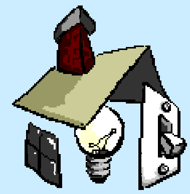
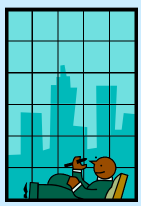
# Building Envelope

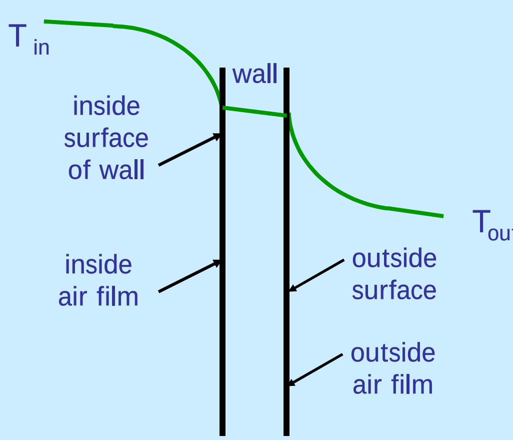


## On-Line Fast Track CEM



# Heat Loss and Gain

- Heat is lost and gained through walls and ceilings.
- Consider a three-quarter inch plywood wall.



## Basic Heat Flow Equations

- Conduction heat losses through walls and ceilings

$$\mathbf{q} = \frac{\mathbf{A} \times \Delta\mathbf{T}}{\Sigma\mathbf{R}} \quad \left[\frac{\mathbf{Btu}}{\mathbf{h}}\right]$$

- Heat loss is proportional to the area A and the temperature difference ΔT between inside and outside.
- ΣR is the sum of the resistances of everything that resists heat flow.

$$\Sigma R = R_{\text{inside air film}} + R_{\text{plywood}} + R_{\text{outside air film}} \quad \left[\frac{h \cdot ft^2 \cdot {}^\circ F}{Btu}\right]$$



## Basic Heat Flow Equations

- The equation often is written

$$q = U \times A \times \Delta T \quad \left[\frac{Btu}{h}\right]$$

- where U is the overall thermal conductance.

$$U = \frac{1}{\Sigma R} = \frac{1}{R_{\text{Total}}} \quad \left[\frac{Btu}{h \cdot ft^2 \cdot {}^\circ F}\right]$$

## Surface Air Film Resistance (Buildings)*

| Wall or roof position | Direction of heat flow | $R_s$ (hr·ft$^2$·°F/Btu) |
|---|---|---|
| Still air | | |
| horizontal | up | 0.61 |
| horizontal | down | 0.92 |
| vertical | horizontal | 0.68 |
| Moving air | | |
| 15 mph (winter) | All | 0.17 |
| 7.5 mph (summer) | All | 0.25 |

*Data from 2001 ASHRAE Fundamentals Handbook, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia. p. 25.2.



## Wall and Insulation Resistances

- R can be obtained from the conductance C, given for a specified thickness of material,

$$R = \frac{1}{C}$$

- If the conductivity k is given, R can be calculated knowing k and the material thickness t.

$$R = \frac{t}{k}$$

## Conductances and Conductivities

**Table 11-2.**

| Material | Description | Conductivity $K^a$ | Conductance $C^{b,c}$ |
|---|---|---|---|
| Building boards | Asbestos-cement board | 4.0 | |
| | Gypsum or plaster board...1/2 in. | | 2.25 |
| | Plywood | 0.80 | |
| | Plywood...3/4 in. | | 1.07 |
| | Sheathing (impregnated or coated) | 0.38 | |
| | Sheathing (impregnated or coated) 25/32 in. | | 0.49 |
| | Wood fiber—hardboard type | 1.40 | |
| Insulating materials | Blanket and Batt: | | |
| | Mineral wool fibers (rock, slag, or glass) | 0.27 | |
| | Wood fiber | 0.25 | |
| | Boards and slabs: | | |
| | Cellular glass | 0.39 | |
| | Corkboard | 0.27 | |
| | Glass fiber | 0.25 | |
| | Insulating roof deck...2 in. | | 0.18 |
| Masonry materials | Loose fill: | | |
| | Mineral wool (glass, slag, or rock) | 0.27 | |
| | Vermiculite (expanded) | 0.46 | |
| | Concrete: | | |
| | Cement mortar | 5.0 | |
| | Lightweight aggregates, expanded shale, clay, slate, slags; cinder; pumice; perlite; vermiculite | 1.7 | |
| | Sand and gravel or stone aggregate | 12.0 | |
| | Stucco | 5.0 | |
| | Brick, tile, block, and stone: | | |
| | Brick, common | 5.0 | |
| | Brick, face | 9.0 | |
| | Tile, hollow clay, 1 cell deep, 4 in. | | 0.90 |
| | Tile, hollow clay, 2 cells, 6 in. | | 0.54 |

**Table 11-2. (*Continued*)**

| Material | Description | Conductivity $K^a$ | Conductance $C^{b,c}$ |
|---|---|---|---|
| Masonry materials (cont'd) | Block, concrete, 3 oval core: | | |
| | Sand & gravel aggregate ............4 in. | | 1.40 |
| | Sand & gravel aggregate ............6 in. | | 0.90 |
| | Cinder aggregate .........................4 in. | | 0.90 |
| | Cinder aggregate .........................6 in. | | 0.58 |
| | Stone, lime or sand | 12.50 | |
| Plastering materials | Cement plaster, sand aggregate | 5.0 | |
| | Gypsum plaster: | | |
| | Lightweight aggregate...1/2 in. | | 3.12 |
| | Lt. wt. agg. on metal lath...3/4 in. | | 2.13 |
| | Perlite aggregate | 1.5 | |
| | Sand aggregate | 5.6 | |
| | Sand aggregate on metal lath 3/4 in. | | 7.70 |
| | Vermiculite aggregate | 1.7 | |
| Roofing | Asphalt roll roofing | | 6.50 |
| | Built-up roofing...3/8 in. | | 3.00 |
| Siding materials | Asbestos-cement, 1/4 in. lapped | | 4.76 |
| | Asphalt insulating (1/2 in. board) | | 0.69 |
| | Wood, bevel, 1/2 × 6, lapped | | 1.23 |
| Woods | Maple, oak, and similar hardwoods | 1.10 | |
| | Fir, pine, and similar softwoods | 0.80 | |
| | Fir, pine & sim. softwoods 25/32 in. | | 1.02 |

[c]Same as *U* value.
[a]Conductivity given in Btu•in./h•ft$^2$•°F
[b]Conductance given in Btu/h•ft$^2$•°F
Source: Extracted with permission from *ASHRAE Guide and Data Book*, 1965. Reprinted with permission from the Trane Co., La Crosse, WI.

B. L. Capehart *et. al.,* Guide to Energy Management, 4th ed., Fairmont Press, 2003, pp. 386-387.



## Basic Heat Flow Problem

- What is the rate of heat loss through a three-quarter inch plywood wall if the inside temperature is 60°F and the outside temperature is 30°F? The area of the wall is 100 square feet. Include surface films.

