LECTURE N° 6

- Whole Building Design & Simulation Tools -

DU

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Lecture contributions

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IDES-EDU

What is IDES-EDU ?

The IDES-EDU project intends to educate and train both students and professionals in order to form specialists in the field of multi-disciplinary design of buildings.

This is pursued through various steps:

- Preparation of curricula and training programs (Master and Post-graduate courses) which reflects the centrality of sustainable requirements in the creation of the built environment, including new methods of teaching that will equip students and professional to work within multi-disciplinary and interdependent problem solving framework.
- Exchange and collaboration between the students and the professionals, involved in these courses to come to a mutual exchange of experience, approach and understanding.
- Certification and accreditation of the courses on national level as well frameworks for European certification for participants and for buildings designed in multi-disciplinary teams.
- An intelligent dynamic and adaptive teaching portal to make the educational packages available to graduate students and building professionals in Europe.
- Increasing European awareness, promoting implementation and commitment on Integral Sustainable Energy Design in the Built environment by promotional campaigns in the building sector as well as by exchange programmers between universities.

In IDES-EDU 15 renowned educational institutes will full fill this need by developing these curricula and training programs for MSc and Professionals.

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Building simulation

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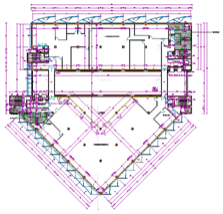
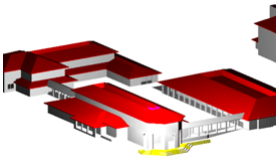
Computer in the design process

Computer Aided Drafting



Computer Aided Design



Computer Aided Engineering (CAE)

- Structural aspects
- Physical aspects
  - Light
  - Sound
  - Energy
  - Comfort

Design Decision Support System

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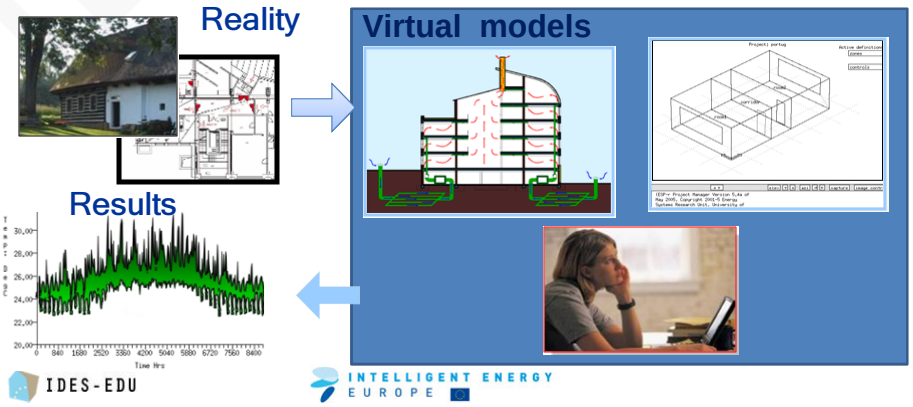
www.ddss.arch.tue.nl

What's simulation ?

A situation in which a particular set of conditions is created artificially in order to study or experience something that could exist in reality



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Role of building simulation

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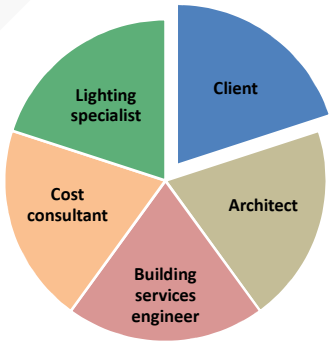
Who can benefit?



1. How do each of the stakeholders benefit from whole building simulation?

2. Can you think of anyone else that can benefit?

Search the internet for examples.

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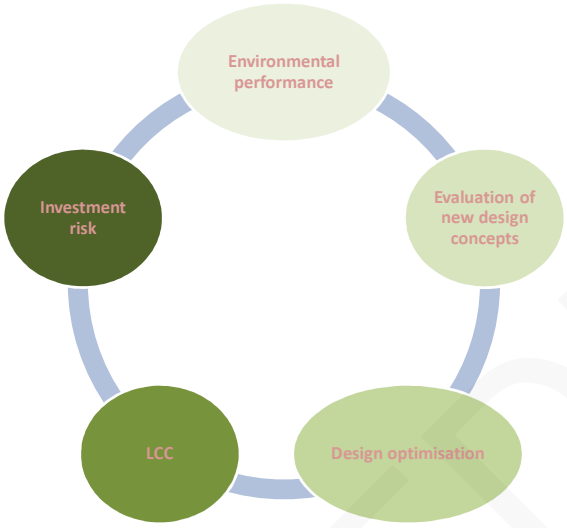
In what ways can a project benefit?



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(CIBSE 1998)
Courtesy of CIBSE, www.cibse.org

Topics for energy simulation programs	When to use simulation in building ?
•**THERMAL SIMULATION** -Building energy use -HVAC systems design and performance -Occupant thermal comfort assessment -Passive solar and PV systems applications	Early phase of building conceptual design to predict energy performance of the alternative solutions to support designer decision process (building shape, initial facade and shading, HVAC concept) modelling non-standard building elements and systems (double-facade, atrium, natural ventilation, renewables, solar technologies, integrated HVAC systems) Investigation of the operational breakdowns and set-up of control systems (HVAC, adaptive control, self-learning systems,…) Indoor environment quality prediction (temperatures, air flow patterns, PMV,PPD) Analysis of energy saving measures to energy use Operation cost calculation and consequently cost distribution among users at multiuser – single meter buildings
•**LIGHTING SIMULATION** -Daylight presence in windowed spaces -Illumination from electric lighting systems -Illumination from multiple sources (electric & daylight)	
•**COMPUTATIONAL FLUID DYNAMICS (CFD)** -modelling of air flow in building spaces	

