Energy Modeling in Architectural Design

Presented by:

Samir R. Traboulsi, PhD., P. Eng.
ASHRAE Fellow
CIBSE Fellow
NEBB Certified Professional

Senior Lecturer at the American University of Beirut
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Energy Modeling in Architectural Design

**Learning Objectives:**

1. To show how important architects should get involved in the energy design of their buildings to enhance energy savings.
2. To allow architects be able to identify available energy modeling tools.
3. To enable practicing the energy design in building and in each stage.
4. To understand the benefits of integrating energy models in the energy design.
Outline of the Presentation:

I. Introduction
II. Background of energy modeling?
III. Design & Modeling Process of Energy
IV. Modeling Tools
V. Conclusions
I. Introduction:

Shanghai Tower underwent testing using Autodesk Ecotect Analysis software, and by incorporating sustainable practices, aims for their ground-breaking design to hold a LEED Gold rating and a China 3 Star rating, being the highest level of performance made only possible through consistent testing during the design stage of the project.
I. Introduction

- 632 meters high with fastest elevator

- Produced a structure and shape that reduces wind loads by 24% which in turn resulted in a saving of $58 million in construction costs.
I. Introduction

- Greater sustainability – vertical-axis wind turbines will generate up to 350,000 kWh of supplementary electricity per year.
- Simulation tools are crucial in facilitating architects on implementing energy efficiency aspects from the conception of design process.
I. Introduction

- The tower features elements such as an innovative curtain wall suspended from the mechanical floors, to carry the load of a transparent ‘glass skin’.
- The double-layered insulating glass façade is calculated to reduce the need for indoor air conditioning, and is made of a reinforced glass with a high tolerance for temperature changes.
I. Introduction

- Architects seek to position themselves as collaborative leaders at higher thresholds of building design and performance.

- This is the desire by not only every member of the built environment players, but also across the marketplace.

- High performance buildings demand also high-performance users.

- With the increasing awareness and focus on sustainability, the century architect must become fluent with vocabulary and technologies that predict, test, and quantify energy performance in buildings.
I. Introduction

• This fluency is essential to respond to the requirements of new green building codes and well informed and shrewd clients.

• Clients who demand to know how actual performance, in the future, matches predictions of energy consumption by their design team.

• Hence the needs of the architect to understand energy requirements and to energy model that focuses on energy performance.
I. Introduction

• A building energy model is a tool that can be utilized throughout the design process to test various design options and optimize the performance of all building typologies.

• Earlier, architects design buildings as formal constructs, and engineers then make them work at the building systems level.

• More integrated design thinking now being driven by the need for highly energy-efficient, high performance buildings.
I. Introduction

• Architects, engineers, and energy modelers can learn how to work better together and more collaboratively than they do under today’s business-as-usual practices.

• Need to better understand each other’s language—or, even better, to forge a new, common, language that comprehends all of the interests of design, including building systems, client requirements, and code requirements.
II. Background of energy modeling?
II. Background of energy modeling

• The change in looking at energy as a design and not as technology.

• High performance design includes energy and energy efficiency.

• An issue starts from the project inception through out construction and Operation.

• Programmatic strategies, building envelope, orientation, and massing, add to them MEP : lighting, energy, comfort and indoor air quality, and O & M.

• Search for a tool : Performance or energy modeling.
II. Background of energy modeling

Twenty years of research efforts have produced a broad understanding of the implications of building energy use, as well as an increasing number of energy-efficient strategies and technologies with significant potential for energy savings.
II. Background of energy modeling

- The algorithms and the lengthy calculations required to estimate year around energy behavior have necessitated the development of building energy design tools, both manual and computer based.
III. Design & Modeling Process of Energy

Defines minimum requirements for providing energy design assistance using building energy simulation and analysis.
III. Design & Modeling Process of Energy

*Standard 209-2018 defines seven design-phase modeling cycles, each with specific modeling goals coordinated with the typical design process.

*Each modeling cycle is an extension of a general modeling cycle that can be applied any time during design.

