CAE 464/517 HVAC Systems Design

Spring 2021

January 28, 2021

Psychrometrics Processes and Space Conditioning

Built Environment Research @ IIT

Advancing energy, environmental, and sustainability research within the built environment

www.built-envi.com

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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

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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

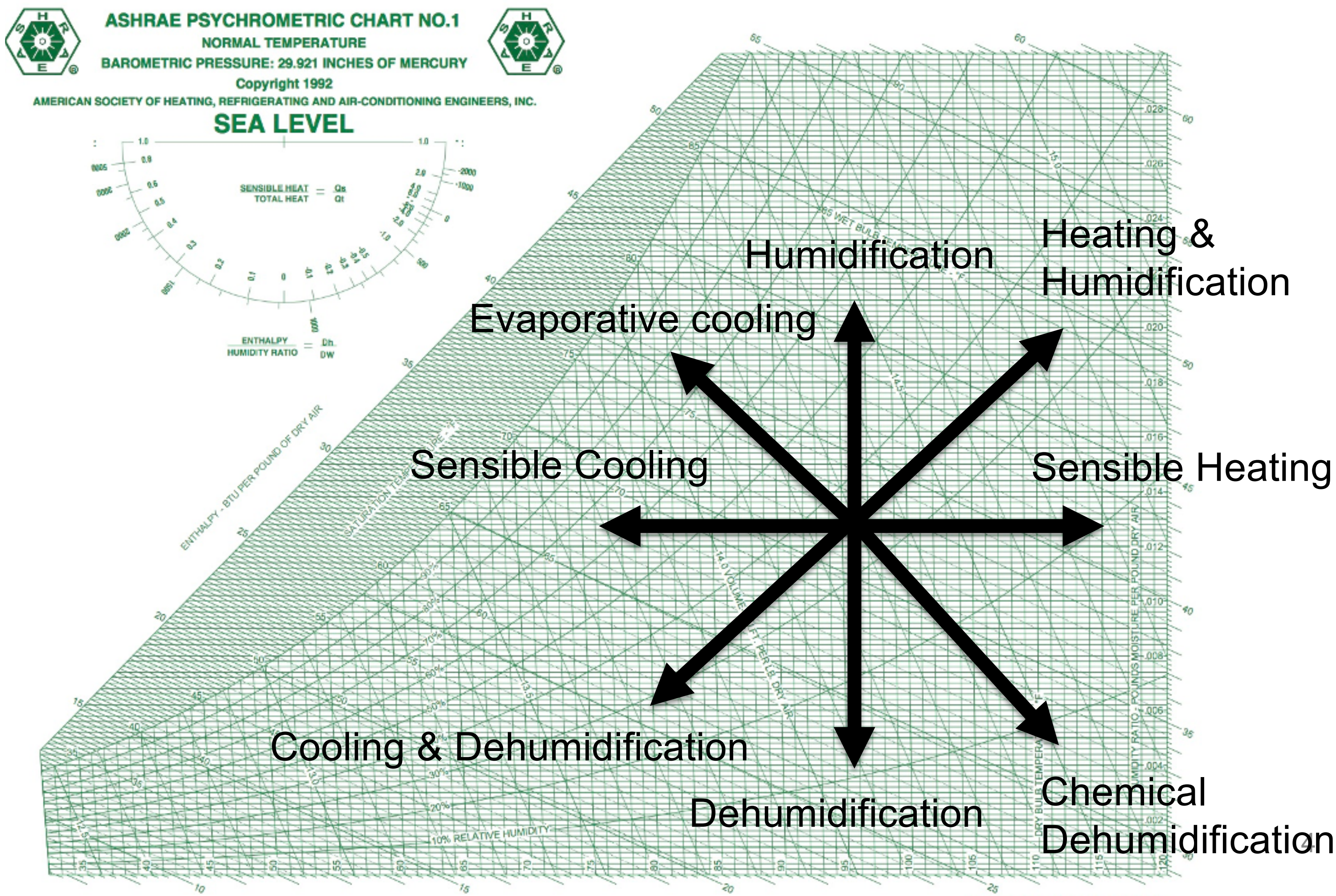
cae331_513_lecture11_psychrometric equations

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

- Enthalpy of moist air is given as:

$h_a = 0.24\,T_{db} + W(1061 + 0.444\,T_{db})$	IP
$h_a = 1.006\,T_{db} + W(2501 + 1.86\,T_{db})$	SI

Recap

- Thermodynamic properties of moist air
- See Table 2 of Chapter 1

Table 2 Thermodynamic Properties of Moist Air at Standard Atmospheric Pressure, 14.696 psia (*Continued*)

Temp., °F	Humidity Ratio	Specific Volume, ft^3/lb_{da}			Specific Enthalpy, Btu/lb_{da}			Specific Entropy, $Btu/lb_{da} \cdot °F$		Temp., °F
t	W_s, lb_w/lb_{da}	v_{da}	v_{as}	v_s	h_{da}	h_{as}	h_s	s_{da}	s_s	t
60	0.011087	13.096	0.233	13.329	14.415	12.052	26.467	0.02947	0.05389	60
61	0.011496	13.122	0.242	13.364	14.655	12.502	27.157	0.02994	0.05522	61
62	0.011919	13.147	0.251	13.398	14.895	12.966	27.862	0.03040	0.05657	62
63	0.012355	13.172	0.261	13.433	15.135	13.446	28.582	0.03086	0.05795	63
64	0.012805	13.198	0.271	13.468	15.376	13.942	29.318	0.03132	0.05936	64
65	0.013270	13.223	0.281	13.504	15.616	14.454	30.071	0.03178	0.06080	65
66	0.013750	13.248	0.292	13.540	15.856	14.983	30.840	0.03223	0.06226	66
67	0.014246	13.273	0.303	13.577	16.097	15.530	31.626	0.03269	0.06376	67
68	0.014758	13.299	0.315	13.613	16.337	16.094	32.431	0.03315	0.06529	68
69	0.015286	13.324	0.326	13.650	16.577	16.677	33.254	0.03360	0.06685	69
70	0.015832	13.349	0.339	13.688	16.818	17.279	34.097	0.03406	0.06844	70
71	0.016395	13.375	0.351	13.726	17.058	17.901	34.959	0.03451	0.07007	71
72	0.016976	13.400	0.365	13.764	17.299	18.543	35.841	0.03496	0.07173	72
73	0.017575	13.425	0.378	13.803	17.539	19.204	36.743	0.03541	0.07343	73
74	0.018194	13.450	0.392	13.843	17.779	19.889	37.668	0.03586	0.07516	74
75	0.018833	13.476	0.407	13.882	18.020	20.595	38.615	0.03631	0.07694	75
76	0.019491	13.501	0.422	13.923	18.260	21.323	39.583	0.03676	0.07875	76
77	0.020170	13.526	0.437	13.963	18.500	22.075	40.576	0.03721	0.08060	77
78	0.020871	13.551	0.453	14.005	18.741	22.851	41.592	0.03766	0.08250	78
79	0.021594	13.577	0.470	14.046	18.981	23.652	42.633	0.03811	0.08444	79

- Additional tables in Chapter 30

Recap

Example: A closed vessel contains 0.1 ft^3 of saturated liquid and 0.9 ft^3 of saturated vapor R-134a in equilibrium at 90 F.

1. Determine the percent vapor on a mass basis.
2. Calculate the quality of the mixture

Recap

Solution: (From Page 30.16 and 30.17)

$$V_{liquid} = m_{liquid} v_f$$

$$m_{liquid} = \frac{V_{liquid}}{v_f} = \frac{0.1}{\frac{1}{73.58}} = 7.358\ lbm$$

$$V_{vapor} = m_{vapor} v_g$$

$$m_{vapor} = \frac{V_{vapor}}{v_g} = \frac{0.9}{0.3999} = 2.250\ lbm$$

Recap

Solution: (From Page 30.16 and 30.17)

$$m = m_{liquid} + m_{vapor} = 7.\ 358\ + 2.250$$ =9.608 lbm

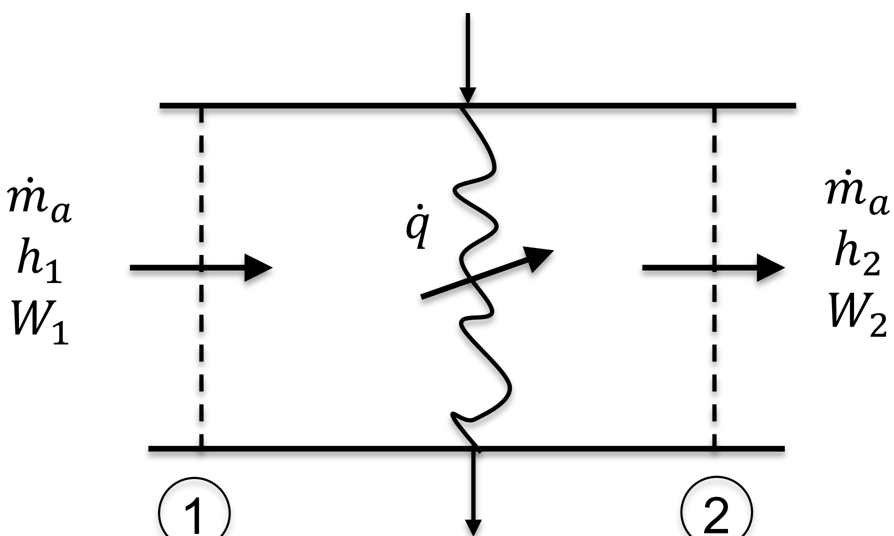
$$x = \frac{m_{vapor}}{m} = \frac{2.250}{9.608} = 0.234\ lbm$$

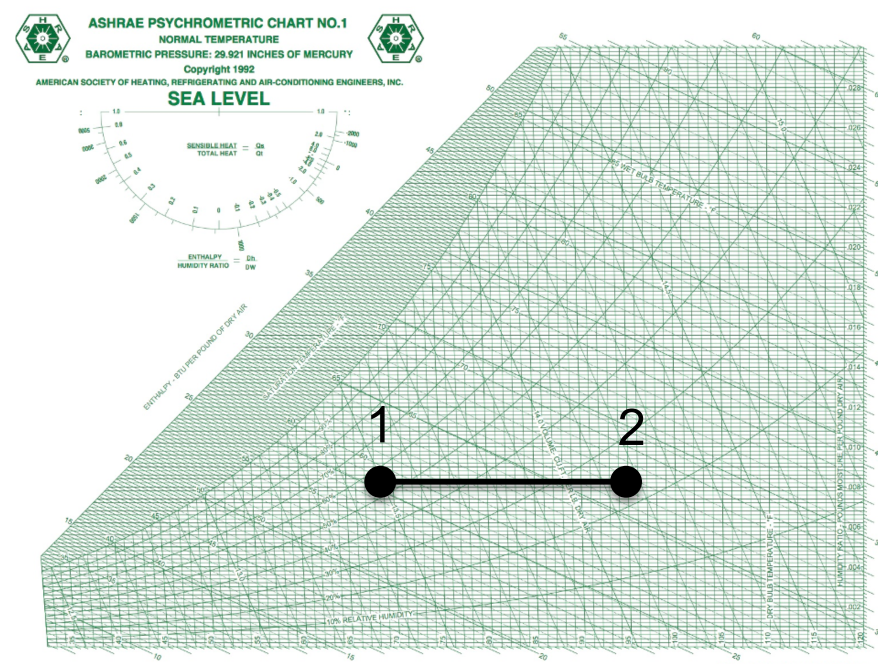
CLASSIFICATION OF AIR PROCESSES (CAE 331, MMAE 320)