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Design question	modelling task
Is air conditioning required?	Calculation of peak summertime temperature frequency of occurrence in free-running mode
Which HVAC system is the most energy efficient?	Comparison of the degree of temperature and humidity control for various system configurations and evaluation of the required capacity and energy consumption
How can daylight penetration be maximised without increasing risk of glare?	Comparison of daylight factors and glare indices for different glazing and shading configurations
Is displacement ventilation appropriate for a certain space?	Determination of the occupied zone comfort levels for a range of loadings and supply air conditions

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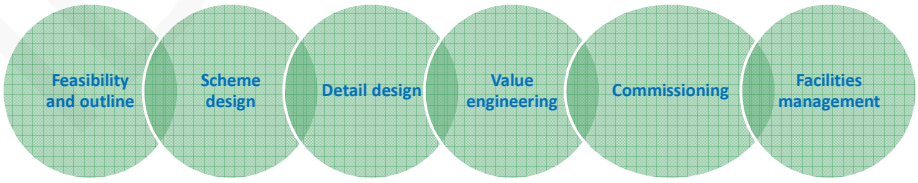
(CIBSE 1998)
Table courtesy of CIBSE, www.cibse.org

Role of modelling into design and operation stages



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(CIBSE 1998)
Courtesy of CIBSE, www.cibse.org

Feasibility and outline

- Only rough estimation of the building performance is normally required; enough to ensure the feasibility of the general design concept therefore any simplified simulation software is adequate at this stage
- More detail could be added for the assessment of specific factors that are considered to have significant impact on building performance (e.g feasibility of natural ventilation in certain spaces)
- modelling input is based mostly on data from inherent program databases, published databases from recognized institutions and associations (e.g. ASHRAE, CIBSE) and 'rules of thumb' since project specific data have not yet been determined

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(CIBSE 1998)
Courtesy of CIBSE, www.cibse.org

Scheme design

- Modelling provides decision support in key architectural design areas such as: orientation, levels of insulation, glazing area and shading but also on building services and other engineering areas such as: main plant and component arrangements, lighting and daylighting systems, controls etc.
- Detailed modelling is justified in order to prove viability of critical design strategies whose revision in future stages of the design can bring a significant time and cost penalty to the project
- modelling should present feedback on the performance of the design in a rapid and relatively accurate way. Most suitable approaches:
  - Reasonably simple modelling methods which nevertheless capture the important system characteristics
  - Sophisticated modelling methods that rely on appropriate default data and assumptions and only create representations of key building elements

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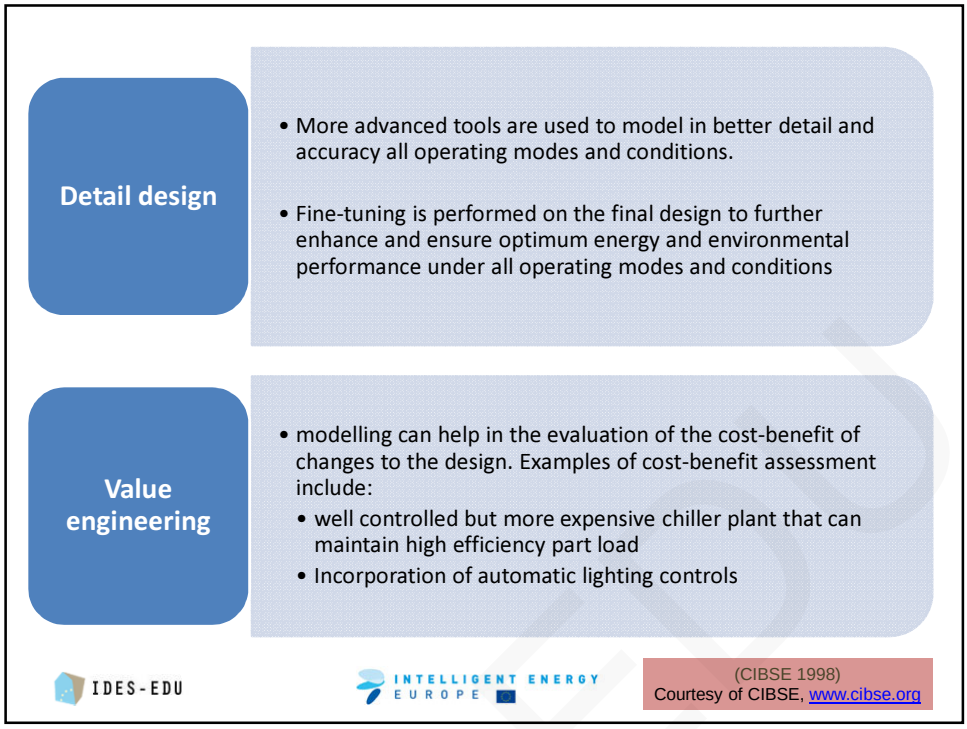
(CIBSE 1998)
Courtesy of CIBSE, www.cibse.org