# Basic Heat Flow Equations

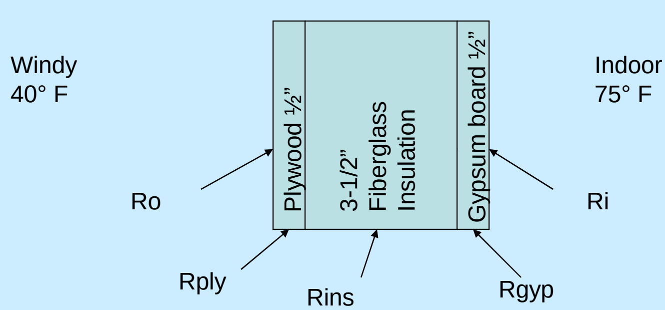
- How could we reduce the heat flow?
- Often the answer is insulation—a simple and inexpensive way of adding more resistance to the denominator of the equation

$$q = \frac{A \times \Delta T}{\Sigma R} \quad \left[\frac{Btu}{h}\right]$$



# Composite Wall Example

A 160 ft$^2$ wall is exposed to an inside temperature of 75 °F and an outside winter temperature of 40 °F in windy weather. The wall consists of ½" plywood, 3 ½" of fiberglass insulation, and ½" gypsum board. How much heat is lost through the wall? Include surface films.



# Basic Heat Flow Equations

- Temperature varies with time of day and season, so we often resort to this heat conduction equation

$$Q = U \times A \times DD \times 24 \quad \left[\frac{\text{Btu}}{\text{yr}}\right]$$

- where DD can be HDD or CDD. Annual units are $\frac{{}^\circ\mathbf{F} \cdot \mathbf{d}}{\mathbf{yr}}$
- UxA is also known as the conduction part of the overall Building Load Coefficient BLC. Other parts include infiltration, ventilation, and slab-on-grade factor.



# Air and Water Heat Flow Problems

$$q = \dot{m}\Delta h \quad \left[\frac{\text{Btu}}{\text{h}}\right] \quad \text{General}$$

$$= \dot{m}C_p\Delta T \quad \left[\frac{\text{Btu}}{\text{h}}\right] \quad \text{Sensible heat only}$$

$\dot{m}$ = Mass Flow Rate (lb/h)

$\Delta h$ = Enthalpy Difference (Btu/lb)

$C_p$ = Heat Capacity (Btu/lb·°F)

$\Delta T$ = Temperature Difference (°F)

# Air and Water Heat Flow Problems

Air: ***Sensible Heat Only***

$$q = \left[ CFM \times \frac{0.075\,lb}{ft^3} \times \frac{60\,min}{h} \right] \times \left[ \frac{0.24\,Btu}{lb \cdot °F} \right] \times \Delta T$$

$$q = CFM \times 1.08 \times \Delta T \quad \left[ \frac{Btu}{h} \right]$$

Sensible heat only



# Air and Water Heat Flow Problems

Air: ***General***

$$q = \left[ CFM \times \frac{0.075\,lb}{ft^3} \times \frac{60\,min}{h} \right] \times \Delta h$$

$$q = CFM \times 4.5 \times \Delta h \quad \left[ \frac{Btu}{h} \right]$$

# Water: Sensible Heat only

$$q = \left( GPM \times \frac{8.34\ lb}{gal} \times \frac{60\ min}{h} \right) \times \left( \frac{1\ Btu}{lb \cdot {}^\circ F} \right) \times \Delta T$$

$$q = GPM \times 500 \times \Delta T \qquad \left[ \frac{Btu}{h} \right]$$

**Sensible heat only**



# Fan Laws - or Affinity Laws - Review

- **Flow and Speed**

$$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$$

- **Pressure (Head) and Speed**

$$\frac{P_2}{P_1} = \left( \frac{RPM_2}{RPM_1} \right)^2 = \left( \frac{CFM_2}{CFM_1} \right)^2$$

- **Power and Speed**

$$\frac{HP_2}{HP_1} = \left( \frac{CFM_2}{CFM_1} \right)^3$$

# The Psychrometric Chart

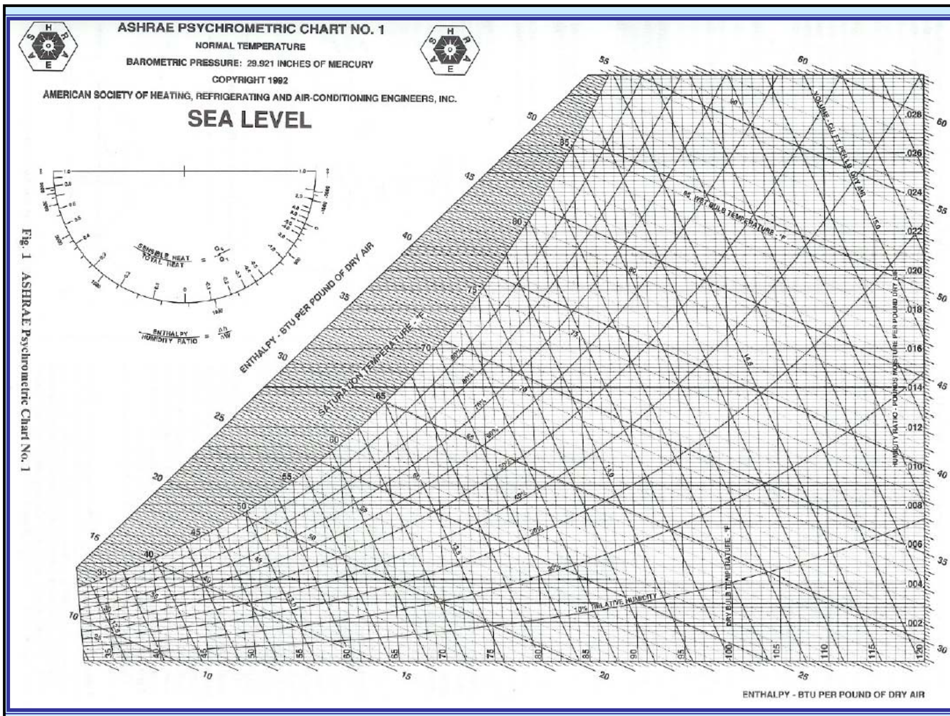
The Psychrometric Chart graphically represents the steam tables for moisture in air at conditions we encounter in HVAC work.

The Psych Chart allows complex problems to be worked out easily, and provides a feel for common HVAC processes that we are interested in.

The standard ASHRAE Psych Chart has a horizontal axis for dry bulb temperature, and a vertical axis for humidity ratio in pounds of moisture per pound of dry air.

Other parameters on the chart are: relative humidity, wet bulb temperature, enthalpy, specific volume, and saturation temperature.





# CEM Review Problems

An absorption chiller with a COP of 0.8 is powered by hot water that enters at 200°F and exits at 180°F at a rate of 25 gpm. The chilled water operates on a 10°F temperature difference. Calculate the chilled water flow rate. Solution of this problem does not require a knowledge of how absorption chillers work internally.

(A) 10 gpm
(B) 20 gpm
(C) 40 gpm
(D) 45 gpm
(E) 30 gpm



# CEM Review Problems

The conduction part of the Building Load Coefficient (U*A) for a building is 5000 Btu/h per degree F. Estimate the seasonal energy consumption for heating if the heating season has 3,500 degree days. The heating unit efficiency is 80%.

(A) 625 MCF/yr
(B) 350 MCF/yr
(C) 420 MCF/yr
(D) 656 MCF/yr
(E) 525 MCF/yr

# Example

A wall has an area of 100 $ft^2$ and has a thermal conductance of 0.25 $Btu/ft^2 \cdot h \cdot °F$. If there are 3000 degree-days in the annual heating season, what is the total amount of heat that must be supplied by the heating system?



