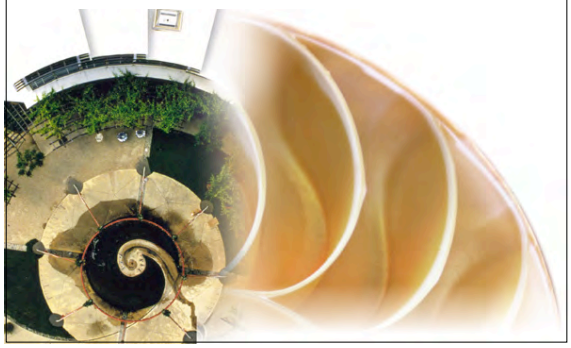
## Thermal Comfort

ARCH 331/431 Spring 2008
Lecture 5



## announcements 4/15/08

**A3: Envelope Heat Transfer**

Available on Thursday, 4/17

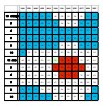
Due: week 5

**Quiz 2: Tuesday 4/22**

## Climate Analysis

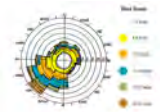
II. Analysis and Graphic Articulation

**1. Temperature:**
**2-hour temperature map**

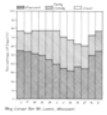


**2. Temperature + Rel. Humidity:**
**Psychrometric Chart**

**3. Wind Direction & Velocity**
**Wind rose**



**4. Sun & Shade**
**Sky Cover Chart**



## Climate Analysis

Additional Metrics

- **Temperature:** monthly normal high & low
- **Relative Humidity:** monthly normal high & low
- **Wind:** normal monthly normal velocity and direction
- **Sky Conditions:** clear, partly cloudy, cloudy
- **Climate Narrative:** description of climate
- **Character/Sense of Place:** images

- **Solar Radiation:** energy incident on a surface
- **Heating & Cooling Degree Day:** cumulative intensity and duration of heating and cooing periods
- **Seasonal Design Temperatures:** summer and winter temperatures (for sizing mechanical equipment)

## Solar Radiation: Horizontal and Vertical Surfaces

Solar radiation

thermal energy measured in

**Btu/h sf**
or
Watts/$m^2$

*both direct + diffuse sunlight*

## Solar Radiation: Horizontal and Vertical Surfaces

MEEB 10th Appendix C: Solar Data

**TABLE C.15**

| | | | Seattle | Phoenix | Denver |
|---|---|---|---|---|---|
| Heating Degree Days | | | 4684 | 1552 | 6016 |
| January | Solar Insolation BTU/day ft² | HS | 262 | 1021 | 840 |
| | | VS | 378 | 1462 | 1465 |
| July | | HS | 2248 | 2486 | 2273 |
| | | VS | 1299 | 964 | 1053 |
| Year (avg.) | | HS | 1056 | 1371 | 1570 |
| | | VS | 857 | 1326 | 1334 |

HS = Horizontal Surface

VS = Vertical South

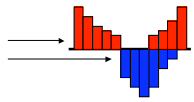
Additional Metrics: Heating and Cooling Degree Days (HDD & CDD)

## Heating Degree Day and Cooling Degree Days

*Intensity of heating + cooling patterns*

heating and cooling degree days:

HDD base 65°F (18 °C) or lower
CDD base 74°F (18 °C) or higher



Additional Metrics: Heating and Cooling Degree Days (HDD & CDD)

## Heating and Cooling Degree-Days

| | HDD65 | CDD74 |
|---|---|---|
| Seattle, WA | 4684 | 37 |
| Dawson Creek, BC | 11,212 | 18 |
| San Juan, PR | 0 | 2,301 |

Additional Metrics: Seasonal Design Temperatures

## Seasonal Design Temperatures

| | Winter | Summer |
|---|---|---|
| Seattle, WA | 27 °F | 82/66 °F |
| Dawson Creek, BC | -33 °F | 79/63 °F |
| San Juan, PR | 68 °F | 88/80 °F |

- **Winter Design Temperature**
  (99.0% or 97.5% condition)
- **Summer Design + Mean Coincident Wet Bulb Temp**
  (1% or 2.5% condition)

Additional Metrics: Outside Design Conditions - Summer & Winter

## Outside Design Conditions
**Seattle**

Climate: Table B.1 MEEB 10th edition:

