or moderate work	Factory	1040	1000	350	650
Bowling	Bowling alley	1200	960	345	615
Heavy work, vigorous sports	Factory, gymnasium	2000	1800	635	1165

Notes:

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

[2] Adjusted total heat value for sedentary work, restaurant, includes 60 Btu/hr for food per individual (30 Btu sensible and 30 Btu latent).

Source: ASHRAE, Cooling and Heating Load Calculation Manual, New York, 1979.

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TABLE 8-17 Recommended Rate of Heat Gain from Selected Cooking Appliances Located in the Air-Conditioned Space

Appliance	Capacity	Overall Dimensions, in. (Width × Depth × Height)	Miscellaneous Data	Rated Watts	Recommended Rate of Heat Gain, Btu/hr			
					Without Hood			With Hood
					Sensible	Latent	Total	All Sensible
GAS-BURNING, COUNTER TYPE								
Coffee brewer per burner			With warm position		1750	750	2500	500
Coffee urn	5 gal	14-in dia.			5250	2250	7500	1500
Deep fat fryer	15 lb fat	14 × 21 × 15			7500	7500	15000	3000
Dry food warmer per ft² of top					560	140	700	140
Griddle, frying per ft² of top					4900	2600	7500	1500
Short order stove per burner			Open grates		3200	1800	5000	1000
ELECTRIC, COUNTER TYPE								
Coffee brewer per burner				625	770	230	1000	340
Coffee urn, electric	5 gal			3000	3850	1250	5100	1600
Hotplate		18 × 20 × 13	2 heating units	5200	5300	3600	8900	2800
Toaster, continuous	720 slices/hr	20 × 15 × 28	4 slices wide	3000	2700	2400	5100	1600

ASHRAE Cooling and Heating Load Calculation Manual, New York, 1979.

TABLE 8-18 Rate of Heat Gain from Miscellaneous Appliances

Appliance	Miscellaneous Data	Manufacturer's Rating		Recommended Rate of Heat Gain, Btu/hr		
		W	Btu/hr	Sensible	Latent	Total
Electrical Appliances						
Hair drier	Blower type	1580	5,400	2,300	400	2,700
Hair drier	Helmet type	705	2,400	1,870	330	2,200
Sterilizer, instrument		1100	3,750	650	1200	1,850
Large copying machine	Operating		12,000	12,000	0	12,000
	Standby		6,000	6,000	0	6,000
Gas-burning Appliances						
Lab burners, Bunsen	7/16-in. barrel		3,000	1,680	420	2,100

ASHRAE Cooling and Heating Load Calculation Manual, New York, 1979.

TABLE 15—SOLAR HEAT GAIN THRU ORDINARY GLASS

Btu/(hr) (sq ft sash area)