# Duct Loss Example

10,000 cfm of air leaves an air handler at 50 °F. It is delivered to a room at 65 °F. There was no air volume loss due to duct air leaks. No moisture was added, or taken away from the air in the duct. How many Btu/h heat gain occurred because of heat transfer by conduction?

(A) 162,000 Btu/h
(B) 75,000 Btu/h
(C)126,000 Btu/h
(D) 256,000 Btu/h
(E) 10,000 Btu/h

## Chilled Water Flow Example

A chiller supplies cold water with a $\Delta T$ of 10 °F.

How many GPM of this water is needed to provide one ton of air conditioning?



## Practice Example

ACE Industries presently has a 5 hp ventilating fan that draws warm air from a production area. The motor recently failed, and they have determined the amount of ventilation can be reduced by one-third.

What size motor is needed now?

Answer: 1.48 HP

## Psychrometric Heating Example

- For air, $q = CFM \times 4.5 \times \Delta h \quad \left[\frac{Btu}{h}\right]$
- Air at 69°F dry bulb and 50% relative humidity flows at 6750 cubic feet per minute and is heated to 90°F dry bulb and humidified to 40% RH. How many Btu/h is required in this process?

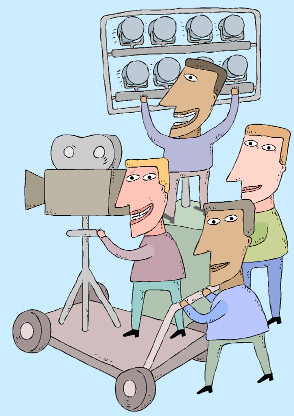
(A) 50,000 Btu/hr
(B) 100,000 Btu/hr
(C) 150,000 Btu/hr
(D) 300,000 Btu/hr



## Psychrometric Cooling Example

- How many tons of air conditioning is required to cool 1000 CFM of air at 90 °F and 60 % relative humidity (RH) to 60 °F and 100 % RH?

# Lighting Basics and Lighting System Improvements





## Principles of Efficient Lighting Design

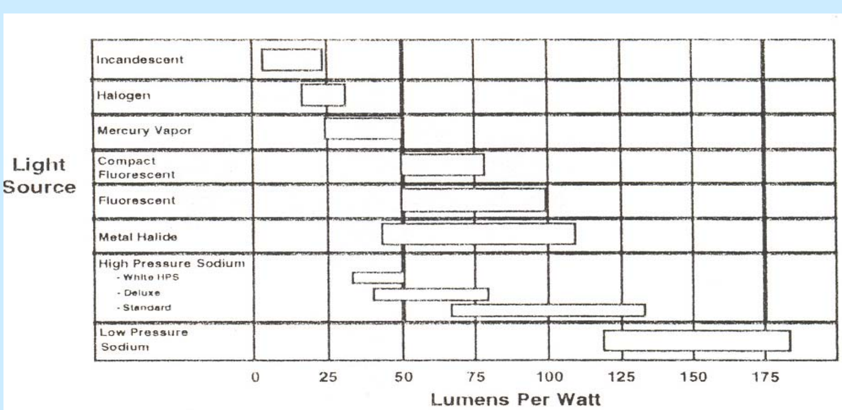
- Meet target light levels
- Efficiently produce light
- Efficiently deliver light
  – Balance efficiency with aesthetics, lighting quality, visual comfort
- Automatically control lighting operation

# Types of Light Sources

- Incandescent
- Tungsten Halogen
- Mercury Vapor
- Fluorescent
- Metal Halide
- High Pressure Sodium
- Low Pressure Sodium
- Induction
- Laser
- LED



# Light Source Efficacy




Note: Source efficacy values include ballast losses

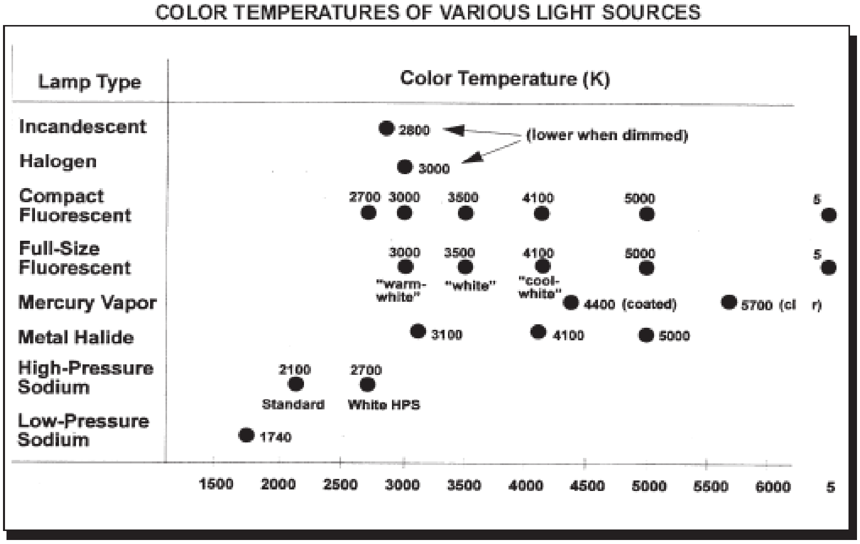
# Color Rendering Index (CRI)

EXHIBIT 3
TYPICAL CRI VALUES FOR SELECTED LIGHT SOURCES

| Source | Typical CRI Value |
|---|---|
| Incandescent/Halogen | 100 |
| Fluorescent | |
| Cool White T12 | 62 |
| Warm White T12 | 53 |
| High Lumen T12 | 73-85 |
| T8 | 75-85 |
| T10 | 80-85 |
| Compact | 80-85 |
| Mercury Vapor (clear/coated) | 15/50 |
| Metal Halide (clear/coated) | 65/70 |
| High-Pressure Sodium | |
| Standard | 22 |
| Deluxe | 65 |
| White HPS | 85 |
| Low-Pressure Sodium | 0 |



EXHIBIT 5
COLOR TEMPERATURES OF VARIOUS LIGHT SOURCES



# Amount of Light Required For Specific Applications

- We often use more light than is needed for many applications and tasks.
  - Light levels are measured in *footcandles (or lux, in SI units)* using an illuminance meter.

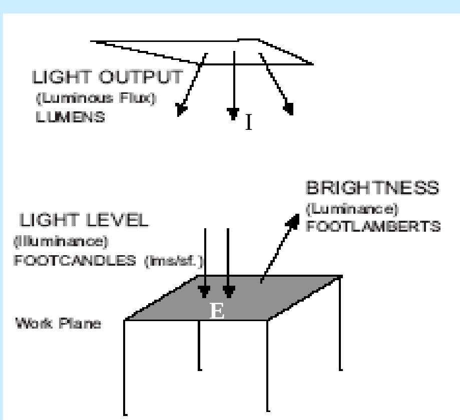
    $FC = lumens / ft^2$

    $Lux = lumens / m^2$

  - Consensus standards for light levels are set by the Illuminating Engineering Society of North America (IESNA.org).



