CAE 464/517 HVAC Systems Design

Spring 2023

January 19, 2023

Space conditioning and intro to the load calculations

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ANNOUNCEMENTS

Announcements

- Regularly check out the Q&A file:

CAE 464/517 Spring 2023 Q&As

Assignment 1

Question: I have a question about the homework for HVAC design. I'm on the part involving the AHU, but I can't find the manufacturer or model number in the plans. I must've just missed it, but I was just wondering where it's supposed to be.

Response: This is a good question. Sometimes major components, especially AHU, are custom made and it might be hard to find the exact model. I would recommend finding something close to the AHU model.

—---

Question: For the question where we're calculating the cfm/ft^2 for the conditioned spaces, is that going to be on a zone by zone basis or is it the total cfm for the entire building? Or for each floor? Also, in the ventilations schedules on the M2-x sheets are we supposed to use the supply or return cfm for calculating the ventilation?

Response: For the cfm/ft^2, you should do it zone by zone similar to the ventilation schedules that you see. You can just report for one floor. No need to do it for all floors.

Ventilation refers to the outdoor air supply, so please just take a look at the supply and no need to report the return at this point.

https://docs.google.com/document/d/1m6ezSI6Bi9wGQcjnaYj_iAXY2kzRlCPYWkKfayNp5WE/

RECAP OF INTRO TO PSYCHROMETRICS

Recap

- If needed, additional resources are available:

The Built Environment Research Group

advancing energy, environmental, and sustainability
research within the built environment
at Illinois Institute of Technology

HOME PEOPLE PROJECTS PUBLICATIONS PRESENTATIONS FACILITIES COURSES BLOG

CAE 331/513 Building Science (Fall 2019)

CAE 331/513 Building Science is the study of the physical interaction of climate (e.g., humidity, temperature, wind, sun, rain, snow, etc.) and buildings. Topics include psychrometrics, indoor air quality, indoor thermal comfort, heat transfer, air infiltration, solar insolation, and heating and cooling load calculations.

Course Syllabus

- Syllabus

Lecture Notes

cae331_513_lecture01_intro to building science

cae331_513_lecture02_review of prereq concepts

cae331_513_lecture03_conduction part1

cae331_513_lecture04_conduction part2

cae331_513_lecture05_convection

cae331_513_lecture06_radiation

cae331_513_lecture07_combined mode heat transfer

cae331_513_lecture08_fenestration

cae331_513_lecture09_thermal comfort

cae331_513_lecture10_psychrometric chart

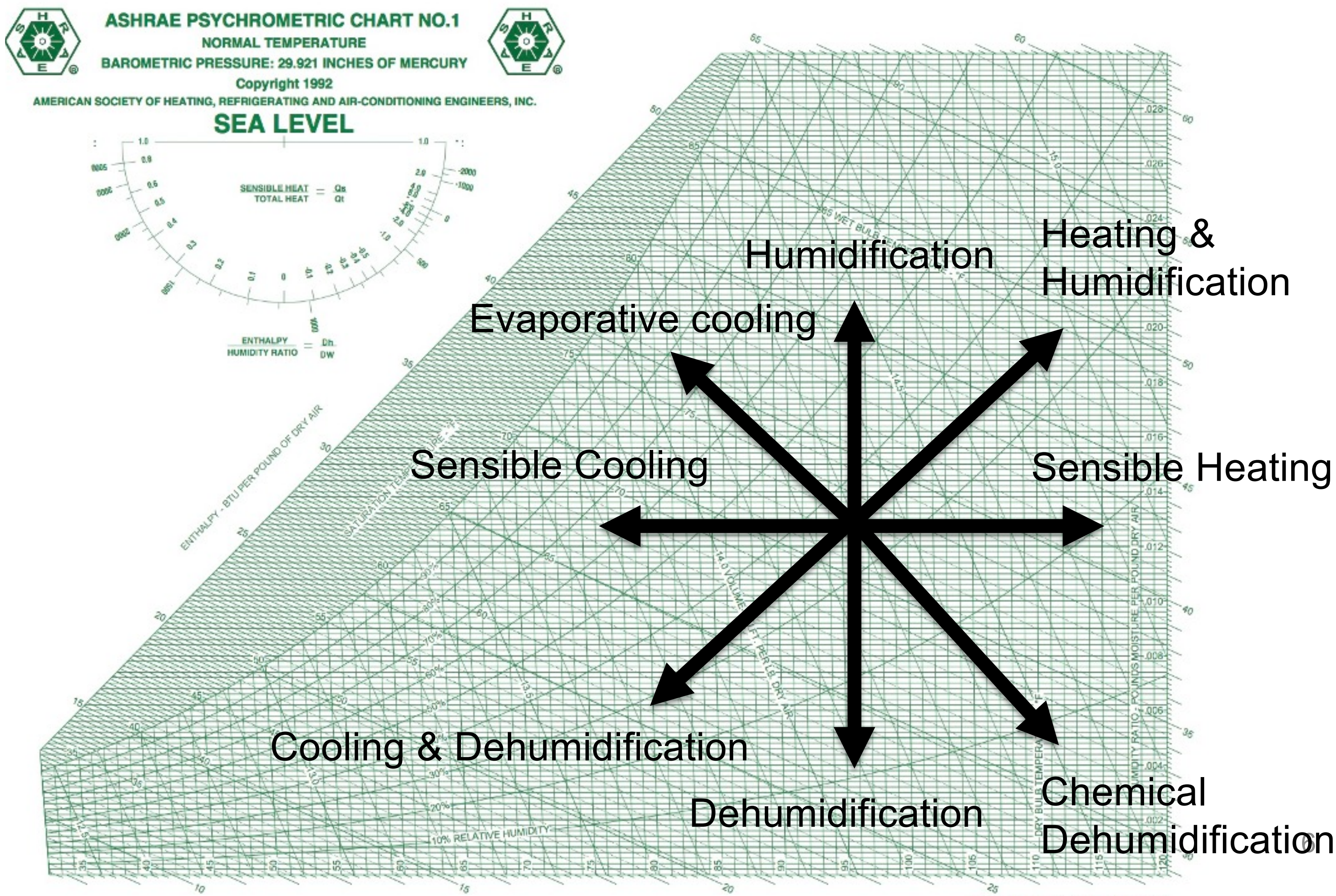
cae331_513_lecture11_psychrometric equations

cae331_513_lecture12_intro to hvac systems part 1

http://built-envi.com/courses/cae-331-513-building-science-fall-2019/

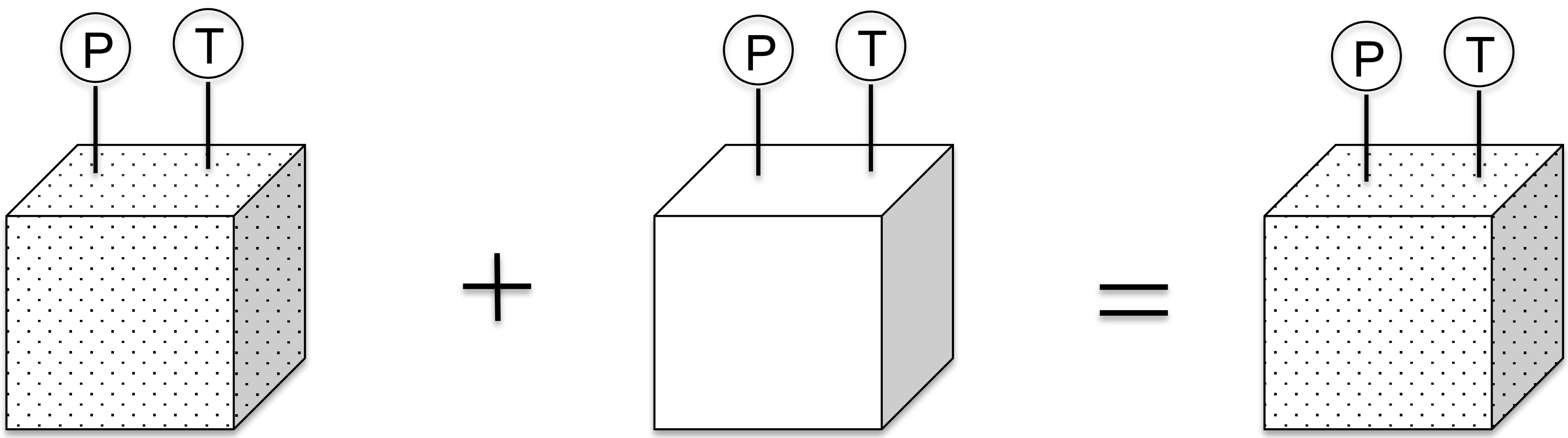
Recap

- Summary of Psychrometric Processes



Recap

- Moist air:
  - ❑ Atmospheric air is a mixture of “dry air and gases” and “water vapor”



Dry Air

T = 75 °F
m_{da} = 1 lb
m_w = 0 lb
p_a = 14.482 psia
p_w = 0 psia
$p_{mixture}$ = 14.482 psia

Water Vapor

T = 75 °F
m_{da} = 0 lb
m_w = 0.0092 lb
p_a = 0 psia
p_w = 0.215 psia
$p_{mixture}$ = 0.215 psia

Moist Air

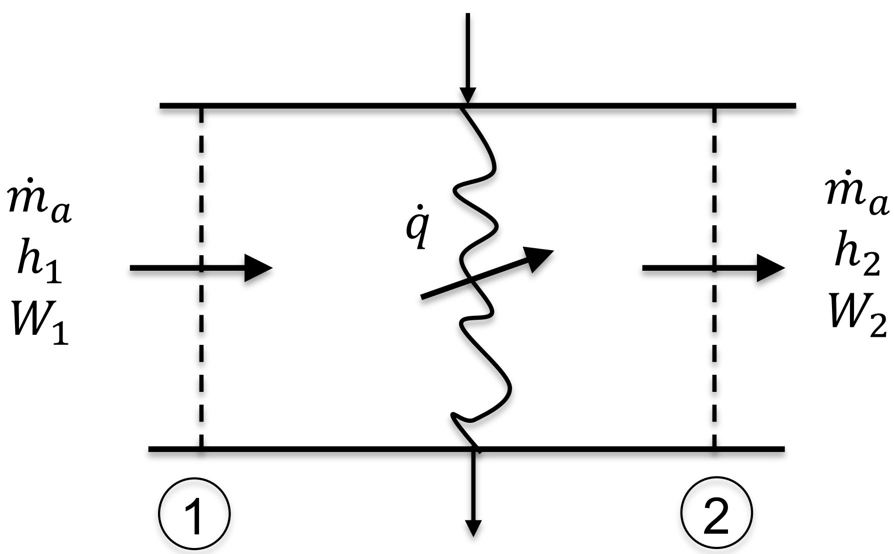
T = 75 °F
m_{da} = 1 lb
m_w = 0.0092 lb
p_a = 14.482 psia
p_w = 0.215 psia
$p_{mixture}$ = 14.697 psia

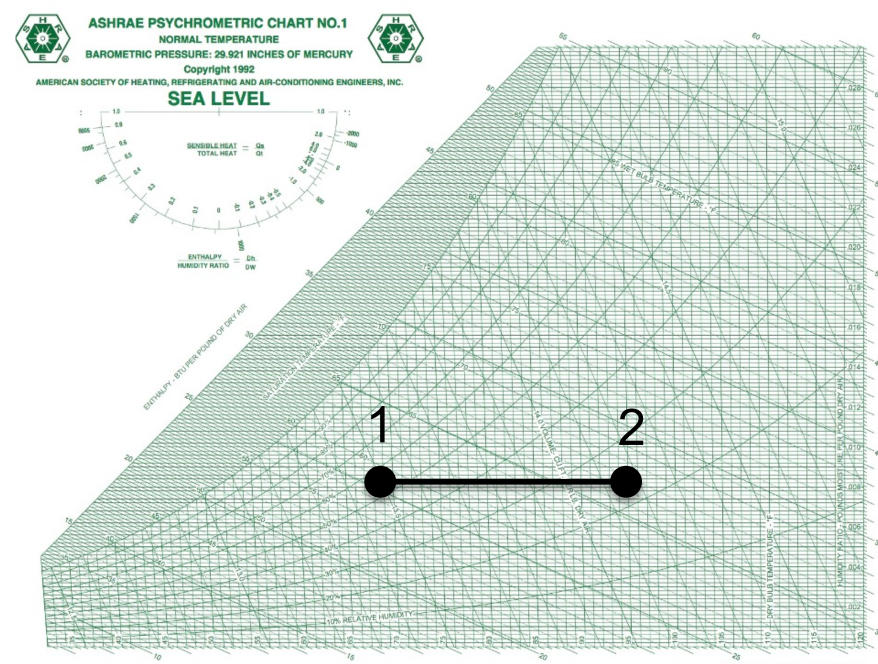
CLASSIFICATION OF AIR PROCESSES (CAE 331, MMAE 320)

Processes

- Sensible heating or cooling:
  - ❑ Steady-state the energy balance is:

$$\dot{m}_a h_2 = \dot{m}_a h_1 + \dot{q}$$





Processes

- Sensible heating or cooling:
  - Sensible

$$W_1 = W_2$$

  - Moist air

$$h_1 = h_{da1} + W_1 h_{v1}$$

$$h_2 = h_{da2} + W_2 h_{v2}$$

  - From perfect gas assumption

$$\dot{q}_s = \dot{m}_a c_p (T_2 - T_1) \qquad heating$$

$$\dot{q}_s = \dot{m}_a c_p (T_1 - T_2) \qquad cooling$$

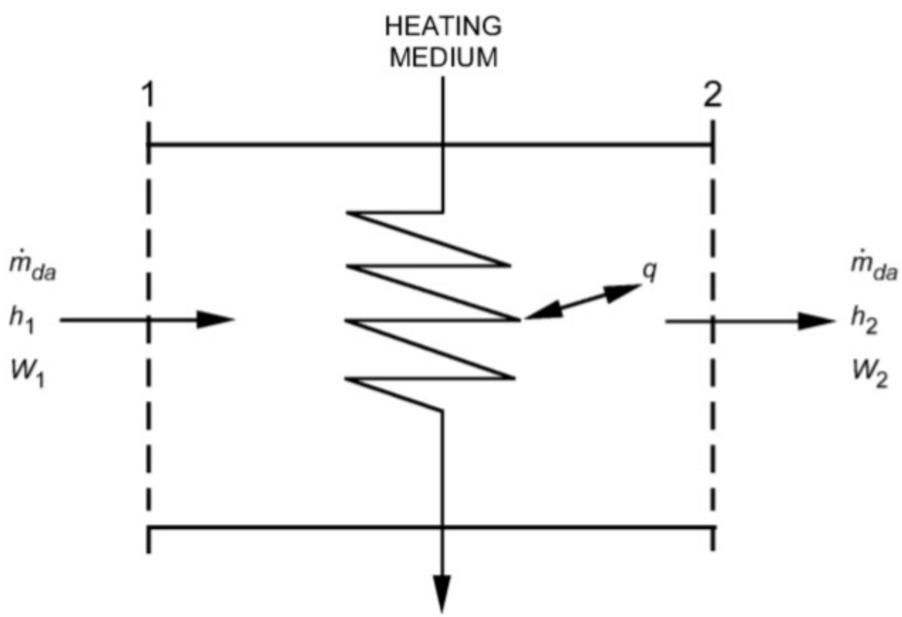
CLASS ACTIVITY

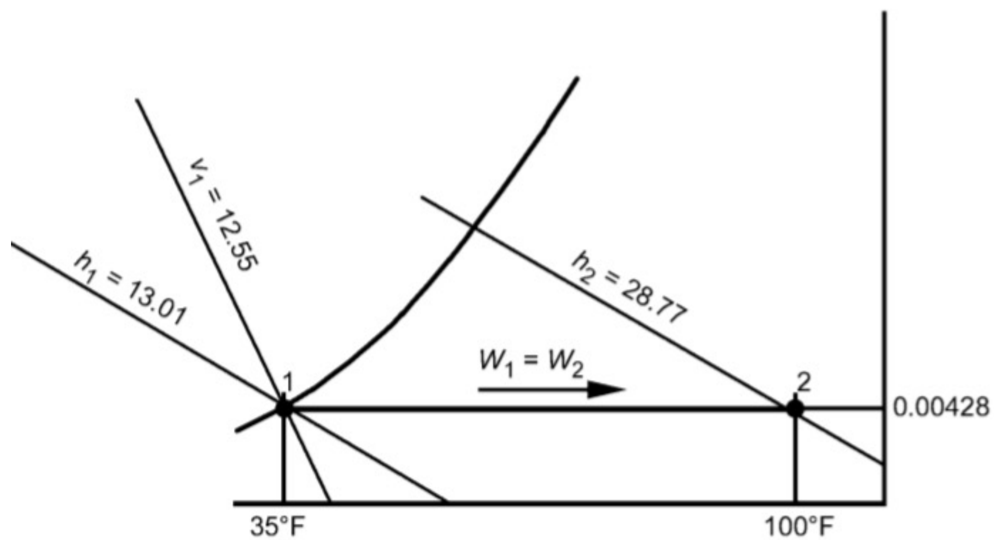
Class Activity

- Example (sensible heating or cooling – Page 1.18): Moist air, saturated at 35 °F, enters a heating coil at a rate of 20,000 CFM. Air leaves the coil at 100 °F. Find the required rate of heat addition.