Detail design
• More advanced tools are used to model in better detail and accuracy all operating modes and conditions.
• Fine-tuning is performed on the final design to further enhance and ensure optimum energy and environmental performance under all operating modes and conditions
Value engineering
• modelling can help in the evaluation of the cost-benefit of changes to the design. Examples of cost-benefit assessment include:
• well controlled but more expensive chiller plant that can maintain high efficiency part load
• Incorporation of automatic lighting controls
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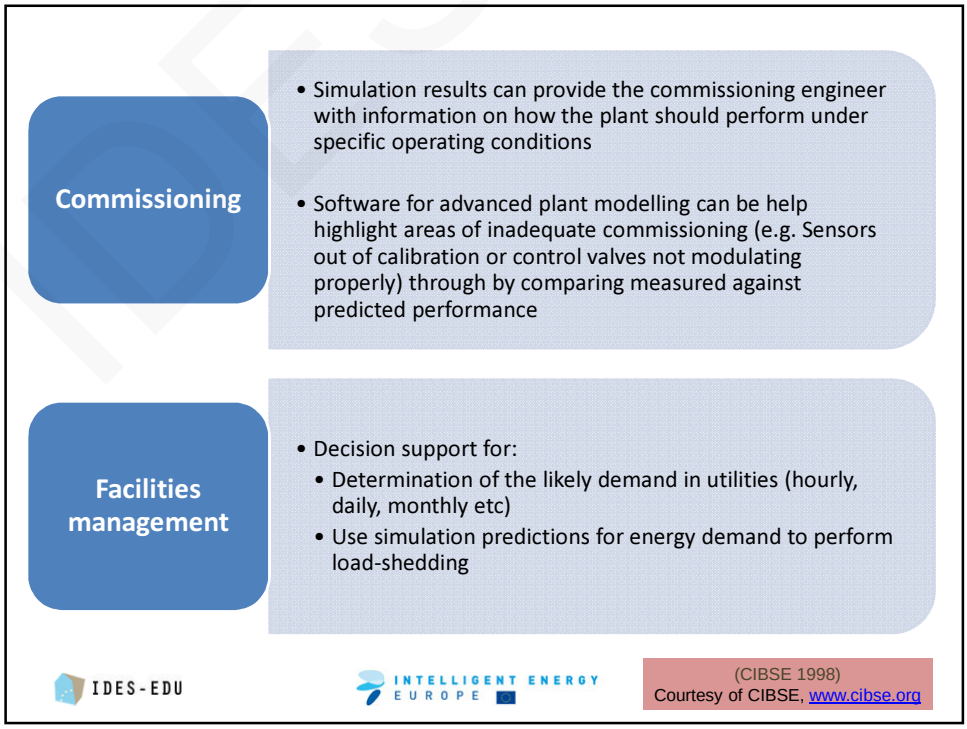
(CIBSE 1998)
Courtesy of CIBSE, www.cibse.org


Commissioning
• Simulation results can provide the commissioning engineer with information on how the plant should perform under specific operating conditions
• Software for advanced plant modelling can be help highlight areas of inadequate commissioning (e.g. Sensors out of calibration or control valves not modulating properly) through by comparing measured against predicted performance
Facilities management
• Decision support for:
• Determination of the likely demand in utilities (hourly, daily, monthly etc)
• Use simulation predictions for energy demand to perform load-shedding
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(CIBSE 1998)
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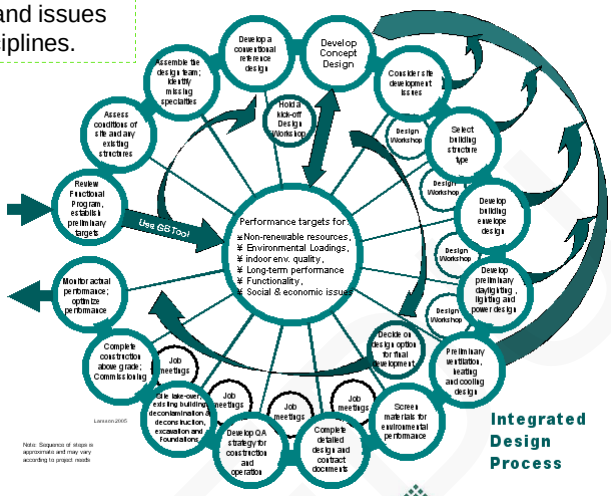
Integrated Design Process

!! modelling enables design team members to understand issues relevant to other disciplines.



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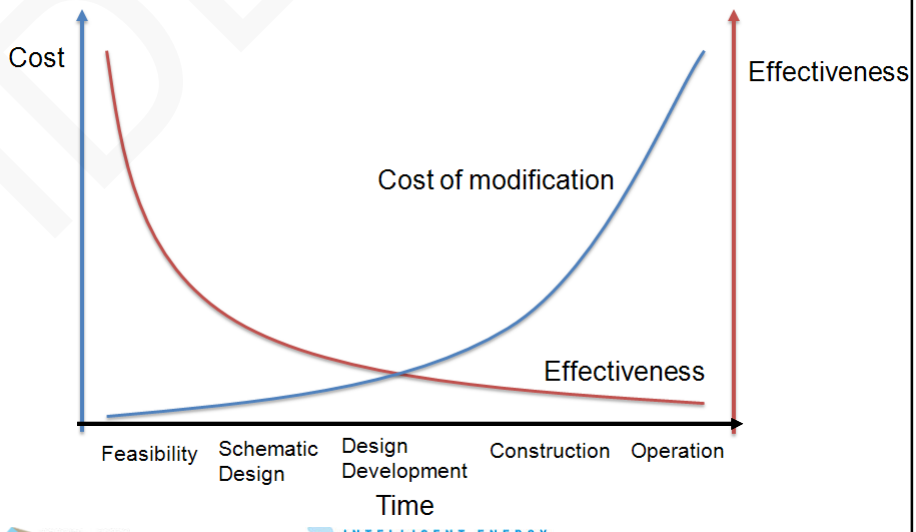
Decision cost and impact on the performance



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Simulation approach and Mathematical modelling

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Basic principle of modelling and simulation approach

- Problem analysis – identification of the zones, systems, plant components and their dependencies
- Assignment definition
- Boundary condition definition
- Definition of detail scale and model range
- Proper tool selection
- Sensitivity analysis
- Results validation

