THE FUNDAMENTALS OF ENERGY CONSERVATION DESIGN

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Outline

• Proper energy conservation design in new construction
• Identify building areas for improvement
• ASHRAE 90.1 and CA Title 24
• Prescriptive vs performance methods
• Solar friendly roof design
• Case Study
Energy Conservation Design

• Approach the building as a dynamic system

• Understand all the tradeoffs to optimize:
  – First cost
  – Energy savings and Return on Investment
  – Material longevity
  – Code mandates
  – Design / aesthetics

• One-off approach will result in higher first cost and higher operating costs…
Conservation Before Generation

Conservation before Generation

Master Plan Conservation & Generation
Energy Conservation & Solar – Driven by Code

- **California Title 24 -2013, ASHRAE 90.1, etc**
  - Lighting Changes
    - Lower Lighting Power Density, daylighting, dimming
  - Glazing
    - Increased glass and frame thermal barrier, orientation requirement
  - Walls
    - Higher R insulation, continuous insulation (U Value)
  - HVAC
    - Higher efficiency equipment, better control
  - Solar Ready Roofs (Title 24 Only)
ASHRAE 90.1

• Provides minimum standards for energy efficient design of buildings

• Reflects Code Requirement in some states – Nevada, Florida

• Define Design and Performance Standards for building assemblies and equipment

• Increased Energy Efficiency
1980 – 2015 ASHRAE Efficiency Guidelines Increased 59%

Source: US Green Building Council
Energy Code in CA - Title 24

- Design and Performance Code for California
- Similarities between ASHRAE 90.1 code updates and Title 24
- More efficient Building Envelope, continuous insulation
Title 24 Increase in Efficiency

- California Energy Code (CEC) – First Adopted 1977
- CEC ahead of Rest of the Country in Performance
- Trend Setter in Energy Efficiency

Source: EIA, SEDS database (2012)
ASHRAE Compliance Paths

• Mandatory Measures

• Prescriptive Path
  – Complex flowchart and checklist path
  – Each category has to qualify on its own

• Performance Path
  – Beat the total energy budget for a building
  – Trade-offs allowed
  – Renewable energy provides strategic advantage
## Prescriptive vs. Performance Compliance

<table>
<thead>
<tr>
<th>Prescriptive</th>
<th>Performance</th>
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<tbody>
<tr>
<td>- Simpler</td>
<td>- More complicated</td>
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<tr>
<td>- Meet a prescribed min efficiency</td>
<td>- Offers considerable design flexibility</td>
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<tr>
<td>- Little design flexibility</td>
<td>- Requires an approved computer software program</td>
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<td>- Easy to use</td>
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- Models a proposed building (Like EnergyPro)
- Determines its allowed Energy Cost Budget (ECB)
- Calculated its energy use
- And determines compliance
Both prescriptive or performance compliance paths require mandatory measures that must always be installed.

**Examples of Mandatory Measures:**
- Air leakage and Infiltration control
- HVAC equipment efficiencies
- Lighting and HVAC controls
- Minimum insulation levels
  - Roofs
  - Walls
  - Heated slabs
  - Foundation perimeter
  - Fenestration
Performance Approach – Energy Cost

• In addition to mandatory requirements

• Baseline is established using energy simulation for a similar building of same size which is constructed as per ASHRAE 90.1

• Each category or the entire building has to come below the ECB Baseline to be acceptable – Possible combinations
  
  – Envelope-only compliance
  – Envelope and lighting compliance
  – Envelope and mechanical compliance
  – Envelope, lighting and mechanical compliance
CEC vs. ASHRAE

- CEC (Title 24) leads the national energy code ASHRAE 90.1
- CEC establishes the standard, 2 years later ASHRAE 90.1 leap frogs
- Site Energy Usage Intensity (EUI) comparison
  - Title 24 2005 250 kbtu/sq. ft.
  - ASHRAE 90.1 2007 243 kbtu/sq. ft.
  - Title 24 2008 210 kbtu/sq. ft.
  - ASHRAE 90.1 2010 198 kbtu/sq. ft.
Title 24 vs. ASHRAE 90.1

- New Construction Building (>100,000 sq. ft.)
  - ASHRAE 90.1 2010 = 1,407 Gbtu/yr*
  - Title 24 2013 = 1,250 Gbtu/yr*
  - Savings = 158 Gbtu/yr
  - 11% Better

*Gbtu = Giga British Thermal Unit, 1000,000 kbtu
ASHRAE 90.1 and Energy Efficiency