Class Activity

- Solution (Psychrometric Chart)





Class Activity

- Solution (Psychrometric Chart):

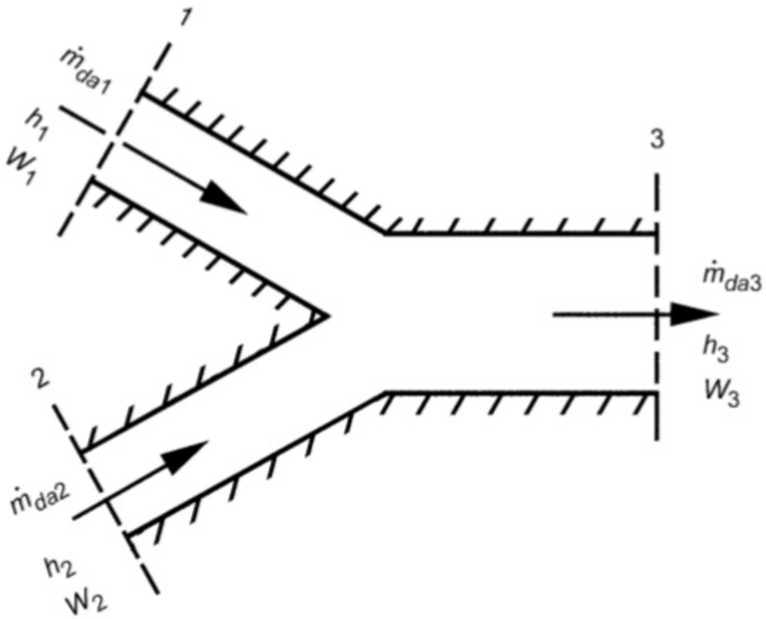
$$\dot{q} = \dot{m}_{da}(h_2 - h_1)$$

$$\dot{m}_{da} = 20{,}000\ CFM \times \frac{60}{12.55} = 95{,}620\ lb_{da}/h$$

$$\dot{m}_{da} = (95{,}620)\times(28.77 - 13.01) = 1{,}507{,}000\ \frac{Btu}{h}$$

Processes

- Adiabatic mixing of two moist stream:



$$\dot{m}_{da1}h_1 + \dot{m}_{da2}h_2 = \dot{m}_{da3}h_3$$

$$\dot{m}_{da1} + \dot{m}_{da2} = \dot{m}_{da3}$$

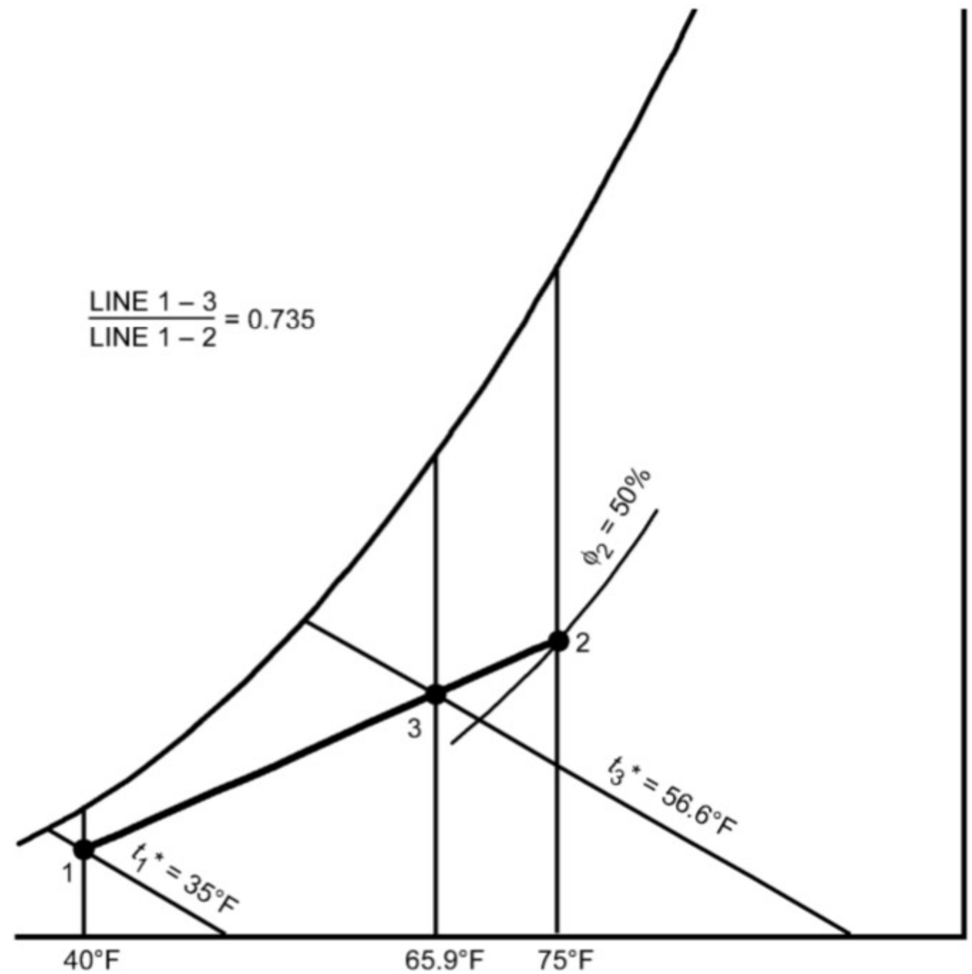
$$\frac{h_2 - h_3}{h_3 - h_1} = \frac{W_2 - W_3}{W_3 - W_1} = \frac{segment2-3}{segment3-1} = \frac{\dot{m}_{da1}}{\dot{m}_{da2}}$$

Processes

- Adiabatic mixing of two moist stream

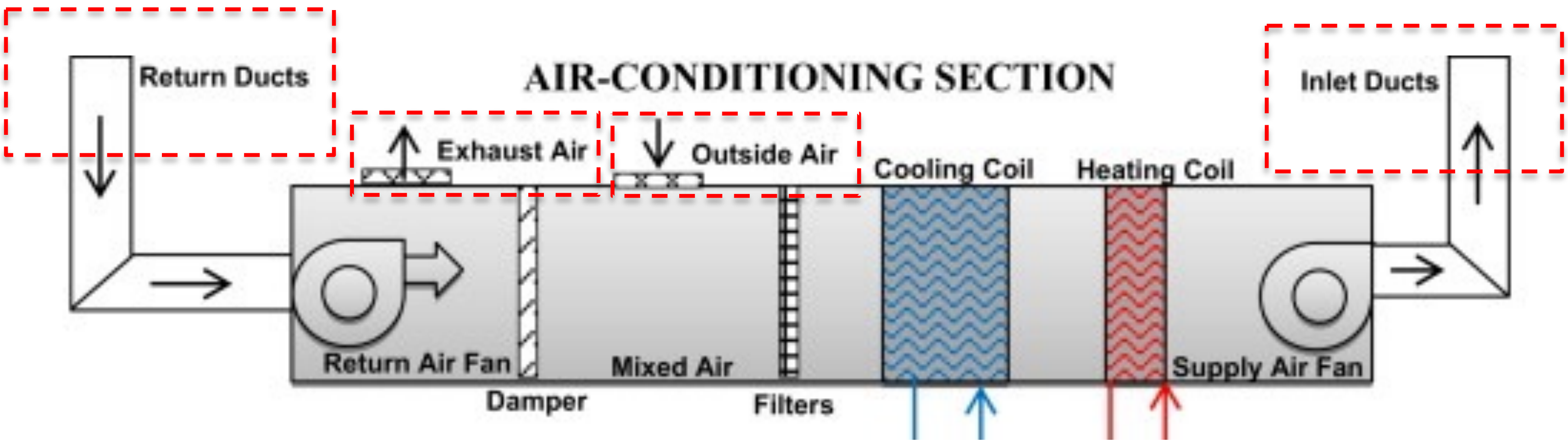
$$\frac{Line\ 3{-}2}{Line\ 1{-}3} = \frac{\dot{m}_{da1}}{\dot{m}_{da2}}$$

$$\frac{Line\ 1{-}3}{Line\ 1{-}2} = \frac{\dot{m}_{da2}}{\dot{m}_{da3}}$$



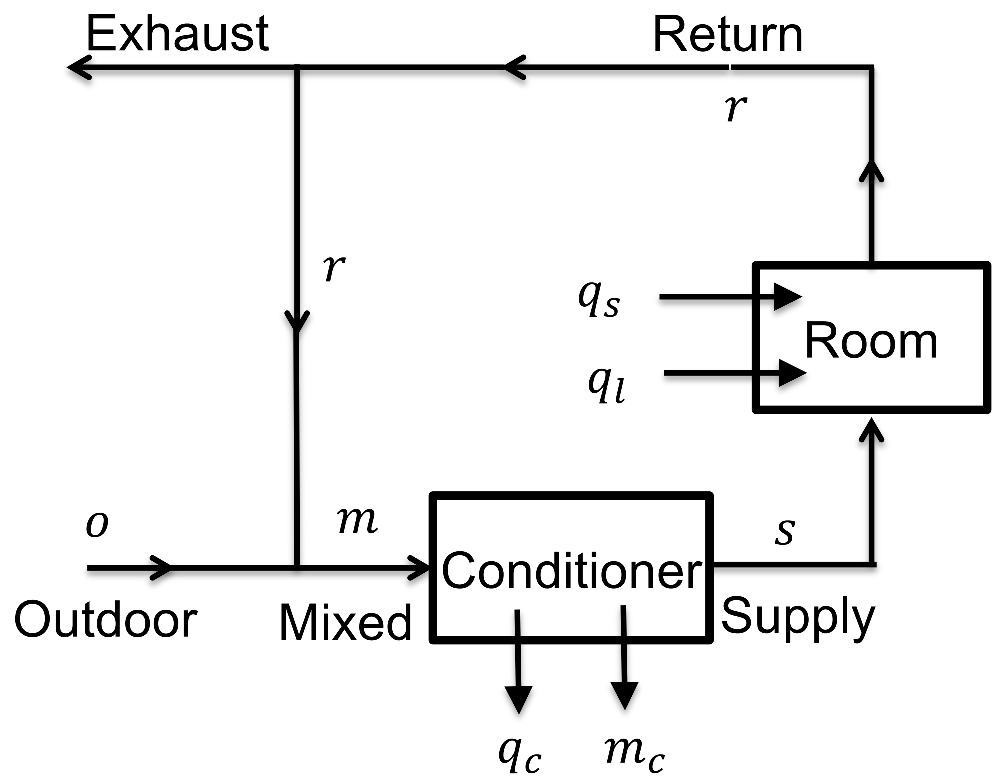
SPACE CONDITIONING

Space Conditioning



Space Conditioning

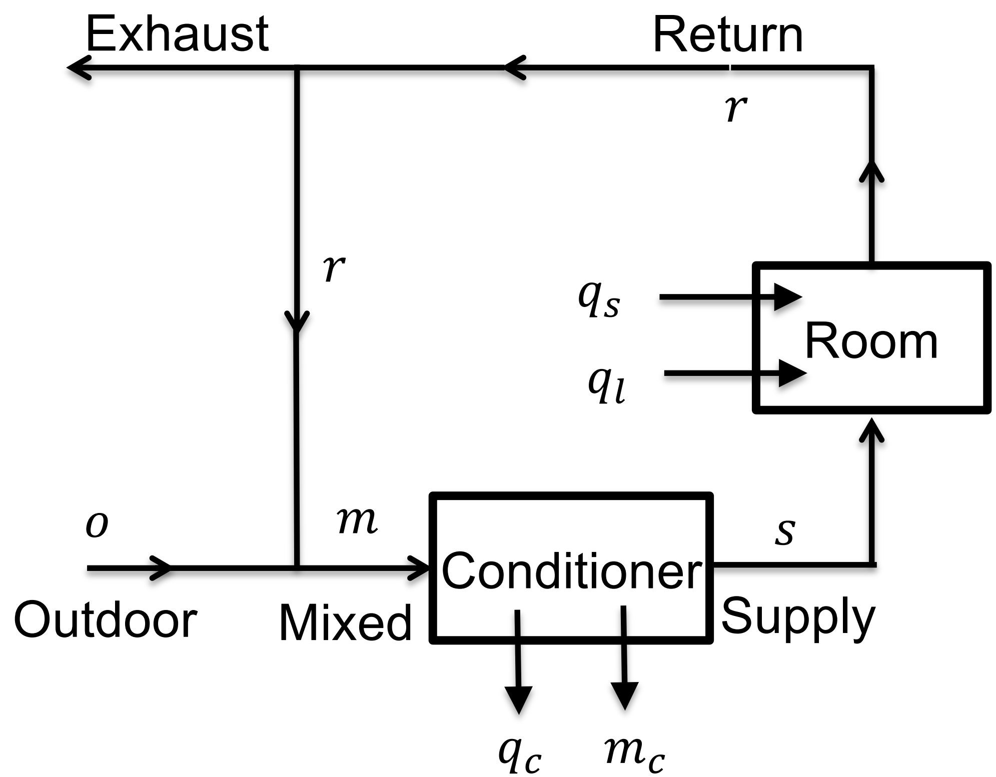
- Step 1: Develop schematic of the processes



Space Conditioning

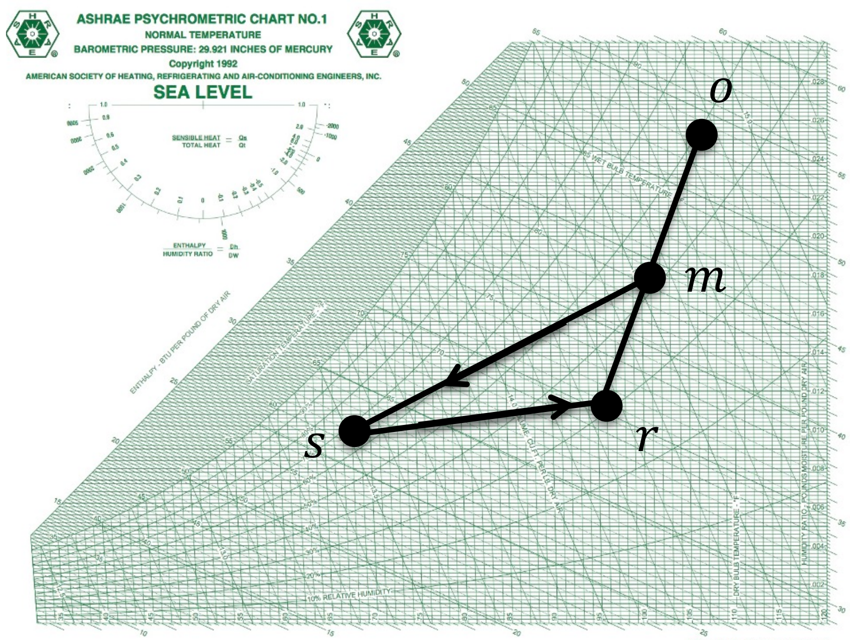
- Step 2: Develop state condition property table