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

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

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

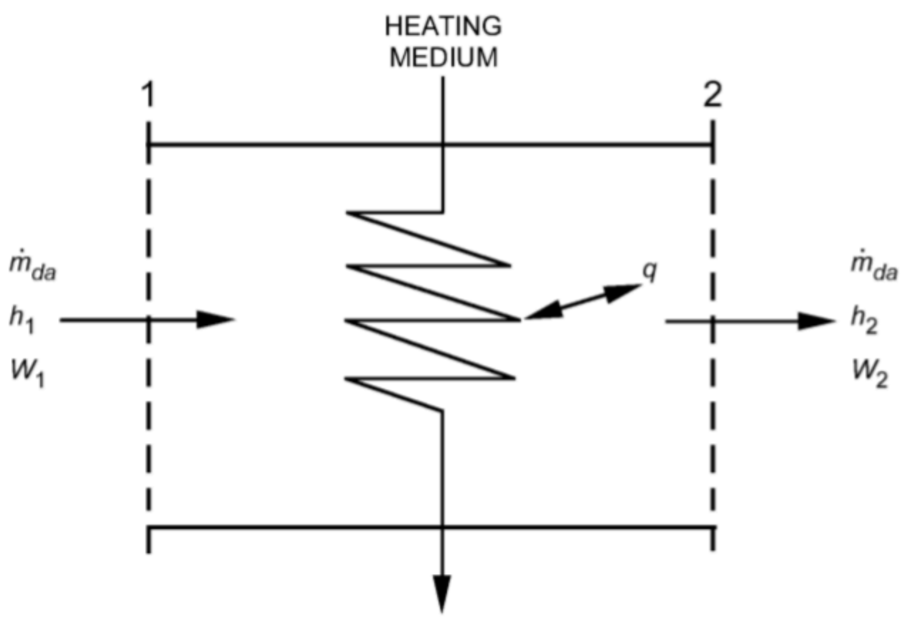
CLASS ACTIVITY

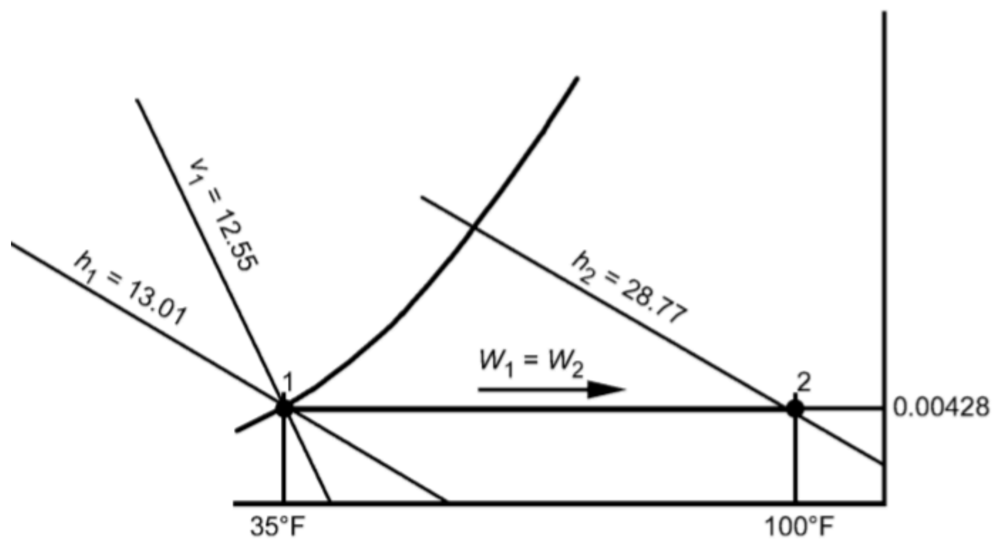
Class Activity

- Example (sensible heating or cooling): 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):

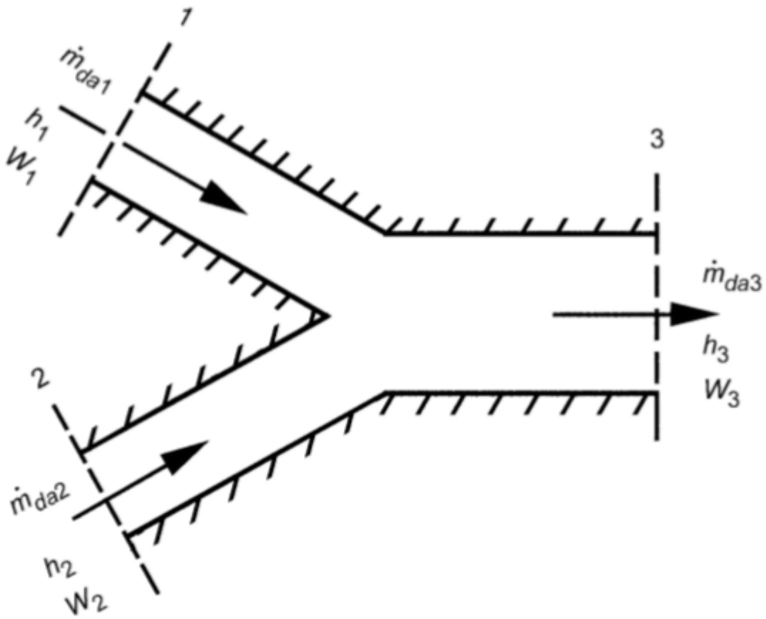
$$\dot{q} = \dot{m}_{da}(h_2 - h_1)$$

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

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

Processes

- Adiabatic mixing of two moist stream:



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

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

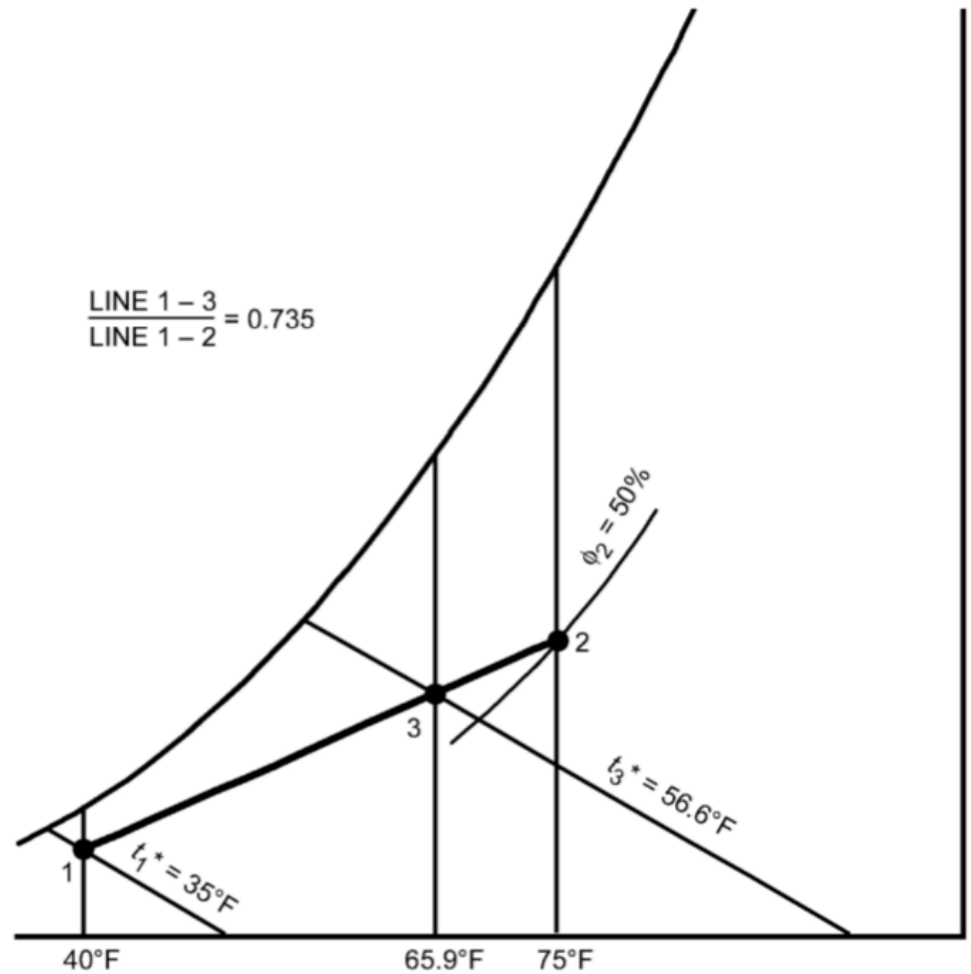
$$\frac{h_2 - h_3}{h_3 - h_1} = \frac{W_2 - W_3}{W_3 - W_1} = \frac{segment2-3}{segment3-1} = \frac{\dot{m}_{da1}}{\dot{m}_{da2}}$$

Processes

- Adiabatic mixing of two moist stream

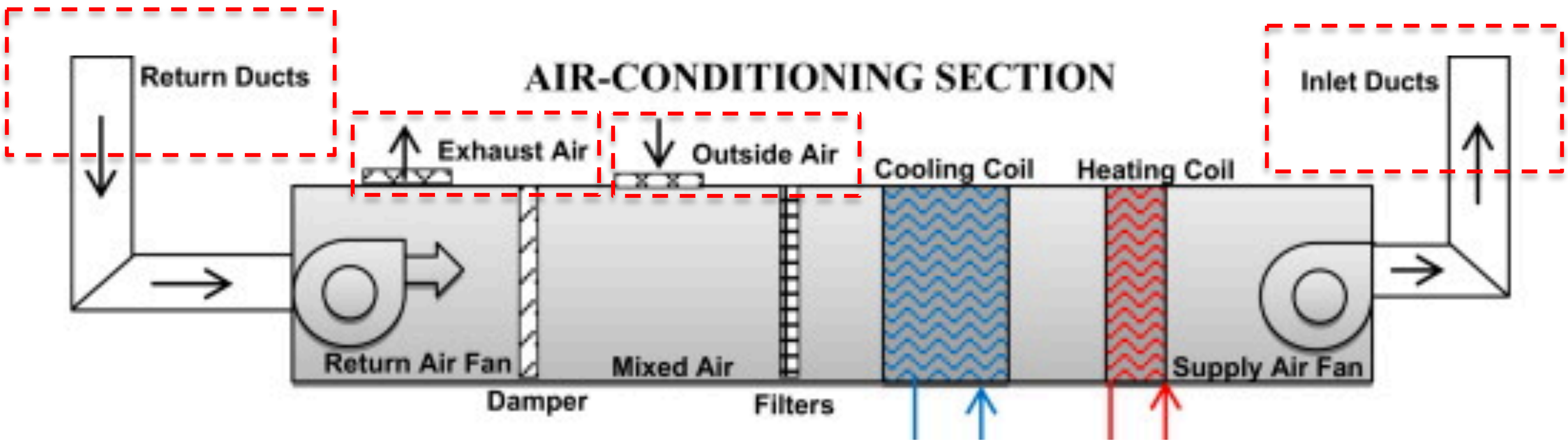
$$\frac{Line\ 3\!-\!2}{Line\ 1\!-\!3} = \frac{\dot{m}_{da1}}{\dot{m}_{da2}}$$