# Quantity of Illumination




**Inverse Square Law**

$$E = \frac{I}{d^2}$$

where d = distance from light source to surface of interest

## RECOMMENDED LIGHT LEVELS

Source: IESNA

| TYPE OF ACTIVITY | RANGE OF ILLUMINANCE |
|---|---|
| Public spaces with dark surroundings | 2-3-5 fc |
| Simple orientation for short temporary visits (typical hallway) | 5-7½-10 fc |
| Working spaces where visual tasks are only occasionally performed | 10-15-20 fc |
| Ambient lighting for computer use | 20-25-30 fc |
| Performance of visual tasks | |
| High contrast or large size (typical office) | 20-30-50 fc |
| Medium contrast or small size | 50-75-100 fc |
| Low contrast or very small size | 100-150-200 fc |
| Low contrast and very small size over a prolonged period | 200-300-500 fc |
| Performance of very prolonged and exacting visual tasks | 500-750-1000 fc |
| Performance of very special visual tasks of extremely low contrast and small size | 1000-1500-2000 fc |



## Some typical light levels needed are:

| | |
|---|---|
| Parking lot | 2 Footcandles |
| Hallways | 10 Footcandles |
| Factory floor | 30 Footcandles |
| Offices | 50 Footcandles |
| Inspection | 100 Footcandles |
| Operating room | 1000 Footcandles |

## Average Rated Life

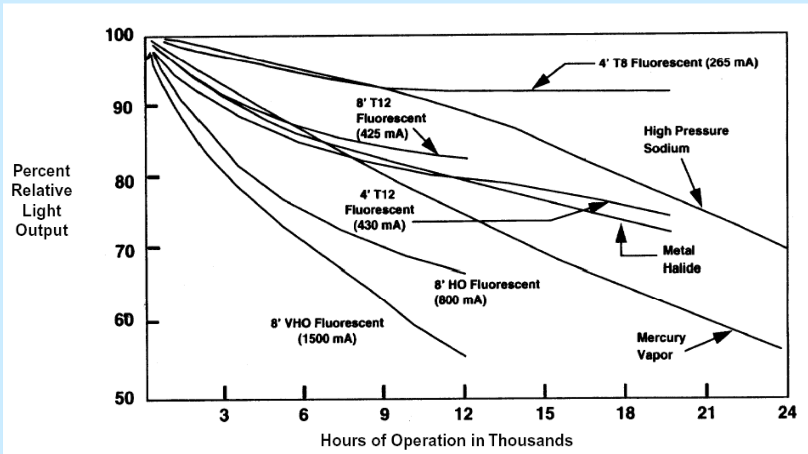
- Average rated life of a lamp is median value of life expectancy of a group of lamps
  - Time at which 50% have failed, 50% are surviving
  - Fluorescent lamps rated at 3 hours on, 20 minutes off per operating cycle
  - HID lamps rated at 10 hours on, one hour off per operating cycle
- Increased frequency of switching will decrease lamp life in hours, but typically increase useful calendar life
  - Energy savings more significant than lamp costs



## Lighting Maintenance Principles

- Light output of all lighting systems decreases over time
- Lighting systems are over-designed to compensate for future light loss
- Improving maintenance practices can reduce light loss (depreciation) and can either:
  - allow reductions in energy consumption (redesign), or
  - improve light levels
- Group maintenance practices save money

# Lamp Lumen Depreciation (LLD)




Source: US DOE



# Lighting System Design Methods

1. **Lumen Method**
   - Assumes an equal footcandle level throughout the area.
   - This method has been used frequently since it is simple.
2. **Point by Point Method**
   - The current method of design based on the Fundamental Law of Illumination.
   - Requires a computer program and extensive computation.

# Lumen Method Formula

$$N = \frac{F1 \times A}{Lu \times LLF \times Cu}$$

where

N = the number of lamps required
F1 = the required footcandle level at the task
A = area of the room in square feet
Lu = the lumen output per lamp
Cu = the coefficient of utilization
LLF = the combined light loss factor



# Example of Lumen Method

Find the number of lamps required to provide a uniform 50 footcandles on the working surface in a 40 x 30 room. Assume two 3000 lumen lamps each per fixture, and assume that LLF is 0.65 and CU is 70%.

$$N = \frac{50 \times 1200}{3000 \times 0.65 \times 0.7} = 44$$

The number of two-lamp fixtures needed is 22.

# The Coefficient of Utilization (CU)

The coefficient of utilization is a measure of how well the light coming out of the lamps and the fixture contributes to the useful light level at the work surface.

It may be given, or you may need to find it:

– Use Room Cavity Ratio (RCR) to incorporate room geometry
– Use Photometric Chart for specific lamp and fixture



# Room Cavity Ratio (RCR)

RCR = 2.5 x h x (Room Perimeter)/(Room Area)

Where

L = room length

W = room width

h = height from lamp to top of working surface

# Example

Find the RCR for a 30 by 40 rectangular room with lamps mounted on the ceiling at a height of 9.5 feet, and the work surface is a standard 30 inch desk.

$$h = 9.5 – 2.5$$
$$= 7 \text{ feet}$$

$$RCR = 2.5 \times h \times (2L+2W)/(L \times W)$$
$$= 2.5 \times 7 \times (60 + 80)/(30 \times 40)$$
$$= 35 \times 70/1200$$
$$= 2.04$$



# Photometric Chart

**Report LS1 1101**
**Lamp: 400 Watt Clear**
**Lumens: 50,000**
**Mounting Surface/Pendant**

**COEFFICIENTS OF UTILIZATION**
**Zonal Cavity Method**
**Effective Floor Cavity Reflectance 0.20**

| RC | 80 | | | 70 | | | 50 | | 30 | |
|---|---|---|---|---|---|---|---|---|---|---|
| RW | 70 | 50 | 30 | 70 | 50 | 30 | 50 | 30 | 50 | 30 |
| RCR 1 | 94 | 91 | 89 | 91 | 88 | 86 | 83 | 81 | 78 | 77 |
| 2 | 88 | 84 | 80 | 86 | 81 | 78 | 77 | 74 | 73 | 71 |
| 3 | 83 | 77 | 72 | 80 | 75 | 70 | 71 | 67 | 67 | 65 |
| 4 | 78 | 71 | 65 | 75 | 69 | 64 | 66 | 61 | 63 | 59 |
| 5 | 73 | 65 | 59 | 70 | 63 | 58 | 60 | 56 | 58 | 54 |
| 6 | 68 | 58 | 52 | 66 | 58 | 52 | 55 | 51 | 53 | 49 |
| 7 | 63 | 54 | 48 | 61 | 53 | 47 | 51 | 46 | 49 | 44 |
| 8 | 59 | 49 | 43 | 57 | 48 | 43 | 46 | 41 | 45 | 40 |
| 9 | 55 | 45 | 39 | 53 | 44 | 38 | 42 | 37 | 41 | 36 |
| 10 | 51 | 41 | 35 | 49 | 40 | 35 | 39 | 34 | 37 | 33 |

# Example

Find the Coefficient of Utilization for a 30 by 40 rectangular room with a ceiling height of 9.5 feet, a ceiling reflectance of 70% and a wall reflectance of 50% using the photometric chart on the previous page.

The RCR from before was 2.04. Using RC = 70% and RW = 50%, the CU is found as CU = 0.81, or 81%



# Fundamental Law of Illumination or Inverse Square Law

$$E = \frac{I}{d^2}$$

where

E = Illuminance in footcandles

I = Luminous intensity in lumens

d = Distance from light source to surface area of interest

One footcandle is equal to one lumen per square foot (One lux is equal to one lumen per square meter)

# Example

In a high bay facility, the lights are mounted on the ceiling which is 40 feet above the floor. The lighting level on the floor is 50 footcandles. No use is made of the space between 20 feet and 40 feet above the floor.