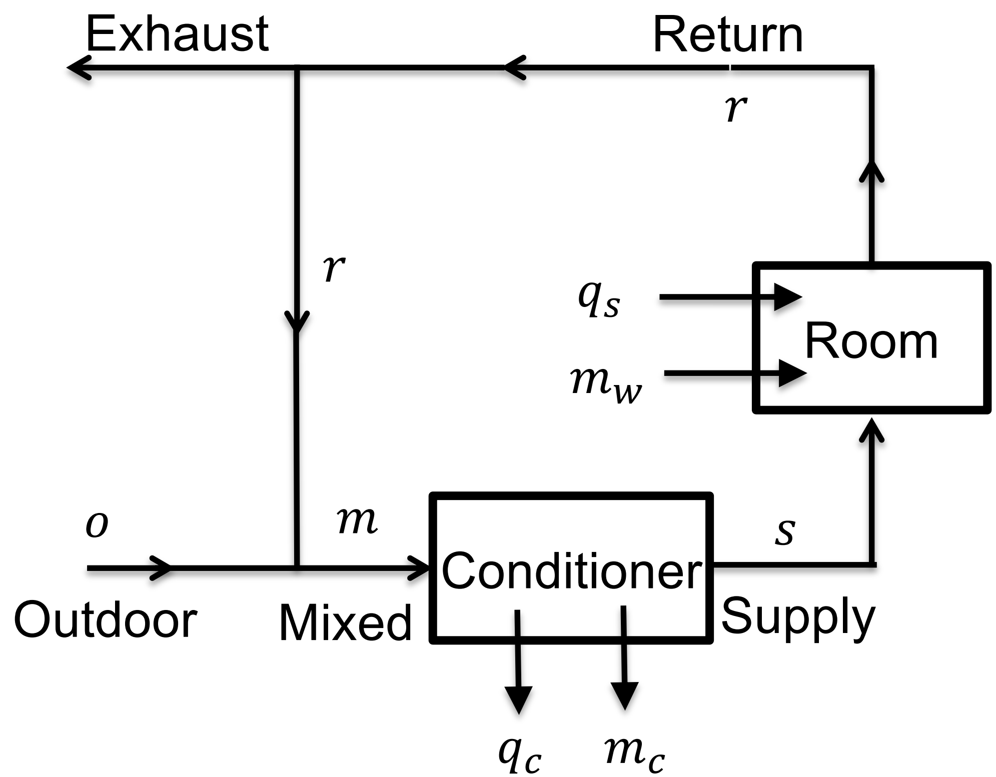
Point	OA	RA	MA	DA	SA
Dry bulb					
Wet bulb					
RH					
Enthalpy					
W					
V					
m_a					
Airflow					



Space Conditioning

- Step 3: Develop Psychrometric chart

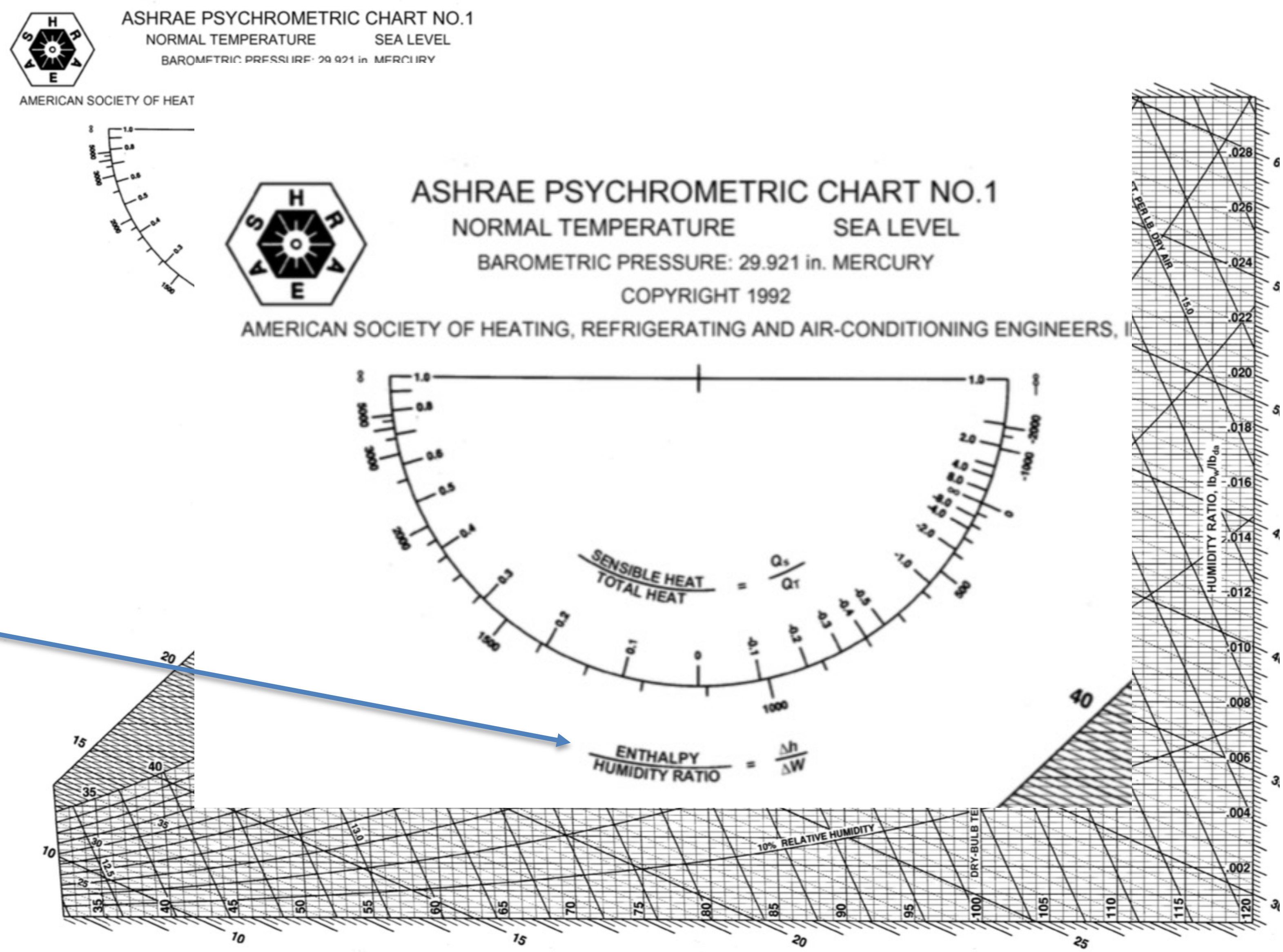




Space Conditioning

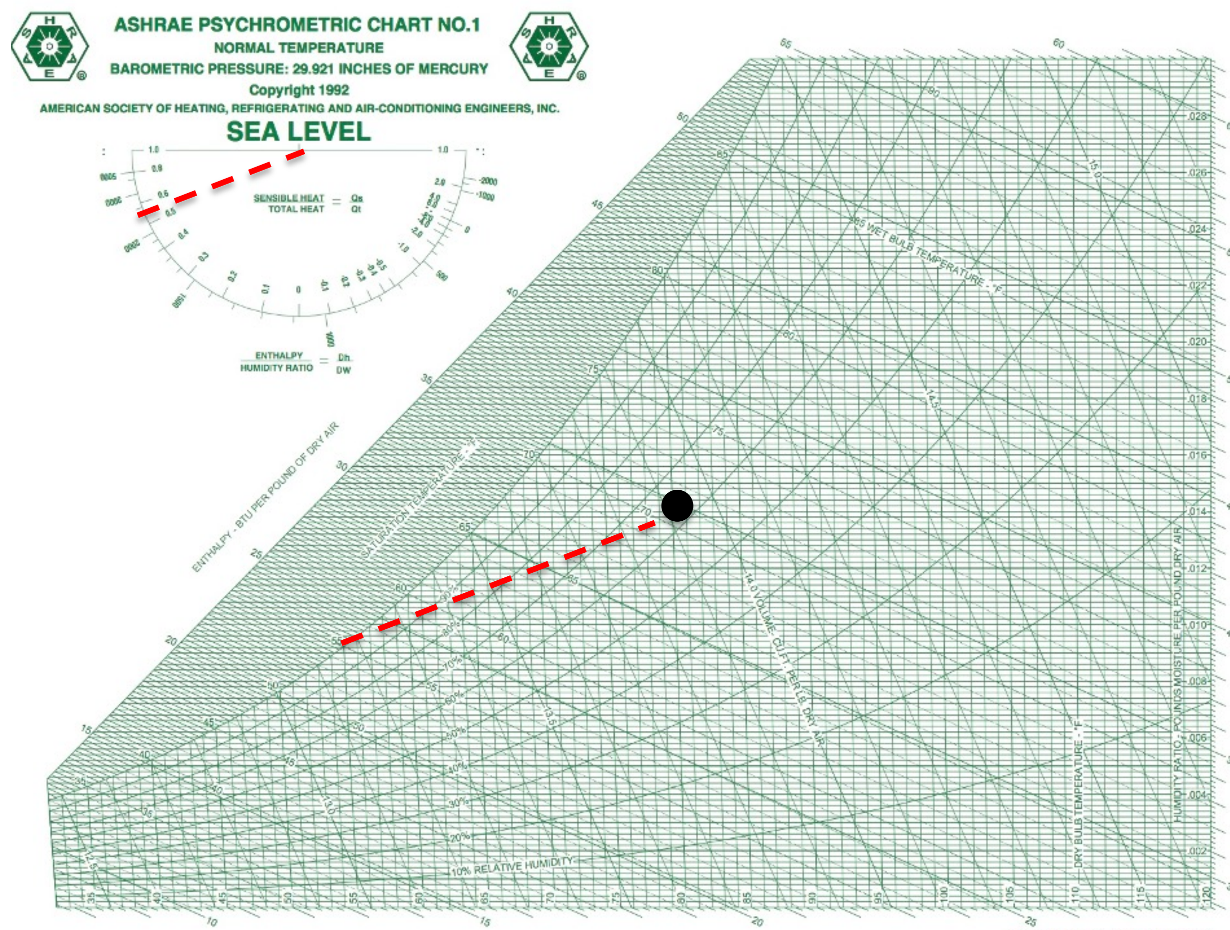
- Sensible Heat Ratio (SHR)

$$\frac{\Delta h}{\Delta W}$$



Space Conditioning

$$SHR = \frac{Sensible\ Heat}{Total\ Heat}$$

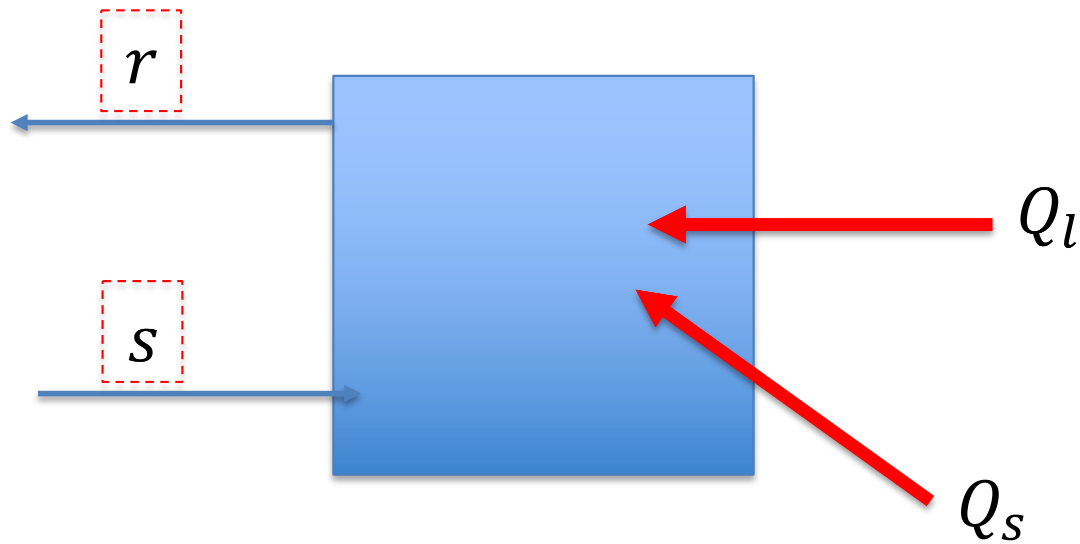


Space Conditioning

- Which space can potentially have the lowest SHR?
  - ❑ Server room
  - ❑ Auditorium
  - ❑ An individual office
  - ❑ School
  - ❑ Restaurant
  - ❑ Grocery store

Space Conditioning

- Important factor to have a good understanding of heating and cooling loads known as "space loads"