*Three additional modeling cycles are defined for construction and operation phases, and include a design and post-occupancy performance comparison to help owners and modelers understand the impact of design phase modeling assumptions and inform future modeling efforts.
III. Design & Modeling Process of Energy

“To exploit the full capability of these modeling tools, we must transform our design approach from a sequential process to a collaborative process, where all of the disciplines involved in the building design and construction work as a team from the beginning.”

—Lynn G. Bellenger, P.E., Fellow ASHRAE President 2010-2011, “Modeling a Sustainable World”
III. Design & Modeling Process of Energy

- Design tools can greatly assist where specialist or expert knowledge of a topic is not available or where the required study of an issue would be prohibitively complex or time consuming.
- Most design tools are based on either mathematical or empirical relationships.
- Many design-related issues can now be analyzed through the use of design tools.
- The various issues which can be addressed are extensive.
III. Design & Modeling Process of Energy

- **Design issues** may be broken down into the following groupings:
  - building fabric
  - thermal performance
  - daylighting and electrical lighting
  - comfort
  - ventilation (mechanical and natural)
  - infiltration
  - services systems
  - energy consumption
  - control
  - shading/overshadowing
III. Design & Modeling Process of Energy

• Several factors are generally taken into account by all design tools:
  1. Location
  2. Building Geometry
  3. Standard energy calculations
  4. Software
III. Design & Modeling Process of Energy

• 1. Location
III. Design & Modeling Process of Energy

Summary of application and capability

Passive Systems

- Direct gain
- Trombe wall
- Attached sun space
- Hybrid
- Cooling

Natural ventilation Zonal Requirements

- Single zone
- Multi-zone
III. Design & Modeling Process of Energy

Heating
- Loads
- Space temperatures
- Active solar
- Shading
- Economics
- Effect of mass
- Domestic Hot Water Cooling

HVAC systems
- Loads
- Space temperatures
- Shading
- Economics
- Mass
- Passive cooling
III. Design & Modeling Process of Energy

Lighting
- Daylighting
- Artificial lighting
- Glare

Ventilation
- Ventilation
- Infiltration
- Air quality
Energy Modeling in Architectural Design

III. Design & Modeling Process of Energy

Summary of intended use and availability

Intended User

- Architect
- Engineer
- Technician
- Researcher

User Support

- User documentation
- Training
- Telephone/fax/e-mail support
- Source code
- Customization

Uses

- Pre-design
- Site analysis
- Schematics
- Design development
- Performance evaluation
- Research
III. Design & Modeling Process of Energy

Summary of results and output Load Determination

- Component
- Zone
- Building

Loads Output By
- Sub hour
- Hour
- Day
- Month
- Season
- Year

Temperatures
- Air
- Surface

Output Format
- Tabular
- Graphic
- Export to other analysis tools
III. Design & Modeling Process of Energy

Fuel Use By

- Consumption (month, year)
- Peak Demand (month, year)
- System components
- Energy system
- Total Building
III. Design & Modeling Process of Energy

Summary of input data

File Type
- Interactive
- Built-in graphics
- Pre-prepared files

Pre-design and Site Analysis Data
- Location
- Building type
- Occupancy
- Building Area
- Space temperature
- Local energy costs
- Generic building shape
- Local code requirements
- Lighting requirements
III. Design & Modeling Process of Energy

**Schematic Design Data**
- Building surface areas
- Glazing areas & orientation
- Zoning
- Room shapes
- Operating schedules & profiles

**Geometric Design Data**
- Building materials-opaque
- Building mass
- Transparent materials
- Interior finishes
III. Design & Modeling Process of Energy

Engineering Design
- Mechanical system
- Electrical system
- Lighting system
- Controls

Data Weather Data
- Solar radiation
- Wind speed
- Air temperatures
- Humidity
III. Design & Modeling Process of Energy