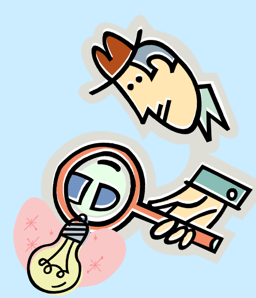
In a theoretical sense – that is, using the fundamental law of illuminance – what would be the light level in footcandles directly below a lamp if the lights were dropped to 20 feet?

$FC = 50(40^2/20^2) = 200$ footcandles



# What to Look for in Lighting Audit

- Lighting Equipment Inventory
- Lighting Loads
- Room Dimensions
- Illumination Levels
- Hours of Use
- Lighting Circuit Voltage



# Potential Lighting ECMs

- Fluorescent Upgrades
- Delamping
- Incandescent Upgrades
- HID Upgrades
- Controls Upgrades
- Daylight compensation



# What Does a Ballast Do?

- A ballast does three things:
  - Conditions the lamp to start
  - Applies a high voltage spike to start the gas discharge process
  - Applies a current limiter to reduce the lamp current to a safe operating level
- Ballast factor
  - Normal light output (0.85-0.95)
  - Can specify reduced or increased light output in electronic ballasts with proportional reduction or increase in power

# New Lighting Technology

- **Induction lamps**
  - Long life -- 100,000 hours for lamp & ballast
  - Phillips QL lamps in 55W, 85W and 165W
  - New application with reflector to replace metal halides as sign lights for road and commercial signs. Last four times as long



- OSRAM/Sylvania is the other maker of long life induction lamps
- Icetron in 70W, 100W and 150W sizes
- Also 100,000 hours
- Properties about same as QL lamp
  - Efficacy around 80 L/W (150 W ICE)
  - CRI 80
  - Instant start, and re-start
  - Operate in hot and cold environments

## LED Lighting

- 80% of all new exit lights are LED lights
- But, there are some other interesting applications
  - **Traffic Signals**
    - Green 12” ball — 140 W to 13 W LED
    - Red 12” ball — 140 W to 11 W LED
    - Life — 1 year to 7 years for LED
    - Cost — $3 to $75 for LED
  - **Commercial Advertising Signs (Neon)**
    - Neon 15 mm tube — 3 W/ft
    - LED 15 mm replacement — 1.03 W/ft



## T5HO and High Bays

**High Bay & Fluorescent T5/HO (it’s not just for HID anymore!)**

| Lamp | Lamp and Ballast * Maintained Light | Wattage |
|---|---|---|
| 4 - T5/HO Lamps | 19,000 Lumens | 242 watts |
| 1 - MVR250/U | 13,500 | 293 |
| 1 - MVR250/Pulse | 17,000 | 288 |
| 6 - T5/HO Lamps | 28,500 Lumens | 363 watts |
| 1 - MVR400/U | 23,500 | 458 |
| 1 - MVR400/Pulse | 33,000 | 456 |

* ( Impact of Fixture Design on Performance NOT included )

***AND: Instant on, dimmable, choice of colors, no color shift…***

## Compare Lighting Power Density to ASHRAE/IES 90.1 Values

- **Example Whole Building Lighting Power Densities (W/ft2)**

| | 1989 | 1999 | 2003 |
|---|---|---|---|
| • Offices | 1.63 | 1.30 | 1.0 |
| • Education | 1.79 | 1.50 | 1.2 |
| • Retail | 2.36 | 1.90 | 1.5 |
| • Warehouse | 0.53 | 1.20 | 0.8 |



# Typical Lighting Operation

| Building Type | Annual Hours of Operation |
|---|---|
| Assembly | 2760 |
| Avg. Non-Residential | 3500 |
| Education | 2605 |
| Food Sales | 5200 |
| Food Service | 4580 |
| Health Care | 7630 |
| Lodging | 8025 |
| Mercantile | 3325 |
| Office | 2730 |
| Warehouse | 3295 |

## Lighting Control Technologies

- On/off snap switch
- Timers and control systems
- Solid-state dimmers
- Dimming electronic ballasts
- Occupancy sensors
- Daylighting level sensors



## Energy Savings Potential With Occupancy Sensors

| Application | Energy Savings |
|---|---|
| Offices (Private) | 25-50% |
| Offices (Open Spaces) | 20-25% |
| Rest Rooms | 30-75% |
| Corridors | 30-40% |
| Storage Areas | 45-65% |
| Meeting Rooms | 45-65% |
| Conference Rooms | 45-65% |
| Warehouses | 50-75% |

# Lighting Appendix

AEE:CEM

# CEM Exam Review Questions

1. The efficacy of a light source refers to the color rendering index of the lamp.
   A) True B) False

2. Increasing the coefficient of utilization of fixtures in a room will in many instances increase the number of lamps required.
   A) True B) False

3. Which HID lamp has the highest efficacy – for the same wattage?
   A) Mercury vapor
   B) Metal halide
   C) High pressure sodium

4. One disadvantage to metal halide lamps is a pronounced tendency to shift colors as the lamp ages.

A) True B) False



5. A 244,000 square foot high bay facility is presently lit with 800 twin 400 watt mercury vapor fixtures (455 watts per lamp including ballast). What are the annual savings of replacing the existing lighting system with 800 single 400-watt high-pressure sodium fixtures (465 watts per lamp

Including ballast)? Assume 8000 hours operation per year, an energy cost of $0.05 per kWh, and a demand cost of $6.00 per kW-month.

Solution

## Solution

$\Delta$kW = (800 fixtures)(.455 kW/lamp)(2 lamps) –
(800 fixtures)(.465 kW/fixture) = 356 kW

Demand $ savings = (356 kW)($6/kW-mo)(12 mo/yr) = $25,632/yr

Energy $ savings = (356 kW)(8000 hrs/yr) )($0.05/kWh)
= $142,400/yr

Total $ savings = ($25,632 + $142,400)/yr = $168,032/yr

Cost = (800 fixtures)($400/fixture) = $320,000 ??



## 7. The Light Switch Problem (Just for Fun)

You must determine which switch on a three switch panel on the first floor of a building controls a light on the fifth floor of the building.

- The other two switches are not connected to anything and there is no way to see any light from the fifth floor without going up stairs.
- You have no tools and you cannot take the switch cover off.
- You can only make one trip up the stairs to the light. How can you determine which switch operates the light?

# Solution

Turn on the middle switch and the right-hand switch, wait 10 minutes.

Turn the middle one off and run up the stairs.
- If the light bulb is off and cold it is the left-hand switch.
- If the bulb is off and hot it is middle switch.
- If the bulb is on it is the right-hand switch.



