# The Use of Building Simulation and Design Software in the Building Design Process

**ASHRAE Twin Tiers**
**Annual Spring Symposium**

**April 19, 2005**

Hugh I. Henderson, Jr., P.E.

CDH Energy Corp.

Cazenovia, NY

# ARTI Project Snapshot
## (Project 605-30020)

ARTI Research
www.arti-research.org

- "State-of-the Art" Review of Software
- Look at software tools and "integrated design" from two perspectives:
  - Architect/General Contractor
  - Engineer/Mechanical Contractor
- Focused on small commercial (<20k)
- How can software tools help to integrate the design process?
- Project completed in 2001… before LEED

# Presentation Overview

- The whole building design concept
- What software do engineers & architects use (based on “market research”)?
- What types of software are available?
- Comparing mainstream simulation tools
- The promise of software interoperability
- What to expect for the future

# Whole Building Design

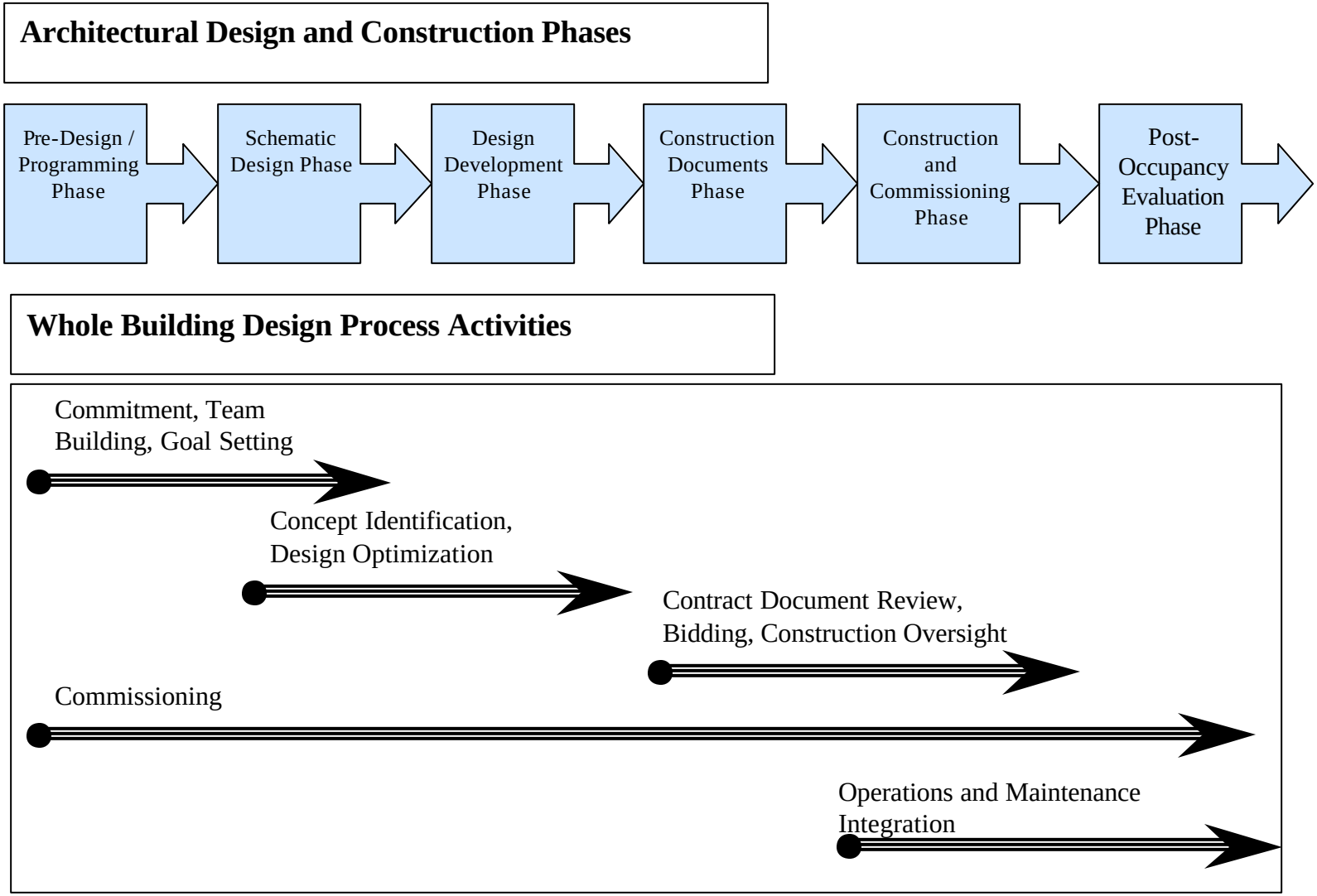
# What is “Whole Building Design”

- Whole-building analysis in the design of small commercial buildings
  - Design the building as a system
  - Consider the mutual interactions of design decisions affecting the architectural form, opaque shell, glazing, lighting, and HVAC systems on building first costs and operating costs
  - Integrate whole-building analysis tools into existing or emerging design practices to encourage widespread use.