r: Return air

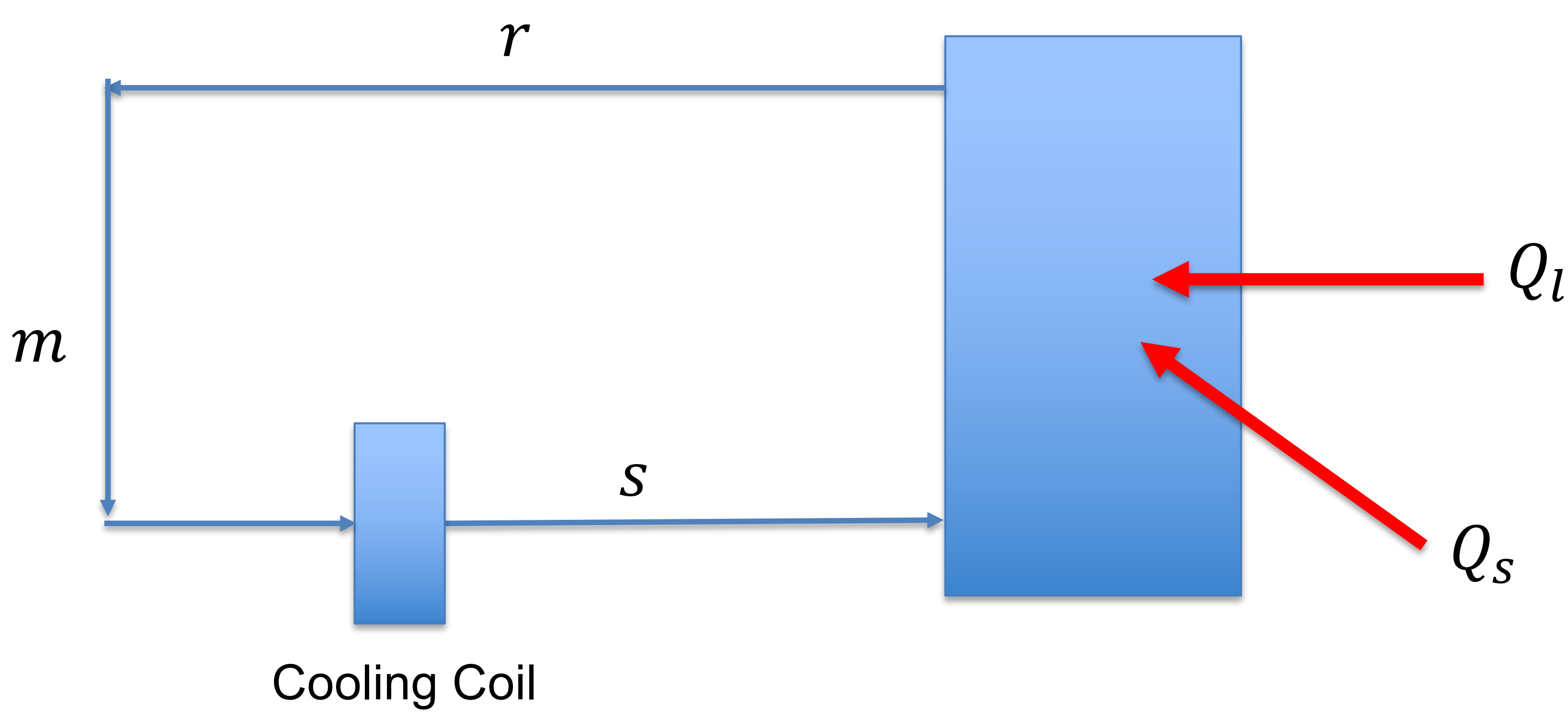
s: Supply air

Q_l: Latent heat transfer

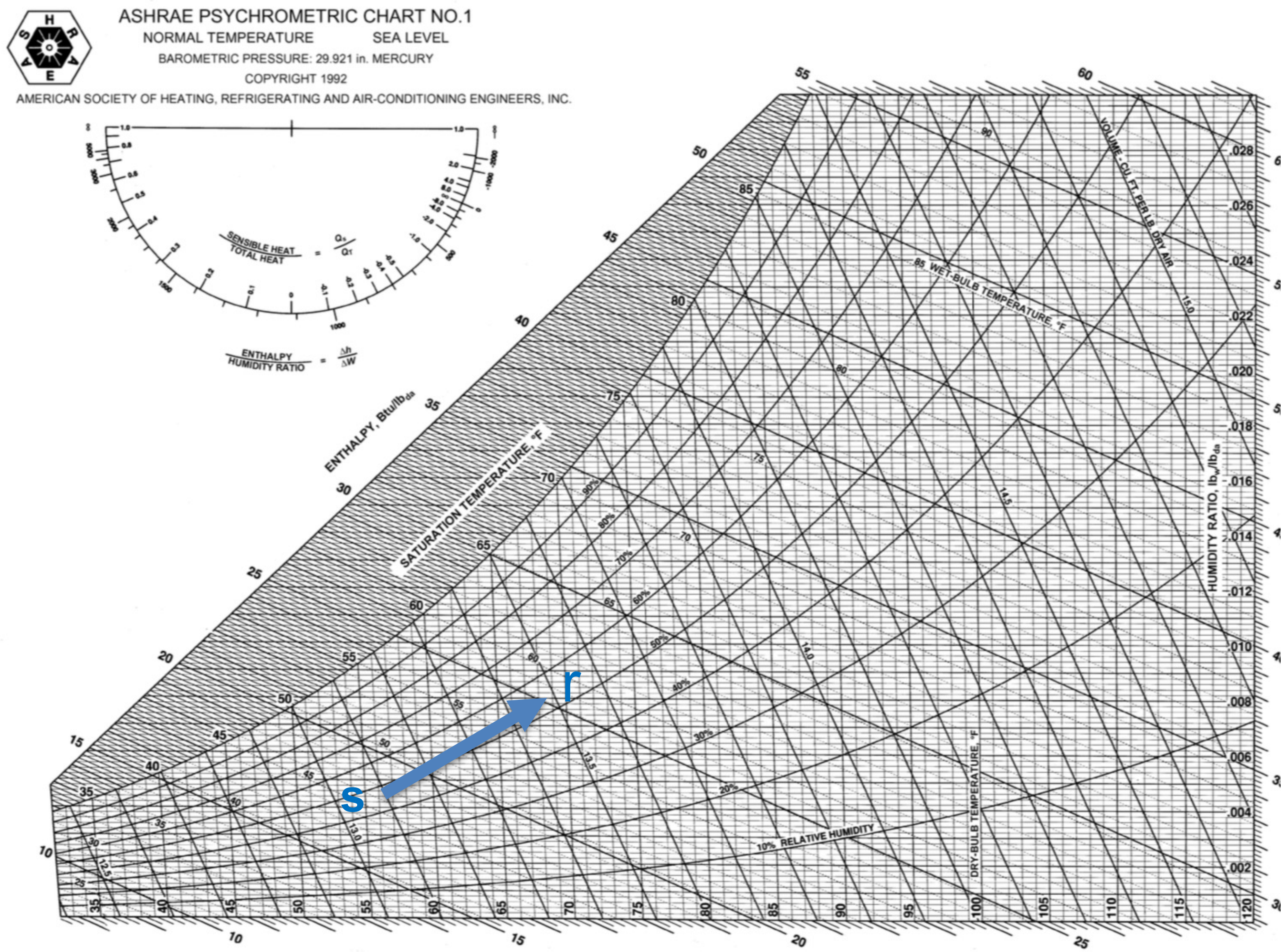
Q_s: Sensible heat transfer

Space Conditioning

- A simple cooling process is the "re-circulation" process

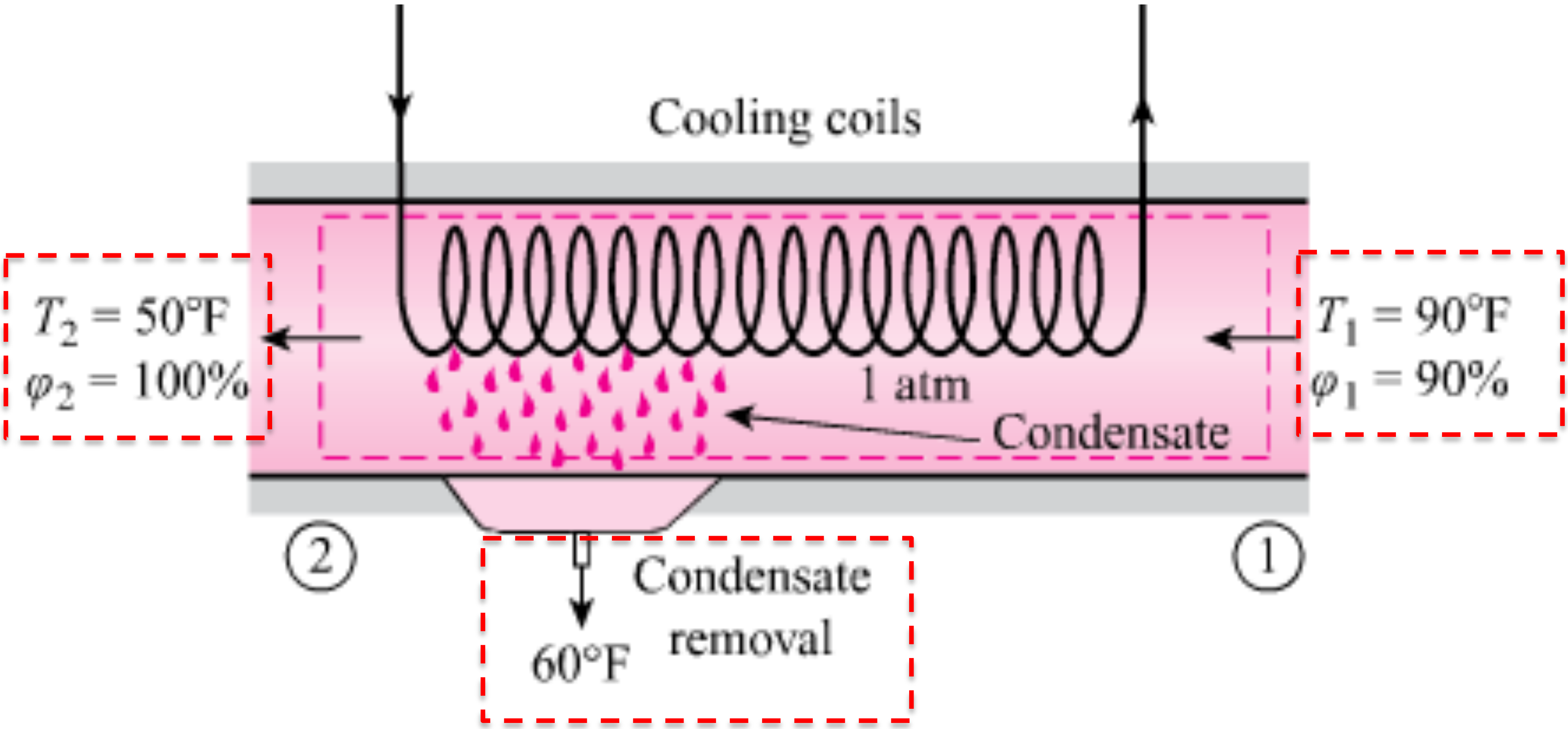


Space Conditioning



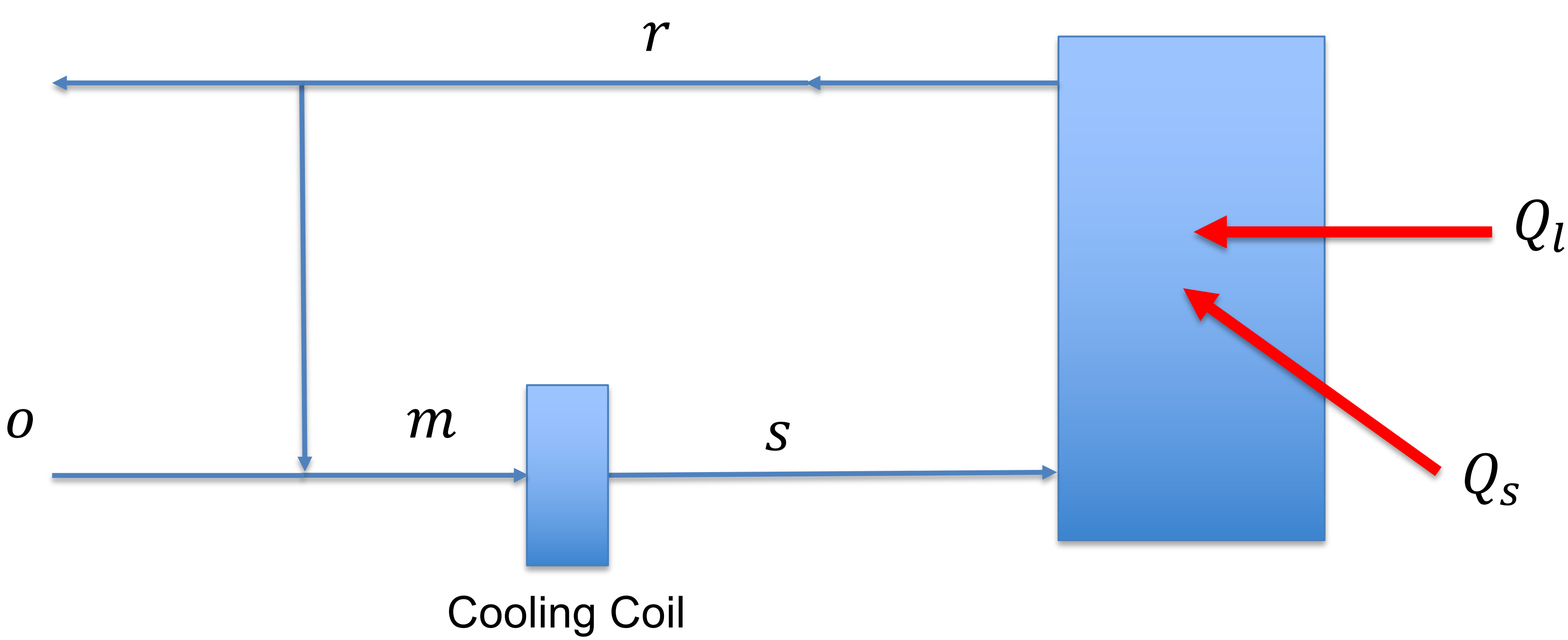
Space Conditioning

- Cooling coil load is different than the space loads

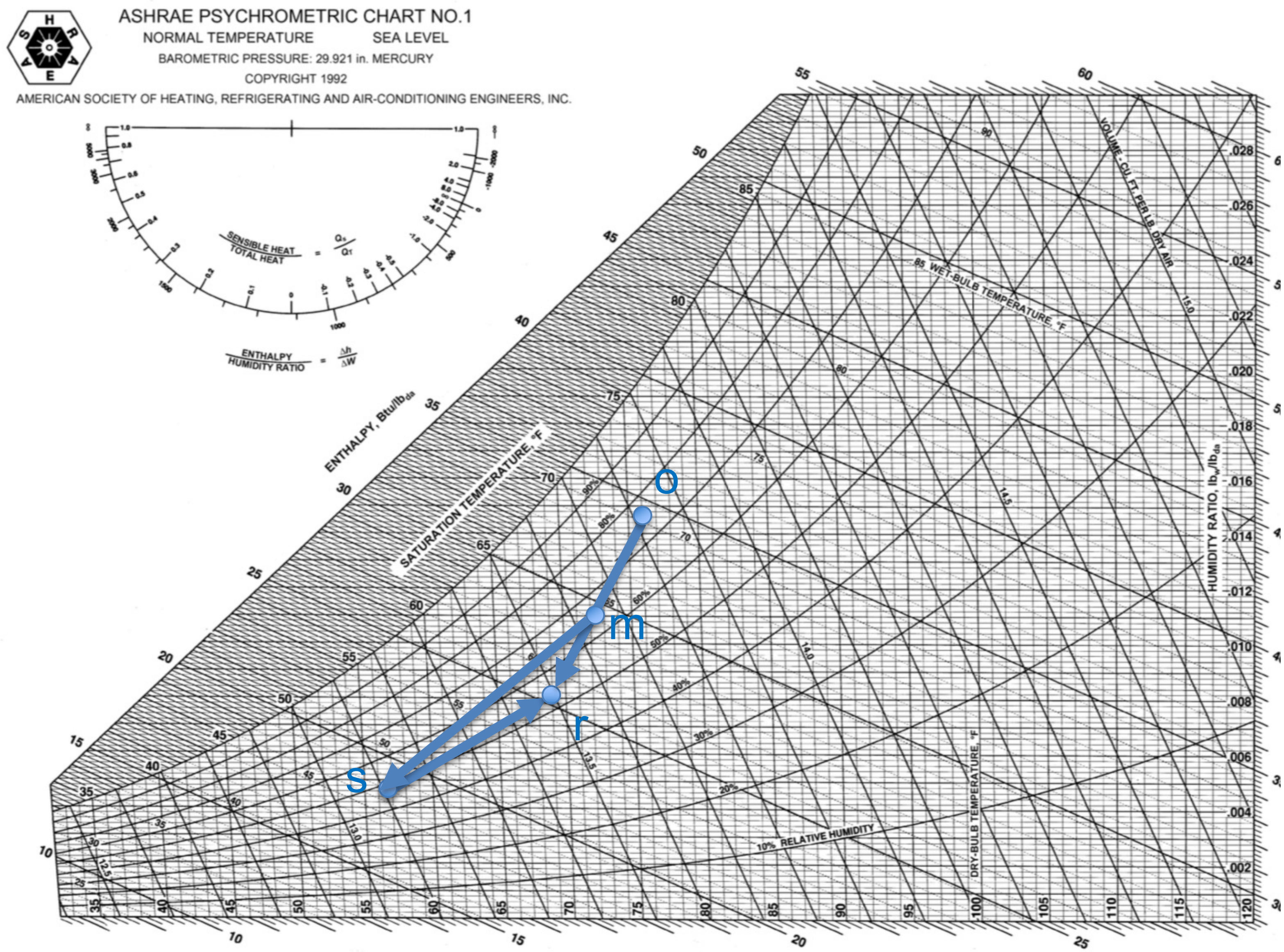


Space Conditioning

- A typical AC system may include outdoor air, mixing, return, and exhaust

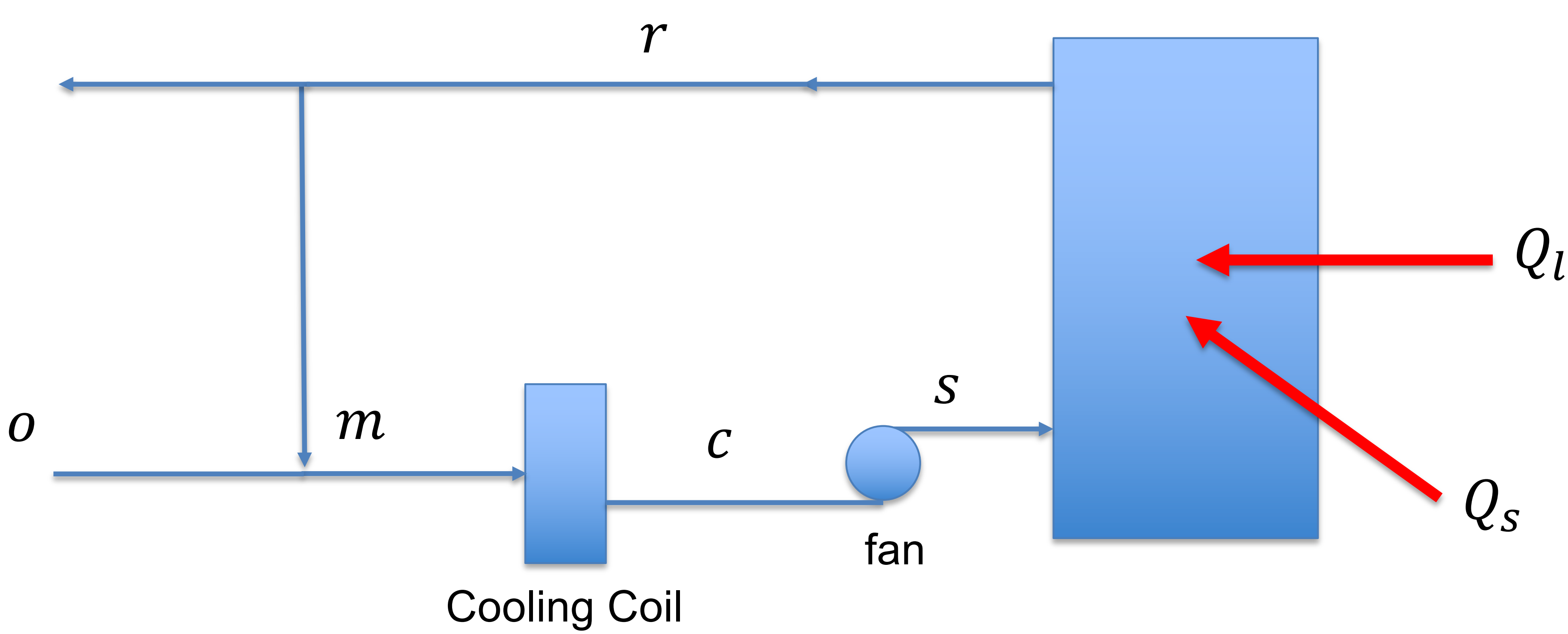


Space Conditioning

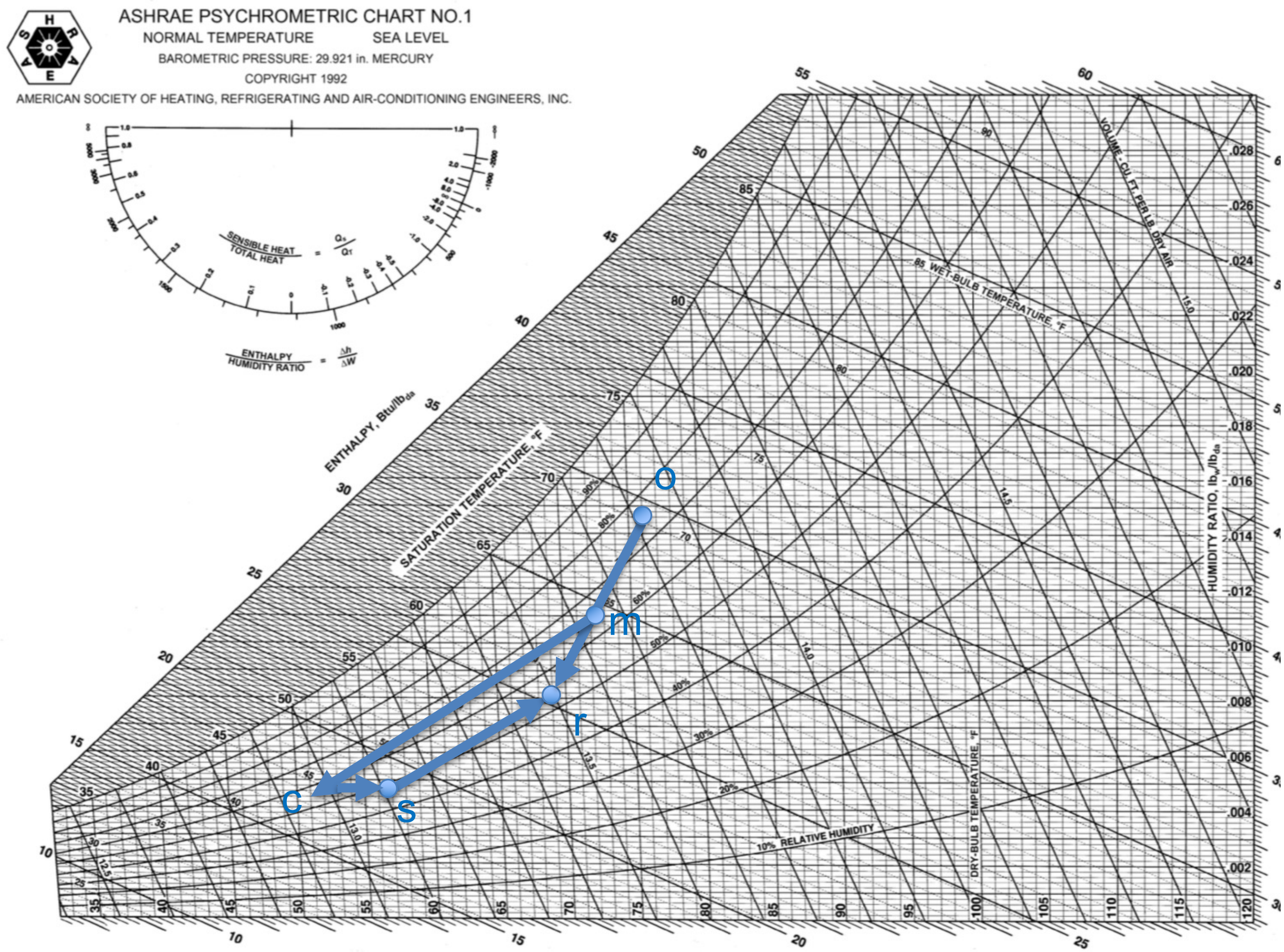


Space Conditioning

- A typical AC system with the influence of the fan falls this process