## EXHIBIT 4
## LAMP CHARACTERISTICS

| | Standard Incandescent | Tungsten-Halogen | Fluorescent | Compact Fluorescent | Mercury Vapor | Metal Halide | High-Pressure Sodium | Low-Pressure Sodium |
|---|---|---|---|---|---|---|---|---|
| Wattage | 3-1,500 | 10-1,500 | 4-215 | 4-55 | 40-1,250 | 32-2,000 | 35-1,000 | 18-180 |
| Average System Efficacy (lm/W) | 4-24 | 8-33 | 49-89 | 24-68 | 19-43 | 38-86 | 22-115 | 50-150 |
| Average Rated Life (hrs) | 750-2,000 | 2,000-4,000 | 7,500-24,000 | 7,000-20,000 | 24,000+ | 6,000-20,000 | 16,000-24,000 | 12,000-18,000 |
| CRI | 100 | 100 | 49-92 | 82-86 | 15-50 | 65-92 | 21-85 | 0 |
| Life Cycle Cost | high | high | low | moderate | moderate | moderate | low | low |
| Fixture Size | compact | compact | extended | compact | compact | compact | compact | extended |
| Start to Full Brightness | immediate | immediate | 0-5 seconds | 0-1 min | 3-9 min | 3-5 min | 3-4 min | 7-9 min |
| Restrike Time | immediate | immediate | immediate | immediate | 10-20 min | 4-20 min | 1 min | immediate |
| Lumen Maintenance | good/excellent | excellent | fair/excellent | good/excellent | poor/fair | good | good/excellent | excellent |

Lighting Fundamentals • Lighting Upgrade Manual • EPA's Green Lights® Program • February 1997

# Lighting Quality Measures

- **Visual comfort probability (VCP)** indicates the percent of people who are comfortable with the glare (brightness) from a fixture
- **Spacing criteria (SC)** refers to the maximum recommended distance between fixtures to ensure uniformity
- **Color rendering index (CRI)** indicates the color appearance of an object under a source as compared to a reference source



# Compact Fluorescent Example

***COMPACT FLUORESCENT LAMPS***

For retrofit applications in task lights, wall sconces, downlights, wallwashers, and outdoor fixtures, a wide variety of lamp shapes and types are available. These include globes, capsules, floods, and twin/quad-tube units. The most common retrofit applications are in open fixtures with mounting heights less than 12 feet. In some applications, users may prefer to hardwire the ballast in the fixture to prevent replacement with incandescent lamps. Lamps with excellent color rendering capabilities (80-85 CRI) are recommended for most indoor applications.

*Wattages:* 5-26W

*Replaces:* 25-100W incandescents

*Energy Savings:* 60-75%

*Efficacy:* 26-58 lm/W

*Lamp Cost:* $3-6

*Ballast Cost:* $9-24

*Rated Lamp Life:* 10,000 hrs

*Color Quality:* 60-85 CRI

*Dimming:* Not in retrofit applications

*Qualifications:* These lamps can have starting limitations in freezing temperatures, and operation in enclosed fixtures may shorten lamp and ballast life and reduce light output. Because compact fluorescents are not point sources; other technologies may be more suitable in applications—such as retail display lighting—where good beam control is required. Some conventional fixture types may not be large enough to accept the larger size of the fluorescent lamp/ballast package. Check manufacturer data to determine impacts of ballast use on power factor and power quality.

**Example: Compact Fluorescent Lamps**

**Old System:** Incandescent hallway recessed downlighting in 12' ceiling; 100 fixtures @ 75 watts (@ $3.50 ); operating hours: 15 hrs/day, 6 days/week (4,680 hrs/yr)

**New System:** Screw-in fluorescent lamps (82 CRI) with integrated magnetic ballasts; downlighting reflectors; 100 fixtures @ 22 watts (including ballast operation)

**Results:** 71% energy savings; virtually unchanged light level and appearance; 10 times longer lamp life

**Savings:** Demand savings: 5.3 kW; energy savings: 24,800 kWh/yr; dollar savings @ $4/kW/mo and $0.08/kWh: $2,238/yr; relamping savings: materials $796/yr; labor $2,106/yr

Net Savings: $5,140/yr

**Cost:** Material: 100 lamp/ballast capsules @ $18; 100 reflectors @ $4; Labor: 100 installations @ $3

Total Project Cost: $2,500

**Payback:** $2,500/$5,140/yr = 0.49 yr

# Calculation for Compact Fluorescent Example

kW savings
100 fixtures (.075 kW/fixture - .022 kW/fixture) = 5.3 kW

kWh savings
(5.3 kW)(4680 hrs/yr) = 24,804 kWh

Demand $ savings
(5.3 kW)($4/kW-mo)(12 mo/yr) = $254.40/yr

Energy $ savings
(24,804 kWh/yr)($0.08/kWh) = $1,984.32/yr

Total dollar savings
($254.40 + $1,984.32)/yr = $2239/yr



# T-8 Example

## Example: T-8 Fluorescent System Retrofit

**Old System:** Office lighting consisting of 360 fluorescent 2'x4' fixtures; operating hours:14 hrs/day, 5 days/week (3640 hrs/yr); each fixture draws 188 watts with 4 standard cool white 40-watt fluorescent lamps (@ $2) and 2 standard magnetic ballasts

**New System:** Each fixture now draws 112 watts with 4 tri-phosphor F40T8 32-watt fluorescent lamps and 1 electronic T-8 instant-start mode ballast*

**Results:** 40% energy savings; 2% reduction in light level; improved color rendering; 50% fewer ballasts to replace; 25% less lamp life using instant-start mode ballasts

**Savings:** Demand savings: 27.4 kW; energy savings: 99,600 kWh/yr; dollar savings @ $4/kW/mo and $0.08/kWh: $9,280/yr; relamping savings: materials <$612/yr>; labor <$437/yr>

**Net Savings:** $8,231/yr

**Cost:** Material: 1440 F32T8 fluorescent lamps @ $3.25; 360 T-8 instant-start mode electronic ballasts @ $31; labor: 360 installations @ $20

Total Project Cost: $23,040

**Payback:** $23,040/$8,231/yr = 2.8 yrs (with 10% a/c factor, payback becomes 2.5 yrs)

*Building codes in some states do not allow all four lamps to be operated by a single ballast. In such cases, two adjacent fixtures can share two ballasts that are wired to leave the two-level switching intact. Assume an additional $15 wiring cost per fixture. The payback period increases to 3.5 years.

# Calculation for T-8 Example

Demand savings

(360 fixtures)(.188 - .112) kW/fixture = 27.4kW

Total $ savings

(27.4 kW)[($4/kW-mo)(12 mo/yr) + (3640 hrs/yr x $0.08/kWh)] = $9290/yr



# Occupancy Sensor Example

**Uncontrolled System:** Six conference rooms, each with four 4-lamp fluorescent fixtures (188 watts) operating 10 hrs/day, 5 days/week (2,600 hrs/yr); lamps @ $2

**Controlled System:** When conference rooms are unoccupied for longer than five minutes, the fixtures are now automatically turned off; they now operate about 7 hrs/day, 5 days/week (1,820 hrs/yr)

**Results:** 30% energy savings; no change in fixture appearance or light level

**Savings:** Energy savings: 3,519 kWh/yr; dollar savings @ $0.08/kWh: $282/yr; relamping savings: materials $7/yr; labor $19/yr

