Building energy analysis

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• Building energy regulations
• Building energy calculations
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• BIM and energy analysis
Building Energy Performance

Critical Design Parameters:

Fixed:
- Climate of location
- Occupancy behavior
- Process energy
- Required air change rate
- Allowed indoor climate variation range

Constraint:
- Wind
- Surroundings (plants, buildings, surfaces etc.)

(Source: Graphisoft BIM Curriculum http://www.graphisoft.com/learning/bim-curriculum/)
Building Energy Performance

Critical Design Parameters:
Alterable by the Architect

- Building orientation
- Building shape
- Physical properties of the building envelope
- Zoning
- Day-lighting
  - Glazing ratio
  - Glazing orientation
- MEP systems (general strategy)

(Source: Graphisoft BIM Curriculum [http://www.graphisoft.com/learning/bim-curriculum/])
Key factors influencing energy consumption
(Adapted from Energy Efficiency in Buildings: CIBSE Guide F)

Passive design elements: building envelope
- Size/mass
- Built form
- Shape
- Materials
- Ventilation
- Location
- Orientation, etc.

Reactive design elements: building services
- Fuels
- Type of systems
- Size of systems
- Plant controls
- Plant efficiency
- Operating regime, etc.

Human factors
- Comfort requirements
- Occupancy regimes
- Management and maintenance
- Activity
- Access to controls, etc.

External factor, e.g. climate

- Reactive design elements
- Passive design elements
- Human factors
- External factor

- e.g. automatic control
- e.g. user controls
- e.g. window controls
Energy flow and concept in buildings

- Energy Waste
  - Heating/Cooling
    - Ventilation
    - Lighting
  - Energy Requirement
    - Processes
    - Internal Load
      - Occupancy
  - Energy Consumption
    - Oil, Coal, Natural gas, Biomass, Other
  - Energy Resources
    - Envelope Load
      - Dry bulb temp
      - Dew point temp
      - Wind vel & dir
      - Contaminants
      - Insolation
    - Outdoor Conditions
    - Building Energy Efficiency = Energy Requirement / Energy Consumption
Building Energy Performance

Benchmarks - Low Energy Houses

• Less than 30kWh/m² energy consumed for heating annually

• Consumes less than 50% energy compared to conventional alternative

Commerzbank, Frankfurt am Main
Sir Norman Foster and Partners

(Source: Graphisoft BIM Curriculum http://www.graphisoft.com/learning/bim-curriculum/)
No conventional heating or cooling
less than 30 kWh/m² energy consumed for heating/cooling

Extremely low primary energy consumption
less than 120 kWh/m²

Airtight construction

(Source: Graphisoft BIM Curriculum http://www.graphisoft.com/learning/bim-curriculum/)
Building Energy Performance

Benchmarks - Net Zero Buildings

- Zero net energy consumption
- Zero CO2 emission
- Can be used separately from the grid supply
- Enough energy produced on-site
- Super-low energy demand

(Source: Graphisoft BIM Curriculum http://www.graphisoft.com/learning/bim-curriculum/)
EU - Climate & Energy objectives by 2020:
  • 20% less greenhouse gas emissions
  • 20% energy savings
  • all new buildings must be net zero buildings

US - all new federal buildings must be at least Silver LEED certified

(Source: Graphisoft BIM Curriculum http://www.graphisoft.com/learning/bim-curriculum/)
Building Energy Regulations

Standards

- Regional (country-specific) vs. global standards
- Mandatory vs. voluntary standards
- Minimum requirements are getting stricter

Define calculation methods and minimum requirements:

Building Energy Codes, e.g. ASHRAE 90.1, International Energy
Conservation Code (IECC), California Title 24

(Source: Mr. Kent W. Peterson, former ASHRAE President)
ASHRAE 90.1 compliance approaches