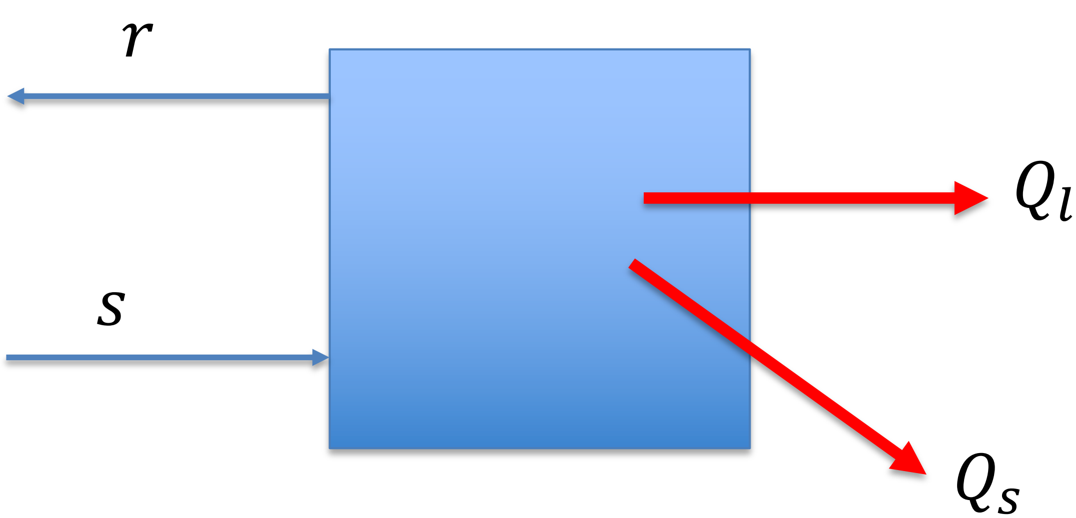


Space Conditioning



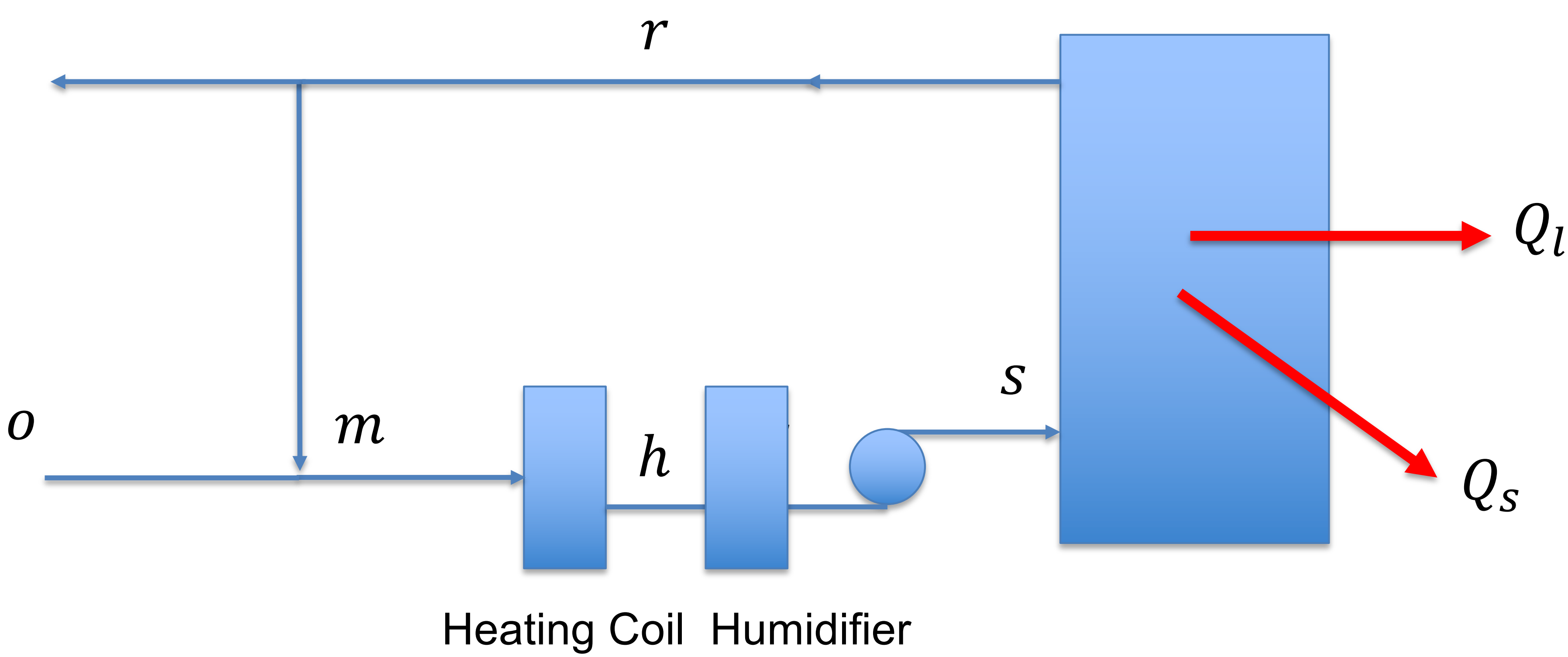
Space Conditioning

- A typical winter heat conditioning space heat loss follows the following schematics



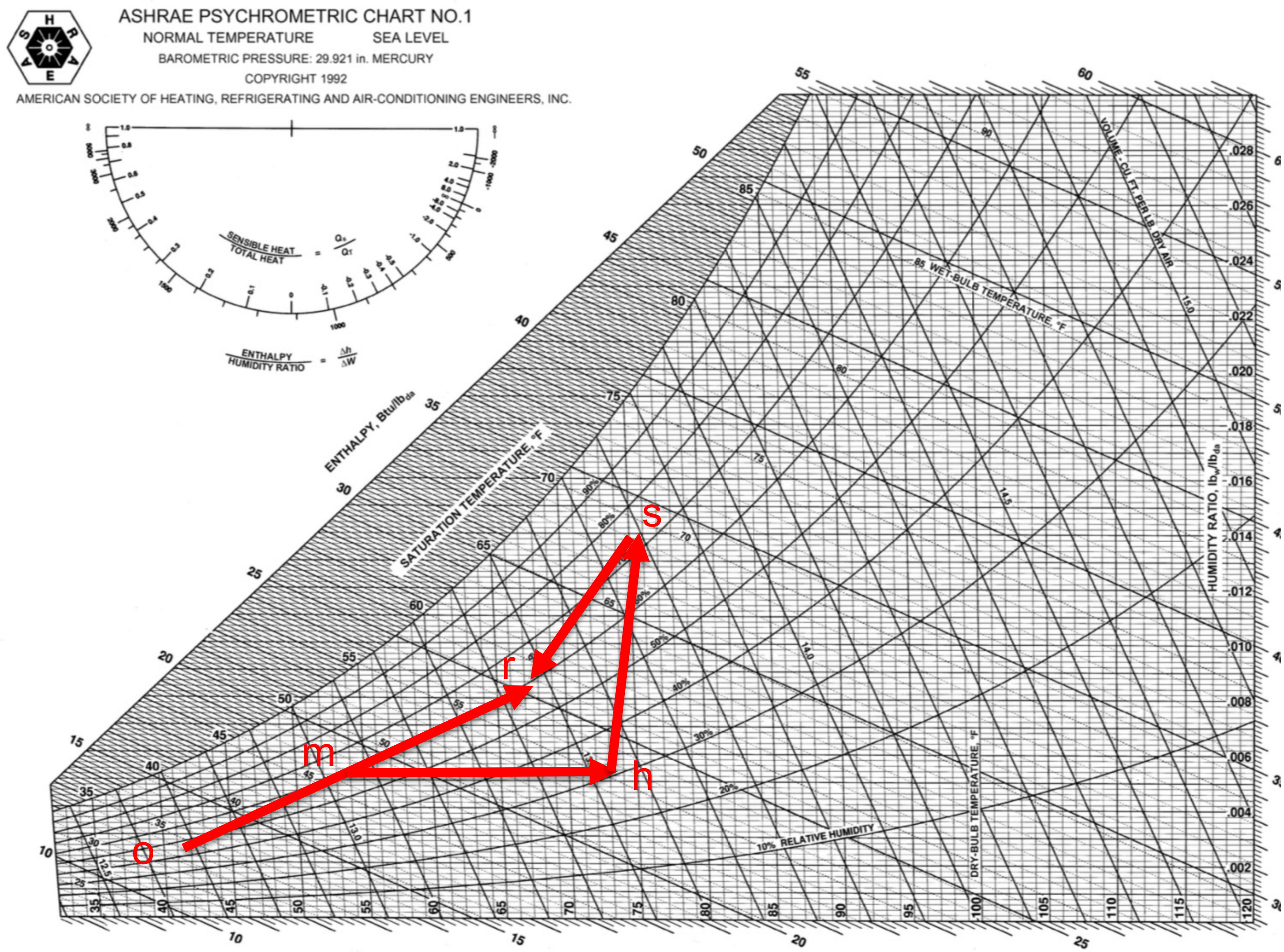
Space Conditioning

- A typical winter system follows this diagram



What do we need a humidifier?

Space Conditioning

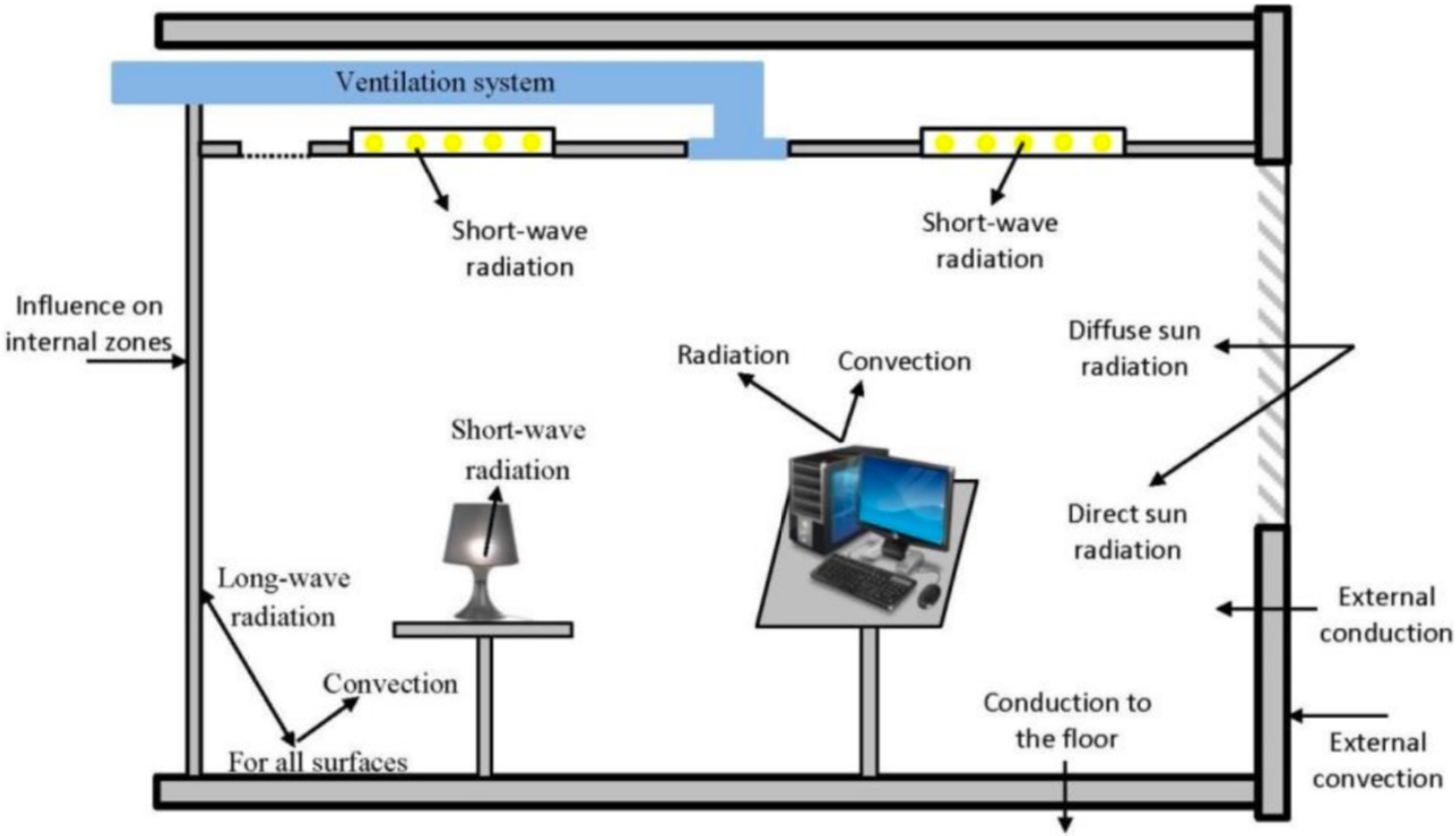


Space Conditioning

- **Additional Problem:** Conditioned air is supplied to a space at a dry bulb of 54 °F and relative humidity of 90% at the rate of 1,500 CFM. The sensible heat ratio for the space is 0.8, and the space is to be maintained at the 75 °F. Determine the sensible and latent cooling loads for the space.