„Virtual laboratory is not a design tool…“

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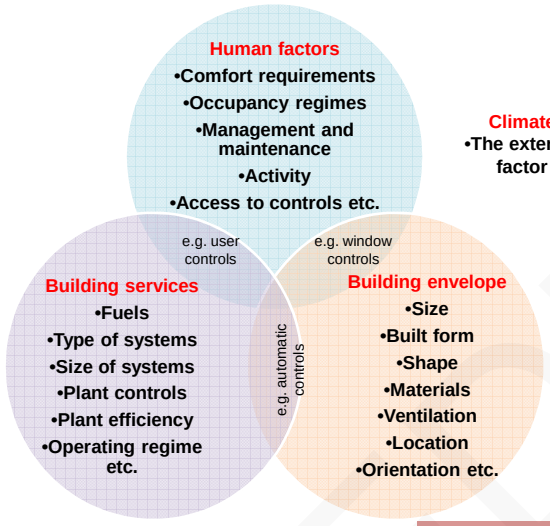
Building energy consumption considerations and interactions



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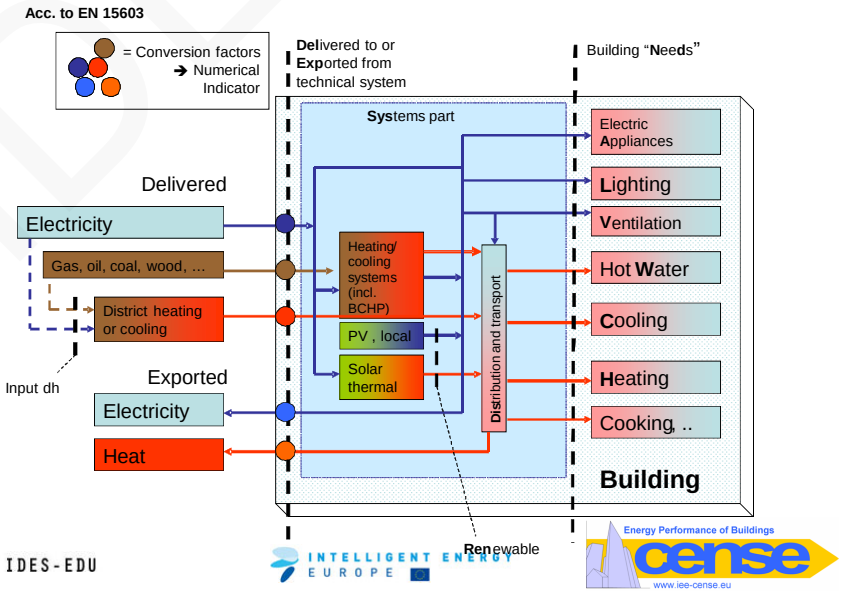
(CIBSE 2004)
Figure courtesy of CIBSE, www.cibse.org

Building boundaries, including systems



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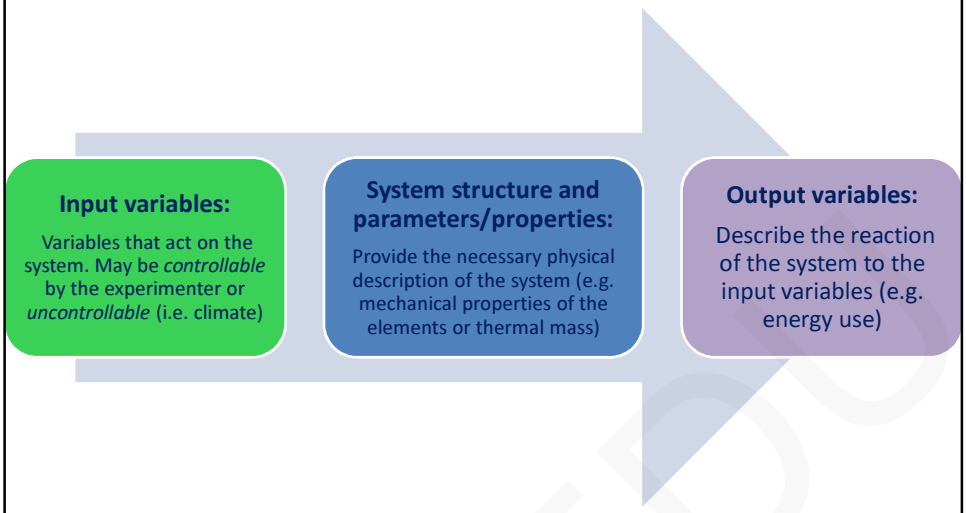
Energy Performance of Buildings
cense
www.iee-cense.eu

Components of a mathematical model



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(Beck and Arnold1977, cited in ASHRAE 2009)

Approaches to energy modelling

Forward (Classical)

- modelling for building and HVAC system design and associated design optimisation (predict end results)

Data-driven (Inverse)

- modelling energy use of existing buildings for the establishment of baselines and the calculation of retrofit savings (identify the physical processes that lead to a given result)

The selection of the appropriate approach is driven by the ***objective*** of the analysis!

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(ASHRAE 2009)

Forward Approach

Objective: to predict the output variables

- Models often significantly complex to ensure accuracy
- Presumes detailed knowledge of:
  - The various natural phenomena which affect system behavior
  - The magnitude of various interactions (e.g. Thermal mass, heat transfer coefficients, mass transfer coefficients, etc)
- Based on sound engineering principles
- Widely accepted by the design and professional community
- Ideal for use in the preliminary design and analysis stage

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Data-driven Approach

Objective: to determine a mathematical description of the system and to estimate system parameters

- Presupposes that:
  - the system has already been built, and;
  - actual performance data are available for model development and/or identification
- Two possible types of performance data:
  1. Intrusive: collected through experiments on the system that study the response that would have occurred under normal system operation. These data allow more accurate model specification and identification.
  2. Nonintrusive: obtained under normal operation conditions when constraints on system operation do not permit testing
- Often allows identification of simpler and more accurate predictions of future system performance than forward models
- Not yet widely adopted in energy-related curricula and by the building professionals

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Steady – state methods

Forward

- Modified degree-day method
  - Based on fixed reference temperature of 18.3°C.
- Variable-base degree-day method, or 3-P change point models
  - Variable base reference temperatures