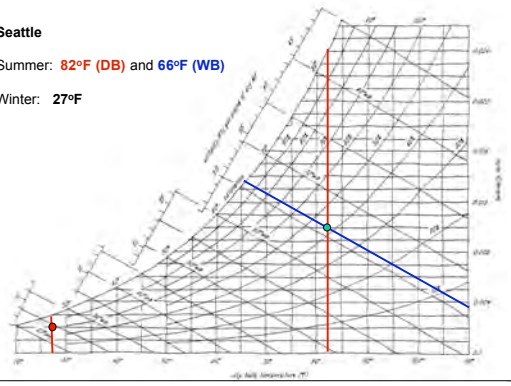
| | |
|---|---|
| HDD65: | 4684 (heating degree days) |
| Winter: | 27°F |
| Summer: | 82°F (DB) and 66°F (WB) |
| Mean daily range: | 19°F |

Additional Metrics: Outside Design Conditions - Summer & Winter

**Seattle**

Summer: **82°F (DB)** and **66°F (WB)**

Winter: **27°F**



## Thermal Comfort

## Thermal Comfort

A Condition of Body

- **A state of equilibrium between internally generated energy and energy loss to the environment.**
- **The lack of discomfort**

**THERMAL NEUTRALITY**

A Condition of Mind

**"... that condition of mind which expresses satisfaction with the thermal environment" ASHRAE**

**THERMAL DELIGHT**

Experiential Goals/Intentions

Thermal Neutrality or Thermal Delight?

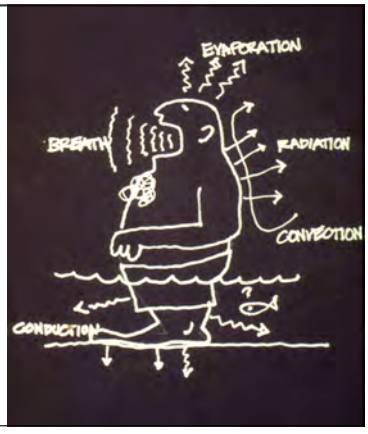
## Human Body

- ***The human body is always producing heat.***
- ***At best our "motors" are 20% efficient in converting food into mechanical energy (movement)***
- ***80% or more of our energy is released as heat.***
- ***We must constantly discard energy not needed to keep us at a core body temperature of 98.6oF.***

What really determines thermal comfort is the rate at which we lose heat to the environment

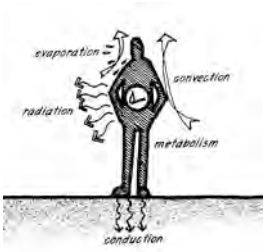
## Heat Transfer Mechanisms:

- CONDUCTION
- CONVECTION
- RADIATION
- EVAPORATION (Phase Change)



## Thermal Balance & Thermal Comfort

$Q_{in} = Q_{out}$

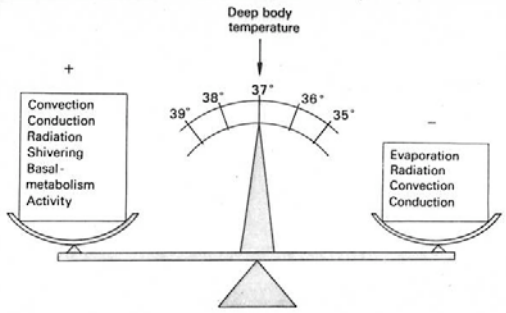



$Q_{in}$ = Metabolism (food)
\+ Environmental

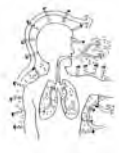
| $Q_{out}$ = | | |
|---|---|---|
| | Sweat | evaporation |
| | Wind/Breeze | convection |
| | Contact | conduction |
| | Breathing | convection |
| | Warmth | radiation |

## Heat Gains & Losses

37 °C = 98.6 °F



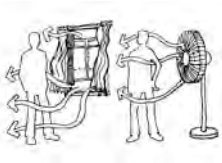

*Physiological Control Mechanisms*
**Involuntary**



respiration

shivering

*Behavioral Control Mechanisms*
**Voluntary**



ventilation & air movement

## Major Variables Influencing Thermal Comfort

**Environmental**

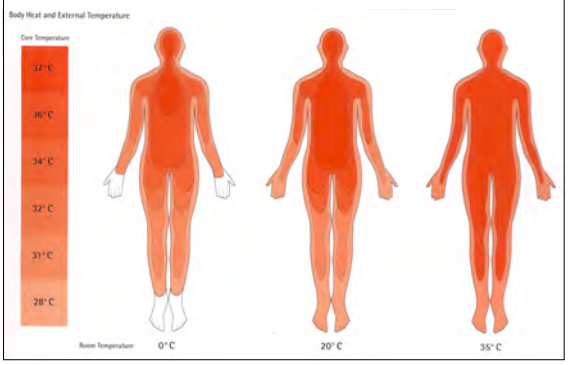
1. **Air temperature**
2. Humidity
3. Air velocity
4. Mean radiant temperature