Summary of calculation procedures

Solution Techniques

☐ First principles
☐ Response factor
☐ Steady state

Solar Orientation

☐ Any, including sloped
☐ Diffuse, direct, reflected.
☐ Total
III. Design & Modeling Process of Energy

**Shading**
- ☐ Any solar obstruction
- ☐ Overhang only
- ☐ Daily switching
- ☐ Seasonal switching

**Room Temperatures**
- ☐ Surface and/or air
- ☐ Input schedules by user
- ☐ Fixed by tool
- ☐ Varied by tool

**U-Values**
- ☐ Variation with wind speed
- ☐ Day and night
- ☐ Constant

**Infiltration**
- ☐ Air change rate per hour
- ☐ Crack method
- ☐ Varied with wind speed
III. Design & Modeling Process of Energy

Internal Loads
- Sensible and latent (separate)
- Sensible and latent (total)
- Sensible only

Ventilation
- Sensible
- Latent
- Varies by schedule
- Calculated as a network
### III. Design & Modeling Process of Energy

#### Levels of Modeling Elements and Inputs

<table>
<thead>
<tr>
<th>MODEL ELEMENT</th>
<th>INPUT INFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural massing + form</td>
<td>Building shape + orientation, Principal building function, Total floor area,</td>
</tr>
<tr>
<td></td>
<td>Number of floors + thermal zoning of floors, Floor-to-floor height + Floor-to-ceiling height</td>
</tr>
<tr>
<td>Envelope</td>
<td>Window dimensions (for different locations), Window sill and head height (above floor), Window to wall ratio, Window+skylight characteristics (SHGC, U-value, VLT, frame-type), External shading geometry, Wall, roof + foundation construction makeup, Interior-partitions, Internal-mass and Infiltration assumptions</td>
</tr>
<tr>
<td>Internal loads</td>
<td>Anticipated building occupancy, lighting power density, plug-load density + exterior lighting peak power, Daylighting and/or occupancy sensors to be used?, Elevator?</td>
</tr>
<tr>
<td>Internal load schedules</td>
<td>Anticipated occupancy, lighting, plug-load + exterior-lighting schedules (summer/winter; weekday, weekend, holiday hours of use)</td>
</tr>
<tr>
<td>HVAC equipment + schedules</td>
<td>Type of system, Size (efficiency, capacity, etc.) Schedule of operation and controls</td>
</tr>
</tbody>
</table>
Desirable Characteristics Of Energy Modeling Tools:

- Data Transfer
- Building System Defaults
- Simulations program calculation Engine: Robust
- Comprehensive Resource Analysis
- Clear Graphic Output
- Real World Accuracy
Architect’s Questions:

- Ease of Use
- Time & Cost
- Interoperability
- Input
- Output
- Accuracy
IV. Modeling Tools

Who Develops Simulation Tools

<table>
<thead>
<tr>
<th>ENGINE</th>
<th>INTERFACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE-2</td>
<td>eQUEST</td>
</tr>
<tr>
<td></td>
<td>Visual DOE</td>
</tr>
<tr>
<td></td>
<td>EnergyPro</td>
</tr>
<tr>
<td></td>
<td>Autodesk GBS</td>
</tr>
<tr>
<td>EnergyPlus</td>
<td>Bentley Hevacompt</td>
</tr>
<tr>
<td></td>
<td>Design Builder</td>
</tr>
<tr>
<td></td>
<td>OpenStudio</td>
</tr>
<tr>
<td></td>
<td>Simergy</td>
</tr>
<tr>
<td>Energy 10</td>
<td>TRNSYS</td>
</tr>
<tr>
<td>TRNSYS</td>
<td>TRNSYS</td>
</tr>
<tr>
<td>HAP</td>
<td>HAP</td>
</tr>
<tr>
<td>IES-VE</td>
<td>IES-VE</td>
</tr>
<tr>
<td>TRACE 700</td>
<td>TRACE 700</td>
</tr>
</tbody>
</table>
## IV. Modeling Tools