Data driven

- Simple linear regression
  - One dependent parameter, one independent parameter. May have slope and *y*-intercept
- Multiple linear regression
  - One dependent parameter, multiple independent parameters.
- Change-point models
  - Uses daily or monthly utility billing data and average period temperatures

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Dynamic methods

Forward

- **Simplified dynamic methods**
  - Regresive result analysis from multiple steady-state model run with variable boundary condition
- **Weighting-Factor Method**
  - With this method, space heat gains at constant space temperature are determined from a physical description of the building, ambient weather conditions, and internal load profiles.
- **Response factor**
  - Simple systems dynamic response is possible to describe by diferential equation. Fourier analysis. Frequency domain analysis convertible to time domain time. Analagy with electrical circuits – resitance, capacity, transformer. Thermal and electricity.
- **Heat balance method**
  - Set of equations, describing energy flow paths between nodes (volumes), solved by numerical methods – finite diference method, finite element method

Data-driven

- **Artificial neural networks**
  - Connectionist models.

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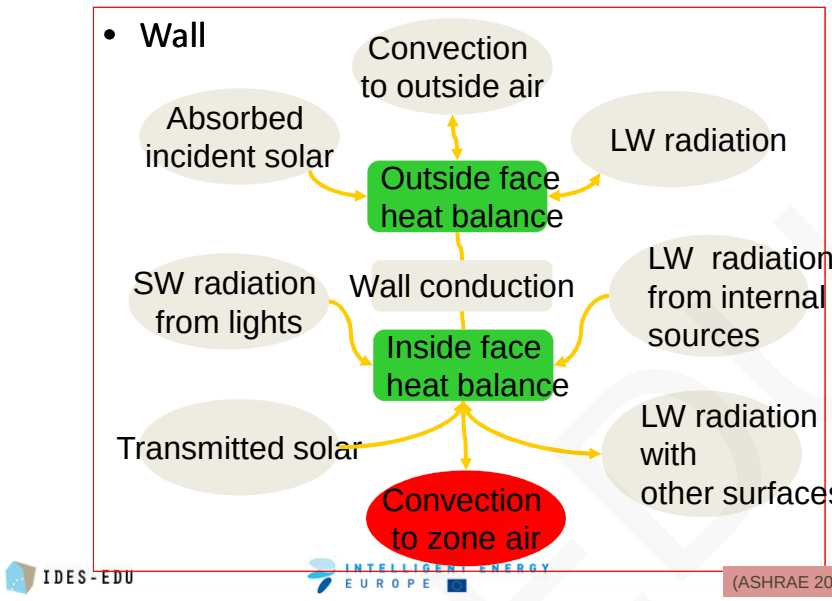
Heat balance method



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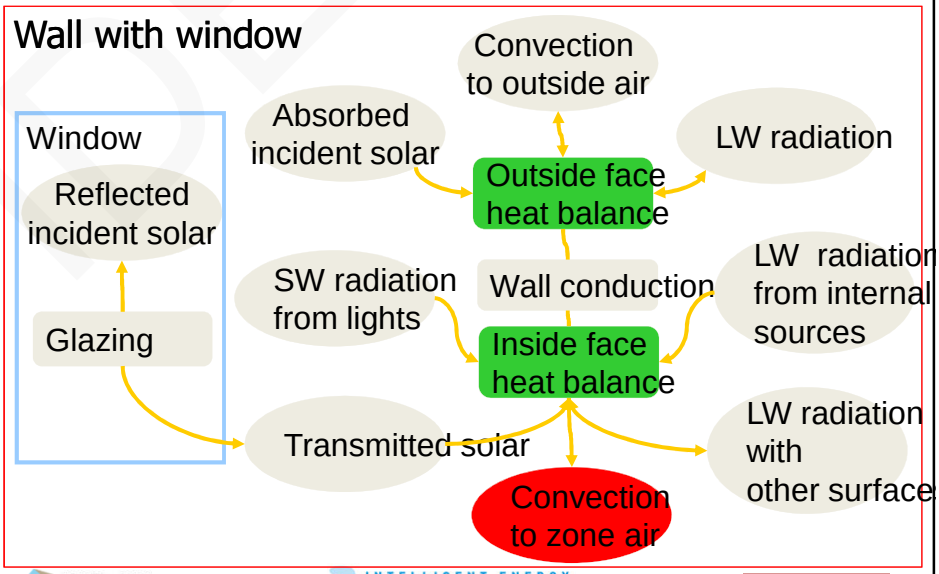
(ASHRAE 2009)

Heat balance method



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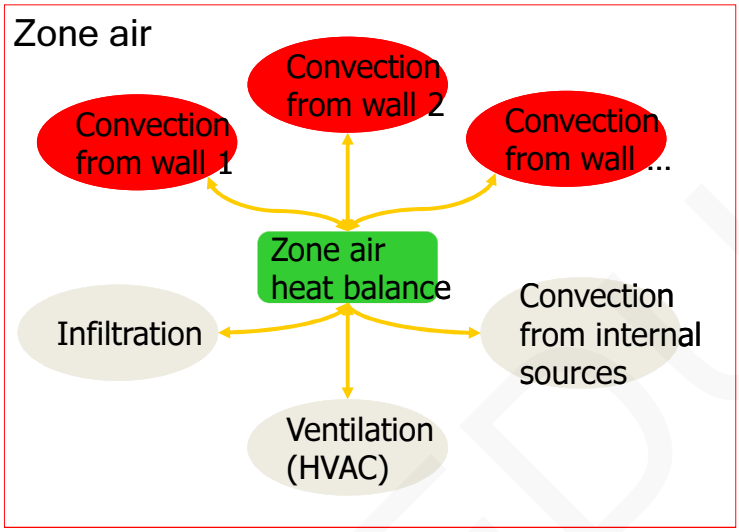
(ASHRAE 2009)