- **Building Envelope:**
  - Wall Insulation Continuous (R Value vs. U Value)
  - Roof Insulation Continuous & Reflectance (R Value vs. U Value)
  - Glazing performance and Orientation (SHGC, VT)

- **HVAC: Equipment Efficiencies and Control Strategies**

- **Lighting:**
  - Lighting power density (LPD, expressed in Watts/Sq.Ft.),
  - Lighting controls,

- **Domestic Hot Water:** minimum equipment efficiency,
  minimum system features

- **Renewable Energy Trade-offs**
R Value vs. U Value

• **R Value**
  – A measure of material’s capability to resist heat transfer
  – Higher is better
  – Typically used for each material (layer)

• **U Value**
  – A measure of material or assembly’s heat transfer efficiency
  – **Lower** is better
  – Typically used for the entire wall/roof/window assembly

• **U value = 1/R Value**
Building Envelope Walls

• Code has gotten smarter

• R value of each layer – is no longer what the assembly design is evaluated by

• U value of the total assembly is considered

• Code putting an end to thermal breaks
Code is Requiring Continuous Outside Insulation

- Code Requires total minimum U Value
- No more individual R Value considerations
Typical Exterior Insulation

Thermal Anomalies
Typical Continuous Exterior Insulation

Smaller Thermal Anomalies

Solar Thermal Anomalies
Real Numbers – Factoring in Thermal Bridging

- Insulation Installed R Value = R30
- Metal Framing with Concrete
- U Value of Assembly = 0.276
- Effective R Value = 3.6
## ASHRAE U Value Requirements and CI

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<th>Opaque Elements</th>
<th>Nonresidential</th>
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California is 350% to 400% More Restrictive

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1. Light mass walls are walls with a heat capacity of at least 7.0 Btu/h-ft² and less than 15.0 Btu/h-ft². Heavy mass walls are walls with a heat capacity of at least 15.0 Btu/h-ft².

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Air Barrier Required in some CZs

1. CEC Steel framed building roof U= 0.062 vs ASHRE U = .22
2. CEC wood framed building wall U = 0.110 vs ASHRE U = 0.504
3. CEC is 350% to 400% more restrictive than ASHRE
Samples of Continuous Outside Insulation

- This system requires clips and mechanical fasteners that bridges heat.
- Adhered EIFS does not require fasteners.
How do we solve the CI challenge?

- Material Selection
- Design Consideration
Building Envelope – Reflective Roofs

- Impacts HVAC
- Code requires high Emissivity Roofs
- New codes driving roof factor for higher reflectivity and lower emissivity
Solar Heat Gain Through Roof

• **Solar reflectance:** Fraction of Heat Reflected

• **Thermal emittance:** Fraction of heat transferred in
Prescriptive Requirements for Envelopes

• Increased low slope cool roof requirements.

• Higher Solar Reflectance from 0.55 to 0.63 for new and alterations

• Lower Thermal Emittance (TE)

• ASHRAE 90.1 2007, TE lowered from 0.9 to 0.75

• Same as CEC
Glazing ASHRAE 90.1 2013

- Low Solar Heat Gain Coefficient (SHGC)
- Higher Visual Transmittance (VT)
- Overall U value of assembly (as opposed to low e)
- Orientation Requirements East- and west-oriented glazing must each be less than 25% of the total glazing
Increased Fenestration Requirements

- Reduce solar gains and increase visual light transmittance for daylighting.
- Typical values for Curtain wall Assembly
- CEC Example Climate Zone 3 – California

<table>
<thead>
<tr>
<th>Metal Framed Operable Fenestration</th>
<th>ASHRAE</th>
<th>CEC</th>
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Glazing Windows Heat Flow
Windows – SGHC & VT

Clear Double Glazing

- Heat Gain
- Light

U-factor = 0.47
SHGC = 0.70
70% of solar heat transmitted
VT = 0.79
79% of visible light transmitted

Low-solar-gain Low-E Double Glazing

- Heat Gain
- Light

Spectrally selective coating

U-factor = 0.25
SHGC = 0.27
27% of solar heat transmitted
VT = 0.69
69% of visible light transmitted
Pick The Right Glazing Code now requires lower
ASHRAE 90.1 and Daylighting

- Requires minimum Skylight for spaces below ceiling
- Restricts maximum Skylighting to 3% of Roof Area
- Limits vertical fenestration to 40% of the total vertical area
Lighting Saving from Skylights Are Offset by Cooling and heating costs. 2-4% of roof area is optimum. 