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



SPACE CONDITIONING

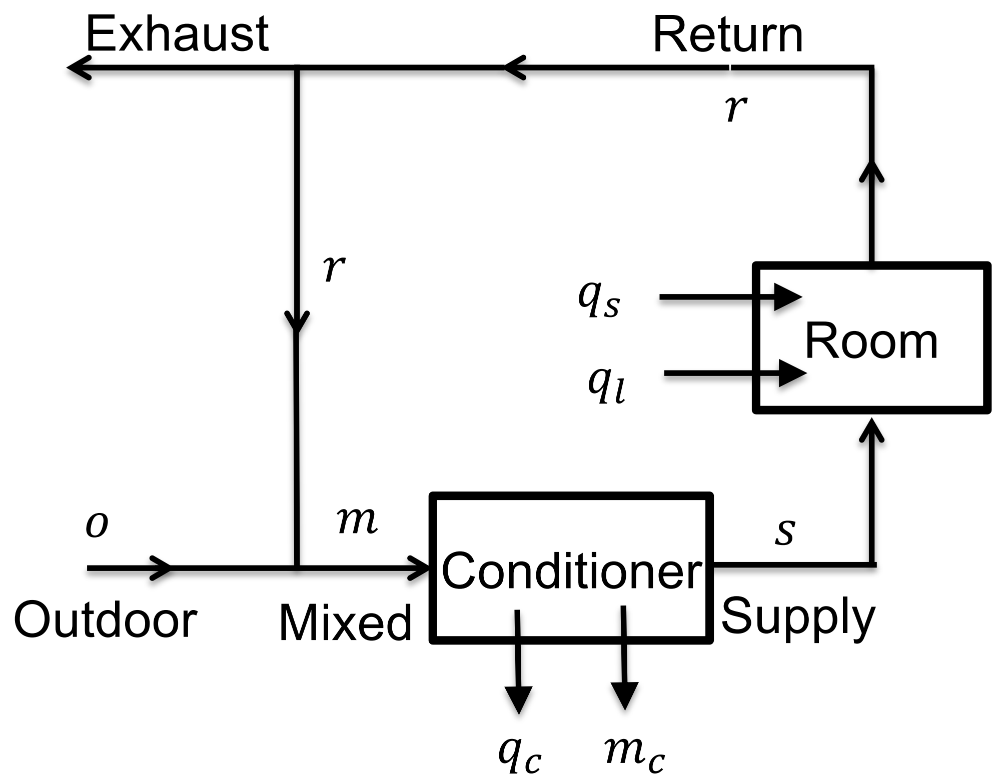
Space Conditioning



Space Conditioning

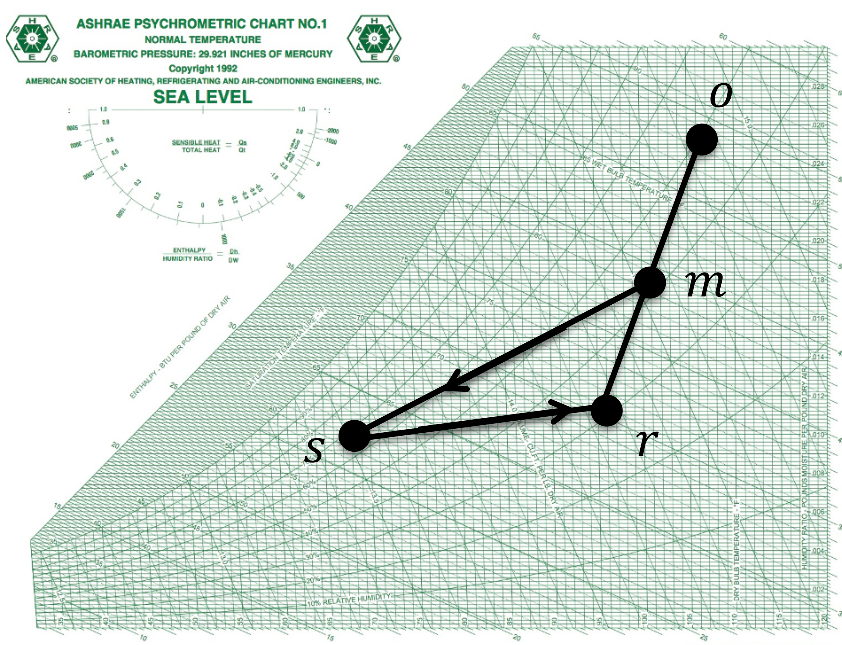
- Step 1: Develop state condition property table

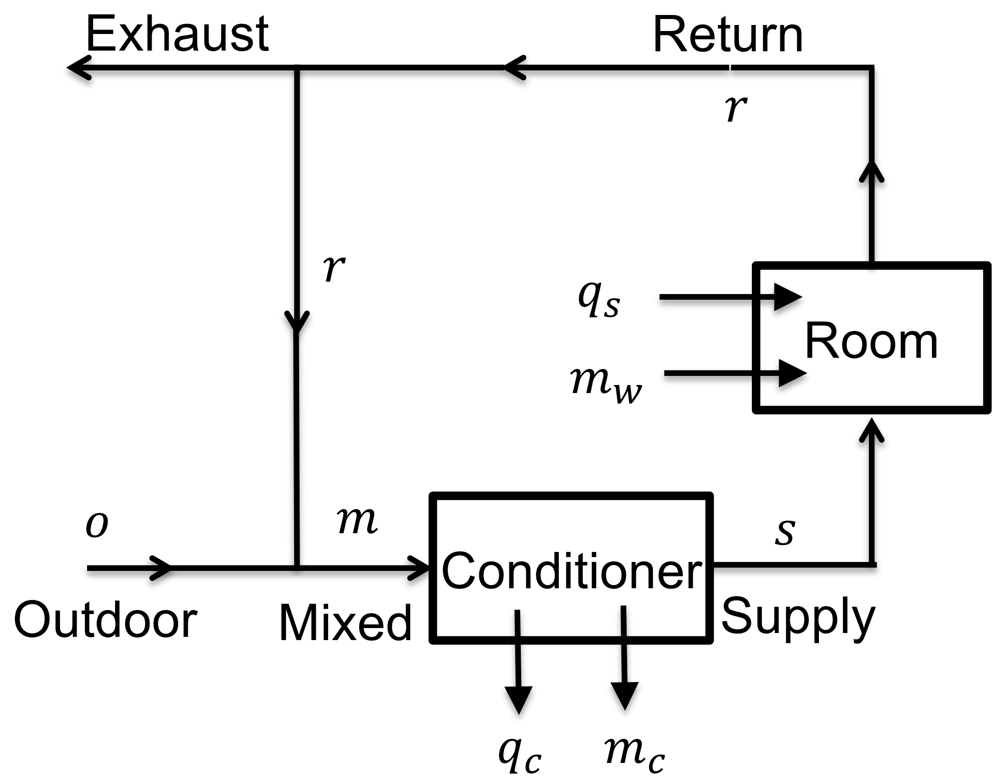
Point	OA	RA	MA	DA	SA
Dry bulb					
Wet bulb					
RH					
Enthalpy					
W					
V					
m_a					
Airflow					