**Building System**
- Envelope
- HVAC
- SWH
- Power
- Lighting
- Other

**Compliance Options**
- Prescriptive Option
- Trade Off Option
- Energy Cost Budget
- Simplified

**Mandatory Provisions**
(required for most compliance options)

(Source: US Department of Energy)
Energy efficiency rating and environmental impact rating in UK

Energy Efficiency Rating

- Very energy efficient - lower running costs
  - A: (93-100)
  - B: (81-92)
  - C: (66-80)
  - D: (51-65)
  - E: (36-50)
  - F: (21-35)
  - G: (1-20)

- Current: 78
- Potential: 55

Environmental Impact Rating

- Very environmentally friendly - lower CO₂ emissions
  - A: (93-100)
  - B: (81-92)
  - C: (66-80)
  - D: (51-65)
  - E: (36-50)
  - F: (21-35)
  - G: (1-20)

- Current: 65
- Potential: 50

UK 2005

Directive 2002/91/EC

(Source: www.energysavingtrust.org.uk)
《建築物能源效益條例》
The Buildings Energy Efficiency Ordinance

空調裝置
Air-conditioning installation

電力裝置
Electrical installation

照明裝置
Lighting installation

升降機及自動梯裝置
Lift & escalator installation

Energy Audit Form
能源審核表格

(Source: EMSD)  (See http://www.beeo.emsd.gov.hk for details)
Stationery Method:

Energy balance for the heating and the cooling season separately

Manual data input exclusively

Usage requires professional expertise

Regional

• Limited to a narrow climate range

Not truly integrated in architecture

• Executed only a couple of times for a project

• Not used to improve the project but only to document it

(Source: Graphisoft BIM Curriculum http://www.graphisoft.com/learning/bim-curriculum/)
Building Energy Calculations

Dynamic Simulation Method:

Energy balance for every hour throughout a year

Semi-automated data input

User-friendly solutions exist

Global
  • Can be used in all climates

Truly integrated in architecture
  • Executed several times for a project
  • Explore what-if scenarios for design optimization

(Source: Graphisoft BIM Curriculum http://www.graphisoft.com/learning/bim-curriculum/)
Building energy calculations

• **Building energy simulation/modelling**
  - Analysis of energy performance of building using computer modelling and simulation techniques

• **Many issues can be studied, such as:**
  - Thermal performance (e.g. bldg. fabric, glazing)
  - Comfort and indoor environment
  - Ventilation and infiltration
  - Daylighting and overshadowing
  - Energy consumption of building systems

Simulation enables the performance of the building to be established before critical design decisions are taken, enabling optimum building performance to be obtained.
Building energy simulation process

**Systems (air-side)**

**HVAC air systems**

**HVAC water systems**

**Energy input by HVAC air/water systems**

**Energy input by HVAC plant**

**Energy input by appliance**

**Energy storage**

**Sources of Cooling Load**

**Thermal Zone**

- Solar radiation
- Conductive heat gains
- Infiltration
- Occupant
- Electric lighting
- Computer & equipment

**Plant (water-side & refrig.)**

**Energy input by HVAC plant**
Building description
- physical data
- design parameters

Simulation tool (computer program)

Simulation outputs
- energy consumption (MWh)
- energy demands (kW)
- environmental conditions

Weather data
Garbage In, Garbage Out (GIGO)
Predesign energy analysis

- Use general information about the building and site to estimate energy performance, characterize energy uses, and identify potential energy savings opportunities.
- The objective is to use results to develop design concepts that minimize energy loads and costs from the outset.
- Results also provide important guidance for setting energy performance goals.
Predesign energy analysis

- **Predesign energy model** is a simplified sketch of a potential building.
- Results are best used to compare and explore alternatives and will not necessarily be representative of the actual performance.
Breakdown of end-use energy consumption
Peak day demand profile