**Net Savings:** $308/yr

**Cost:** Material: 6 switch-mount occupancy sensors @ $70; labor: 6 installations @ $10

Total Project Cost: $480

**Payback:** $480/$308/yr = 1.6 yrs (with 10% a/c factor, payback becomes 1.4 yrs)

Energy savings

(24 fixture)(.188 kW/fixture)(2600 hrs/yr)(0.30)($0.08/kWh) = $282/yr

## Example Lighting / HVAC Interaction

| Location | Cooling Loads | Heating Loads Large Building | Heating Loads Small Building |
|---|---|---|---|
| Tampa, FL | -33% | 0% | 0% |
| Phoenix, AZ | -30% | 0% | 0% |
| New Orleans, LA | -29% | 1% | 2% |
| Los Angeles, CA | -23% | 0% | 0% |
| Knoxville, TN | -21% | 4% | 11% |
| Philadelphia, PA | -17% | 6% | 18% |
| Denver, CO | -16% | 7% | 22% |
| San Francisco, CA | -16% | 1% | 2% |
| Detroit, MI | -14% | 8% | 23% |
| Providence, RI | -13% | 7% | 22% |
| Seattle, WA | -7% | 4% | 13% |

Source: Advanced Lighting Guidelines 2003
(based on methodology of Rundquist, et.al. 1993)

# Thermal Energy Storage

Session 4.3.1

# Why is There Interest in Thermal Energy Storage?

- Reduced peak demand costs
- Some utilities offer rebates and rate incentives
- Reduced equipment size and cost (new)
- May be improved reliability due to production and storage
- Smaller fans and pumps (colder water with ice storage)

Session 4.3.2

# Economic Payback Time

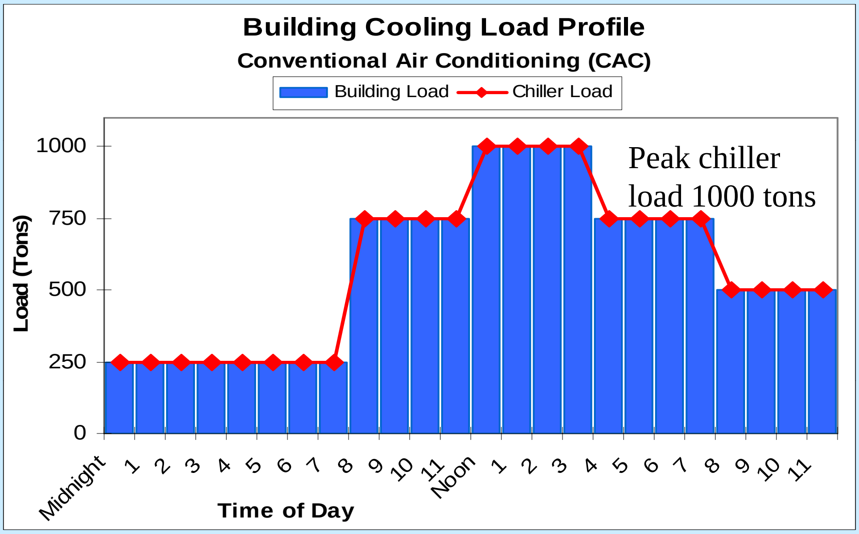
- Typical simple payback of 5 to 7 years (maybe 3 to 5 in some cases) for existing buildings and chillers.
- Recent examples from ASHRAE and others are showing the payback may be immediate to 1 – 2 years for good design in new construction.



# Conventional Air Conditioning Operation

- CAC system peaks at peak cooling time
- CAC system is sized to meet peak cooling load
- CAC system may have its lowest efficiency at the time it is needed the most

# CAC Operation





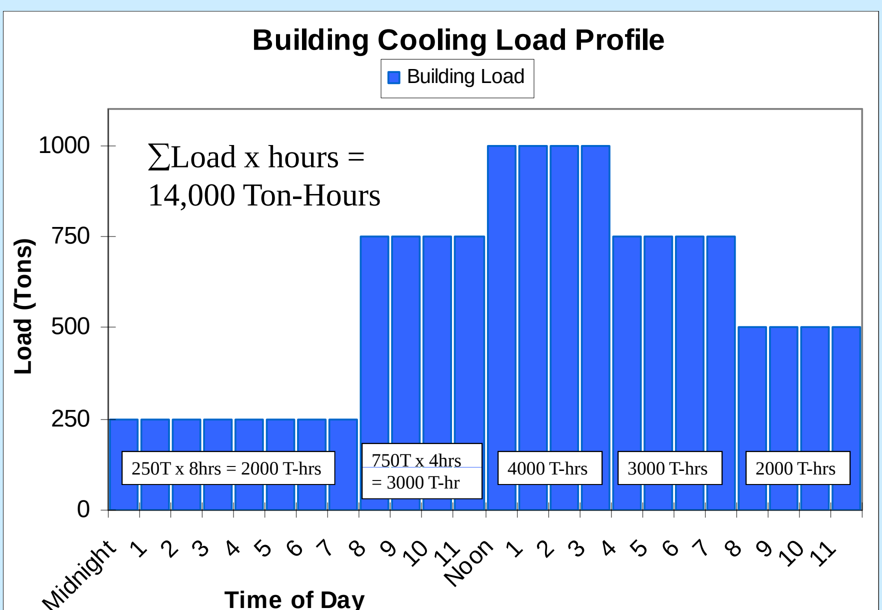

# Off-Peak Air Conditioning Operation

- CAC together with storage is used to meet peak cooling loads
- Chilled water or ice is used for storage medium
- Daytime peak load is reduced or eliminated
- OPAC system operates at night when efficiencies are usually higher due to lower outside temperatures

# Off-Peak Air Conditioning Operation

- The *Total Daily Cooling Load* (plus system losses) must be met
- The *Instantaneous Cooling Loads* must also be met when they occur, just not directly from the chillers.
- We are simply decoupling the Load (demand) from the Chiller (supply)
- If we take advantage of optimal chiller loading (sweet spot) and cooler condenser temperatures, we may gain significant efficiencies.





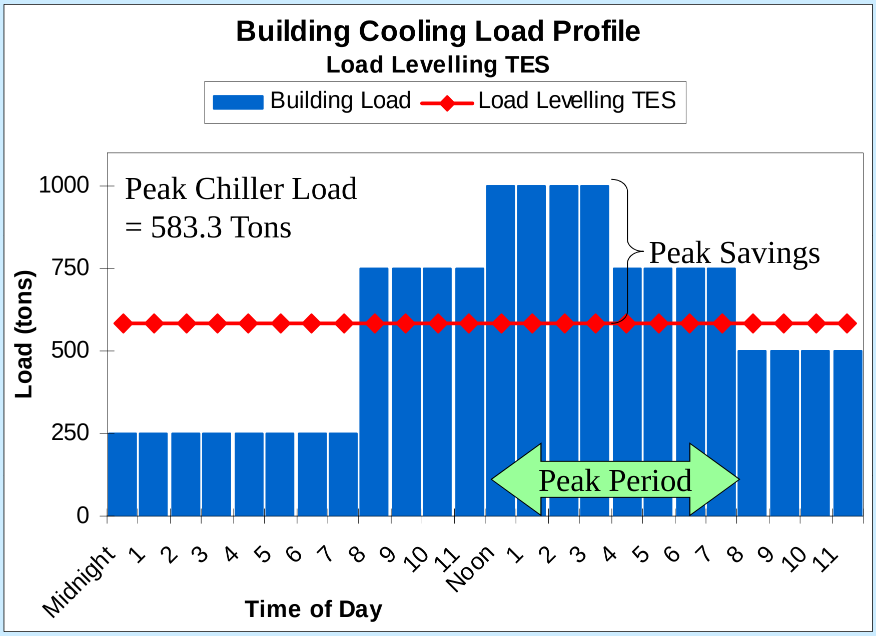
# OPAC Operating Strategies

- **Load leveling**
  - Partial shifting of AC load to off-peak hours
  - Chiller runs at constant load or near constant load for 24 hours per day
  - Very cost effective for new construction
  - Less costly to purchase
  - Less space needed
  - But ~ less savings