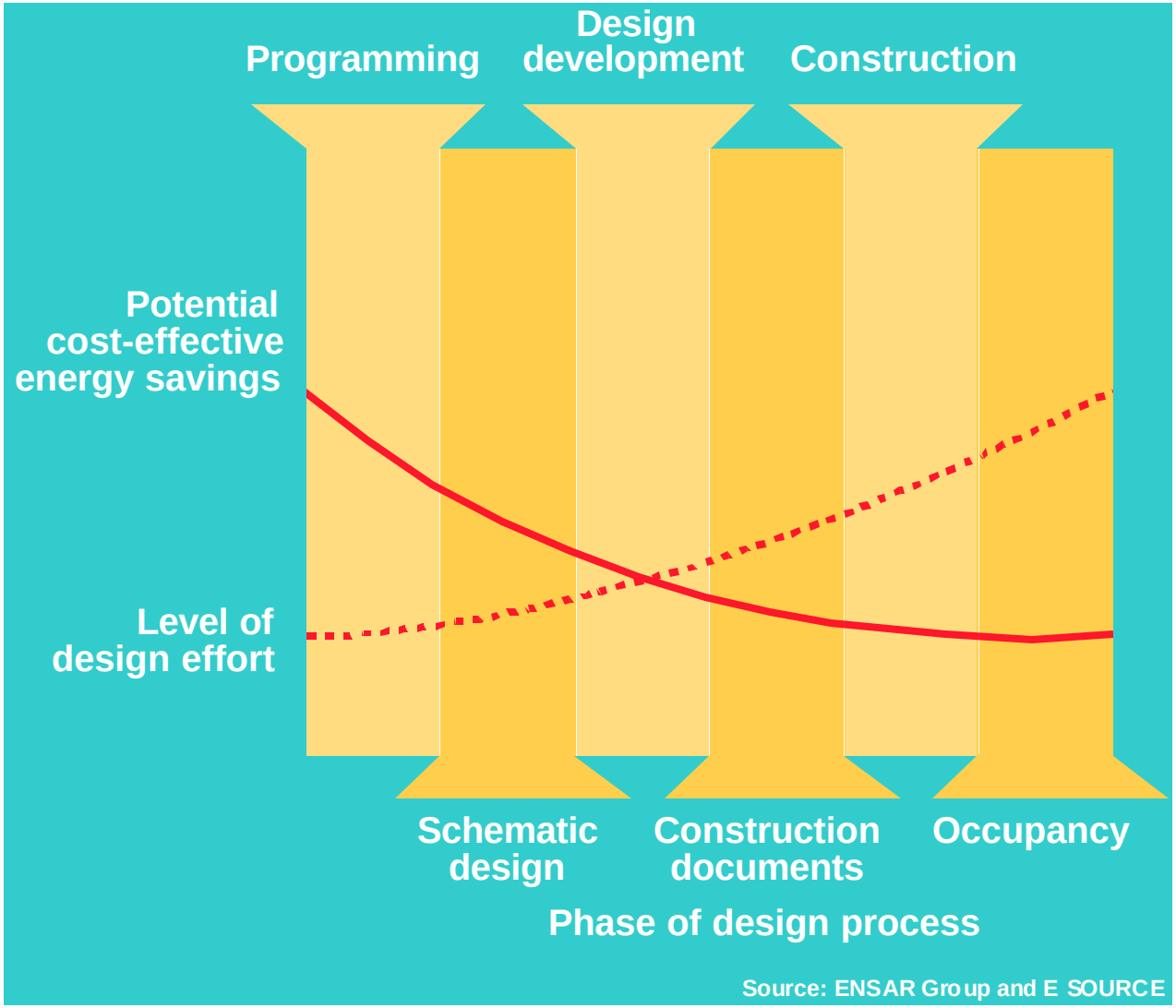
# “Can’t we all just get along..”

- Whole building design:  architectural and engineering teams have to work together from beginning
  - Often means engineer should be involved sooner
  - Engineer (or specialized consultant) generally has knowledge of specialized software tools
  - Can quantitative tools be used before design is finalized?
- Examples of benefits:
  - Better windows vs. less HVAC
- Its about better communication
- Can software interoperability help?

# Whole Building Design Process



# Design Sequence



# Whole Building Design Benefits

- Simple upgrade approach
  - Standard design is upgraded with energy efficient equipment
  - 10-30% energy savings with 5-10 yr. simple payback
- Whole building approach
  - Design philosophy incorporates energy issues
  - Building designed to meet the budget
  - 20-50% energy savings at little or no capital cost impact
- Whole building energy analysis (WBEA) tools facilitate design process

# Why Use WBEA ?

## When more than just size matters?

Examples where simple load and sizing analysis is not enough:

- Daylighting benefits/tradeoffs
- HVAC control issues (economizer, DCV)
- Refrigeration/HVAC interactions and tradeoffs (supermarkets)
- Geothermal Heat Pumps vs. other systems
- Dehumidification performance
- Thermal storage
- Distributed generation / BCHP benefits
- Natural /Mixed Ventilation

# The Impact of LEED & NYSERDA

- LEED is now #1 driver of whole building design process
  - *"….energy savings? Who cares, just give me my points!"*
- LEED has been highly successful promoting the use of whole building design.
- NYSERDA New Construction Program has also been successfully promoting whole building design approach in NY for many years
  - generally using building simulation tools (DOE-2, HAP, TRACE, etc)
  - Consultant supports the design team

# What Software to Practitioners Use?

# “Market Research” Approach

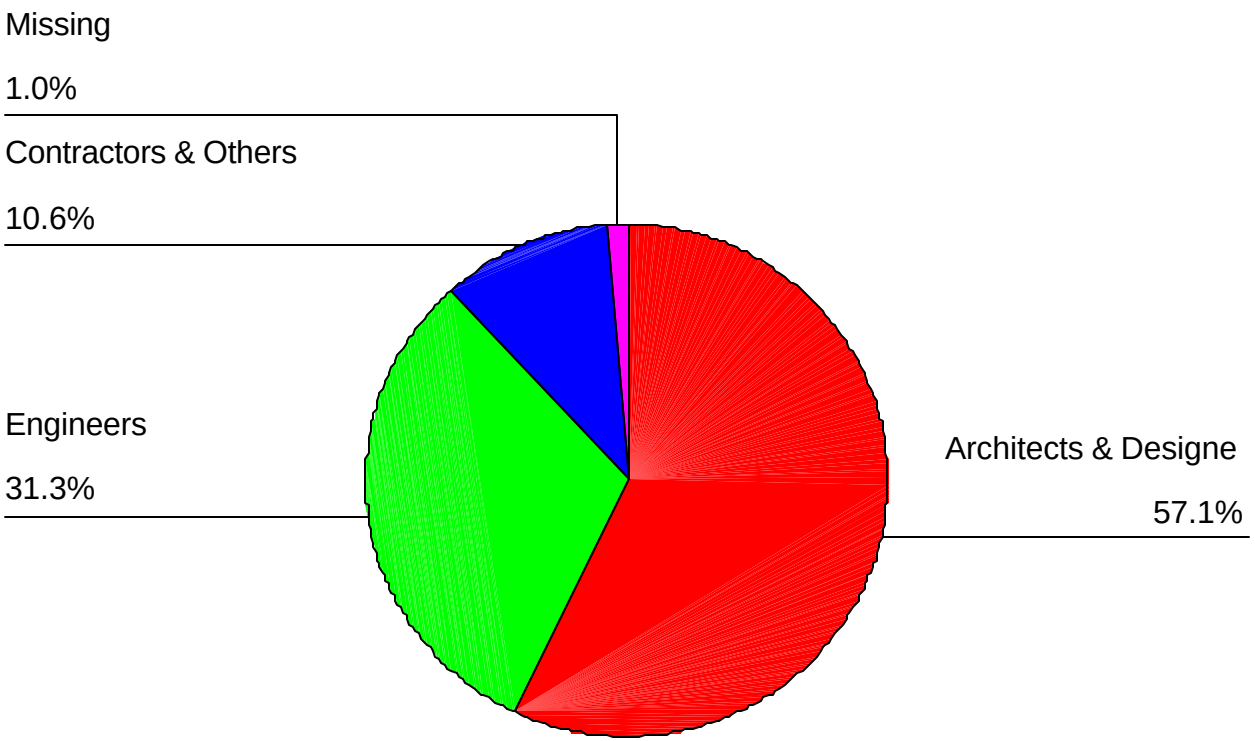
- Research and understand customer needs
  - Designers and builders of small commercial buildings
- Evaluate existing tools/software against customer needs
- Suggest enhancements to tools based on customer needs
  - Customer identified
  - Anticipated
- Data collection
  1. Web Survey
  2. Focus Groups