(Source: Lindsey, G., et al., 2009. *A Handbook for Planning and Conducting Charrettes for High-Performance Projects*)
Presentation of results from building energy simulation
<table>
<thead>
<tr>
<th>Stage</th>
<th>Requirements</th>
<th>Tools</th>
<th>Checks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scoping</td>
<td>-Quick analysis</td>
<td>-Ecotect</td>
<td>-kWh/m²</td>
</tr>
<tr>
<td></td>
<td>-Comparative results</td>
<td>-Energy-10</td>
<td>-Energy cost</td>
</tr>
<tr>
<td></td>
<td>-Reduce alternatives</td>
<td>-eQUEST</td>
<td>-Payback or other financial measure</td>
</tr>
<tr>
<td></td>
<td>-Control strategy modelling (simple)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System design</td>
<td>-Accurate output</td>
<td>-Carrier HAP</td>
<td>-design flow</td>
</tr>
<tr>
<td></td>
<td>-Industry-accepted methods</td>
<td>-TRACE 700</td>
<td>-Load intensity</td>
</tr>
<tr>
<td>Energy/cost</td>
<td>-Accurate</td>
<td>-DOE-2</td>
<td>-Detailed kWh/m²</td>
</tr>
<tr>
<td>analysis</td>
<td>-Industry-accepted methods</td>
<td>-EnergyPlus</td>
<td>-Detailed energy cost</td>
</tr>
<tr>
<td></td>
<td>-Flexible</td>
<td>-Carrier HAP</td>
<td>-Economic indexes</td>
</tr>
<tr>
<td></td>
<td>-Modelling of complex control strategies</td>
<td>-TRACE 700</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Energy code compliance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-For existing buildings too</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring</td>
<td>-Simplicity</td>
<td>-BACnet</td>
<td>-Trended operating characteristics</td>
</tr>
<tr>
<td></td>
<td>-Intuitive interface</td>
<td>-Building automation</td>
<td>-Benchmark comparison</td>
</tr>
<tr>
<td></td>
<td>-Interoperable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Adapted from ASHRAE, 2006. *ASHRAE GreenGuide*)
BIM and energy analysis

- Use of BIM for facility energy analysis
  - In the facility design phase which one or more building energy simulation programs use a properly adjusted BIM model to conduct energy assessments for the current building design
  - The core goal is to inspect building energy standard compatibility and seek opportunities to optimize proposed design to reduce structure’s life-cycle costs

(Source: Facility Energy Analysis http://bim.psu.edu/Uses/Energy_Analysis.aspx)
Energy analysis has an important role in the use of BIM.

BIM and energy analysis

• Combining BIM and energy analysis can potentially increase efficiency and accuracy, but can be time consuming and tedious if not done properly
  • Before the BIM model is created, it is important to determine which software is best for the desired energy analysis
  • The BIM model may need to be simplified in different ways for different software

### Export file type that the energy analysis tool requires from BIM software

<table>
<thead>
<tr>
<th>Software</th>
<th>Export from BIM software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Building Studio (GBS)</td>
<td>gbXML</td>
</tr>
<tr>
<td>eQUEST</td>
<td>gbXML --&gt; GBS (DOE-2 file)</td>
</tr>
<tr>
<td>Ecotect Analysis</td>
<td>gbXML or .DXF file (best for sloped ceilings)</td>
</tr>
<tr>
<td>CFD design</td>
<td>Directly from BIM software via add-in</td>
</tr>
</tbody>
</table>

**Note:**
The .DXF export from BIM software is most useful for odd geometries for use in Ecotect. However, gbXML is usually the preferred output.