**Personal**

1. **Activity**
2. **Clothing**

## Air Temperature


## Air Temperature

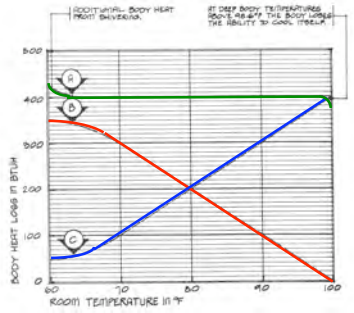


## Effect of Air Temperature & Heat Loss

A =
Total Body Heat Loss

B =
"Dry" Heat Loss
(convection +radiation)

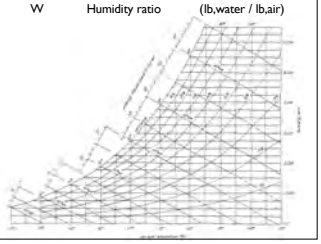
C =
"Wet" Heat Loss
(evaporation)




## Humidity

Measures of Humidity

| | | |
|---|---|---|
| RH | Relative Humidity | (%) |
| DP | Dew Point temperature | (°F) |
| WB | Wet-Bulb temperature | (°F) |
| W | Humidity ratio | (lb,water / lb,air) |



## Air Velocity

## Mean Radiant Temperature

## Mean Radiant Temperature

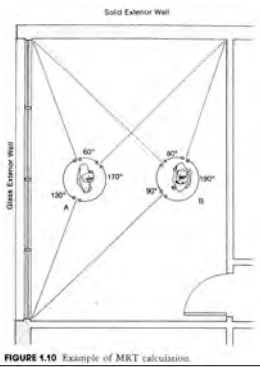



FIGURE 1.10 Example of MRT calculation.

## Major Variables Influencing Thermal Comfort

**Environmental**

1. **Air temperature**
2. Humidity
3. Air velocity
4. Mean radiant temperature

**Personal**

1. **Activity**
2. **Clothing**

## clothing level

activity level

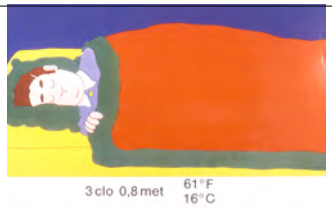
- 1.0 clo = heavy slacks, light sweater, shirt, and jacket for women and men
- 0.5-0.7 clo = light office clothing

## activity level

clothing level

METS

| Activity | Met units | Kcal/hr | Watts | Btu/h |
|---|---|---|---|---|
| Sleeping | 0.7 | 64 | 74 | 253 |
| Drafting | 1.2 | 109 | 127 | 433 |
| Sawing | 4.4 | 400 | 466 | 1588 |



3 clo 0,8 met 61°F 16°C

0,1 clo 0,8 met 86°F 30°C

0,3 clo 4 met 61°F 16°C

0,8 clo 1,6 met 70°F 21°C

0,6 clo 4 met 54°F 12°C

0,8 clo 6 met 37°F 3°C

1.0 – 1.3 clo

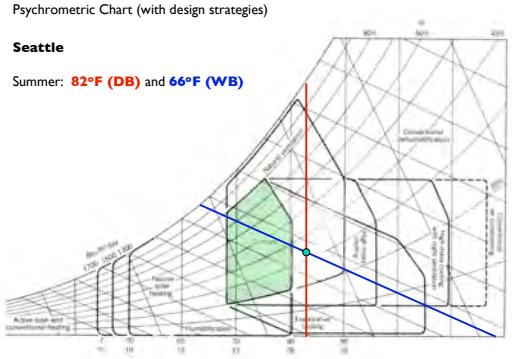
0.7 – 0.8 clo

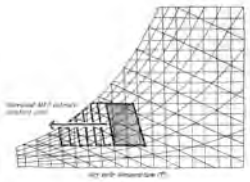
0.1 – 0.4 clo

Psychrometric Chart (with design strategies)

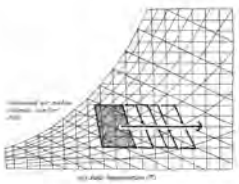
**Seattle**

Summer: **82°F (DB)** and **66°F (WB)**





Effect of Radiation
on the Comfort Zone



Effect of Wind
(convection)
on the Comfort Zone

Boundaries of the comfort zone