# Web Survey

- Posted a questionnaire at web site for 2-3 months in **late 2000**
- Motivated respondents with a giveaway
- Solicited respondents by email from targeted lists
- Nearly 200 qualified respondents completed the survey

# Respondent Demographics

N=198



# Office-Wide Design Practices

| | >20,000 Sq.Ft. (% “always”) | <20,000 Sq. Ft. (% “always”) |
|---|---|---|
| 2D-CAD | 82.2% | 76.3% |
| 3D-CAD Simple | 10.3% | 9.7% |
| 3D-CAD Detailed | 7.4% | 6.9% |
| Web-Based Project Mgmt. | 3.3% | 2.7% |

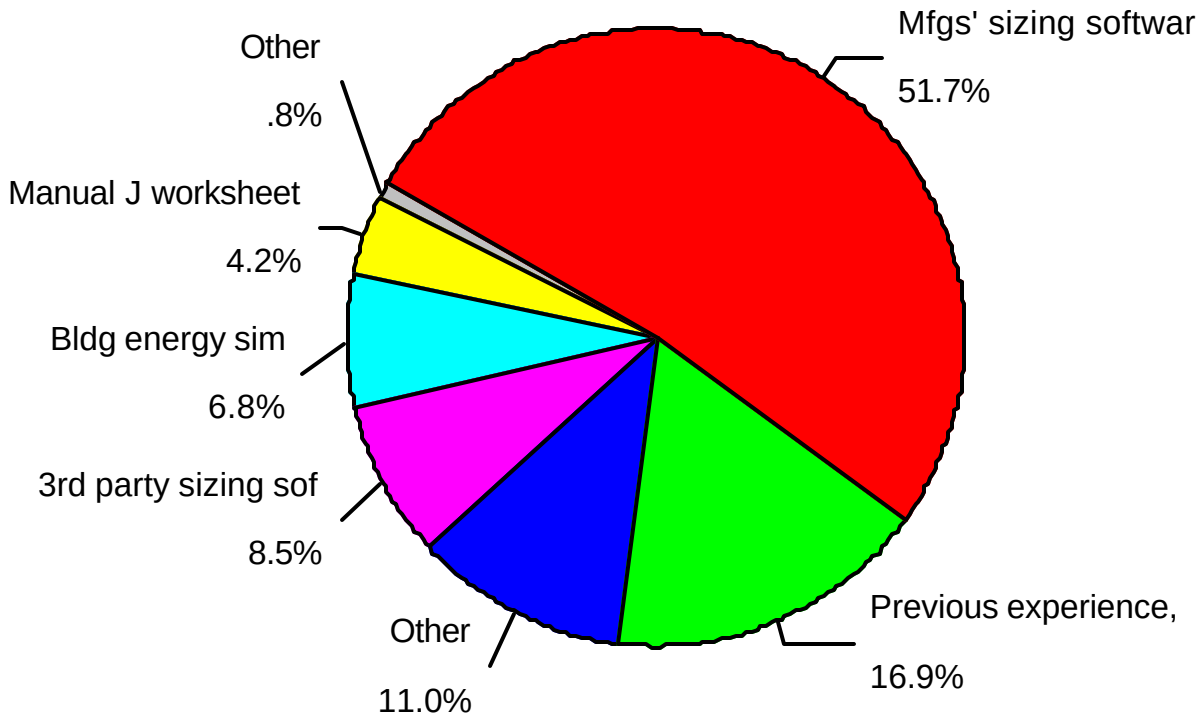
# Office-Wide Design Practices

| | >20,000 Sq.Ft. (% “always”) | <20,000 Sq. Ft. (% “always”) |
|---|---|---|
| Paper-based energy code compliance | 14.9% | 15.3% |
| Software-based energy code compliance | 14.8% | 13.6% |
| Advanced energy analysis beyond requirements | 5.0% | 5.4% |

# Tools Used “Most Often”

HVAC Equipment Sizing:

What Method Do You Use Most Often?



# Top Three Tools Used Most Often

- Form, Siting, Orient.
  - Renderings (33%)
  - Prev. exper. (32%)
  - 3D software (13%)
- Lighting & Daylighting
  - Prev. exper. (50%)
  - Mfg. literature (13%)
  - Ltg. Software (11%)
- Envelope and Glazing
  - Prev. exper. (38%)
  - Mfg. literature (18%)
  - HVAC load calcs (10%)
- HVAC Equip Sizing
  - Mfg. software (52%)
  - Prev. exper. (11%)
  - 3rd party software (9%)
- Duct and Pipe Design
  - Ductilator (58%)
  - Prev. exper. (18%)
  - Mfg. software (8%)
- HVAC Equip Selection
  - Mfg. literature (47%)
  - Mfg. software (16%)
  - Prev. exper. (14%)

# Top 3 Tools Used Most Often

- IAQ and Vent Analysis
  - ASHRAE 62 (38%)
  - Prev. exper. (26%)
  - State code (23%)
- Refrigeration System Design and Spec.
  - Mfg. literature (49%)
  - Prev. exper. (26%)
  - Mfg. software (12%)
- Green Design
  - Prev. exper. (31%)
  - Mfg. literature (20%)
  - Rating system (13%)
- Energy Analysis & Code Compliance
  - Paper forms (27%)
  - Mfg. software (18%)
  - Prev. exper. (10%)

# Focus Group Participants

## Denver Focus Group

- Firms
  - 4 Architecture firms
  - 3 Design/build firms
  - 1 Engineering firm
- Disciplines
  - 5 Architects
  - 3 Engineers
- Software Tools Used
  - 2D CAD, 3D CAD, Code compliance, Estimating, Mfg. product selection and sizing software