**Consideration for interoperability of energy analysis tools:**
1. Integrate with BIM software (e.g. Revit, ArchiCAD and SketchUp)
2. Exchange or import files (e.g. DXF and gbXML)
3. Accuracy of translation (e.g. geometry, materials, openings)
4. Default data, libraries and weather information
5. Potential for customization (e.g. for special cases)
6. Provide feedbacks for potential design change to improve energy efficiency

An example of linking a BIM software to building energy analysis tools

Energy balance evaluation on BIM software

(Source: Graphisoft http://www.graphisoft.com/)
Multiple thermal block building energy model shown in BIM software

(Source: Graphisoft http://www.graphisoft.com/)
Energy analysis workflows

(Video: Energy Simulation Workflow Overview (5:59) [https://youtu.be/nldU3ZIQpbg](https://youtu.be/nldU3ZIQpbg))

(Source: Getting Started with Autodesk Energy Analysis
Results of energy analysis and decision-making

(Source: Getting Started with Autodesk Energy Analysis
http://help.autodesk.com/view/BUILDING_PERFORMANCE_ANALYSIS/ENU/?guid=GUID-E85A114E-BA0D-4811-B1A5-4EE26462708A)
Workflow 1: for separate architectural and engineering firms

Architects build model for construction documents

Engineers build energy model by linking in architecture model and tracing

Engineers build spaces in energy model

MOST IDEAL FOR:
Separate architectural and engineering firms

Engineers perform Analysis

Engineers edit the energy model architecture

Engineers edit the spaces again

Architects make a change in the design

Workflow 2: for architectural/engineering firms (in house)

MOST IDEAL FOR:
architectural/engineering firms (in house)

Engineers build spaces in energy model

Engineers perform Analysis

Architects build simple architectural model for energy analysis

Architects change architecture in energy model

Architects make a change in the design

Engineers edit the spaces again

SIMPLIFY the energy model for the analysis: curved wall conversion

The methods of modeling the energy model may result in a model that does not visually look like the actual design, but provides the correct information for the analysis to be done. For example, a curved shading device may have to be split up into multiple small rectangular pieces.

Geometry modelling and energy analysis model (EAM)

BIM and energy analysis

• Building energy models for large buildings are more prone to have errors in the export to an energy analysis tool.

• For multilevel buildings, spaces should be added to one level at a time and exported to the tool (e.g. eQUEST) to check that the spaces translate properly.
  • It is easier to troubleshoot areas that have errors when spaces are added in this manner.
Curtain walls are “converted” into surfaces and openings in the analytical model

The Curtain Wall object does not maintain the proper area. The simple window should be used to represent Curtain Wall by extending the window from the floor to the next level. One reason that the curtain wall area may be incorrect is that the mullions are being accounted for in the glazing area, but even when the grid pattern is set to none, the area is still reduced.

### Information available in different design phases in BIM energy modelling

<table>
<thead>
<tr>
<th>Design phase</th>
<th>Preliminary design</th>
<th>Early design</th>
<th>Detailed design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information available</td>
<td>Total floor areas, building shape, orientation and so on</td>
<td>HVAC, occupancy schedule, outside air flow per person, outside air flow per floor area, outside air change per hour value, number of users, and so on</td>
<td>Detailed types of HVAC, walls, roof construction, lighting efficiency, lighting control, equipment power density value, light power density value, equipment efficiency, daylighting control, occupancy sensor, glazing, window to wall ratio, and so on</td>
</tr>
<tr>
<td>Accuracy of energy modelling</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

(Source: Adapted from Kim, H. et al., 2016. BIM IFC information mapping to building energy analysis (BEA) model with manually extended material information, *Automation in Construction*, 68:183-193.)
BIM and energy analysis

• Rapid energy modelling (REM)
  • Evaluate numerous design alternatives with less time and cost
  • Shortcut to estimating actual energy use
  • Focus on retrofitting of existing buildings

• Analyse the building energy characteristics
  • 1. Model (capture by digital photos)
  • 2. Evaluate (building energy model)
  • 3. Report (energy & carbon analysis)

Further reading

• Getting Started with Autodesk Energy Analysis

• Leveraging BIM for Energy Analysis

• Autodesk Insight - High performance and sustainable building design analysis
  • [https://insight.autodesk.com/oneenergy](https://insight.autodesk.com/oneenergy)
  • Sample Insights
    • [https://insight.autodesk.com/oneenergy/Sample](https://insight.autodesk.com/oneenergy/Sample)