“Sweet spot”
Building Systems - HVAC

• **ASHRAE 90.1 2013 Requires**
  – Higher Equipment Efficiencies
  – Direct Digital Controls (DDC)
    • Central Cooling and Heating Plants over 300 MBH
    • Zoned HVAC Systems
    • Multi Cell Cooling Towers

• **Total 8.5% Reduction from 2010 code**
Building Systems - Lighting

• Impacts HVAC

• One of the major energy consumers

• New Code requires
  – Lower Lighting Power Density (LPD)
    • *It's time for LED*
  – Automatic Controls
  – Limitations on exterior lighting
  – Better efficiency and efficacy
Lighting Energy Consumption

Consumption (kWh)

- Lighting: 27%
- Cooling: 22%
- Fans: 10%
- Pumps: 0%
- Other: 41%

High Energy Consumer
Lighting Types & Technology

- **Incandescent**
  - Edison bulb
  - Metal Halide
  - HPS

- **Fluorescent**
  - T5, 8, 12 Tubes
  - CFL

- **LED**
  - Lamps
  - Fixtures
Lighting - Efficacy

- Lumens of Light per Watt of Energy Consumed

- Incandescent – 20 lm/W

- Fluorescent – 46 to 75 lm/W (230% to 375% Increase)

- LED – 87 to 100 lm/W (133% to 189% Increase)
  - Theoretical Limit of what is possible – 300 lm/W
  - Almost 60 times more efficient than incandescent
  - New Technology – No more blue glare
CA Leading Solar Ready Design

• **Designated Solar Zones on roof**
  – At least 10% of roof area
  – No shading in solar zones

• **Orientation of Building**

• **Minimized Shading**

• **Structural Design**

• **Interconnection Pathways**
Example – NOT Solar Friendly Roof

Mechanical fan assembly (typ)
Window washing
davit/stanchions and clearances
Performance Based Renewable Energy Trade-offs

• **Site-recovered & Site-generated energy credit allowed**
  - Not considered “purchased energy”
  - Deducted from “proposed design” energy consumption via Energy Cost Budget Method

• **Renewables**
  - Solar Photovoltaic – Electric
  - Solar Thermal – Thermal
Case Study

- 75,000 Sq. Ft. Skilled Nursing Facility
- Las Vegas, Nevada
- New construction on a 2.3 acre site
- Designed to ASHRAE 90.1 2007 Energy Standards
- LEED Silver objective
Case Study – General Construction

- Steel Frame Building
- Punched Windows – Aluminum Frame
- Fenestration – Glass store front and Punched windows
Case Study - Owner’s Objectives

• Analyze potential energy efficiency improvements beyond ASHRAE 90.1 2007 baseline for CD’s

• **Identify package of Energy Conservation Measures (ECM)**
  – 15 Year Payback Test
  – Prefer 2x Increase In Building Value
  – Marginal payback considered if other soft benefits
Theoretical Building Utility Baseline

928,796 kWh / Year

47,633 Therms / Year
Baseline Consumption

- Desert climate with extreme hot & cold
  
  - Electric Usage:
    - 27% Lighting
    - 32% HVAC
    - 41% Plug loads etc.
  
  - Gas Usage:
    - 77% Heating
    - 8% Hot Water
Baseline Energy Consumption

- **First Year (estimated)**
  - Total Utility Cost = $128,000
  - Electric Utility Cost = $117,000
  - Gas Utility Cost = $11,000

- **Lifetime Costs (30YR)**
  - Approximately $8,000,000
Case Study – Wall Assembly

- Wall Assembly
- Proposed Changes
- Changes to R and U value
- Financial Analysis
ECM - Walls

- Exterior Walls Design – R13
- Explored additional rigid insulation
- A consistent value for rigid insulation is R5 per inch
- Explored additional R5, R10, R15, R20
- Selected Additional R10 (total R23)
- Reduced Peak Solar Gain by 50%
Original vs. ECM – Wall

- Exterior Continuous 2 inch Insulation
- Metal Studs
- Thermal Breaks at Studs
- R Value = 13
- Old U Value = 0.217

- Additional exterior insulation of R 10
- New U Value (assembly) = 0.068
- Lower the better
- Effective R Value = 14.6
Financial Analysis Results – With Continuous Exterior Wall R-10