0°

0°

0° NORTH LATITUDE		AM					SUN TIME				PM			0° SOUTH LATITUDE	
Time of Year	Exposure	6	7	8	9	10	11	Noon	1	2	3	4	5	6	Exposure	Time of Year
JUNE 21	North	0	45	65	74	78	80	82	80	78	74	65	45	0	South	DEC 22
	Northeast	0	119	156	154	133	95	53	20	14	13	11	6	0	Southeast	
	East	0	114	147	135	97	47	14	14	14	13	11	6	0	East	
	Southeast	0	37	42	27	15	14	14	14	14	13	11	6	0	Northeast	
	South	0	6	11	13	14	14	14	14	14	13	11	6	0	North	
	Southwest	0	6	11	13	14	14	14	14	15	22	47	77	0	Northwest	
	West	0	6	11	13	14	14	14	43	93	135	147	116	0	West	
	Northwest	0	6	11	13	14	20	53	95	133	154	156	119	0	Southwest	
	Horizontal	0	28	87	147	191	217	226	217	191	147	87	28	0	Horizontal	
JULY 23 & MAY 21	North	0	37	54	61	65	66	67	66	65	61	54	37	0	South	JAN 21 & NOV 21
	Northeast	0	118	153	150	124	86	43	16	14	13	11	6	0	Southeast	
	East	0	121	157	139	96	43	14	14	14	13	11	6	0	East	
	Southeast	0	46	52	36	18	14	14	14	14	13	11	6	0	Northeast	
	South	0	6	11	13	14	14	14	14	14	13	11	6	0	North	
	Southwest	0	6	11	13	14	14	14	14	18	36	52	46	0	Northwest	
	West	0	6	11	13	14	14	14	43	96	139	152	121	0	West	
	Northwest	0	6	11	13	14	16	43	86	124	150	153	118	0	Southwest	
	Horizontal	0	29	91	151	195	223	233	223	195	151	91	29	0	Horizontal	
AUG 24 & APR 20	North	0	17	28	31	33	34	34	34	33	31	28	17	0	South	FEB 20 & OCT 23
	Northeast	0	110	141	133	102	61	24	14	14	13	12	6	0	Southeast	
	East	0	129	163	148	103	46	14	14	14	13	12	6	0	East	
	Southeast	0	87	79	55	35	15	14	14	14	13	12	6	0	Northeast	
	South	0	6	12	13	14	14	14	14	14	13	12	6	0	North	
	Southwest	0	6	12	13	14	14	14	15	35	65	79	67	0	Northwest	
	West	0	6	12	13	14	14	14	46	103	146	163	129	0	West	
	Northwest	0	6	12	13	14	14	24	61	102	133	141	110	0	Southwest	
	Horizontal	0	31	97	150	206	234	245	234	206	150	97	31	0	Horizontal	
SEPT 22 & MAR 22	North	0	6	12	13	14	14	14	14	14	13	12	6	0	South	MAR 22 & SEPT 22
	Northeast	0	95	118	101	68	31	14	14	14	13	12	6	0	Southeast	
	East	0	124	167	151	107	47	14	14	14	13	12	6	0	East	
	Southeast	0	95	118	101	68	31	14	14	14	13	12	6	0	Northeast	
	South	0	6	12	13	14	14	14	14	14	13	12	6	0	North	
	Southwest	0	6	12	13	14	14	14	31	68	101	118	95	0	Northwest	
	West	0	6	12	13	14	14	14	47	107	151	167	134	0	West	
	Northwest	0	6	12	13	14	14	14	31	68	101	118	95	0	Southwest	
	Horizontal	0	33	100	163	210	240	250	240	210	163	100	33	0	Horizontal	
OCT 23 & FEB 20	North	0	6	12	13	14	14	14	14	14	13	12	6	0	South	APR 20 & AUG 24
	Northeast	0	87	79	55	35	15	14	14	14	13	12	6	0	Southeast	
	East	0	129	163	148	103	46	14	14	14	13	12	6	0	East	
	Southeast	0	110	141	133	102	61	24	14	14	13	12	6	0	Northeast	
	South	0	17	28	31	33	34	34	34	33	31	28	17	0	North	
	Southwest	0	6	12	13	14	14	24	61	102	133	141	110	0	Northwest	
	West	0	6	12	13	14	14	14	46	103	148	163	129	0	West	
	Northwest	0	6	12	13	14	14	14	15	35	65	79	67	0	Southwest	
	Horizontal	0	31	97	150	206	234	245	234	206	150	97	31	0	Horizontal	
NOV 21 & JAN 21	North	0	6	11	13	14	14	14	14	14	13	11	6	0	South	MAY 21 & JULY 23
	Northeast	0	46	52	36	18	14	14	14	14	13	11	6	0	Southeast	
	East	0	121	152	139	96	43	14	14	14	13	11	6	0	East	
	Southeast	0	118	153	150	124	86	43	16	14	13	11	6	0	Northeast	
	South	0	37	54	61	65	66	67	66	65	61	54	37	0	North	
	Southwest	0	6	11	13	14	16	43	86	124	150	153	118	0	Northwest	
	West	0	6	11	13	14	14	14	43	96	139	152	121	0	West	
	Northwest	0	6	11	13	14	14	14	14	18	36	52	46	0	Southwest	
	Horizontal	0	29	91	151	195	223	233	223	195	151	91	29	0	Horizontal	
DEC 22	North	0	6	11	13	14	14	14	14	14	13	11	6	0	South	JUNE 21
	Northeast	0	37	42	27	15	14	14	14	14	13	11	6	0	Southeast	
	East	0	116	147	135	97	47	14	14	14	13	11	6	0	East	
	Southeast	0	119	156	154	133	95	53	20	14	13	11	6	0	Northeast	
	South	0	45	65	74	78	80	82	80	78	74	65	45	0	North	
	Southwest	0	6	11	13	14	20	53	95	133	154	156	119	0	Northwest	
	West	0	6	11	13	14	14	14	43	93	135	147	116	0	West	
	Northwest	0	6	11	13	14	14	14	14	15	27	42	37	0	Southwest	
	Horizontal	0	28	87	147	191	217	226	217	191	147	87	28	0	Horizontal	