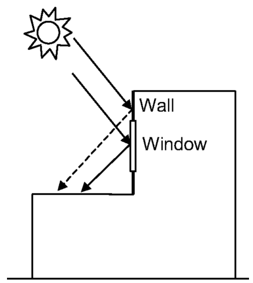
CONTRIBUTION OF DIFFERENT LOAD COMPONENTS (CAE 331)

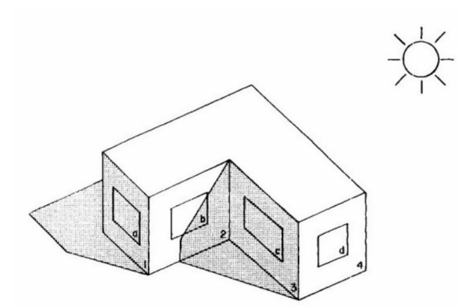
Contribution of Different Load Components



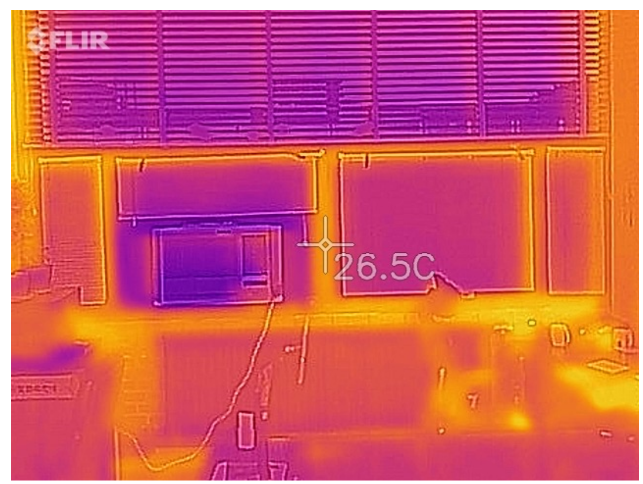
Contribution of Different Load Components

- What heat transfer processes do we have in a building?
  - ❑ Radiation (e.g., indoor and outdoor shortwave, longwave)





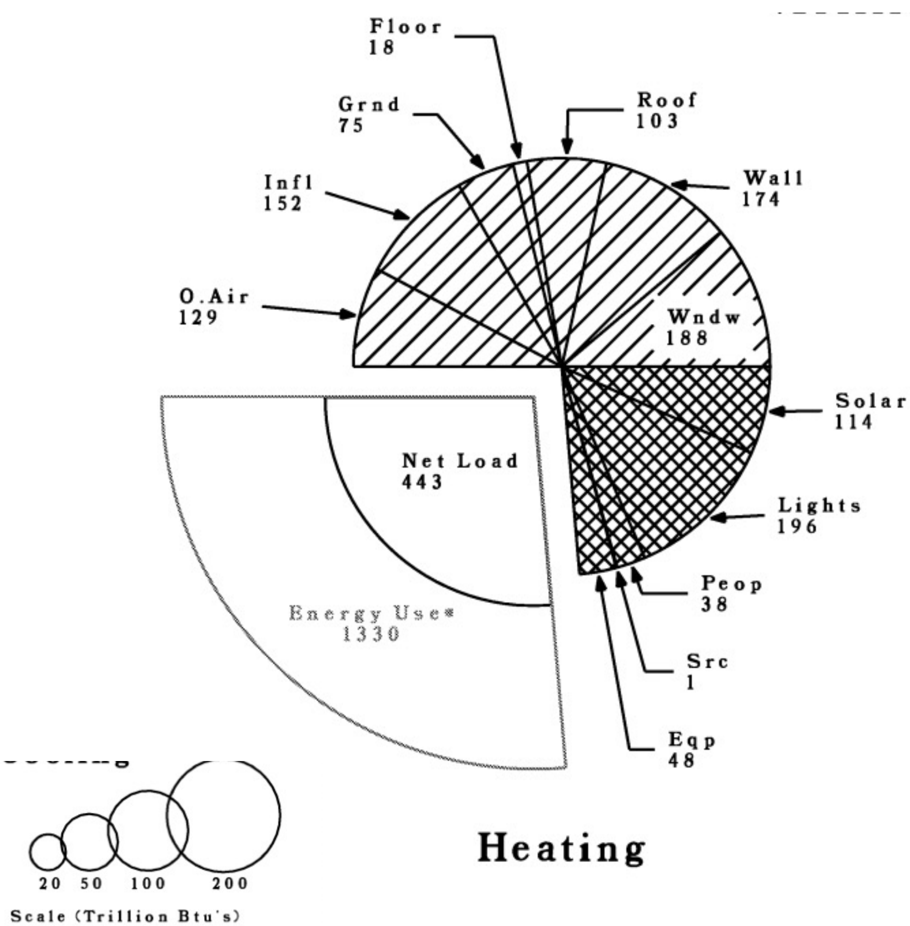
  - ❑ Conduction (e.g., through wall, window)



  - ❑ Convection (e.g., outdoor and indoor convection, infiltration, ventilation)

Contribution of Different Load Components

- Residential buildings



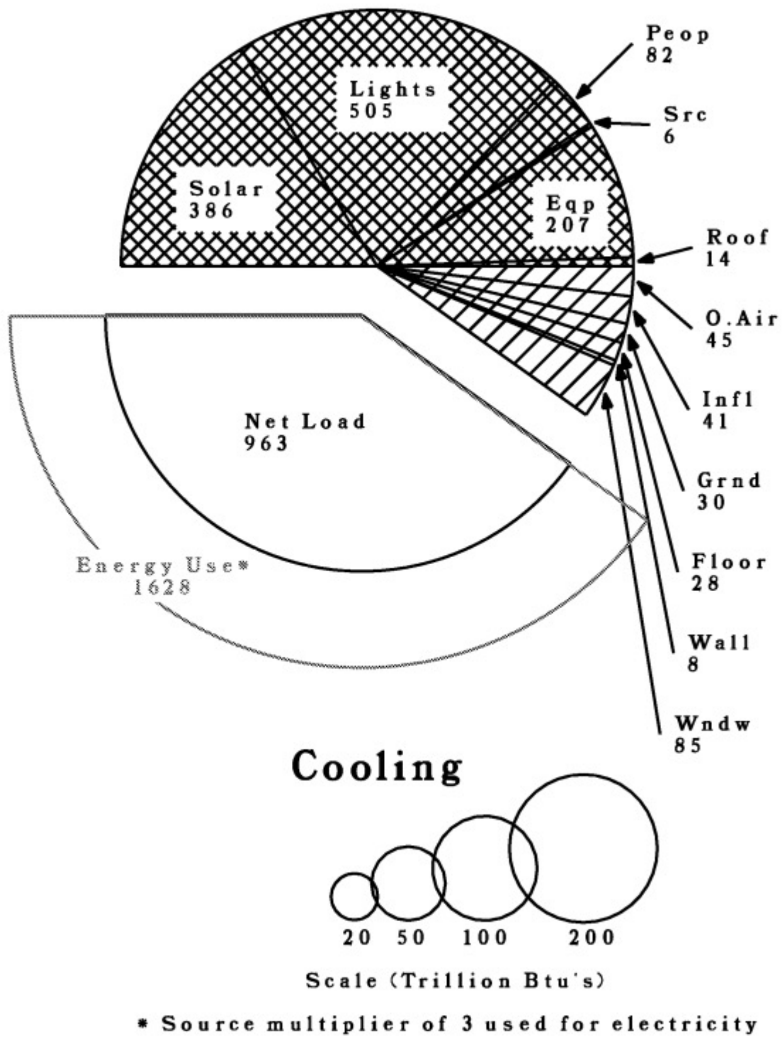
Heat Losses

Window Conduction	22%
Wall	21%
Infiltration	18%
Outside air	15%
Roof	12%
Ground	6%
Floor	2%

A Bottom-Up Engineering Estimate of the Aggregate Heating and Cooling Loads of the Entire US Building Stock

Contribution of Different Load Components

- Residential buildings



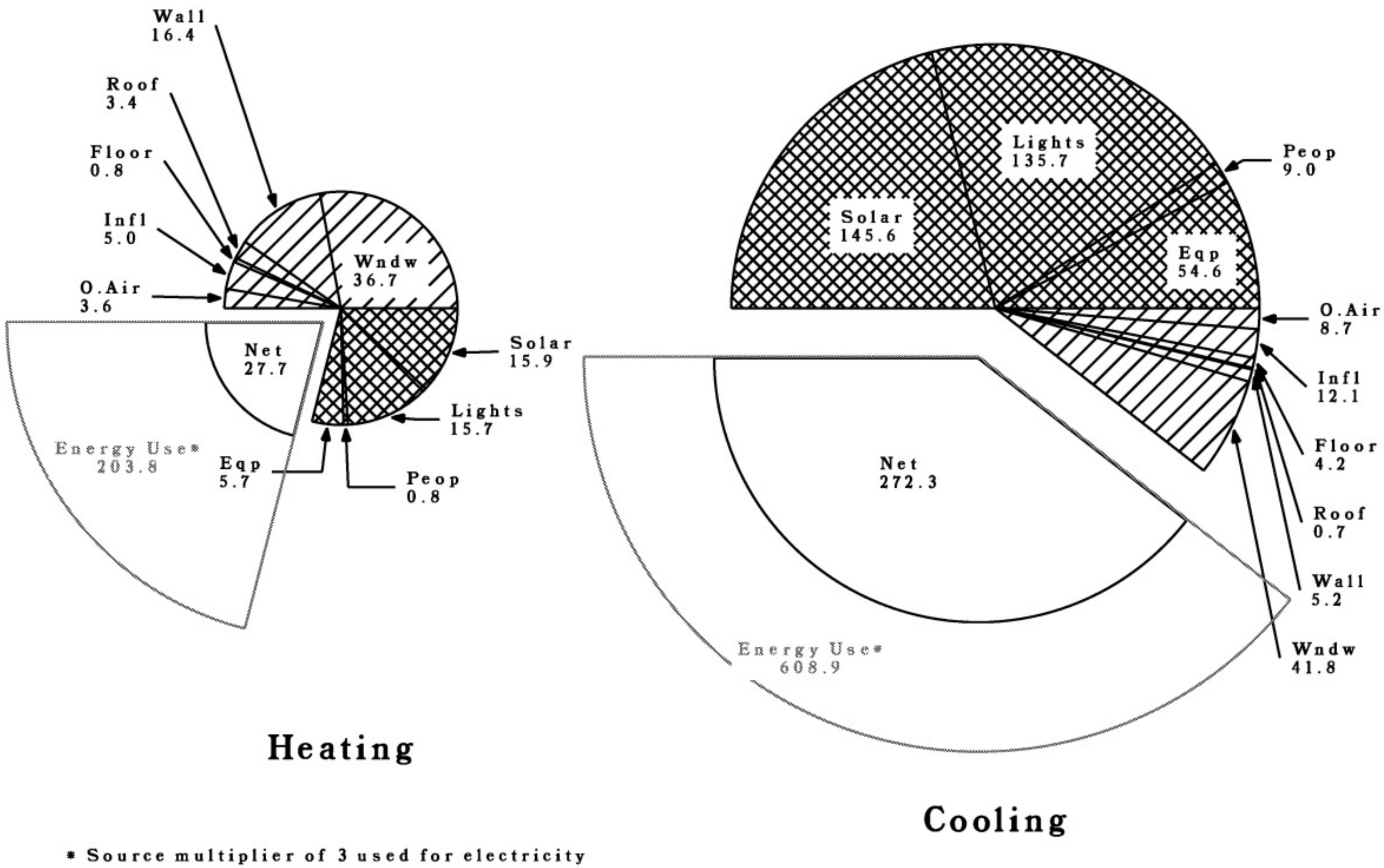
Heat Gains

Lighting	42%
Solar gain through windows	32%
Equipment	17%

A Bottom-Up Engineering Estimate of the Aggregate Heating and Cooling Loads of the Entire US Building Stock

Contribution of Different Load Components

- Large office building



Contribution of Different Load Components

- Conduction

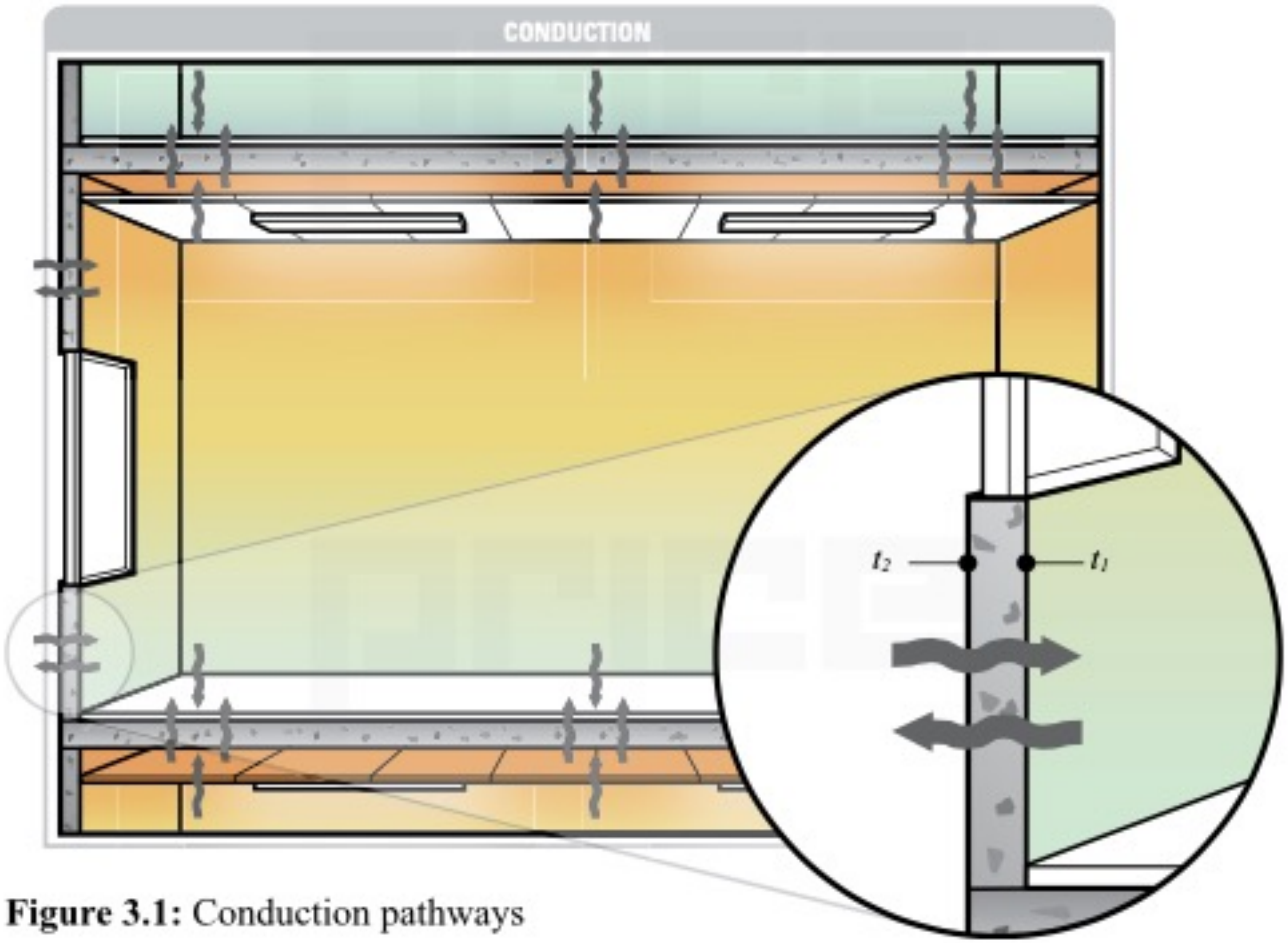
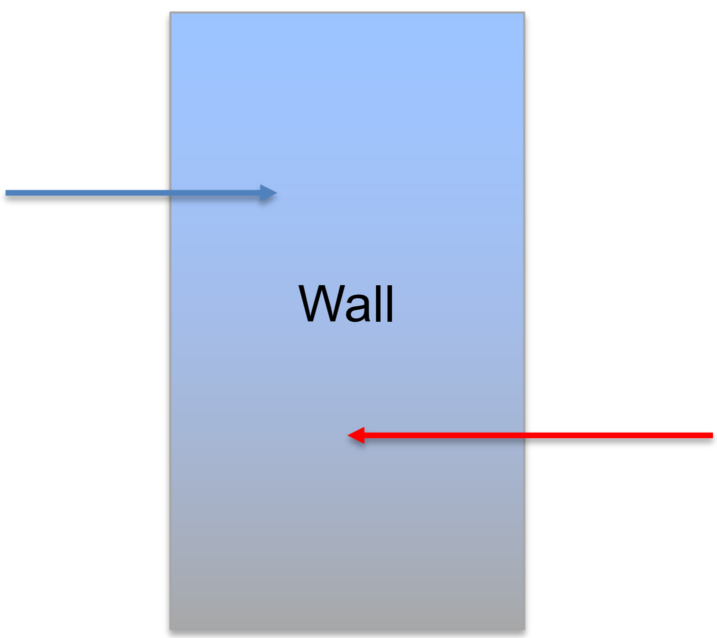