Heat balance method



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Simulation tools

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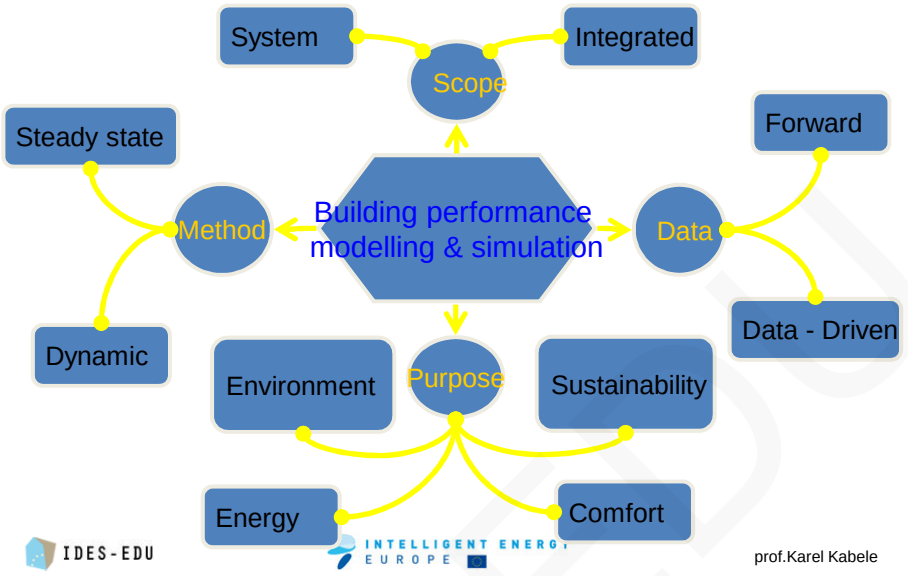
Modelling and simulation tools clasification



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Considerations for program selection

- Program documentation
- Compatibility with other packages
- Flexibility
- Available support
- Existence of user forums for exchange of experiences
- Validity of the program
- Use approval
- Existence of application examples similar to those for which it is required

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Considerations for program selection

- Guidance for its use when carrying out specific performance assessments
- Sensitivity
- Versatility
- Cost of program
- Speed and cost of analysis
- Ease of use

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(IEA 1994, ASHRAE Handbook 2009)

Accuracy

External errors

Improper use of the program (user mistakes and misinterpretation)

- Follow Good Practice principles
- User friendly interface
- Good quality input databases

Internal errors

Weaknesses inherent in the program itself

- Validated and Tested program
- Program sensitive to the design options considered

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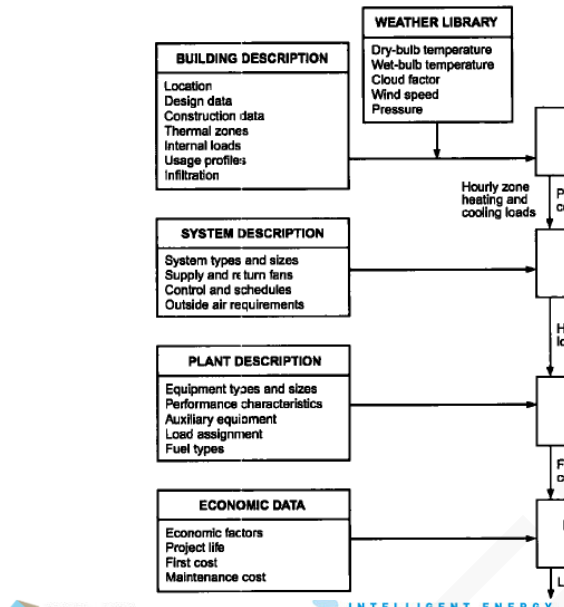
Flow chart for building energy simulation program



(Ayres and Stamper 1995 cited in ASHRAE 2009)

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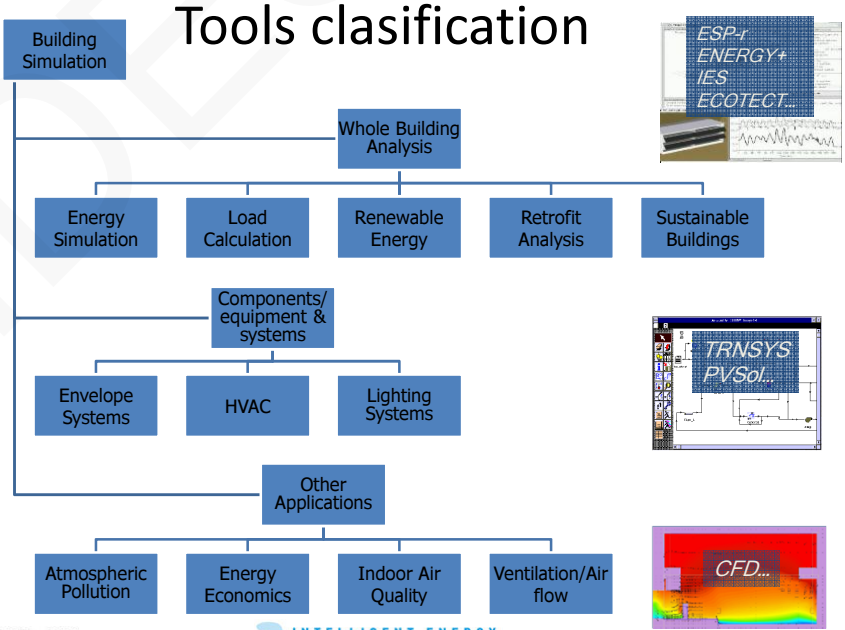
Tools clasification