## Syracuse Focus Group

- Firms
  - 4 Architecture firms
  - 1 Design/build firm
  - 3 Engineering firms
- Disciplines
  - 4 Architects
  - 3 Engineers
  - 1 Construction Mgr.
- Sofware Tools Used
  - 2D CAD, 3D CAD, Mfg. product selection and sizing software, duct design software

# Focus Group Findings

- Lots of software being used
  - CAD
  - Equipment selection
  - System sizing
  - Cost estimating
- Lots of redundant data entry
- CAD is mostly 2D; going to 3D is a big step

# Focus Group Findings

- Computerized HVAC Loads common
  - Tradeoffs are evaluated in some cases
    - Mostly glazing; lighting generally not considered
    - Depends on when the ME is brought into the process
  - Schedules don't permit a lot of interaction between disciplines
    - Design-build projects more likely to encourage collaboration
  - Iterations, especially cost estimating, are time consuming

# Focus Group Findings

- Software supplied by HVAC equipment manufacturers most common
- Not very happy with software provided by manufacturers
  - expensive, hard to use, not well supported
  - …but, very well marketed
- Energy simulations rarely done
  - Incremental data entry should be small
  - Software hard to use; not well linked

# Focus Group Findings

- Time and training are major barriers to increased software use
- Limiting liability is major motivator
- Reps are important part of process
  - Push software
  - Provide analysis
- Lack of tools a barrier to increased use of daylighting and innovative electric lighting
- Web-based tools starting to be used
  - Catalogs
  - Selection software

# Market Research Conclusions: Designers' Needs

- Simplified tools for use during concept design
  - Evaluate options
  - Set goals
- Improve usability and interoperability of software tools
  - 3D CAD software that is easier to use
  - Load and energy programs linked with CAD
  - Links to cost estimating software/databases
  - Improve interface between lighting and building energy packages
  - Automated parametrics

# Overview of Software Tools

# Broad Spectrum of Software Tools Related to Buildings/HVAC

- What are capabilities of each tool?
- Who uses them for what purpose?
  - Building designers (sizing / design)
  - ESCO or utilities
  - Researchers / policy wonks
- Who created or promoted the tool and for what purpose?
  - Assist designers
  - Promote technology / products
  - Promote energy efficiency
  - Environmental Impacts
  - Evaluate building science

# Software Tool "Taxonomy"

- Previous lists of tools have been "self classified" (e.g., DOE's list)
- We looked at who uses (or is likely to use) each tool
- What tools currently are used by "Design Practitioners"
- What tools require expert "knowledge" or complex input data
- Distinguish between detailed hourly energy analysis and simplified approaches

DOE Software List:
www.eere.energy.gov/buildings/tools_directory/

# Tool Categories

| Practitioner Design Tools |
|---|
| CAD Environments |
| Lighting Design Tools |
| Architectural Visualization Tools |
| Fenestration Selection Tools |
| Shading / Solar Angle Tools |
| Code Compliance Tools |
| Single-Zone Load Tools |
| Multi-Zone HVAC System Load Tools |
| Duct Sizing / Layout Tools |
| Cost Estimating Tools |
| Integrated Design Suites |
| HVAC Product Selection and Configuration Tools |
| Engineers “Toolbox” |
| Piping Analysis and Pump Sizing Tools |
| IAQ / Standard 62 Compliance Tools |
| Psychrometric Tools |
| Refrigeration Load Tools |
| Coil Selection Tools |
| Geothermal HP Loop Sizing Tools |
| Acoustics Analysis Tools |
| Solar DHW / PV System Design Tools |
| Weather Tools and Utilities |

| Whole Building Energy Analysis Tools |
|---|
| Simplified Energy Analysis Models (DD, bin analysis, day profile per month) |
| Basic Hourly Simulation Models (calculation engines) |
| General Hourly Simulation Models |
| Special Purpose Hourly Simulation Models |
| Screening Tools |

| Economic & Environmental Tools |
|---|
| General Life Cycle Tools |
| Technology Screening / Assessment Tools |
| Environmental Impact Assessment Tools |

| Specialized Analysis Tools |
|---|
| Daylighting / Illumination Models |
| Fenestration Models |
| Infiltration / Pollutant / Pressurization Models |
| 2D & 3D Heat and Moisture Transfer Models |
| Computational Fluid Dynamics Models |
| Equation-Based Solvers |
| General Component-Based Mechanical Models |
| Refrigeration System (Hardware-Based) Models |
| Refrigeration System Performance-Based) Models |

DOE List: www.eere.energy.gov/buildings/tools_directory/

# Practitioner Design Tools

- Automate or assist with day-to-day aspects of design process
  - CAD tools
  - duct design and layout
  - loads / HVAC sizing
  - energy code compliance
  - piping
  - cost estimating
  - many other tools to assist architects, etc
- Focus on practitioners in North America
  - European practitioners may do more energy analysis

# Whole Building Energy Analysis Tools (WBEA...our focus)

- Becoming part of the design process.
  - mainly when incentives are provided
- Historically simplified tools have been used
  - based on degree-day, bin methods, or daily profile for each month
- Many detailed calculation engines have been incorporated into general purpose tools with highly-developed user interfaces
- Other technology-specific “screening tools” have been developed using detailed calculation engines

# Economic & Environmental Tools

- Detailed life-cycle economic analysis tools
- Simplified screening tools
  - often spreadsheet based
- Environmental impact and green building compliance tools
  - energy, emissions, materials, IAQ
  - code or standard compliance

# Specialized Tools

- Building science research tools
  - conduction, fenestration
  - infiltration, multi-zone airflow, pressurization, contaminant transport
  - daylighting, illuminance
  - equation-based solvers
- Refrigeration-side models
  - hardware based (component details)
  - performance based (alternative refrigerant studies)

# Whole Building Energy Analysis (WBEA) Tools

# Review WBEA Tool Capabilities

- Selected 5 mainstream tools for detailed comparisons
- Looked at their ability to consider various technologies or technical issues
- Compared to “best available” specialty tools
  - are the WBEA tools state of the art?
  - where should improvements be made?
- Usability matters

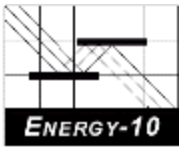
# Loads vs. Energy Analysis

Major manufacturer's (Carrier & Trane) offer two types of software:

- multi-zone load and system sizing
  - meets day-to-day needs of engineers
  - much larger user base (2-5 times larger)
- hourly whole building energy analysis
  - less popular among engineers
    - typically done only when client requires it (e.g., federal projects, EO111, LEED)
  - manufacturers focus less effort on these versions (most tools still in DOS circa 2001)
- With the info input for loads, very little extra effort is required for energy analysis

# Mainstream "Whole" Building Energy Analysis Tools


- DOE-2 - hourly simulation program from Lawrence Berkeley Laboratory & JJ Hirsch (DOE-2.1e, DOE-2.2, PowerDOE, **eQUEST**, etc...)