Figure 3.1: Conduction pathways

Photo credit: Price Industries HVAC Handbook

Contribution of Different Load Components

- Conduction



$$q''_x = \frac{q_x}{A_x} = -k\,\frac{\Delta T}{\Delta x}$$

$$q = \frac{\Delta T}{R_{Cond}}$$

$$R_{cond} = \frac{L}{kA}$$

Contribution of Different Load Components

- Convection

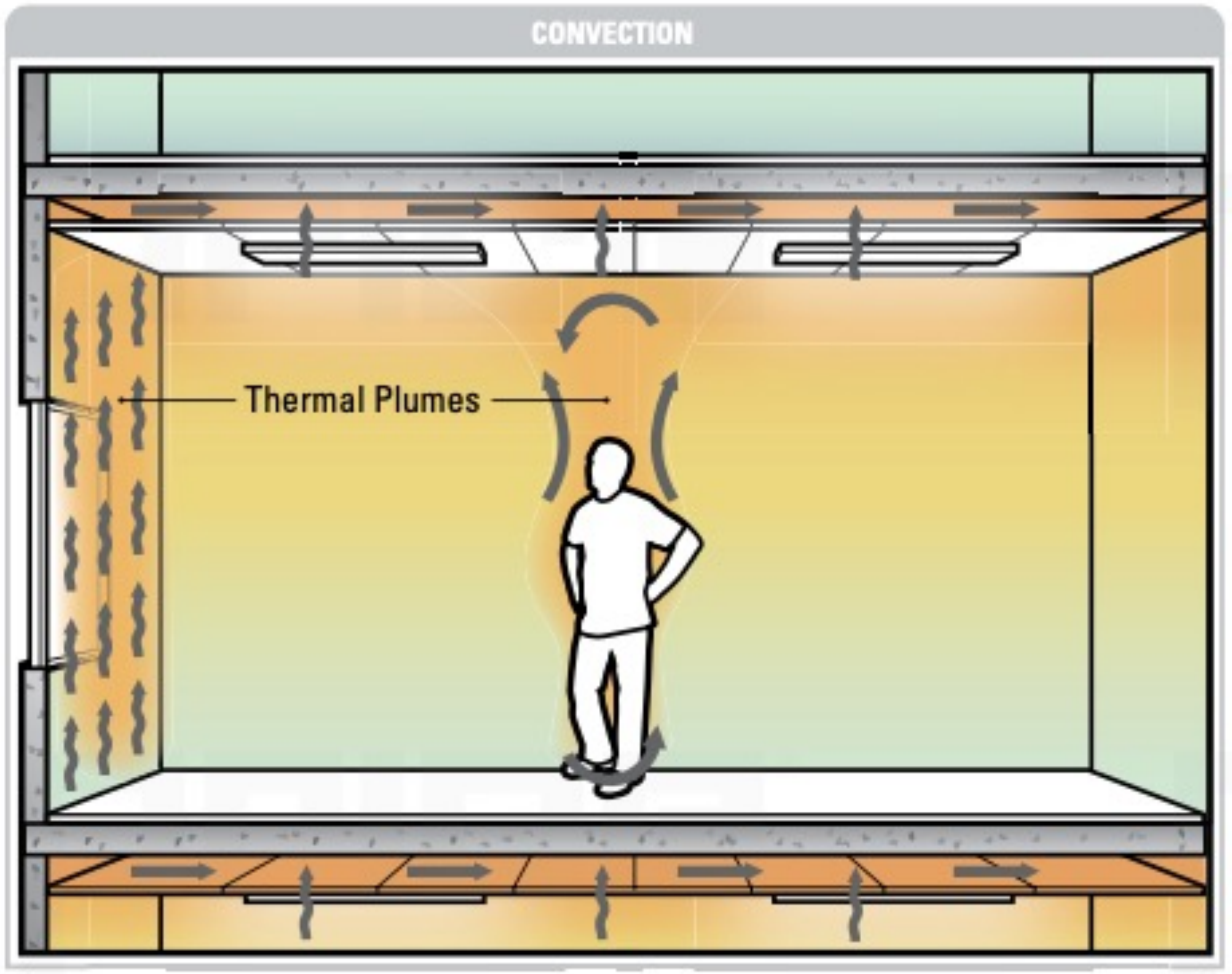


Photo credit: Price Industries HVAC Handbook

Contribution of Different Load Components

- Convection

$$q''_x = \frac{q_x}{A_S} = h \times \Delta T$$

$$q = \frac{\Delta T}{R_{Conv}}$$

$$R_{conv} = \frac{1}{hA_S}$$

Contribution of Different Load Components

- Radiation

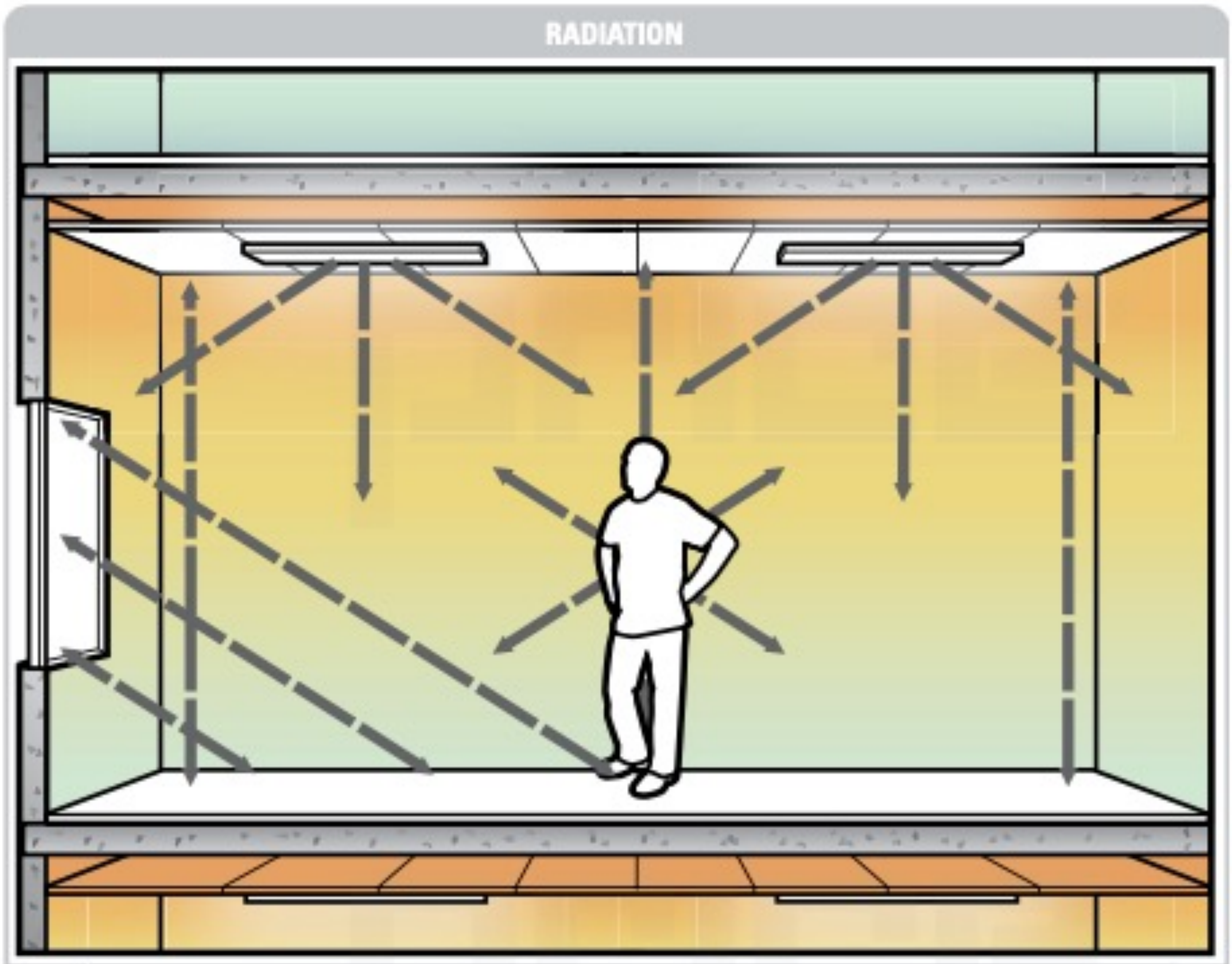


Photo credit: Price Industries HVAC Handbook

Contribution of Different Load Components

- Radiation

$$q_x'' = \frac{q_x}{A} = \varepsilon\sigma T^4$$

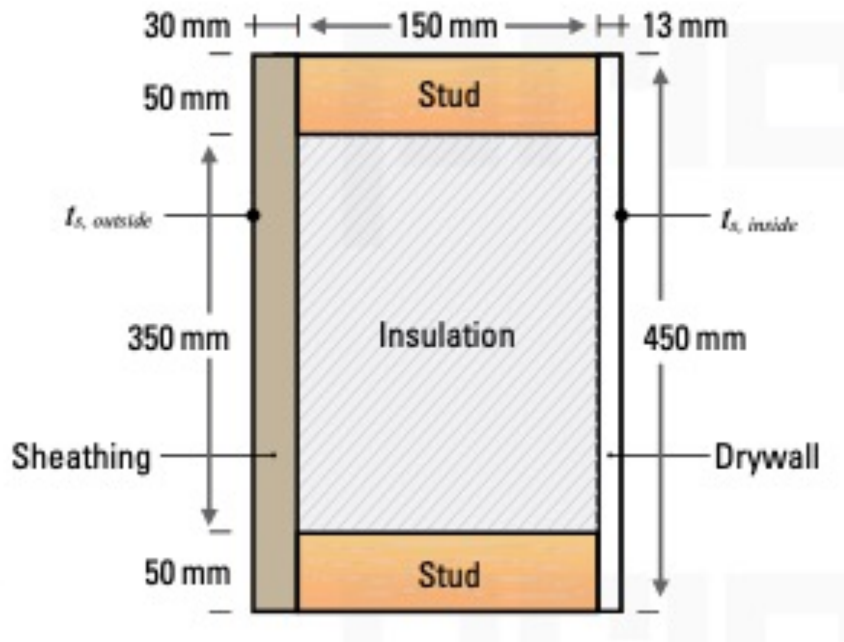
$$\sigma = 0.1712 \times 10^{-8} \frac{Btu}{h - ft^2 - R^4}$$

$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

$$R_{rad} = \frac{1}{h_{rad} A}$$

Contribution of Different Load Components

- For a wall assembly, a combination of series and parallel resistances is typical



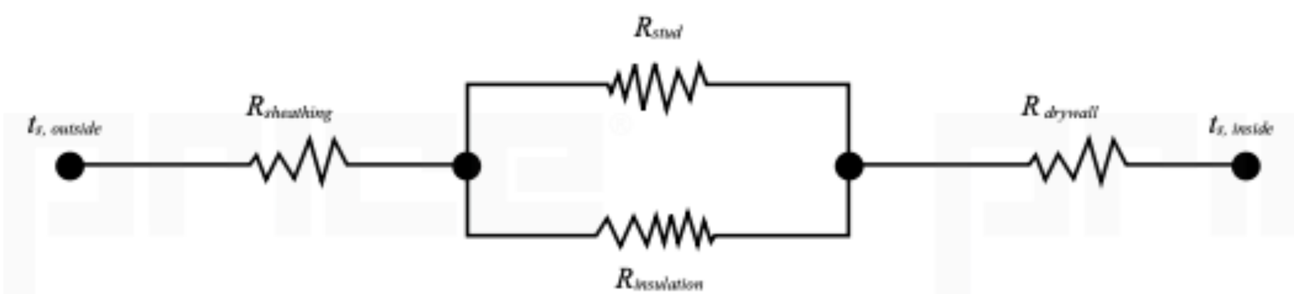


Photo credit: Price Industries HVAC Handbook

Contribution of Different Load Components

- Overall heat transfer coefficient (U) is defined as:

$$q_x = \frac{T_{oudoor\ air} - T_{indoor\ air}}{\sum R_t}$$

$$q_x = UA\Delta T_{overall}$$

$$\sum R_t = \frac{1}{UA}$$

DESIGN CONDITIONS

Design Conditions

- Temperature difference is the main driver for the heat transfer (How about moisture?):

$$\Delta T = T_i - T_o$$

- T_i:
  - Varies from space to space (e.g., from an office space to a classroom)
  - Exists reference for various environments
  - Uses rules of thumbs

- T_o:
  - Outdoor design conditions

Design Conditions

- Indoor design conditions
  - ❑ Temperature
  - ❑ Relative humidity

- Outdoor design conditions
  - ❑ Temperature (e.g., dry bulb, wet bulb, …)
  - ❑ Solar radiation
  - ❑ …

Design Conditions

- Relevant standards to determine the indoor and outdoor conditions are:
  - ❑ ASHRAE Handbook-Fundamentals
  - ❑ ASHRAE 55 Thermal Environmental Conditions for Human Occupancy
  - ❑ ASHRAE 62.1: Ventilation for Acceptable Indoor Air Quality (IAQ) (Commercial)
  - ❑ ASHRAE 62.2: Ventilation for Acceptable Indoor Air Quality (IAQ) (Residential)
  - ❑ ASHRAE 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings

Access to standards: https://www.ashrae.org/technical-resources/standards-and-guidelines

INDOOR DESIGN CONDITIONS

(Please, see Chapter 9 for additional materials)

Indoor Design Conditions

- Indoor heating design condition:
  - ❑ Temperature: 70 °F – 72 °F
  - ❑ RH = 30%

- Indoor cooling design condition:
  - ❑ Temperature: 75°F – 78 °F
  - ❑ RH = 50%

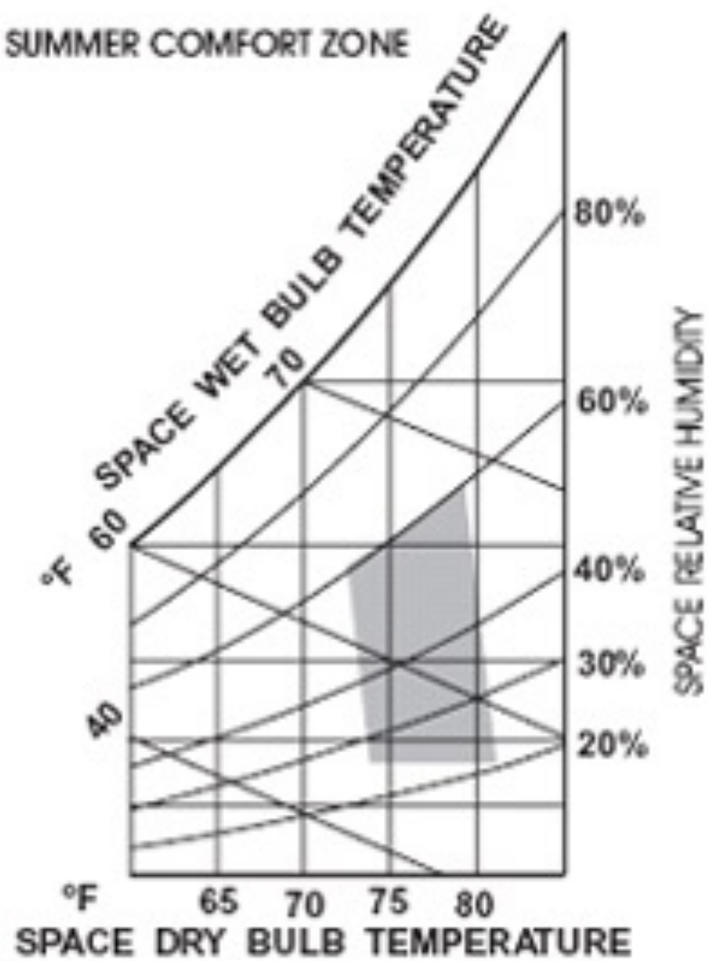
What do these temperatures and relative humidity mean?