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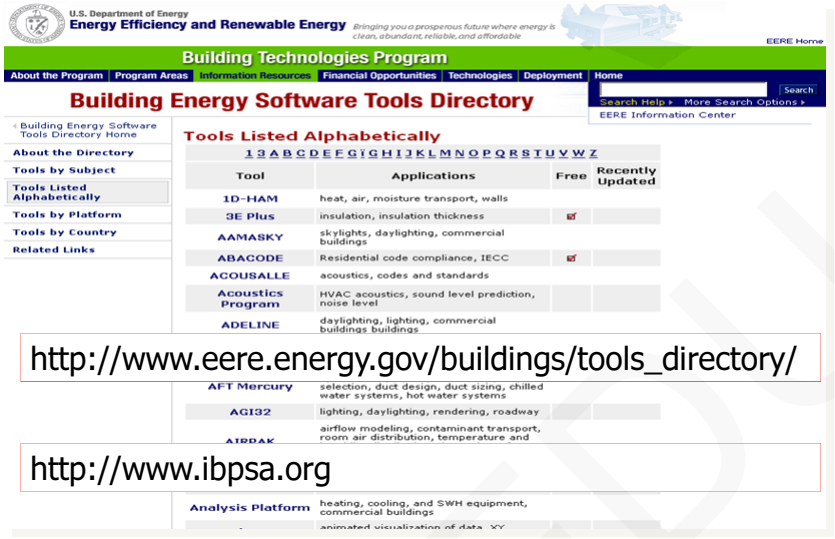
Tools overview



http://www.eere.energy.gov/buildings/tools_directory/

http://www.ibpsa.org

Building Energy Simulation Software

- ❑BLAST
- ❑BSim
- ❑DeST
- ❑DOE-2.1E
- ❑ECOTECT
- ❑Ener-Win
- ❑Energy Express
- ❑Energy-10
- ❑EnergyPlus
- ❑eQUEST
- ❑ESP-r
- ❑IDA ICE
- ❑IES <VE>
- ❑HAP
- ❑HEED
- ❑PowerDomus
- ❑SUNREL
- ❑Tas
- ❑TRACE
- ❑TRNSYS

Crawley DB, Hand JW, Kummert M, Griffith BT. Contrasting the capabilities of building energy performance simulation programs. Washington, DC: US Department of Energy; 2005.

Explore the different features and capabilities that individual building energy performance simulation programs have to offer (Tables 1-14).

US Department of Building Energy Software Tools Directory!

Look up the description of these tools (where listed)

http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename_submenu=energy_simulation

ESP-r background

UNIVERSITY OF STRATHCLYDE

- ESP-r (Environmental Systems Performance; r for „research“)
- Dynamic, whole building simulation finite volume, finite difference sw based on heat balance method.
- Academic, research / non commercial
- Developed at ESRU, Dept.of Mech. Eng. University of Strathclyde, Glasgow, UK by prof. Joseph Clarke and his team since 1974
- ESP-r is released under the terms of the GNU General Public License. It can be used for commercial or non-commercial work subject to the terms of this open source licence agreement.
- UNIX, Cygwin, Windows

http://www.esru.strath.ac.uk/

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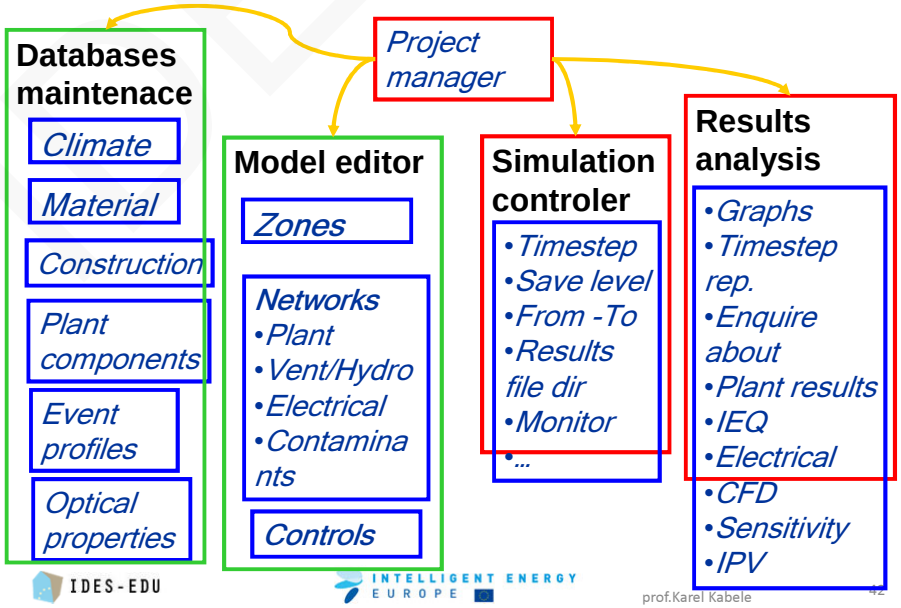
ESP-r architecture



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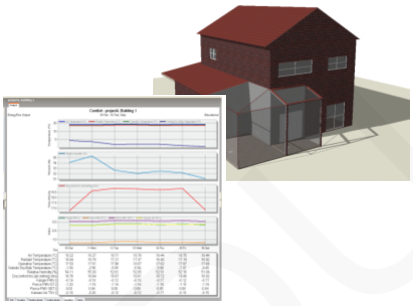
Design Builder for Energy+