- Energy-10 - simplified energy analysis program from NREL

- EnergyPlus - next generation simulation program from USDOE. No interface yet!

- Trane Trace - hourly energy analysis/loads program from Trane Corporation


- Carrier HAP - hourly energy analysis/loads program from Carrier Corporation

# Technical:  Daylighting

- DOE-2.1, 2.2 and Energy-10  use same engine
  - Simple geometry
  - Rectilinear surfaces
- Energy-10 will add Superlite algorithms in ver. 2
  - roof monitors, light shelves, other complex fenestration

# Technical:  Glazing and Shell

- Most programs use annual average value for SC or SHGC
- Energy-10 and eQUEST have glazing system library
- Hourly Window 4 calculations planned for DOE2.2 (eQUEST)
- Most programs use 1-D heat transfer through layers
- Thermal bridge calculations done elsewhere
- Energy-10 provides worksheet to calculate thermal bridge effects

# Technical: HVAC

- Most programs use simple empirical or semi-theoretical curve fits for HVAC equipment
- Most have “hardwired calculations” for predefined HVAC system types (Energy Plus is the exception)
- Various program versions address specific issues:
  - Desiccants (DESICALC version of DOE-2)
  - Distributed generation / BCHP (eQUEST & DOE-2)
  - Duct leakage (FSEC mods to DOE-2)
  - Ground source heat pumps (1st order version in DOE-2)
  - Indirect/direct evap cooling (DOE-2)
  - Grocery refrigeration (simple version in DOE-2)
  - VVT systems (HAP, DOE-2)

# Other Technical/Modeling Issues

- Ground coupling
  - Most programs use SS 1D heat transfer to deep ground temp
  - HAP uses ASHRAE procedure, updates ground temp hourly
- Indoor Air Quality
  - HAP and Trace ASHRAE critical zone calculations from Std 62
  - Other programs accept CFM/person and SF/person as input
- Moisture Ad/Desorption in Building Materials
  - Not covered by “Mainstream” programs (except Energyplus)
  - FSEC also has modified version of DOE-2.1E

# Compare Capabilities

## report has more “consumer report-type” tables

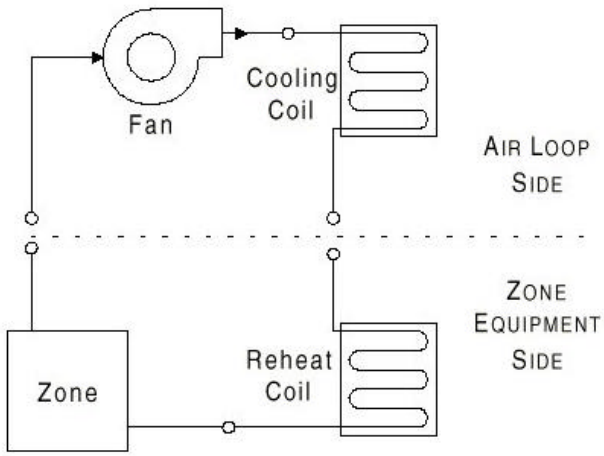
| | CAD interface | Code Compliance | System Sizing | IAQ | Thermal Comfort |
|---|---|---|---|---|---|
| DOE-2 | Future | 🗐 | 🗐 | | |
| ENERGY-10 | | | 🗐 | | |
| EnergyPlus | 🗐 | | 🗐 | 🗐 | 🗐 |
| Trane Trace | Future | | 🗐 | 🗐 | |
| Carrier HAP | Future | Future | 🗐 | | |

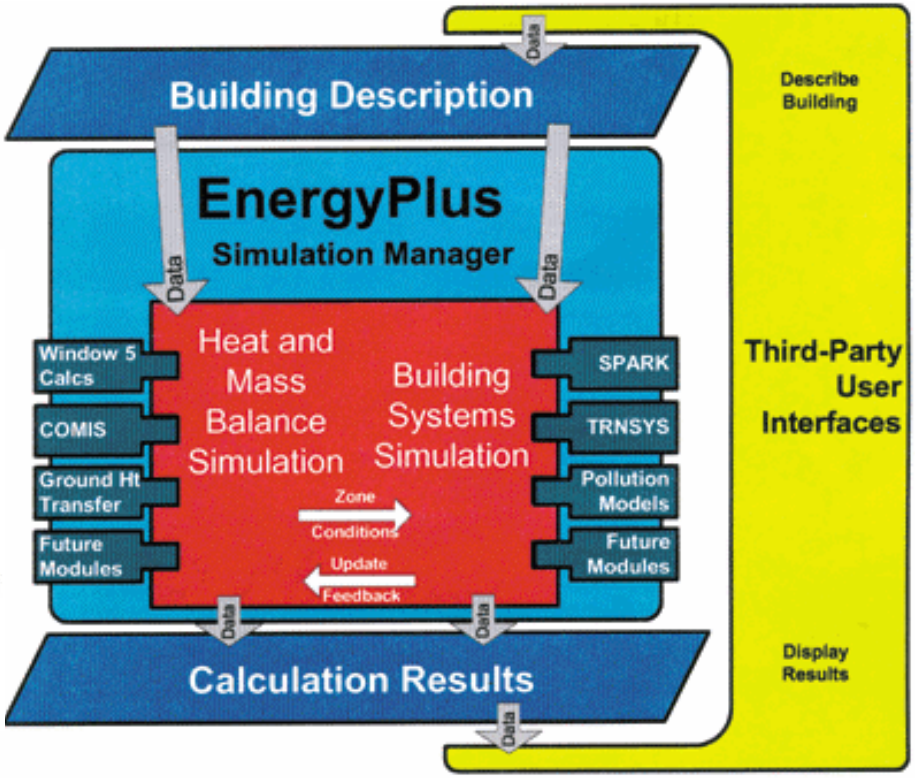
# Interfaces vs. Calculation Engines

- Trend toward developing easy-to-use interfaces for complex engines (DOE-2)
  - general purpose (PowerDOE)
  - specific purpose (DesiCalc)
  - quick screening tools (EDR Charette, eQuest)
- Healthy trend
  - uniform calculation methods
  - people focus on what they do best
- Is a better user interface always the answer?