Solar Gain Correction	Steel Sash, or No Sash	Haze	Altitude	Dewpoint Decrease From 67 F	Dewpoint Increase From 67 F	South Lat. Dec. or Jan.
	× 1/.85 or 1.17	−15% (Max.)	+0.7% per 1000 Ft	− 7% per 10 F	− 7% per 10 F	− 7%

Bold Face Values — Monthly Maximums Based Values — Yearly maximums

[11/12]

TABLE 28—TRANSMISSION COEFFICIENT U—PITCHED ROOFS*

FOR HEAT FLOW DOWN—SUMMER. FOR HEAT FLOW UP—WINTER (See Equation at Bottom of Page)

Btu/(hr) (sq ft projected area) (deg F temp diff)

All numbers in parentheses indicate weight per sq ft. Total weight per sq ft is sum of component materials.

PITCHED ROOFS		CEILING											
		None	⅜" Wood Panel (2)	½" Gypsum Board (Plaster Board) (2)	Metal Lath Plastered		⅜" Gypsum or Wood Lath Plastered		Insulating Board Plain or ½" Sand Agg Plastered		Acoustical Tile on Furring or ¾" Gypsum	
					¾" Sand Plaster (7)	¾" Lt Wt Plaster (3)	½" Sand Plaster (5)	½" Lt Wt Plaster (2)	½" Board (2)	1" Board (4)	½" Tile (2)	¾" Tile (3)
EXTERIOR SURFACE	SHEATHING											
Asphalt Shingles. (2)	Bldg paper on ⅜" plywood (2)	.51	.27	.30	.32	.29	.29	.28	.22	.17	.23	.21
	Bldg paper on 25/32" wood sheathing (3)	.30	.22	.26	.27	.25	.25	.24	.20	.16	.21	.19
Asbestos-Cement Shingles (3) or Asphalt Roll Roofing (1)	Bldg paper on ⅜" plywood (2)	.59	.28	.34	.37	.33	.33	.31	.25	.18	.25	.22
	Bldg paper on 25/32" wood sheathing (3)	.45	.25	.29	.31	.28	.28	.27	.22	.17	.22	.20
Slates (8) Tile (10) or Sheet Metal (1)	Bldg paper on ⅜" plywood (2)	.64	.29	.36	.38	.34	.35	.47	.26	.19	.26	.23
	Bldg paper on 25/32" wood sheathing (3)	.48	.25	.29	.31	.28	.28	.27	.22	.17	.23	.20
Wood Shingles (2)	Bldg paper on 1" x 4" strips (1)	.53	.26	.31	.33	.30	.30	.28	.23	.17	.24	.21
	Bldg paper on ⅜" plywood (2)	.41	.23	.27	.29	.26	.27	.25	.21	.16	.21	.19
	Bldg paper on 25/32" wood sheathing (3)	.34	.21	.24	.25	.23	.23	.22	.19	.15	.19	.17

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Equations: Summer (Heat Flow Down) Heat Gain, Btu/hr = (horizontal projected area, sq ft) × (U value) × (equivalent temp diff, Table 20).

TABLE 18-2 Recommended NC (Noise Criteria) for Selection of Diffusers and Various Applications

Recommended Noise Criteria (dB Attenuation)		
NC Curve	*Communication Environment*	*Typical Occupancy*
Below NC 25	Extremely quiet environment, suppressed speech is quite audible, suitable for acute pickup of all sounds. Recording and performing studios require NC levels below 20	Broadcasting studios, concert halls, music rooms, church sanctuaries
NC 30	Very quiet office, suitable for large conferences, telephone use satisfactory. Levels below NC 30 are considered "very quiet"	Residences, theaters, libraries, executive offices directors' rooms
NC 35	Quiet office; satisfactory for conference at a 15-ft table; normal voice 10–30 ft; telephone use satisfactory	Private offices, schools, hotel rooms, courtrooms, hospital rooms
NC 40	Satisfactory for conferences at a 6–8-ft table; normal voice 6–12 ft; telephone use occasionally difficult	General offices, labs, dining rooms, building lobbies
NC 45	Satisfactory for conferences at a 4–5-ft table; normal voice 3–6 ft; raised voice 6–12 ft; telephone use occasionally difficult	Retail stores, cafeterias, corridors, large drafting & engineering offices, noisy reception areas
Above NC 50	Unsatisfactory for conferences of more than two or three persons; normal voice 1–2 ft; raised voice 3–6 ft; telephone use often difficult. Levels above NC 50 are considered "noisy"	Noisy offices, stenographic pools, print machine rooms, process areas, manufacturing

Source: Tuttle and Bailey Manufacturing Company.