Space Conditioning

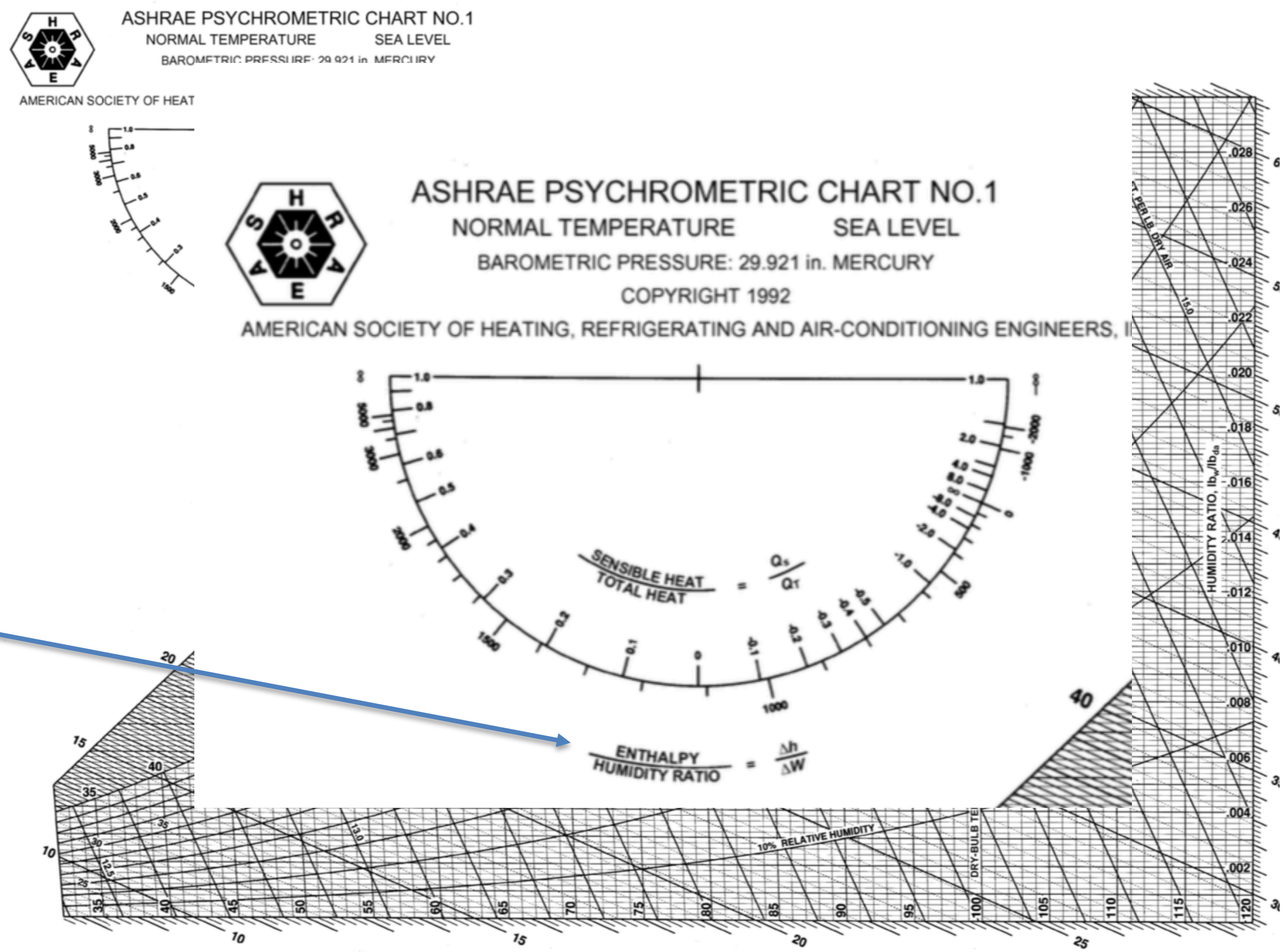
- Step 2: Develop Psychrometric chart





Space Conditioning

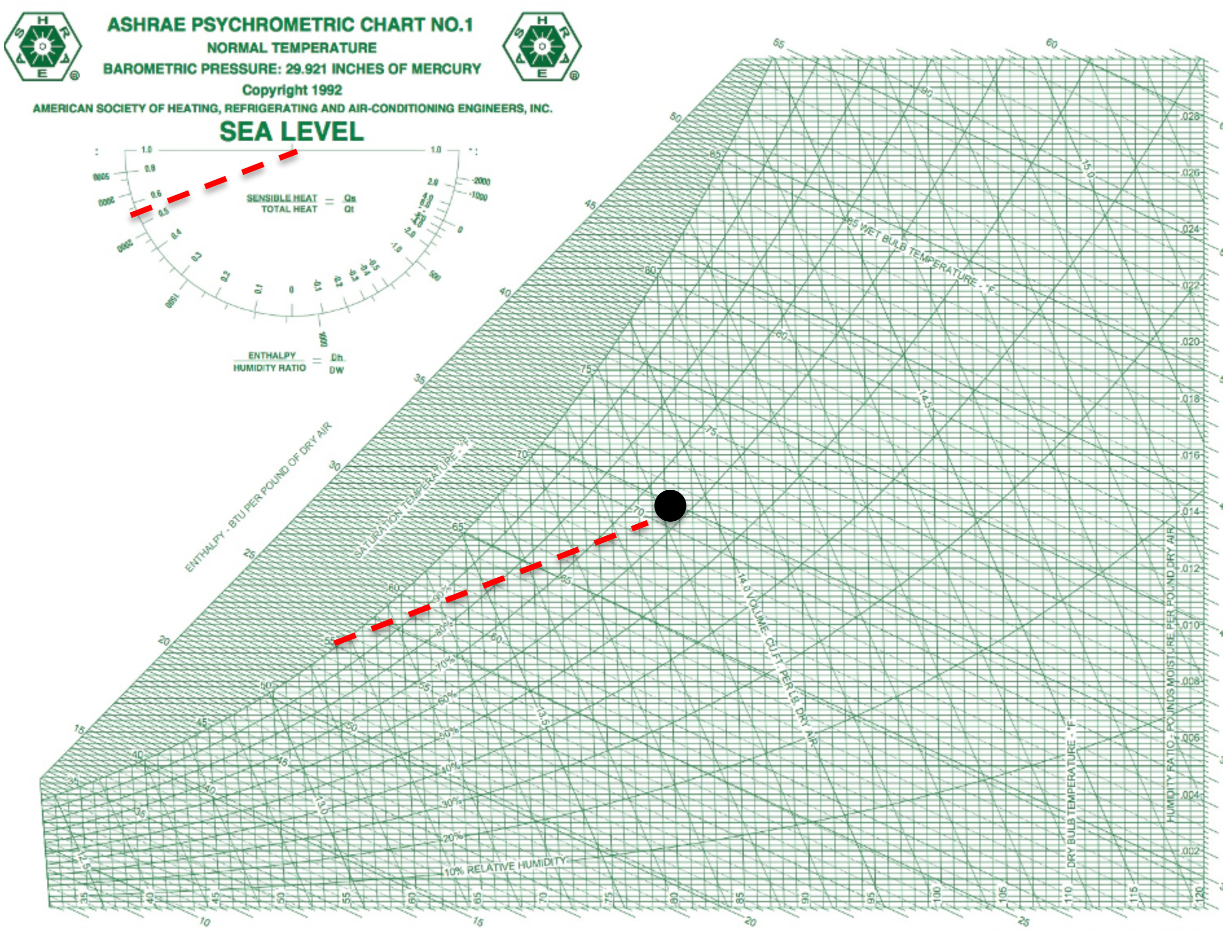
- Sensible Heat Ratio (SHR)