# EnergyPlus – technically the best

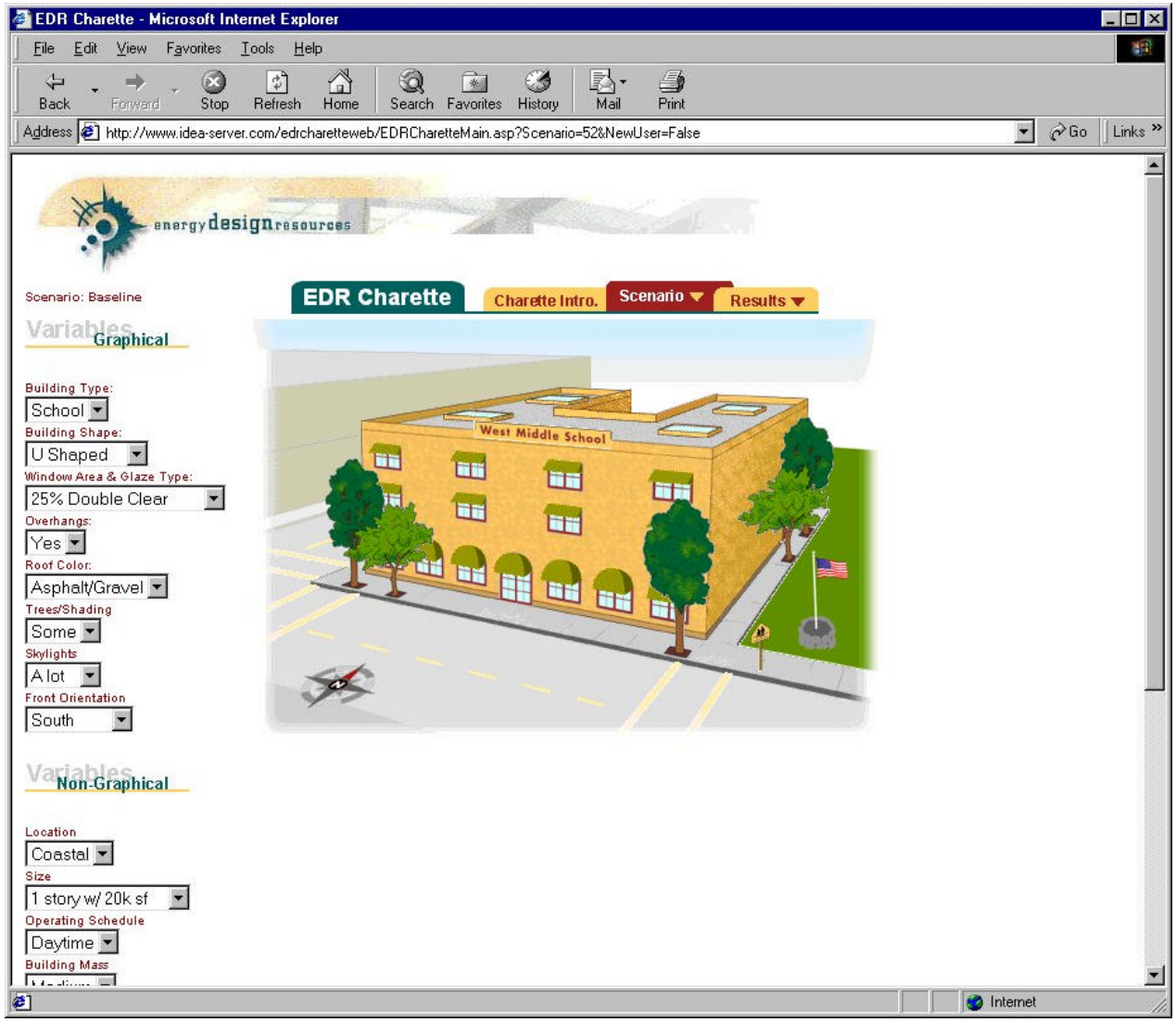
- "Best of" DOE-2, BLAST and others
- Calculations engine only (interfaces coming)
- Includes many of the features of other tools