- Pay Back: 19.1 Years
- Result: Fail
- Included in Final Design: No
- Key Financial Information:
  - Cost to install: $95,000
  - Year 1 savings: $2,046
  - ROI: 2.2%
  - Year 1 increase in property value: $29,235
  - Year 10 increase in property value: $45,353
Case Study – Roof Assembly

- Reflective White Roof
- R30 Rigid Tapered insulation
- Moisture Barrier
ECM – Roof Improvement

- Current Assembly U Value = 0.033 Explored additional R35, R40, R45, R50
- Installed Continuous Insulation – R35
- New U Value = 0.015
- Effective R Value = 38.6
Financial Analysis Results – Upgrade to Additional R-35

• Pay Back: Never
• Result: Fail
• Included in Final Design: No
• Key Financial Information:
  – Cost to install: $147,000
  – Year 1 savings: $1,200
  – ROI: 0.01%
  – Year 1 increase in property value: $16,000
  – Year 10 increase in property value: $26,000
### Increased Insulation Can Reduce HVAC Sizing

<table>
<thead>
<tr>
<th>Roof &amp; Wall Insulation Only</th>
<th>Reduction in HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost:</strong> $242,000</td>
<td><strong>tonnage:</strong> 25%</td>
</tr>
<tr>
<td><strong>Savings:</strong> $3,220</td>
<td><strong>-</strong>$173,000</td>
</tr>
<tr>
<td><strong>ROI:</strong> 1.3%</td>
<td><strong>Net Cost:</strong> $69,000</td>
</tr>
<tr>
<td><strong>Payback:</strong> 30+ YR</td>
<td><strong>ROI:</strong> 4.7%</td>
</tr>
<tr>
<td><strong>Result:</strong> FAIL</td>
<td><strong>Payback:</strong> 16 YR</td>
</tr>
<tr>
<td></td>
<td><strong>Result: Fail (Barely)</strong></td>
</tr>
<tr>
<td></td>
<td>− Perceived riskiness to downsize</td>
</tr>
</tbody>
</table>
Case Study – Glazing

- Current Window Glazing
- Proposed Glazing
- Financial Analysis
Original Design – Window Section

- Low E
- Solar Heat Gain Coefficient (SHGC) of 0.32
ECM - Windows

- Design Windows Glazing - SB60 and SB70XL series of glass (SGHC 0.4 and 0.32)

- Options Explored
  - SGHC 0.27, 0.24, 0.17

- Selected SGHC 0.24 Glazing

- Reduced Peak Heat Gain by 45%
ECM Window SGHC Change

Baseline Design - SHGC - 0.32


New Improved Design - SHGC - 0.24

Financial Analysis Results – Windows

- Pay Back: 16.9
- Result: Fail
- Included in Final Design: No
- Key Financial Information:
  - Cost to install: $30,000
  - Year 1 savings: $762
  - ROI: 2.5%
  - Year 1 increase in property value: $10,887
  - Year 10 increase in property value: $16,890
Case Study – Lighting

• Lighting Types
• LED vs. Other
• Benefits of Improved Lighting Design
Case Study Facility – Lighting

- Combination of T8 and Can CFL lights
- Limited controls of fixtures with occupancy sensors
- Simple daylighting controls with on/off photo-switches
Original Design Lighting Fixtures

T8 Lamp Fixture

CFL Cans
ECM - Lighting

• Original Design = Fluorescent and CFL

• Proposed design switch all fixtures to LED

• Lighting Control expanded to all fixtures
  – Photo-switches for exterior fixtures
  – Occupancy controls for office spaces with active dimming
Savings from Lighting Project

- **3 Types of Savings**
  - Utility Savings
  - Maintenance Savings
  - HVAC Savings

Year 1 Savings from Lighting

- $10,771 Utility Savings
- $8,352 Maintenance Savings
- $9,164 HVAC Savings

![Bar chart showing savings categories and amounts](chart.png)
Proposed Fixtures - LED

Advanced Optics

No Blue Glare
Financial Analysis Results - Lighting

- Pay Back: 5.2 Years
- Result: Pass
- Included in Final Design: Yes

Key Financial Information:
- Cost to install: $177,932
- Year 1 savings: $28,287
- ROI: 15.9%
- Year 1 increase in property value: $404,000
- Year 10 increase in property value: $624,000
Case Study – HVAC

- Variable Flow Refrigerant System
- Duct Design Changes
- Financial Analysis
HVAC ECM Options