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

Space Conditioning

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

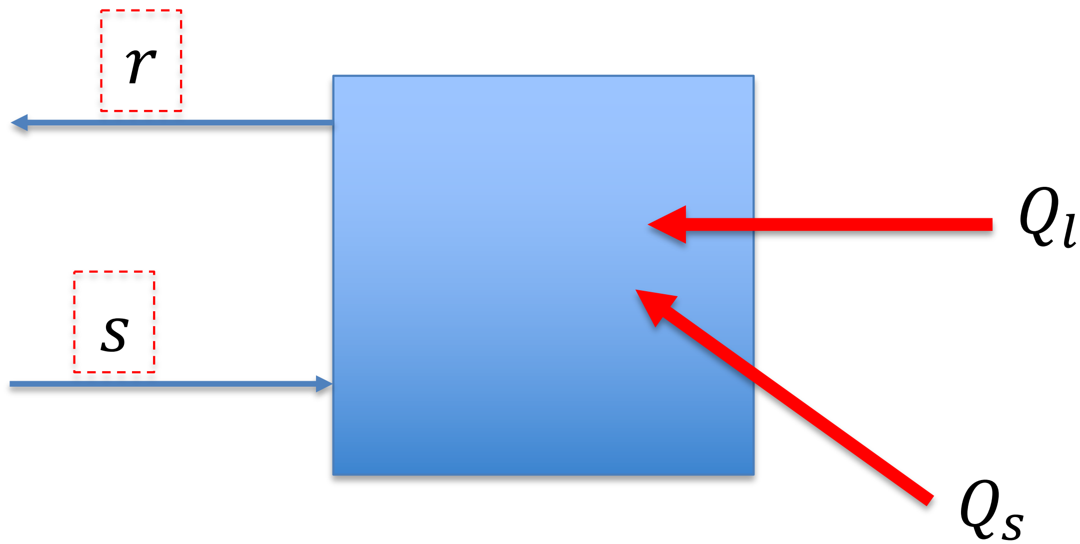


Space Conditioning

- 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

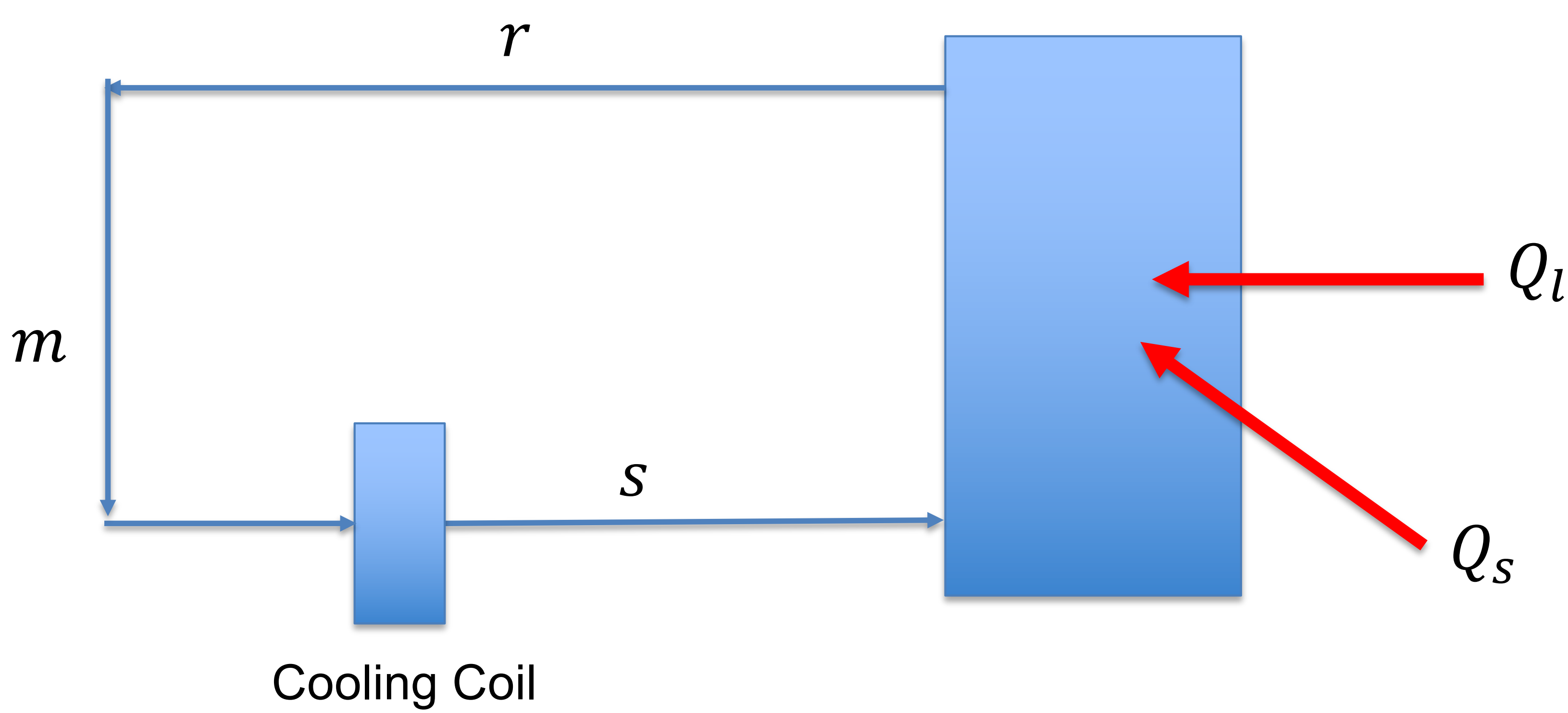
s: Supply air

Q_l: Latent heat transfer

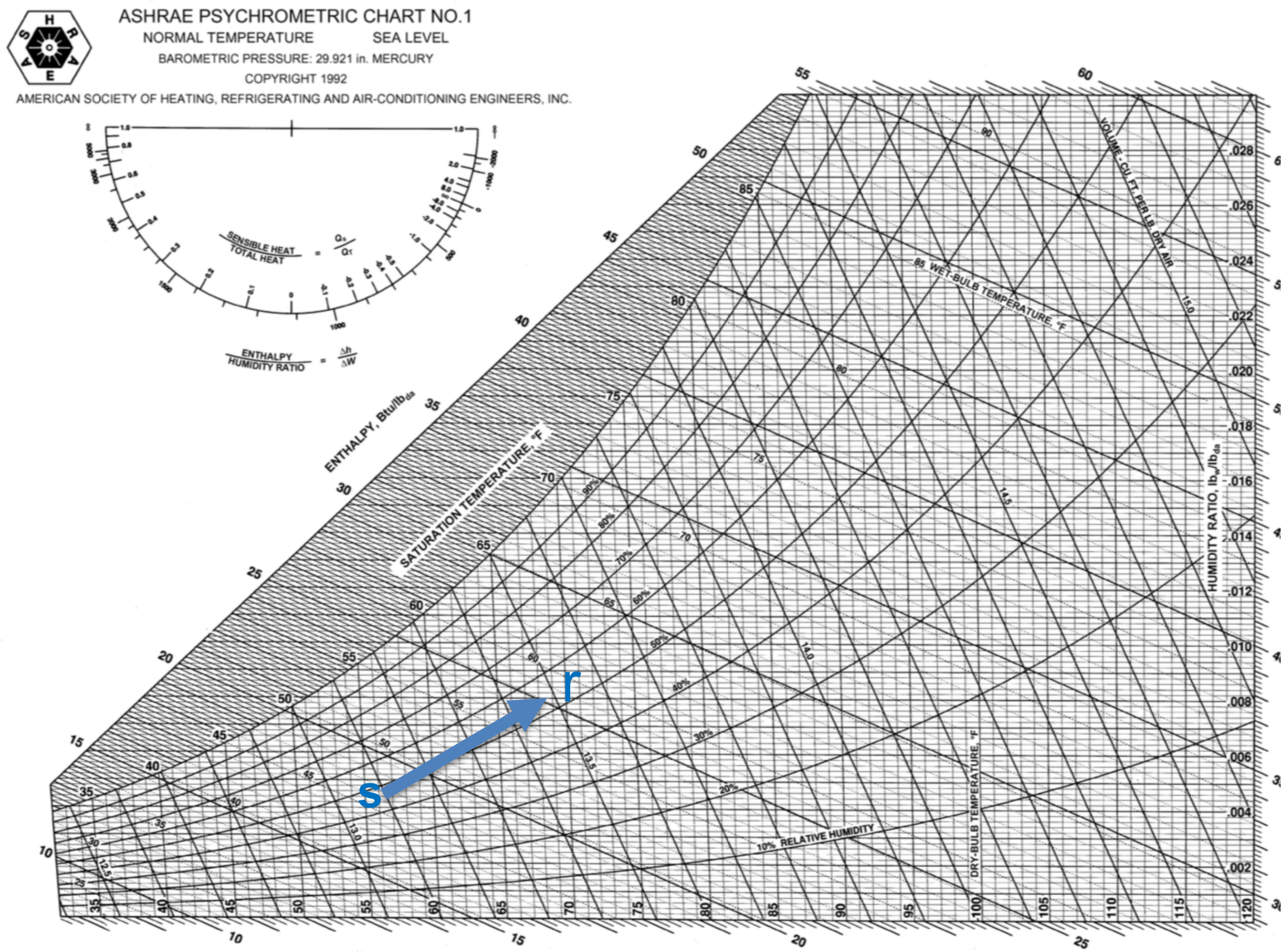
Q_s: Sensible heat transfer

Space Conditioning

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