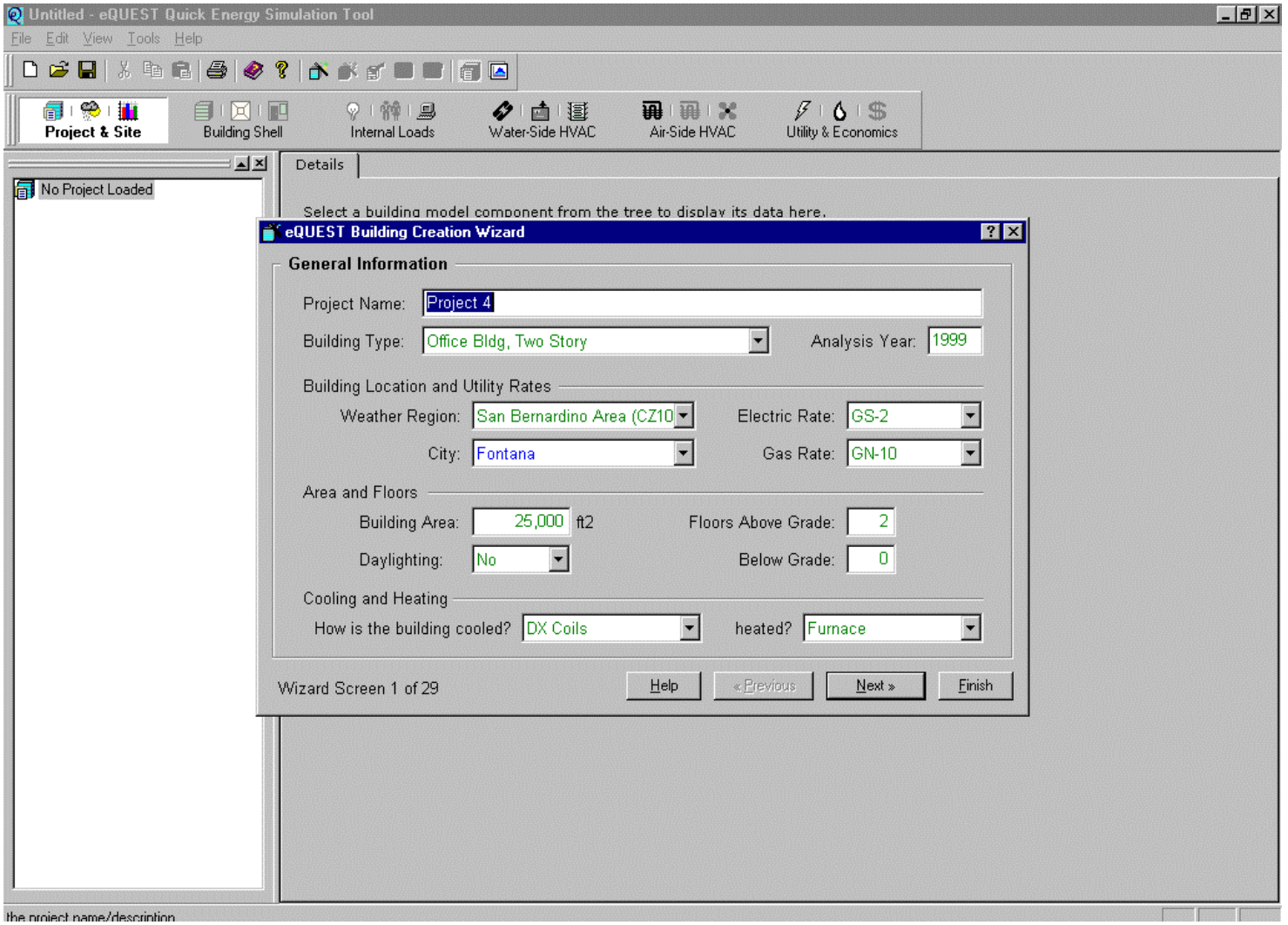
# Web-based Screening Tools

## www.energydesignresources.com



# eQUEST "Wizard" Approach

## www.doe2.com



# The Other Issue: Intelligent Default Data

- To make tools easy to use, the interface must also make “intelligent” decisions for the user
  - i.e., “give me in the schedules, settings, and internal loads for a typical school”
- Default Libraries
  - good libraries are available for a windows, building materials, etc
  - needed for HVAC equipment, components, etc
  - Good role for AHSHRAE
- Interoperability will have a dramatic impact

# Summary of Findings

- Lots of software tools being used by practitioners
- Even more software tools are available
- Loads tools much more common used than WBEA tools
- Extra time and effort for energy analysis is not normally done
- Interoperability & data exchange will have a huge impact

# Software Interoperability

# Software Interoperability

- The means to allow the easy exchange of data between programs
  - Use available data in CAD programs
  - Easily integrate vendor data
  - no more redundant data entry!
- Interoperability may be the key to wide spread adoption of
  - Building simulation models (WBEA)
  - Cost estimating tools

# Standards for Data Exchange

- EXtensible Markup Language (XML)
  - cousin of HTML
  - architecture, engineering & construction industry has **aecXML** (Bentley Systems)
  - green building XML (**gbXML**) is first representation for building simulation models (GeoPraxis/CEC)
- Industry Foundation Classes (IFC) approach
  - Used by EnergyPlus
  - A more complete data model
- Update since 2001: gbXML may be winning

# HVAC Sample of gbXML

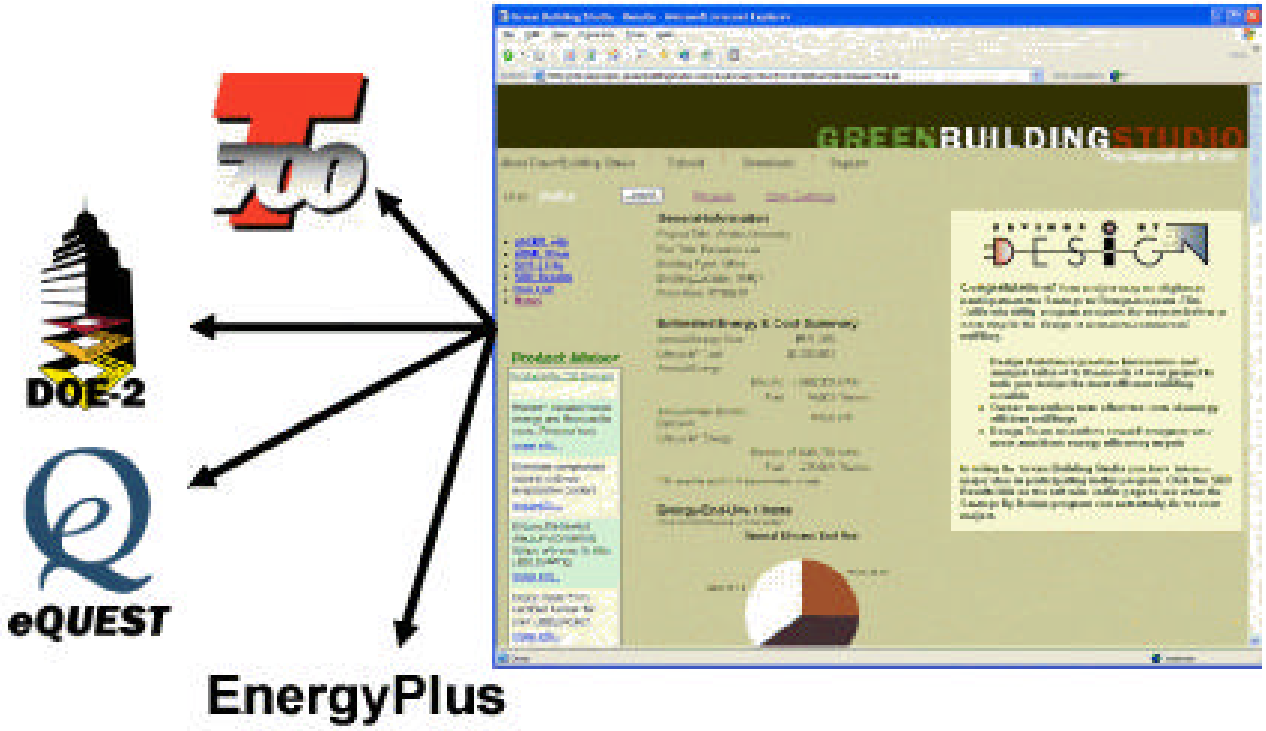
```
- <AirLoop id="al2">
  <Name>HVAC System 2</Name>
- <AirLoopEquipment id="ale2" equipmentType="Unitary">
  <Name>Package2</Name>
  <RatedFlow>1200</RatedFlow>
  <EnergySource energySourceType="Natural Gas" energySourceUse="Heating" />
  <EnergySource energySourceType="Electricity" energySourceUse="Cooling" />
  <Capacity capacityType="CoolingTotal ">36000</Capacity>
  </AirLoopEquipment>
  </AirLoop>
- <AirLoop id="al3">
  <Name>HVAC System 3</Name>
- <AirLoopEquipment id="ale3" equipmentType="Unitary">
  <Name>Package3</Name>
  <RatedFlow>1200</RatedFlow>
  <EnergySource energySourceType="Natural Gas" energySourceUse="Heating" />
  <EnergySource energySourceType="Electricity" energySourceUse="Cooling" />
  <Capacity capacityType="CoolingTotal ">36000</Capacity>
  </AirLoopEquipment>
  </AirLoop>
```