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TABLE 18-5. Selection and Performance Data for Round Ceiling Diffusers
(a Portion of a Manufacturer's Table with NC Numbers Added)

Size, in.: *Neck Area, ft²*	*Neck Vel., fpm*	*700*	*800*	*900*	*1000*	*1100*	*1200*	*1300*	*1400*	*1600*	*1800*	*2000*
	CFM	95	110	120	135	150	165	175	190	220	245	270
5	SP	0.07	0.09	0.12	0.15	0.18	0.21	0.25	0.29	0.37	0.47	0.58
0.136	RAD	3–5	3–5	3–5	3–6	3–6	3–7	4–7	4–8	5–10	6–12	7–14
	NC	18	22	25	28	31	34	36	37	41	44	46
	CFM	135	155	175	195	215	235	255	275	315	355	390
6	SP	0.07	0.09	0.11	0.14	0.16	0.2	0.24	0.27	0.36	0.45	0.56
	RAD	3–5	3–6	3–6	3–7	4–7	4–8	4–9	5–10	6–12	6–14	7–15
	NC	18	22	26	29	31	34	36	37	41	44	46
	CFM	245	280	315	350	385	420	455	490	560	630	700
8	SP	0.06	0.08	0.1	0.13	0.16	0.19	0.22	0.25	0.33	0.42	0.52
0.349	RAD	4–7	4–8	4–9	5–10	5–11	5–12	6–12	6–13	7–15	9–18	10–20
	NC	19	23	29	30	33	35	37	39	43	46	49
	CFM	380	435	490	545	600	655	710	765	870	980	1090
10	SP	0.05	0.07	0.09	0.11	0.13	0.16	0.19	0.22	0.28	0.36	0.44
0.545	RAD	5–11	6–12	6–13	7–14	7–15	8–15	8–17	8–18	10–20	11–22	13–26
	NC	21	25	29	32	34	37	39	41	44	48	51
	CFM	550	630	705	785	865	940	1020	1100	1260	1410	1570
12	SP	0.05	0.06	0.08	0.1	0.12	0.14	0.17	0.19	0.25	0.32	0.39
0.785	RAD	7–14	7–15	8–16	8–17	9–18	9–19	13–20	10–21	12–25	13–27	15–30
	NC	23	26	30	33	36	38	41	43	47	50	53
	CFM	860	980	1100	1230	1350	1470	1600	1720	1960	2210	2450
15	SP	0.04	0.05	0.06	0.08	0.09	0.11	0.13	0.15	0.19	0.24	0.3
1.227	RAD	8–17	9–18	9–19	10–21	11–22	12–24	13–26	13–27	15–30	17–35	18–39
	NC	24	28	32	35	38	40	41	43	48	51	54
	CFM	1240	1410	1590	1770	1940	2120	2300	2470	2830	3180	3530
18	SP	0.03	0.04	0.05	0.06	0.08	0.09	0.11	0.12	0.16	0.2	0.25
1.767	RAD	11–22	12–25	13–26	14–28	15–30	15–32	16–33	17–34	19–38	21–43	23–46
	NC	26	30	32	35	38	41	43	45	49	52	54
	CFM	1680	1920	2160	2400	2650	2890	3130	3370	3850	4330	4810
21	SP	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.12	0.15	0.19
2.405	RAD	12–24	14–28	15–30	16–32	17–34	18–36	19–38	20–40	22–44	24–48	27–55
	NC	27	30	34	37	40	43	45	46	50	54	57
	CFM	2200	2510	2830	3140	3460	3770	4080	4400	5030	5660	6280
24	SP	0.04	0.06	0.07	0.09	0.1	0.12	0.15	0.17	0.22	0.28	0.35
3.142	RAD	15–30	16–33	17–35	18–37	19–38	20–40	21–42	23–45	25–51	28–57	31–63
	NC	28	32	35	38	40	43	45	47	51	55	58

Source: Anemostat Products Division, Dynamics Corporation of America