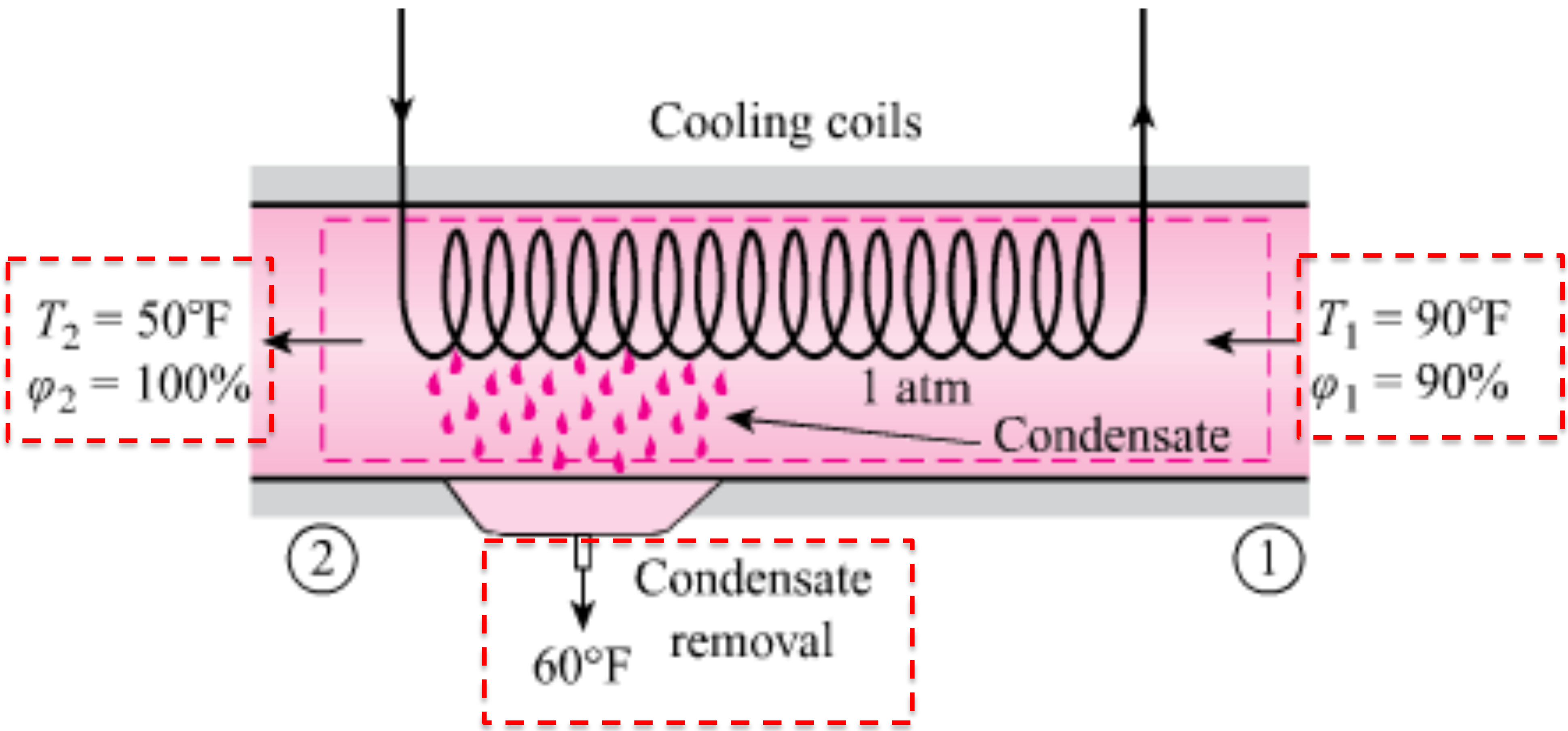


Space Conditioning



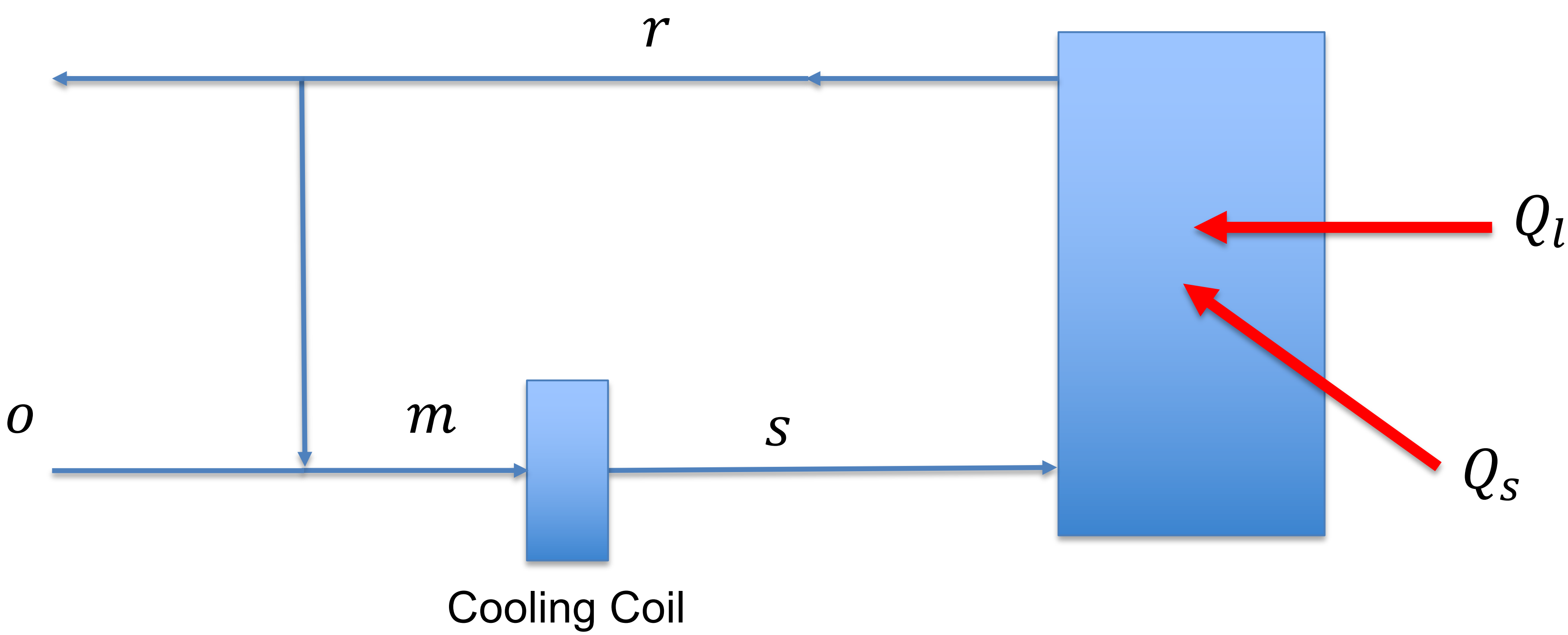
Space Conditioning

- Cooling coil load is different than the space loads

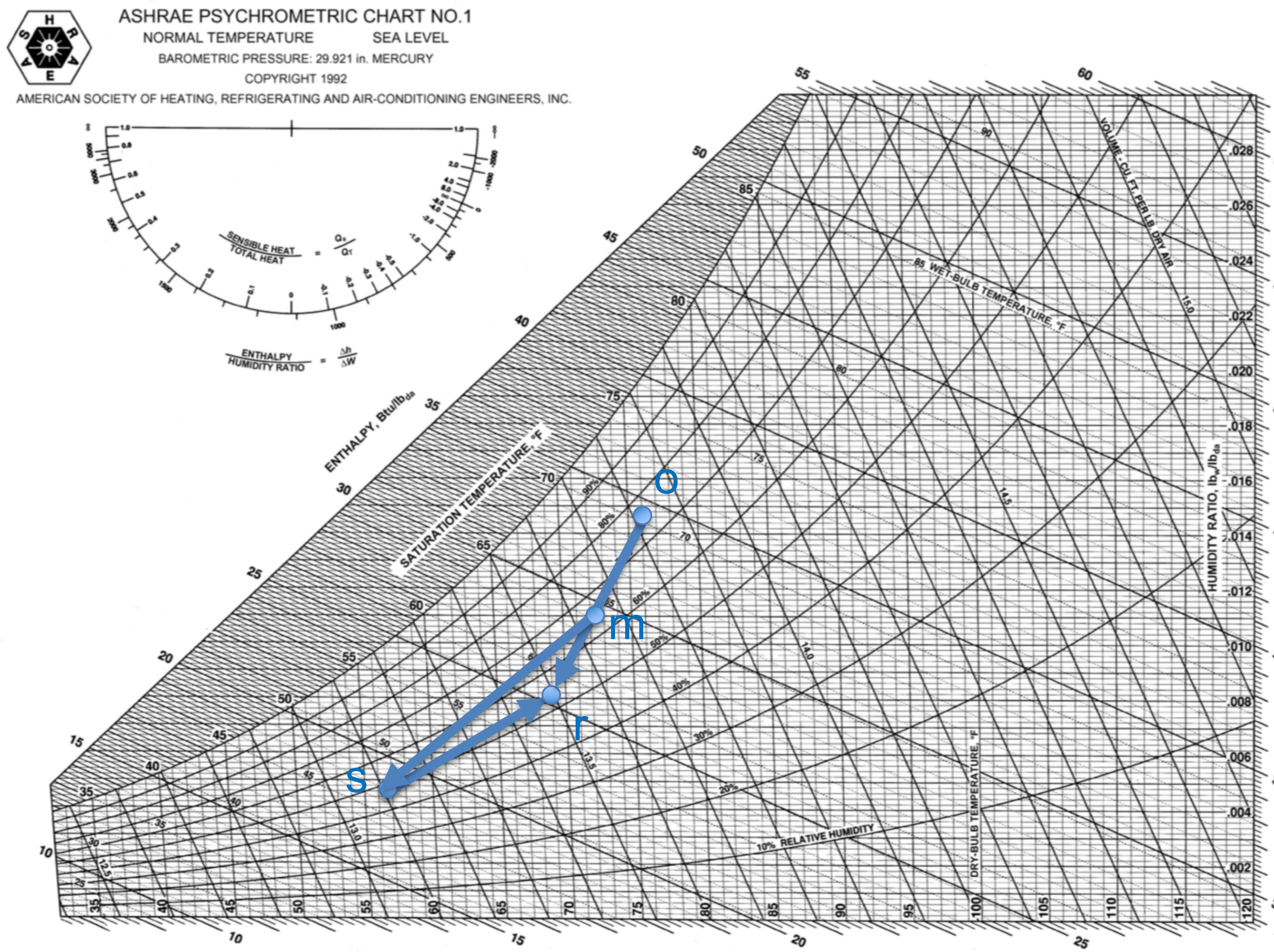


Space Conditioning

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

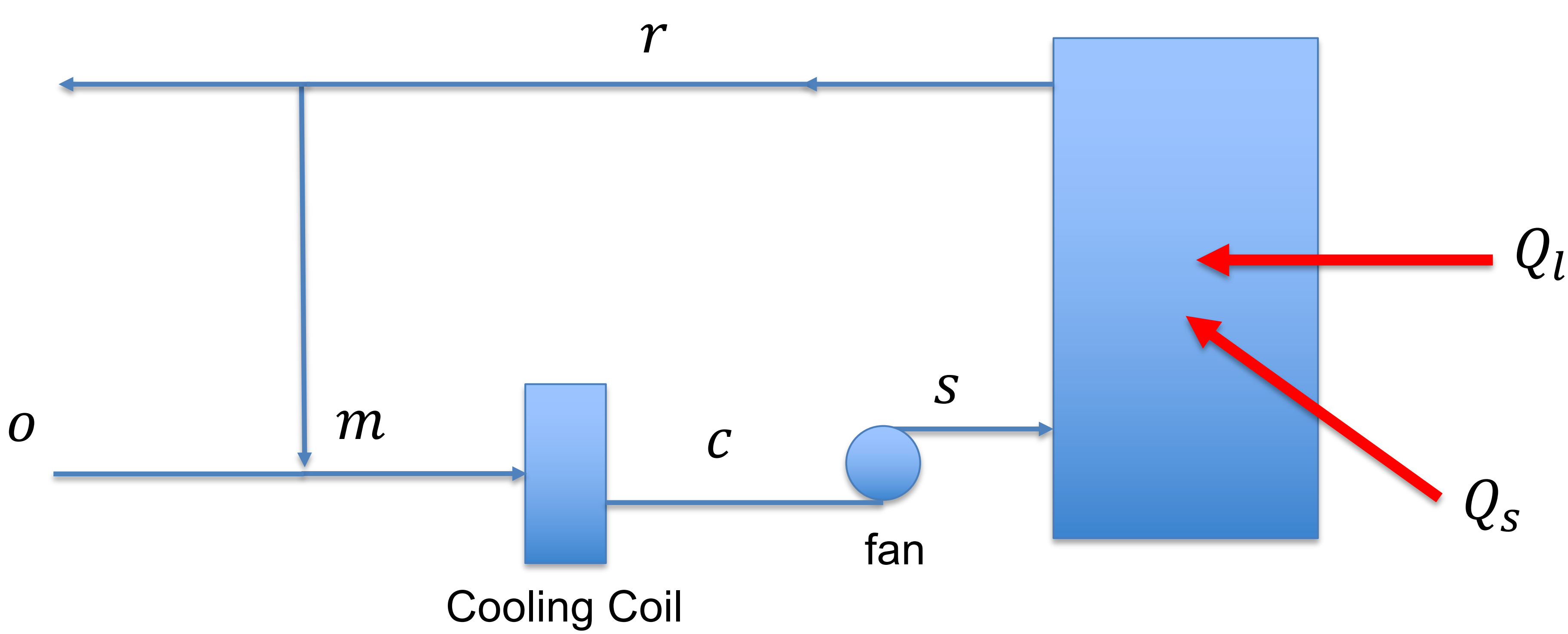


Space Conditioning

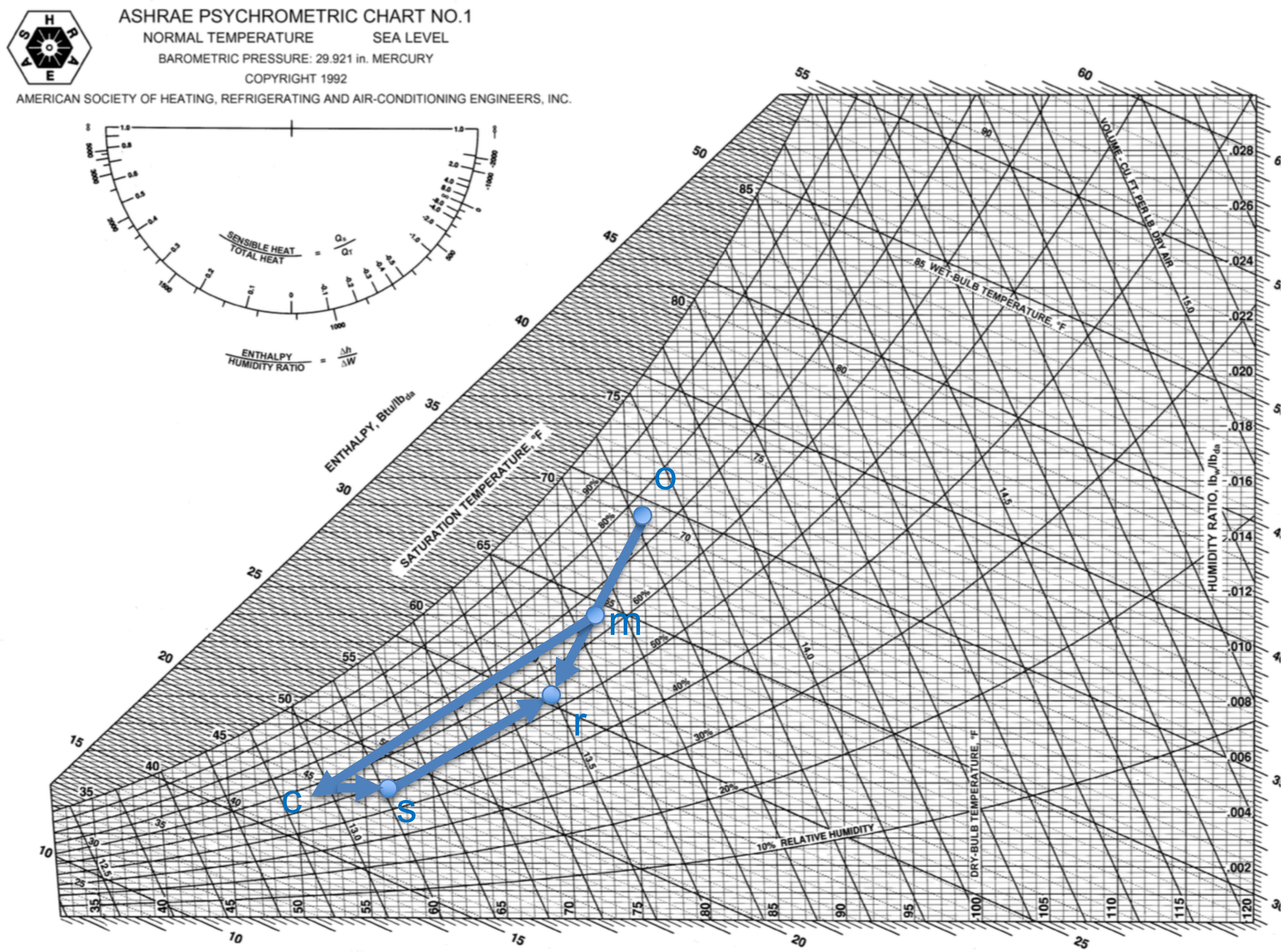


Space Conditioning

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