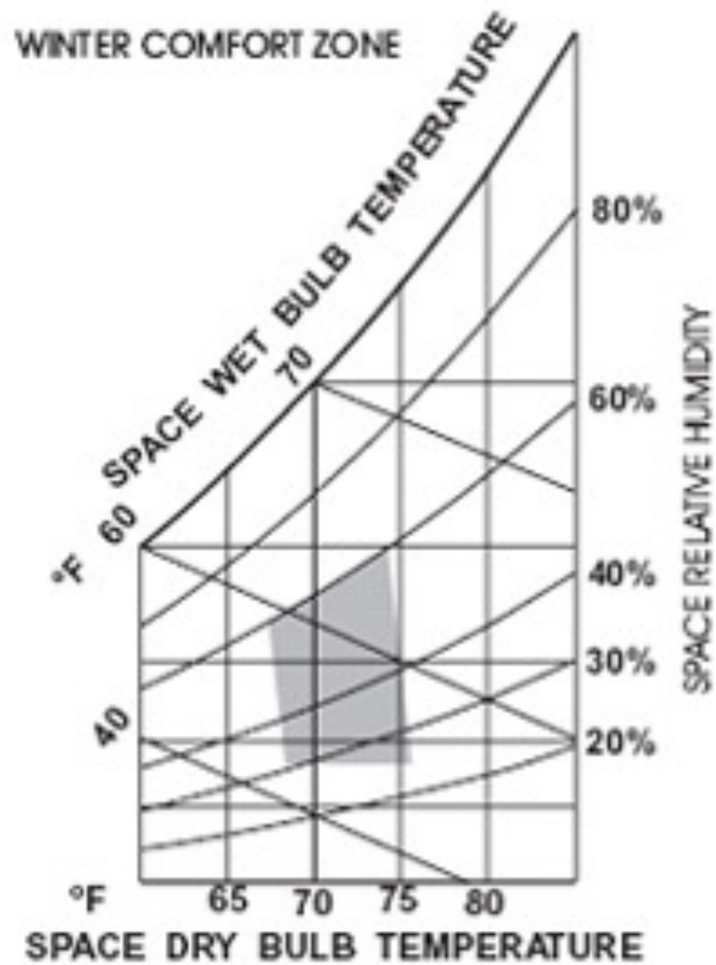
Where do you find more accurate values?

Reference: ASHRAE Load Calculation Applications Manual, 2nd Version

Indoor Design Conditions

- Consider the middle of the ASHRAE comfort zone for the appropriate season





ASHRAE 55, ASHRAE Fundamentals

Indoor Design Conditions

- Other resources to find the setpoints:
  - ASHRAE 170 for healthcare facilities (e.g., Table 7-1, 2017):

Function of Space	Design Temperature (ºF)
Inpatient nursing – all room	70 - 75
Physical therapy	72 – 80
…	…

Reference: ASHRAE Standard 170

Indoor Design Conditions

- Other resources to find the setpoints:
  - ❑ DOE Reference Buildings:

Table B-4 Large Office Hourly Operation Schedules

Schedule	Day of Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ALWAYS_ON	All	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_ELEVATORS	All	0.05	0.05	0.05	0.05	0.1	0.2	0.4	0.5	0.5	0.35	0.15	0.15	0.15	0.15	0.15	0.15	0.35	0.5	0.5	0.4	0.4	0.3	0.2	0.1
INFIL_QUARTER_ON_SCH	WD, SummerDesign	1	1	1	1	1	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1	1
	Sat, WinterDesign	1	1	1	1	1	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1	1	1	1	1	1
	Sun, Hol, Other	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_OCC_SCH	SummerDesign	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.05	0.05
	WD	0	0	0	0	0	0	0.1	0.2	0.95	0.95	0.95	0.95	0.5	0.95	0.95	0.95	0.95	0.7	0.4	0.4	0.1	0.1	0.05	0.05
	Sat	0	0	0	0	0	0	0.1	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0.1	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BLDG_LIGHT_SCH	WD	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.5	0.5	0.3	0.3	0.1	0.05
	Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.15	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	SummerDesign	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	WinterDesign	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
BLDG_EQUIP_SCH	WD	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.8	0.6	0.6	0.5	0.5	0.4	0.4
	Sat	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.35	0.35	0.35	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	SummerDesign	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	WinterDesign	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
ACTIVITY_SCH	All	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
WORK_EFF_SCH	All	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AIR_VELO_SCH	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CLOTHING_SCH	All	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	All	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	All	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CLGSETP_SCH	WD, SummerDesign	26.7	26.7	26.7	26.7	26.7	26.7	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	26.7	26.7
	Sat	26.7	26.7	26.7	26.7	26.7	26.7	24	24	24	24	24	24	24	24	24	24	24	24	26.7	26.7	26.7	26.7	26.7	26.7
	WinterDesign	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
	Other	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
HTGSETP_SCH	WD	15.6	15.6	15.6	15.6	15.6	15.6	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	15.6	15.6
	SummerDesign	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
	Sat	15.6	15.6	15.6	15.6	15.6	15.6	21	21	21	21	21	21	21	21	21	21	21	21	15.6	15.6	15.6	15.6	15.6	15.6
	WinterDesign	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
	Other	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
Seasonal-Reset-Supply-Air-Temp-Sch	All	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
MinOA_MotorizedDamper_Sched	WD, SummerDesign	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
	Sat, WinterDesign	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dual Zone Control Type Sched	All	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
HVACOperationSchd	WD, SummerDesign	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
	Sat, WinterDesign	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CW-Loop-Temp-Schedule	All	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
HW-Loop-Temp-Schedule	All	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2	82.2

Reference: DOE Reference Buildings: https://www.nrel.gov/docs/fy11osti/46861.pdf

Outdoor Design Conditions

- Design HVAC system capacity based on the peak loads which is a combination of:
  - ❑ Internal loads
  - ❑ External loads

What does this mean for heating and cooling loads?

OUTDOOR DESIGN CONDITIONS

(Please, see Chapter 14)

Outdoor Design Conditions

- Winter design conditions:
  - ❑ Use ASHRAE Design Data from the Fundamentals Handbook
  - ❑ The 99.6% and 99% indicate the risk level desired
  - ❑ When 99% is selected, it means the outdoor temperatures have been equaled or exceeded by 99% of the total number of hours in a year (8760 hours):
    - 99.6% (0.4%) ~ 35 hours
    - 99.0% (1.0%) ~ 88 hours
    - 98.0 (2.0%) ~ 175 hours
    - 95.0 (5.0%) ~ 438 hours

Outdoor Design Conditions

- Summer design conditions
  - DB is dry-bulb temperature
  - MWB is the mean-coincident-wet-bulb temperature
  - The 0.4%, 1% and 2% mean the percentile of the total hours may not meet indoor design conditions

Outdoor Design Conditions

- Basic Information →
- Annual Heating →
- Annual Cooling →
- Extreme Annual →
- Monthly Design →

Design conditions for CHICAGO, IL, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	*1b*	*1c*	*1d*	*1e*	*1f*	*1g*	*1h*	*1i*
CHICAGO	**725300**	**42.00N**	**87.88W**	**623**	**14.368**	**-6.00**	**NAC**	**7201**

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	*3a*	*3b*	*4a*	*4b*	*4c*	*4d*	*4e*	*4f*	*5a*	*5b*	*5c*	*5d*	*6a*	*6b*
1	**-5.0**	**0.8**	**-15.7**	**2.4**	**-3.5**	**-9.8**	**3.3**	**1.7**	**28.6**	**23.5**	**26.3**	**24.6**	**10.9**	**270**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
7	**19.2**	**91.7**	**74.9**	**88.7**	**73.4**	**85.9**	**71.8**	**77.8**	**88.1**	**76.1**	**85.2**	**74.3**	**82.6**	**11.8**	**230**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
74.8	**133.3**	**84.2**	**73.0**	**125.6**	**82.1**	**71.4**	**118.4**	**80.1**	**34.0**	**88.2**	**32.2**	**85.2**	**30.4**	**82.5**

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	*14b*	*14c*	*15*	*16a*	*16b*	*16c*	*16d*	*17a*	*17b*	*17c*	*17d*	*17e*	*17f*	*17g*	*17h*
25.0	**22.1**	**19.6**	**83.3**	**96.3**	**-11.5**	**3.1**	**7.5**	**98.5**	**-16.9**	**100.3**	**-21.3**	**102.1**	**-25.5**	**104.3**	**-30.9**

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	*18b*	*18c*	*18d*	*18e*	*18f*	*18g*	*18h*	*18i*	*18j*	*18k*	*18l*
0.4%	**54.4**	**51.3**	**60.3**	**51.4**	**74.1**	**60.9**	**82.9**	**64.0**	**88.5**	**69.1**	**93.3**	**72.4**
1%	**50.6**	**47.1**	**56.3**	**49.1**	**70.5**	**58.5**	**79.8**	**63.1**	**86.3**	**68.7**	**91.3**	**72.3**
2%	**45.8**	**42.0**	**52.9**	**46.8**	**67.1**	**56.5**	**76.0**	**61.7**	**84.2**	**67.8**	**89.3**	**71.6**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	*18n*	*18o*	*18p*	*18q*	*18r*	*18s*	*18t*	*18u*	*18v*	*18w*	*18x*
0.4%	**96.3**	**76.8**	**94.3**	**76.9**	**90.2**	**73.0**	**81.1**	**65.2**	**69.7**	**59.1**	**61.9**	**58.1**
1%	**94.2**	**76.5**	**92.1**	**76.0**	**87.6**	**71.7**	**78.0**	**63.9**	**66.6**	**58.9**	**59.0**	**56.1**
2%	**92.4**	**76.3**	**90.0**	**75.5**	**85.0**	**70.2**	**75.4**	**62.2**	**64.2**	**57.6**	**54.9**	**50.4**

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	*19b*	*19c*	*19d*	*19e*	*19f*	*19g*	*19h*	*19i*	*19j*	*19k*	*19l*
0.4%	**51.8**	**54.2**	**53.4**	**57.6**	**63.0**	**71.5**	**66.8**	**78.3**	**73.6**	**83.7**	**77.3**	**87.6**
1%	**47.5**	**50.6**	**50.1**	**56.0**	**60.9**	**68.6**	**65.3**	**75.3**	**72.1**	**81.6**	**76.2**	**86.7**
2%	**42.6**	**44.9**	**46.8**	**52.2**	**58.4**	**64.9**	**63.7**	**72.2**	**70.6**	**79.7**	**75.1**	**85.3**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	*19n*	*19o*	*19p*	*19q*	*19r*	*19s*	*19t*	*19u*	*19v*	*19w*	*19x*
0.4%	**80.8**	**91.9**	**79.5**	**90.2**	**76.0**	**85.1**	**67.9**	**75.8**	**62.2**	**66.1**	**58.8**	**61.8**
1%	**79.5**	**89.8**	**78.5**	**88.8**	**74.6**	**83.1**	**66.3**	**73.8**	**60.7**	**64.7**	**56.3**	**59.0**
2%	**78.3**	**88.7**	**77.6**	**87.5**	**73.1**	**81.3**	**64.9**	**72.3**	**59.2**	**63.3**	**51.3**	**54.1**

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	*20b*	*20c*	*20d*	*20e*	*20f*	*20g*	*20h*	*20i*	*20j*	*20k*	*20l*
14.2	**14.3**	**16.2**	**18.7**	**20.7**	**20.6**	**19.2**	**17.9**	**19.2**	**19.0**	**14.8**	**13.5**

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, ft	StdP	Standard pressure at station elevation, psi		
DB	Dry bulb temperature, °F	DP	Dew point temperature, °F	WB	Wet bulb temperature, °F
WS	Wind speed, mph	Enth	Enthalpy, Btu/lb	HR	Humidity ratio, grains of moisture per lb of dry air
MCDB	Mean coincident dry bulb temperature, °F	MCDP	Mean coincident dew point temperature, °F	MCWB	Mean coincident wet bulb temperature, °F
MCWS	Mean coincident wind speed, mph	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

Outdoor Design Conditions

- Heating Load Design

Design conditions for CHICAGO, IL, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	*1b*	*1c*	*1d*	*1e*	*1f*	*1g*	*1h*	*1i*
CHICAGO	**725300**	**42.00N**	**87.88W**	**623**	**14.368**	**-6.00**	**NAC**	**7201**

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	*3a*	*3b*	*4a*	*4b*	*4c*	*4d*	*4e*	*4f*	*5a*	*5b*	*5c*	*5d*	*6a*	*6b*
1	**-5.0**	**0.8**	**-15.7**	**2.4**	**-3.5**	**-9.8**	**3.3**	**1.7**	**28.6**	**23.5**	**26.3**	**24.6**	**10.9**	**270**

Outdoor Design Conditions

- Cooling Load Design

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
7	**19.2**	**91.7**	**74.9**	**88.7**	**73.4**	**85.9**	**71.8**	**77.8**	**88.1**	**76.1**	**85.2**	**74.3**	**82.6**	**11.8**	**230**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
74.8	**133.3**	**84.2**	**73.0**	**125.6**	**82.1**	**71.4**	**118.4**	**80.1**	**34.0**	**88.2**	**32.2**	**85.2**	**30.4**	**82.5**

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	*20b*	*20c*	*20d*	*20e*	*20f*	*20g*	*20h*	*20i*	*20j*	*20k*	*20l*
14.2	**14.3**	**16.2**	**18.7**	**20.7**	**20.6**	**19.2**	**17.9**	**19.2**	**19.0**	**14.8**	**13.5**

Outdoor Design Conditions

$$t = t_{peak} - DR \sum_{i=0}^{11} [a_i \cos\left(\frac{2 \times \pi \times \theta}{24}\right) + b_i \sin\left(\frac{2 \times \pi \times \theta}{24}\right)]$$

- t = air temperature $°F$
- t_{peak} = peak design temperature $°F$
- DR = daily range $°F$
- a_i, b_i = coefficients from the ASHRAE Load Calculation Table
- θ = The apparent solar time in decimal form, dimensionless

i	0	1	2	3	4	5	6	7	8	9	10	11
a_i	0.5363	0.3482	-0.0732	0.002	0.0104	-0.0041	0.0025	-0.0004	-0.0038	-0.0003	0.0032	-0.0005
b_i	0	0.3426	-0.0491	-0.0194	0.0123	0.0049	-0.0017	-0.0027	0.0036	0.0006	0	0.0002

Outdoor Design Conditions

- Use proxy for the series part of calculation:

$$t = t_{peak} - DR \times f$$

Time (Hr)	f	Time (Hr)	f	Time (Hr)	f
1	0.88	9	0.55	17	0.14
2	0.92	10	0.38	18	0.24
3	0.95	11	0.23	19	0.39
4	0.98	12	0.13	20	0.5
5	1	13	0.05	21	0.59
6	0.98	14	0	22	0.68
7	0.91	15	0	23	0.75
8	0.74	16	0.06	24	0.82

DR: Daily range $°F$

CLASS ACTIVITY

Class Activity

- Question: From the tables, calculate the following variables (Use both the uploaded page and your handbook):
  - ❑ 1% condition in Chicago for the hottest month
  - ❑ Daily range
  - ❑ Temperature at 5 PM

Class Activity

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
7	**19.2**	**91.7**	**74.9**	**88.7**	**73.4**	**85.9**	**71.8**	**77.8**	**88.1**	**76.1**	**85.2**	**74.3**	**82.6**	**11.8**	**230**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
74.8	**133.3**	**84.2**	**73.0**	**125.6**	**82.1**	**71.4**	**118.4**	**80.1**	**34.0**	**88.2**	**32.2**	**85.2**	**30.4**	**82.5**

Time (Hr)	f	Time (Hr)	f	Time (Hr)	f
1	0.88	9	0.55	17	0.14
2	0.92	10	0.38	18	0.24
3	0.95	11	0.23	19	0.39
4	0.98	12	0.13	20	0.5
5	1	13	0.05	21	0.59
6	0.98	14	0	22	0.68
7	0.91	15	0	23	0.75
8	0.74	16	0.06	24	0.82

$$t = 88.7\ °F\ - 0.14 \times 19.2\ °F = 86.01\ °F$$

Class Activity

- How does the daily hourly design temperature profile look like?