<table>
<thead>
<tr>
<th>Modeling Tool</th>
<th>Calculation Engine</th>
<th>Graphic Interface for Front-end Input</th>
<th>Graphic Results Provided</th>
<th>Appropriate for Early Design Phase</th>
<th>Approved for Code Compliance Modeling</th>
<th>Freeware</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMFEN (RESFEN – residential)</td>
<td>EnergyPlus</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>DesignBuilder</td>
<td>EnergyPlus</td>
<td>Yes</td>
<td>Limited</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Ecotect</td>
<td>CIBSE Admittance Method</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<tr>
<td>EMIT1.2</td>
<td>None (spread-sheet)</td>
<td>No</td>
<td>Not specifically, (but t/s capability)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>EnergyPro</td>
<td>DOE-2.1E</td>
<td>No</td>
<td>No</td>
<td>Yes (easiest to use)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>eQUEST®</td>
<td>DOE-2.2</td>
<td>Yes</td>
<td>No</td>
<td>Must be far enough along to input HVAC</td>
<td>Yes (most popular)</td>
<td>Yes</td>
</tr>
<tr>
<td>Green Building Studio / Vasari</td>
<td>DOE-2.2</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Hourly Analysis Program (RAP)</td>
<td>Transfer Function Method</td>
<td>Limited</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<td>IES Virtual Environment</td>
<td>Apache</td>
<td>Yes</td>
<td>Yes</td>
<td>Gaia + Toolkit Yes Pro requires input of HVAC</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>OpenStudio</td>
<td>EnergyPlus</td>
<td>Yes (similar to SketchUp)</td>
<td>Yes</td>
<td>Must be far enough along to input HVAC</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Sefaira Concept</td>
<td>Sefaira</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>No</td>
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<tr>
<td>Simergy</td>
<td>EnergyPlus</td>
<td>Yes</td>
<td>Limited</td>
<td>Not yet</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>TAS</td>
<td>TAS</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>TRACE® 700</td>
<td>TRACE</td>
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<td>Limited</td>
<td>Must be far enough along to input HVAC</td>
<td>Yes</td>
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<tr>
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<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
IV. Modeling Tools

• There are many software packages available which analyze a specific aspect of one or more building components.

• For example, PHYSIBEL, developed in Belgium which allows the heat transfer phenomena of construction elements to be analyzed in great detail.

• Suited to detailed investigation or research studies.

• Software to model, analyze and optimize whole buildings, 2D/3D building.
**IV. Modeling Tools**

**IV.2 PASSPORT**: correlation-based evaluation tool enabling an assessment of the residential building heat requirement.

- Has a close link to a preliminary European Standard for calculating energy requirements for heating in residential buildings.

- The development team and a working group of the European Standardization Committee (CEN TC 89 WG4), having similar concerns, worked in close collaboration in the development of the theoretical basis for the design tool.
IV. Modeling Tools

IV.3 New Method 5000:

- A manual and computer-based design tool developed to determine quickly and approximately the performance of passive solar buildings.
- It provides a procedure based on a set of data forms which are filled out in sequence with appropriate calculations.
- It is used to predict the auxiliary heating required for any specified month.
- This is done by subtracting the useful heat gains and heat losses (both in kWh) for a given month.
IV.4 The ADELINE software tool provides architects and engineers with detailed information about the behavior and the performance of indoor lighting systems.

Both natural and electrical lighting problems can be solved for rooms of simple and complex geometry.

ADELINE predicts lighting performance by processing a variety of data (including geometric, photometric, climatic, optic and human response) to perform light simulations and to produce extensive numeric and graphic information.
IV. Modeling Tools

IV.5 ESP-r: A dynamic thermal simulation environment, used to explore a range of issues including building fabric, mass flow, ideal and detailed plant systems—separately or in combination—at timesteps ranging from seconds to an hour.

It is composed of a number of programs, each contributing certain facilities to the simulation process but the primary interface is provided by way of a project management facility.

It attempts to simulate the real world as rigorously as possible at a level which is consistent with current best practice in the international computer simulation community.