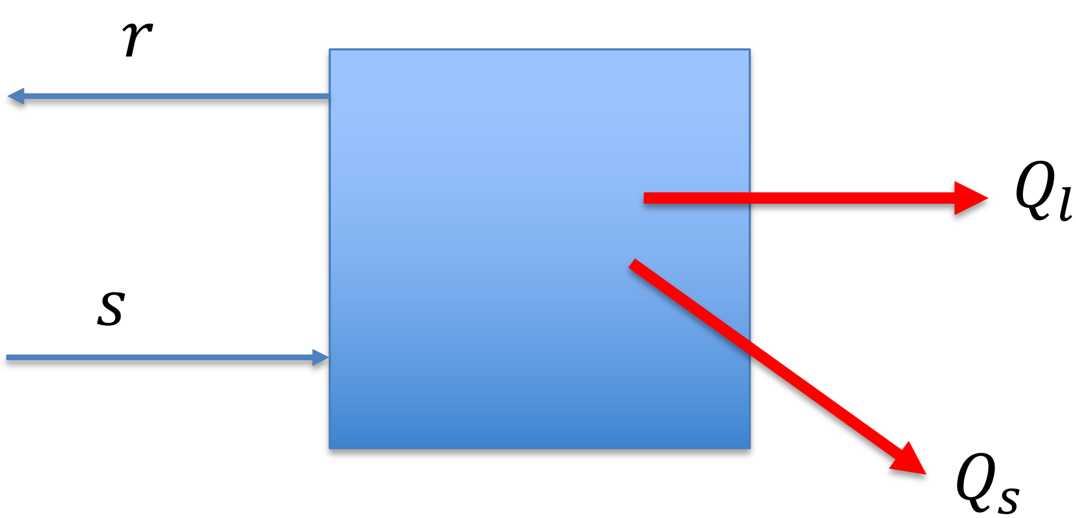


Space Conditioning



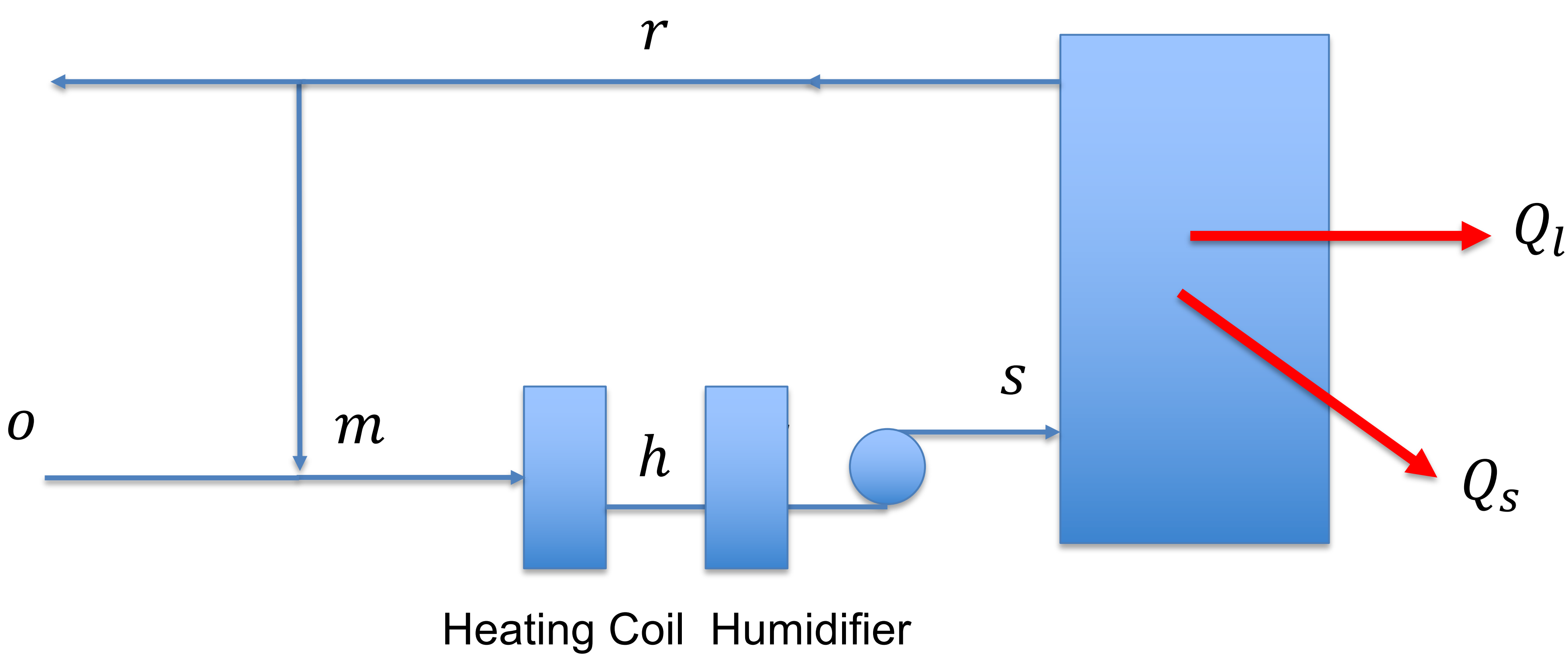
Space Conditioning

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



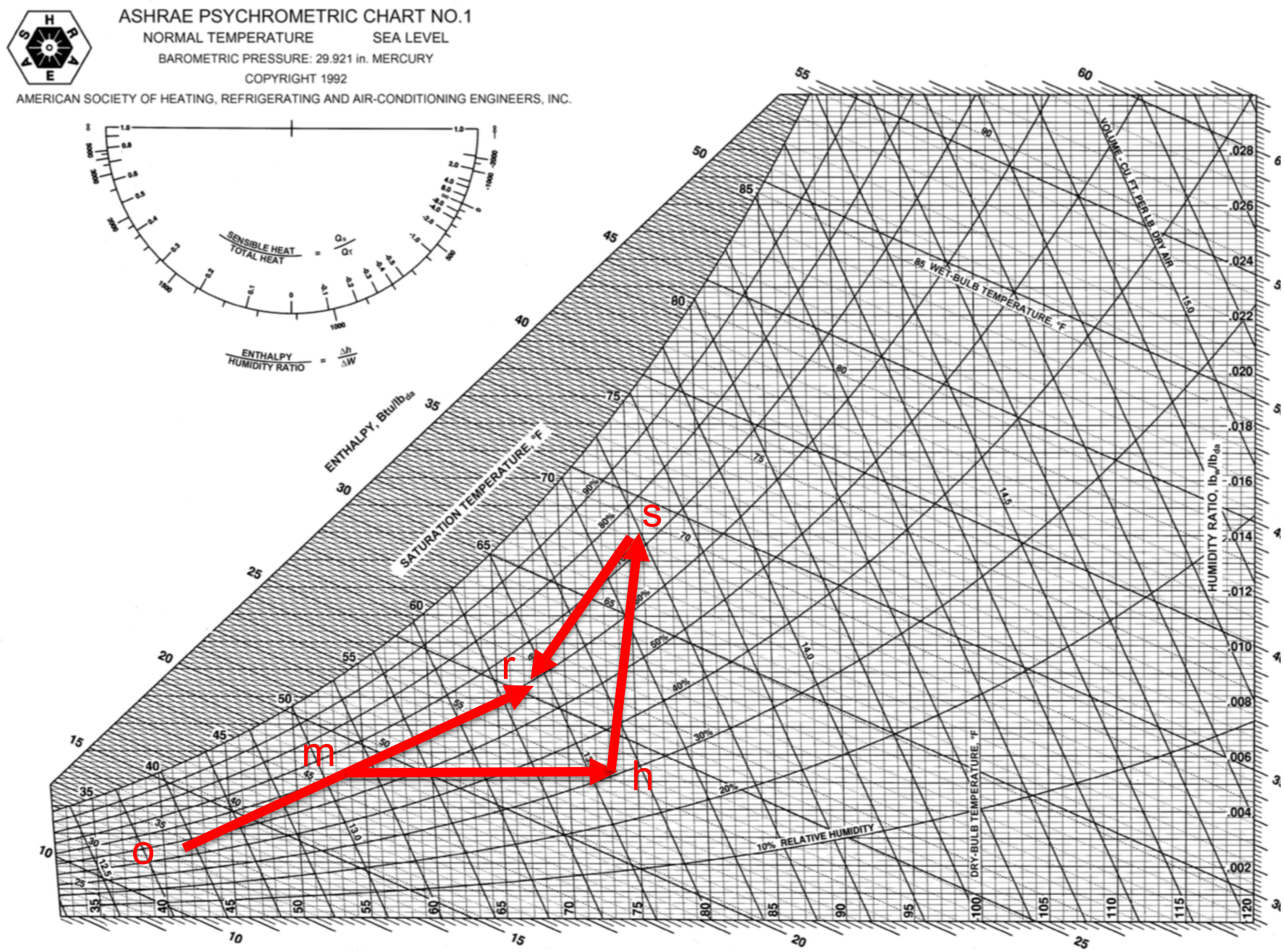
Space Conditioning

- A typical winter system follows this diagram



What do we need a humidifier?

Space Conditioning



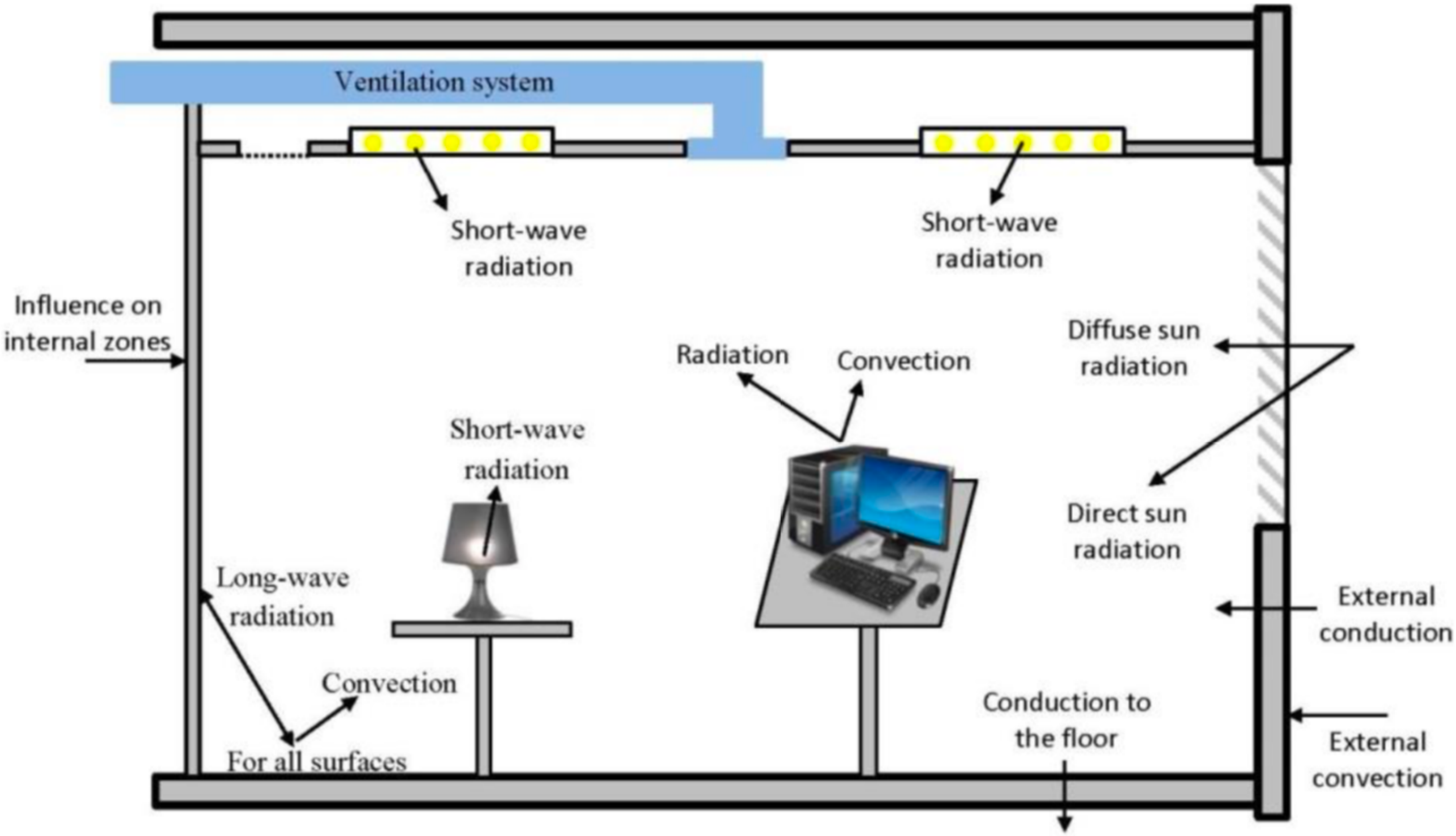
CLASS ACTIVITY

Class Activity

- **Question:** 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.