• Change Primary Cooling From Split System to Mitsubishi Variable Refrigerant Flow (VRF) design
  – Split System (9.5 EER, 3.2 COP)
  – VRF System (15.7 EER, 8.5 COP)

• Change Energy Recovery Ventilation design to reduce fan run time
Variable Refrigerant Flow System

- Moves liquid refrigerant from central unit to each part of the building
- Very Efficient System
- Individually Controllable
- EER 15.7, COP 8.5
Financial Analysis Results – Upgrade to Mitsubishi VRF

- **Pay Back:** 14.8 Years
- **Result:** Pass
- **Included in Final Design:** Yes
- **Key Financial Information:**
  - Cost to install: $989,000
  - Year 1 savings: $36,406
  - ROI: 3.7%
  - Year 1 increase in property value: $520,086
  - Year 10 increase in property value: $758,922
ECM – Change Ventilation Recovery Design

- Changed the duct design for energy recovery system to allow fans to run intermittently

Results
- Fan Coil Units now operation intermittently
- Fan operation energy savings
Financial Analysis Results – Change Ventilation Recovery

• Pay Back: 17.6 Years
• Result: Fail
• Included in Final Design: No
• Key Financial Information:
  – Cost to install: $479,224
  – Year 1 savings: $12,184
  – ROI: 2.5%
  – Year 1 increase in property value: $174,000
  – Year 10 increase in property value: $270,000
Case Study – Energy Generation Solar

- Understanding Location and Solar Irradiance
- Installed Solar PV and Solar Thermal
- System Details
- Financial Analysis
Nevada - Solar Irradiance

‘Red’ = Higher irradiance
Energy Generation – Solar PV

• Proposed System Size – 205 kW DC
• Annual kWh Production – 338,112
• Installed on
  – Roofs
  – Carports
Financial Analysis – Solar PV

- **Pay Back:** 8.2 Years
- **Result:** Pass
- **Included in Final Design:** Yes
- **Key Financial Information:**
  - Cost to install after rebate: $387,545
  - Year 1 savings: $19,435
  - ROI: 5.0%
  - Year 1 increase in property value: $236,000
  - Year 10 increase in property value: $349,000
Energy Generation Solar Thermal

- Two types available
  - Evacuated Tube
  - Flat Plate

- Evacuated Tube used

- 35% Solar Fraction

- Annual Therm offset - 6956
Financial Analysis – Solar Thermal

- Pay Back: 13.8 Years
- Result: Pass
- Included in Final Design: Yes
- Key Financial Information:
  - Cost to install after rebate: $118,785
  - Year 1 savings: $4,566
  - ROI: 3.5%
  - Year 1 increase in property value: $60,226
  - Year 10 increase in property value: $74,989
Case Study – Results of Improvements

• Improvement in Delivered Power Quality

• Financial Analysis
Electrical Consumption Reduction
Gas Consumption Reduction

Monthly Natural Gas Usage (therms)

- Baseline
- Proposed

<table>
<thead>
<tr>
<th>Month</th>
<th>Baseline</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1400</td>
<td>600</td>
</tr>
<tr>
<td>Feb</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Mar</td>
<td>1300</td>
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<tr>
<td>Apr</td>
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<tr>
<td>Nov</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Dec</td>
<td>1400</td>
<td>600</td>
</tr>
</tbody>
</table>
Summary of ECMs and Solar

Year 1 Utility Bill

Before

After

Electricity Cost

Water Features Pumps

Mechanical/HVAC

Power Optimization

Lighting

AES

Solar PV

Gas Cost

Solar Thermal
Summary of ECMs and Solar

1st Year Energy Cost $:

Before Project: $111,729
After Project: $25,228
Before Project (Gas): $16,326
After Project (Gas): $11,760
Summary of Selected ECM - Financial

- Total Investment - $2,404,986
- Year 1 Utility Savings - $107,999
- Year 1 Cash Flow – $184,430
- ROI – 4.2%
- Payback – 12.5 YR
- Property Value Increase - $1,542,842
Case Study - Conservation Before Generation

- Both conservation and generation measures were analyzed in proper order

- Combining conservation and generation presented the opportunity to deliver 72% reduction in utility cost
Conclusions

• Higher building envelope insulation did not make financial sense

• Lower equipment cost and continuous run times will make more financial sense than more energy efficient designs

• Energy generation like solar PV and Thermal has better payback

• LED has huge impact
If performance based approach is used as opposed to prescriptive based:

- Energy generation like solar thermal and solar PV can be used as trade-off
- LED can be used to trade-off