# Interoperability Benefits

- Software Interoperability will change everything
  - 3D CAD drawings → project data model
  - vendor data can be more easily integrated
  - changes will be easier / better QC
  - no more redundant data entry
  - more integrated tools (**architects & engineers can share data**)

# Interoperability Example: GreenBuildingStudio.com

- Conceptual/schematic design tool has the ability to generate input decks for several simulation tools
- Compatible with AutoCAD, Graphisoft, etc



# What Interoperability Means to CAD

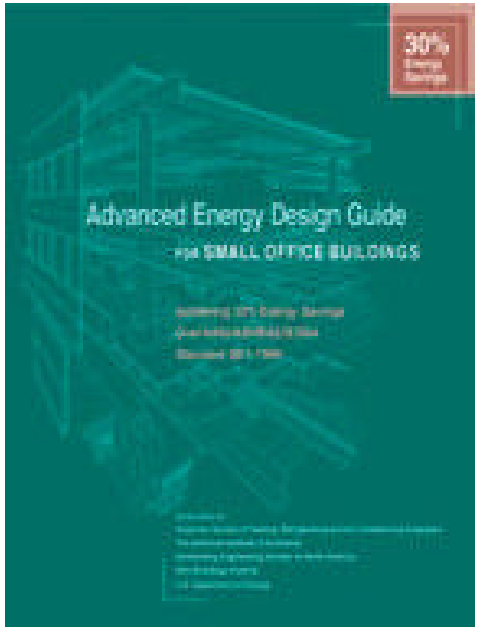
## Is that line a wall, pipe, conduit or piece of hair?

- CAD is a data base not an electronic drawing board
- Both Architects and Engineers will need to enter drawing information differently:
  - As Objects with properties (wall, pipe, HVAC unit, zones, etc.)
  - Instead of Lines, arcs and text
- Extra work upfront can help with down stream process
  - Take-offs, cost estimating, code compliance, simulations and other downstream activities become much easier
  - Design-build teams may adopt this first

# What’s in The Future

# LEED will Drive WBEA Use

- LEED requirement for energy simulations will expose more of architecture/ engineering community to Whole Building Energy Analysis (WBEA)
- Future versions of LEED NC will more fully use potential of WBEA tools
  - ASHRAE-produced guides will improve technical rigor
  - Points will better reflect energy & environmental potential
- Likely to have a lasting impact for WBEA



# Interoperability makes WBEA Practical

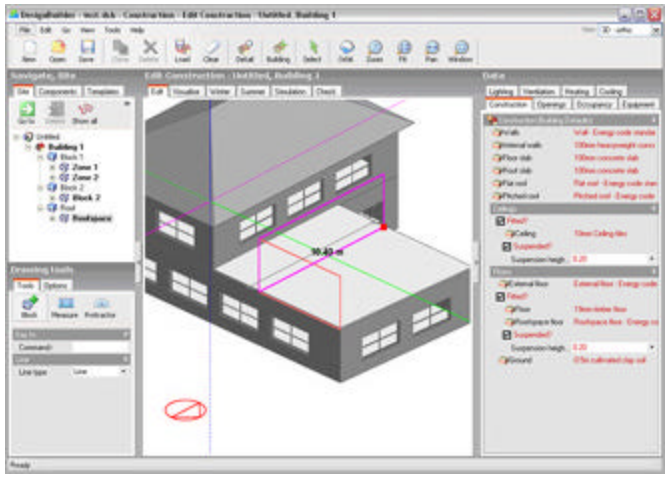
- Software inoperability will reduce the time and drudgery, making tools more accessible to practitioners
- May provide the reason for jumping to full 3-D CAD
- WBEA will be just one of the beneficiaries
  - Cost estimating and take-offs made easier
  - Other downstream benefits (contractors, commissioning, O&M documentation)

# EnergyPlus will Make WBEA Technically Accurate

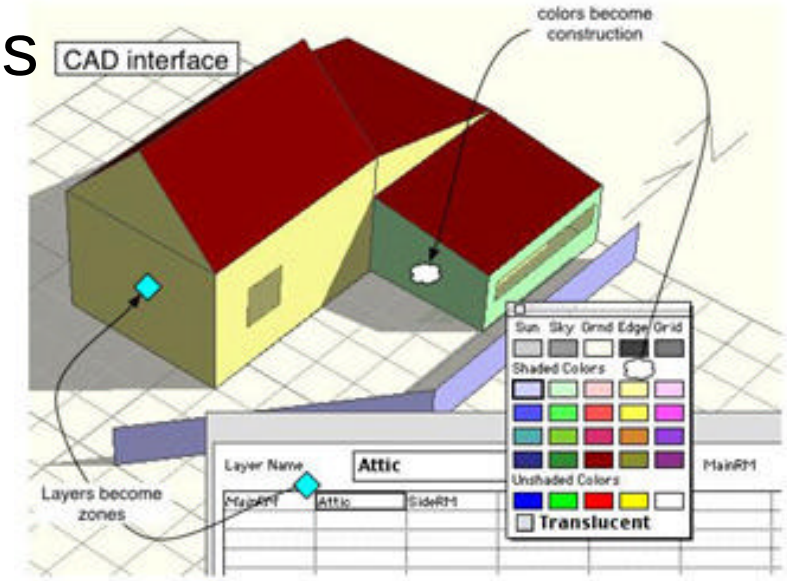
- EnergyPlus addresses may technical shortfalls of other tools
  - Even if the “market” is not asking these hard questions now
- EnergyPlus “business model” makes sense:
  - Calculation engine open source/in public domain
  - Software developers can develop proprietary interfaces and tools around it
  - Multiple technical sources can contribute to engine improvements
    - 3rd parties can focus on their favorite technical issues

# EnergyPlus
## Development & Interfaces

- Some interfaces are being developed
  - DesignBuilder (UK) →
  - E+IEQ (Taitem)
  - Others



- CAD Tools & libraries are also being developed



# What can ASHRAE do?

- Toolkits
  - become standardized & accepted calculation algorithms
- Default data sets
  - can help to provide more intelligent & documented inputs for simulation models
- Develop standards or templates for best ways to represent HVAC performance data
  - such as ASHRAE RP-1197

# Thank you!
# Questions?