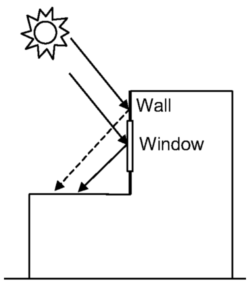
CONTRIBUTION OF DIFFERENT LOAD COMPONENTS (CAE 331)

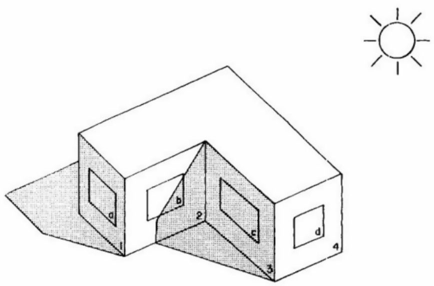
Contribution of Different Load Components



Contribution of Different Load Components

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



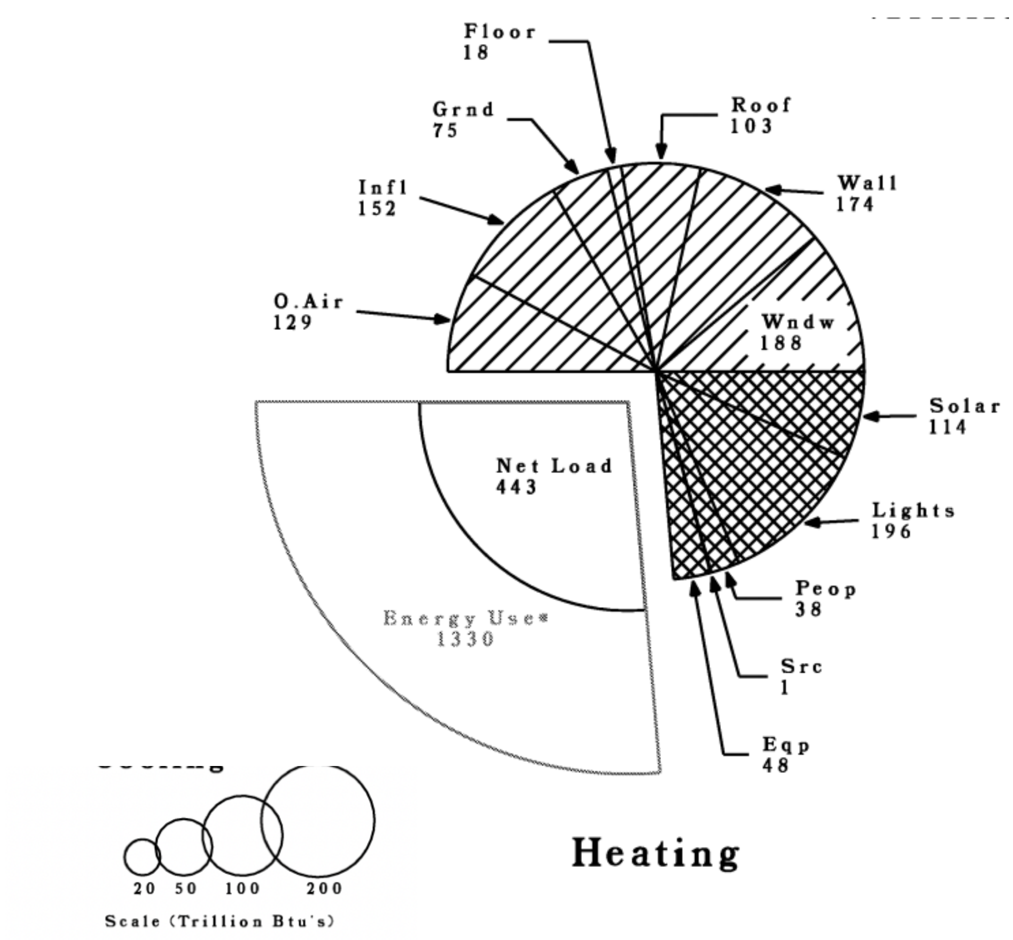


  - ❑ Conduction (e.g. through wall, window)

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

Contribution of Different Load Components

- Residential buildings



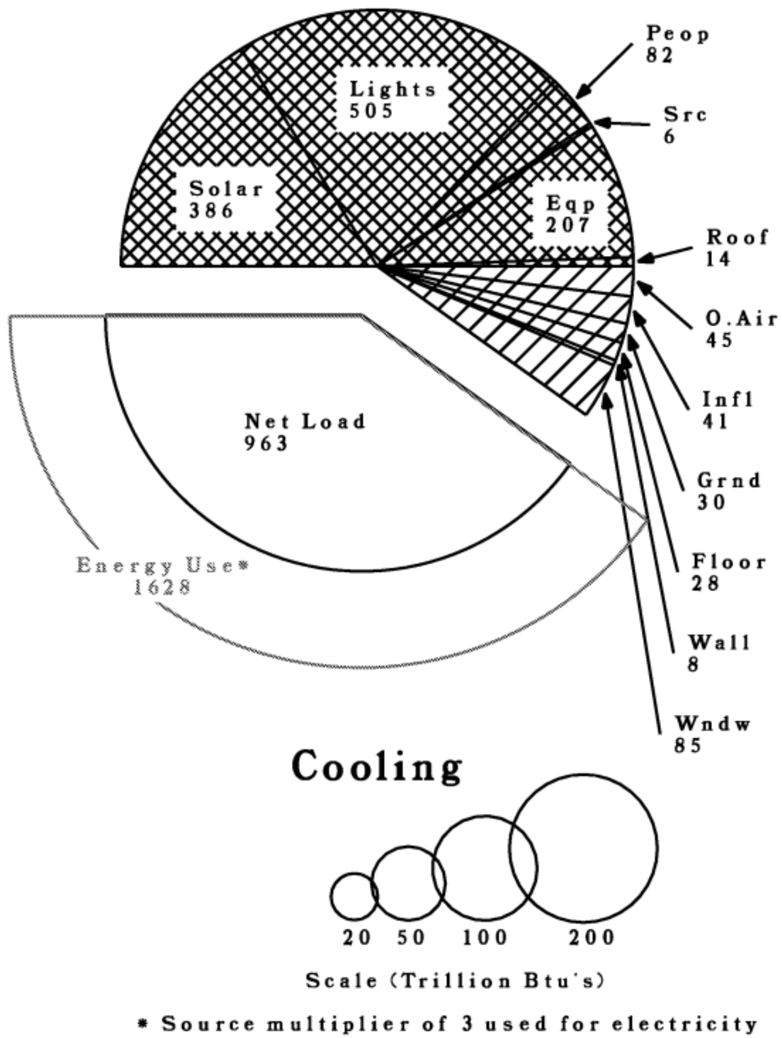
Heat Losses

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



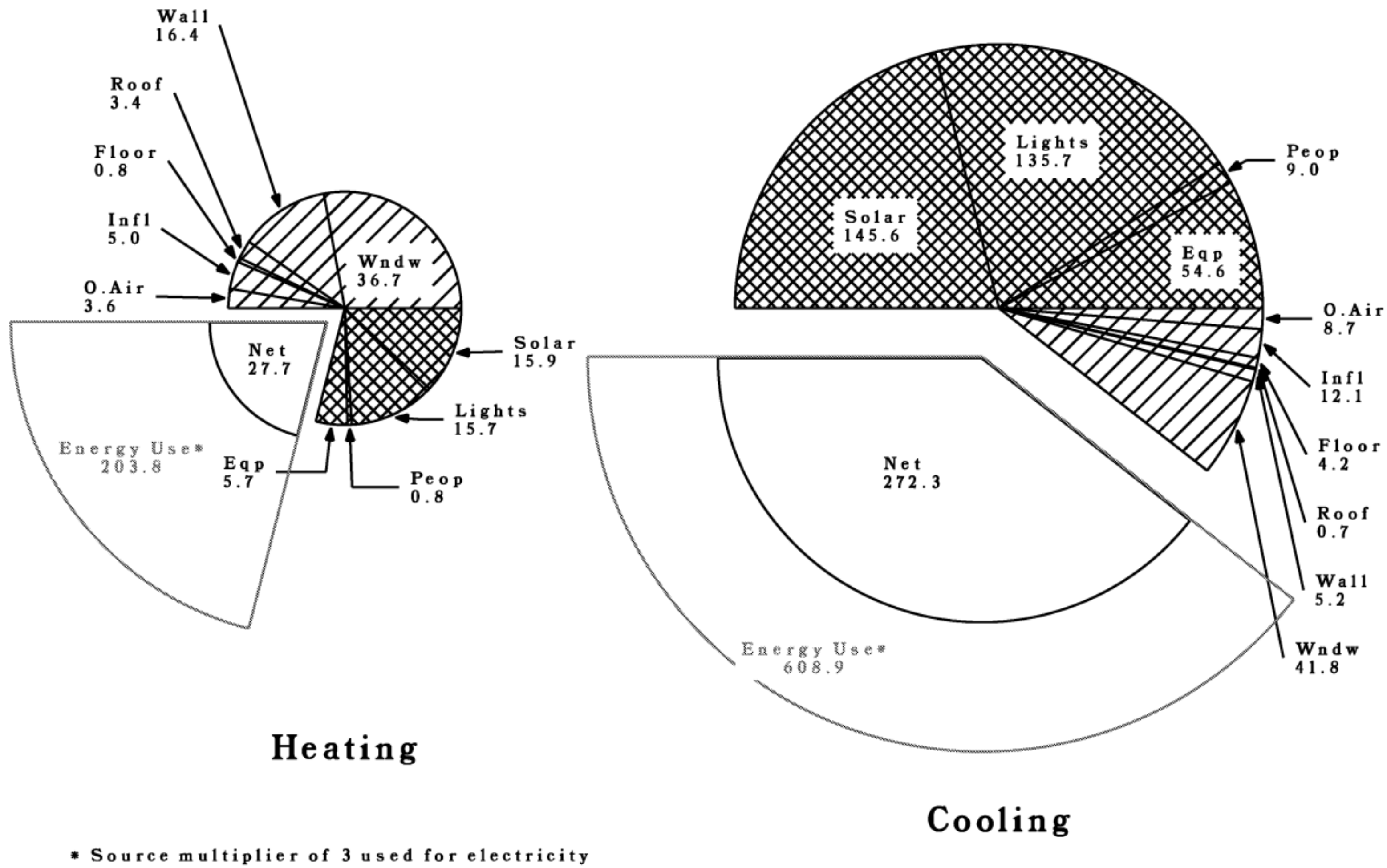
Heat Gains

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



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