It combines building, plant, electrical power, with network and/or CFD based air flow simulation.
IV. Modeling Tools:

IV.6 Design Performance Modeling (DPM):

- A tool to inform design decisions by predicting a building’s performance with respect to energy efficiency, daylight penetration, glare control, thermal comfort, natural ventilation, and similar factors.

- Typically prepared during the early stages of design, before engineering systems are incorporated.
IV. Modeling Tools:

IV.6 Design Performance Modeling (DPM):

- Its analysis of energy use is less complex and time consuming than that of Building Energy Modeling.
- It allows for more rapid exploration of a greater number of parameters, which may include architectural form impacts, window-to-wall ratio implications, glazing and shading options, R-values of opaque walls, and the like.
- DPM allows cost, aesthetics, and performance (including energy performance) to be given value to discuss among the project team and with the client in real or almost real time.
IV. Modeling Tools:

IV.7 Building Energy Modeling (BEM)

- Predicts a building’s anticipated energy use and corresponding energy savings, as compared to a standard baseline.
- It demonstrates project compliance with local, regional or national energy codes (if they exist).
- Predicts energy performance based on Typical Meteorological Year (TMY) data, as well as assumptions about building operation and maintenance.
IV. Modeling Tools:

IV.7 Building Energy Modeling (BEM)

- The prediction is only as accurate as the assumptions, which should be documented and understood by the project team, as well as the client, the building operator, and the end users.

- Changes made during the design and construction process should be used to update the BEM, to increase its utility and predictive accuracy.
IV. Modeling Tools

IV.8 Building Operation Modeling (BOM):

- Introduces actual utility bills, use patterns, hours of operation, functioning of systems, and real weather conditions for a completed building into a model structured similarly to the Building Energy Model.
- Allows the comparison of actual energy use with the predicted use.
- Determines causes of discrepancies between predicted energy use and actual energy use, which in turn facilitates tuning of systems to better meet—or even exceed—the design goals.
IV. Modeling Tools

IV.8 Building Operation Modeling (BOM):

- ASHRAE Guideline 14 and the USDOE’s International Performance Measurement & Verification Protocol (IPMVP) provide the currently agreed methods for this type of work.

- The Building Operation Model is used to satisfy emerging building code requirements for post-occupancy monitoring.
IV. Modeling Tools

IV.9 Project Resources Modeling (PRM):

- The most extensive and broad one.
- It assesses multiple resource issues that affect and are affected by the development of a project, including energy, water, material selection, and solid waste.
- It may also include transportation, primary growth issues, manufacturing, social and agricultural elements, embodied energy, carbon emissions, health, and other factors.
IV. Modeling Tools

IV.9 Project Resources Modeling (PRM):

- It addresses the interrelationships among resources, their consumption, efficiencies, and conservation.

- PRM can assess existing site resources, as well as components that may be brought to the site.
IV. Modeling Tools

IV.10 Energy Use Intensity (EUI):

- A measurement that describes a building’s annual energy consumption relative to the building’s gross square footage.
- Used as an expression of an existing building’s actual, metered energy consumption, or as a comparative average, which is derived from a data set of metered information for a particular building use type in a specific location.
- Both of these uses of EUI are based on real, measured building energy use data.
IV. Modeling Tools

IV. 10 EUI can be relative to either site or source energy:

- **Site energy**
  - The measure generally familiar to the design profession.
  - It is the amount of energy consumed by a building and is reflected in utility bills paid by the building owner.

- **Source energy**
  - A more accurate measure of a building’s energy footprint. It includes energy that is lost during production, transmission, and delivery to the building.
  
  * Electricity is the prime example; what is consumed at the building is only a proportion of the fuel energy fed into the power plant.
IV. Modeling Tools

IV.11 E-Grid

- A multiplier that describes the mix of electrical generation types (e.g., coal, natural gas, nuclear, solar, hydro, etc.) that make up national and regional power grids.
- Accounts for differences in electricity generation source capacities, which has implications on the amount of resulting carbon dioxide emissions.
IV. Modeling Tools

IV.11 E-Grid

- It provides data that enable architects to understand the real environmental impact of building design’s energy consumption.