## Load Leveling Chiller Load Calculations

- Where would we need to operate the chiller(s) in order to satisfy the building load? Peak period between 12:00 p.m. to 8 p.m.
- Total Ton Hours / Hours available to operate chillers
- For the Load Leveling Strategy, the chiller will operate 24 hours per day, at a load of:
  - 14,000 Ton-hours / 24 hours = 583.3 Tons



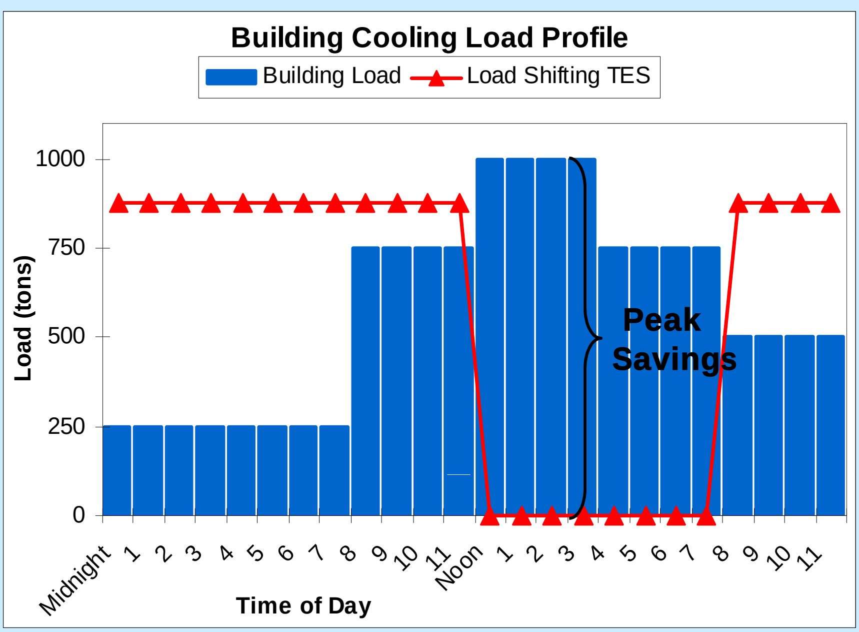



- **Load shifting**
  - Complete shifting of peak hour AC load to off-peak hours
  - OPAC system must be sized to meet peak cooling load in ton-h
  - Usually more cost effective for retrofit situations because of large existing chiller load that can be moved mostly off peak
  - More costly to purchase and install
  - Requires more space for storage tanks
  - But ~ more savings

# OPAC Load Calculations

- Total Ton Hours / Hours available to operate chillers
- A peak period from noon to 8 p.m. would only leave 16 hours to generate cooling capacity.
- For the Load Shifting Strategy, the chiller will operate at a load of:
  - 14,000 Ton-hours / 16 hours = 875 Tons





# TES Storage Media

- Chilled water storage
  - Simple ~ but large tanks needed; lots of space. Requires 4 to 5 times the space of ice storage
  - Typical water temperatures of 39 to 40 deg F
  - Practical considerations for water storage tanks
    - Need to minimize mixing of warm return water with the cold water in storage
    - May need two tanks ~ if full capacity of a tank is needed. If temperature stratification of tank is used, the tank may need to be up to 20% bigger



- **Ice Storage**
  - More complex tanks and auxiliary equipment needed; more complex to maintain
  - Ice/water requires around 20 to 30% of the space needed for chilled water tanks
  - Solid ice requires around 10% of the space needed for chilled water tanks
  - Very low temperature water can be used ~ around 34 degrees F
  - Can use ice harvester, ice on coil, or ice/water (slush)

# Properties of Storage Media

- Chilled water systems are typically operated in a manner to use only sensible heat storage and thus stores one Btu per pound of water for each ºF of temperature difference between the stored water and the returned water
- Ice systems are typically operated in a manner to use only latent heat associated with freezing and melting, and one pound of ice at 32ºF absorbs 144 Btu to become 32ºF water



# Sizing Chilled Water Storage Tanks

Assume that chilled water is stored at 39ºF and is returned at the standard temperature of 54ºF

- This is a 15º$\Delta$T for the AC system.
- Thus, one pound of water stores 15 Btu.
- One ton-h of AC is 12,000 Btu

So, to store 1 ton-h you need:

(1 lb H20/15 btu)(12,000 btu/ton-h)

800 lbs/ton-h

## Sizing Chilled Water Storage Tanks

Assuming there are 8.34 lbs/gal. We have approximately:

(800 lbs H20/ton-hr)(1 gal H20/8.34 lbs)

96 ~ 100 gals/ton hr @ 15 dT

So our full storage system of 7000 ton-hr would be around 700,000 gallons

Or a tank 60' dia, and 30' high.



## Conditions That Favor TES

- High peak demand charges
- Low cost of energy used at night
- High on-peak loads
- Low AC loads at night
- Need for increased cooling system capacity

## CEM Review Problems

1. TES systems yield large energy savings.

   A) True B) False

2. Distinguish between full and partial storage systems. Which would likely be better in new system design?

3. Why are utilities encouraging TES?



4. Temperature stratification can occur in
   (A) Chilled water storage
   (B) Hot water storage
   (C) A & B
   (D) None of the above

5. TES for heating uses some of the following storages: 1) building mass; 2) hot water; 3) ground couple; 4) compressed air tanks; 5) rocks; and 6) propane containers. Select the right combination:

   (A) 1,2,3,4 (B) 3,4,5,6
   (C) 1,2,3,5 (D) 2,4,5,6

6. With a load leveling TES strategy, a building manager will
   - (A) Not operate the chiller during peak hours
   - (B) Essentially base load the chiller (i.e., operate at high load most of the time)
   - (C) Operate only during the peak times
   - (D) Operate in the "off" season

7. A large commercial building will be retrofitted with a closed loop water to air heat pump system. Individual department meters will meter costs to each department. Demand billing is a small part of the total electrical cost. Would you recommend a TES?
   (A) Yes (B) No



# TES Appendix

# Another Storage Medium

- There is one more storage medium that is available, but it is almost never used. It is Eutectic Salt.
- Eutectic salt was used some in the 1970s and early 1980s for storage of heat, but its use for air conditioning is not common today. But, it could be used.



- **Eutectic Salt Storage**
  - Expensive, high tech solution
  - Allows use of existing 44 degree F chillers
  - Typical melt range is 41 to 47 degrees F
  - Requires only 30 to 50% of the space needed for chilled water tanks
  - Requires secondary heat exchanger
  - May be considered hazardous
  - The salt has a useful life of about five years, and must then be sent back and replaced

## Storage Capability of Eutectic Salts

- Eutectic salts use latent heat associated with freezing and melting, but one pound of solid eutectic salt absorbs only about 50 Btu to become liquid



## Summary of Storage Tank Sizing

**These are real world, practical numbers – not for use on CEM test**

- Chilled water

  15 to 18 cubic feet per ton-hr

- Eutectic salt

  3.5 to 6 cubic feet per ton-h

- Ice

  3 to 3.5 cubic feet per ton-h