- E-Grid relates the energy lost due to inefficiencies inherent in generation and distribution systems to the on-site electrical consumption of a building, which accounts for only a portion of the electrical power generated to serve the building.

- Understanding the full impact of building designs means understanding how the electricity is generated that serves the building as well as the associated emissions.

- E-Grid is currently accepted as the way to convert site energy to source energy.
IV. Modeling Tools

IV.12 Predicted Energy use intensity (pEui):

- Energy use for a project base on modeled site energy.
- A modeled number very likely will not match actual building operations.

- pEUI = site KW/m²-yr
**IV. Modeling Tools**

**IV.13 Energy use intensity proposed (EUIp)**

- The energy use for a project based on modeled source energy.
- It includes energy generation and transmission losses and is therefore a better prediction of the total energy footprint of your project than pEUI.
- \( \text{EUIp} = \text{site KW/m}^2\text{-yr} \).
IV.14 Zero Energy performance index (zEpi)

- A value that represents the ratio of energy performance of a proposed building design compared to the average energy performance of buildings with similar occupancy and climate types, benchmarked to the year 2000.
IV. Modeling Tools

IV.14 Zero Energy performance index (zEPI)

- The ratio of a proposed building’s EUIp to the EUI of a baseline or reference building model, multiplied by 100 to give a scalar value, which can range from zero (for a zero-energy building) to 100 (for a building that uses the same amount of energy as the baseline model).

- The lower the value, the better the energy performance.

- The 2012 International Energy Conservation Code (IECC) requires a zEPI of 57; the 2012 International Green Construction Code (IgCC) requires a zEPI of 51, which represents a 10% increase in efficiency over the 2012 IECC.
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IV. Modeling Tools

IV.14 Zero Energy performance index (zEPI)

- Understanding the zEPI and its implications are necessary for establishing appropriate energy consumption goals for buildings designed and constructed under the new IgCC.

- Understanding the implications of design choices on zEPI for a project will help the design team to design to an energy budget and to succinctly communicate design ramifications to interested parties, such as the client, financers, and donors.
zEPI = zero Energy Performance Index

\[
\text{zEPI } \leq 57 \times \text{EUIp} \div \text{EUI (BASELINE MODELED AS PER GCC)}
\]
IV. Modeling Tools

EUI, EUI (baseline modeled as per IgCC), pEUI and EUlp Are Not Equal
IV. Modeling Tools

IV.15 ASHRAE 90.1 – 2016 – APPENDIX G

- In Compliance with the Standard 90.1-2016 and beyond.
VI. Conclusions

• Enhance broad staff participation and understanding, rather than believe that modeling should be left to isolated subject experts.

• Engage actively through collaborative attitudes and gain collaborative skills.

• Teamwork and coordination tend to be more effective.

• Architects and engineers should keep pace with the development of new tools.
VI. The Future & Conclusions

- The majority of buildings (whether new, or rehabilitation projects) are still designed without any energy-related considerations beyond those enforced by energy codes.

- Architects should have the means to assess the impact of new strategies and technologies efficiently and reliably during the building design process.
VI. Conclusions

- Architectural practice by delivering better projects and feedback will encourage associations to continue improving and simplifying the utilization of available tools.

- Practicing the use of modeling tools will help authorities to set cap of energy utilization index.

- Information and feedback from building constructed and in operation, communicate obstacles identified along the way.
VI. Conclusions

- The decisions made by architects, engineers and other design team members can have a significant impact on the eventual energy consumption of a building and the quality of its internal environment.

- This huge amount of data (Big Data) allows to build a constantly updated library of buildings, that will encourage architects to improve in the energy design.

- Increased processor power and reduced computer costs will make these tools more accessible to the ordinary building architect.
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Q & A

traboulsi.Samir@gmail.com