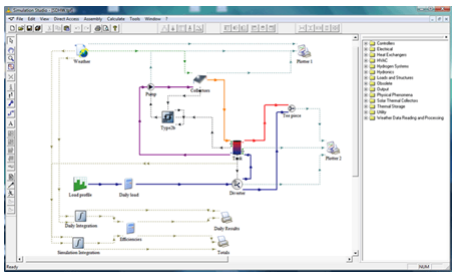
- modelling and simulation of buildings (and systems)
- Different levels of model detail
- 3D realistic model
- Commercial tool/ free calculation kernel



http://www.designbuilder.co.uk/

TRNSYS

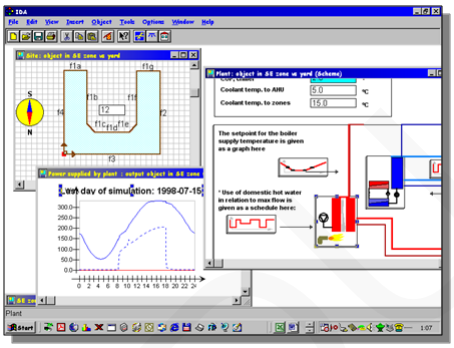
- Simulation buildings and energy systems
- Open structure
- Elements library
- Commercial product



http://www.trnsys.com/

IDA Indoor Climate and Energy

- modelling and simulation of Buildings and systems
- Databases
- Standard climate data files
- Commercial tool

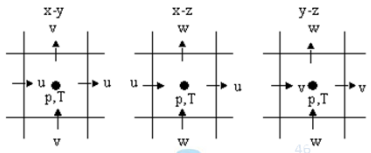


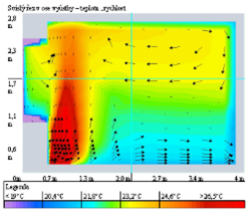
http://www.equa.co/

Computational Fluid Dynamics

- modelling of indoor environment - air flow patterns, temperature distribution, polutantat concentration
  - Aerodynamics of interior or exterior
  - Navier- Stokes equations
  - Temperature, pressure, air flow velocity and direction, radiation
  - Convergence calculation – turbulent fows, symetry, sensitivity
  - **Tools: Fluent, Flovent,ESP-r…**

$$T = \frac{(C_0T_0 + C_1T_1 + C_2T_2 + C_3T_3 + C_4T_4 + C_5T_5 + C_6T_6 + S)}{(C_0 + C_1 + C_2 + C_3 + C_4 + C_5 + C_6)}$$





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How to perform building simulation ?

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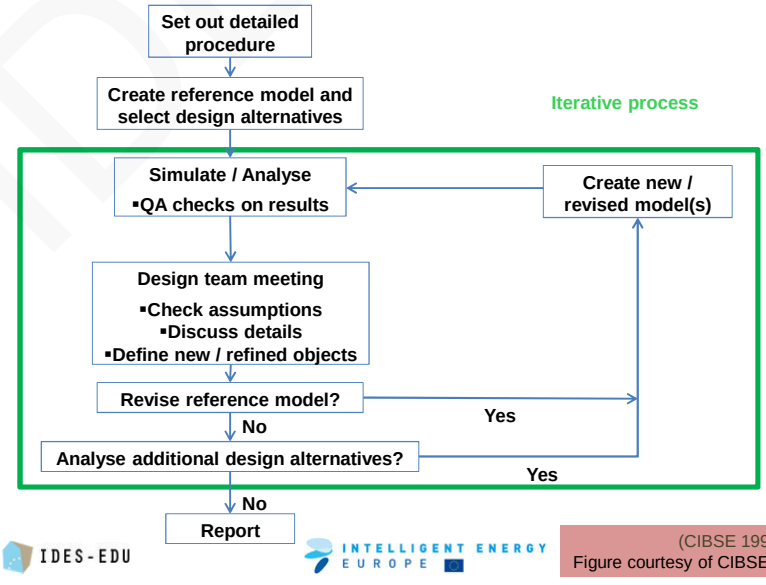
Typical modelling procedure



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(CIBSE 1998)
Figure courtesy of CIBSE, www.cibse.org

Good practice principles (QA) for *Software users*

I. Document modelling assumptions and the procedures used and approaches taken to generate and evolve the model

II. Perform Good Housekeeping (regular back-up and effective archiving)

III. Set up an error log book and document each and every error found

IV. Always check the input files thoroughly

V. Always carry out a test run and look for unexpected results; if routine checks are available use these to identify possible errors

VI. If possible, have a second person check the work carried out

VII. Create a database of results from previous projects to be used for comparison

VIII. For frequently used materials and components, create databases

IX. Give logical and meaningful names to input parameters (e.g. operation schedule, zoning etc)

X. Give logical and meaningful names to simulation files with different parameter testing or iteration (e.g. operation schedule, zoning etc)

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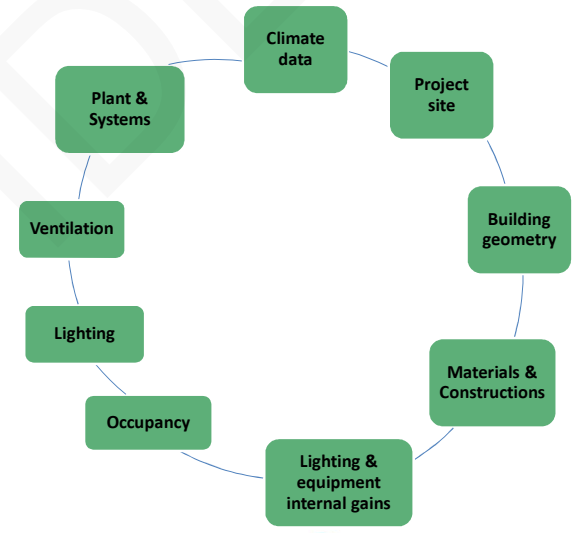
Input data categories



IEA, 1994

Study the detail of input data required for the base case in page 8.11

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Climate data

Input data

•Hourly weather data (in most cases for an entire year). Main climate parameters:

–Dry-bulb temperature

–RH

–Wind speed and wind direction

–Solar radiation (direct and diffuse)

Data Sources

- Simulation programs file libraries or embedded files
- Energy plus website
- Meteonorm
- ASHRAE

Conversion of data formats possible through

- Weather Tool (Square One)
- Esp-r
- Weather manager

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Climate data

Weather data formats

- *.epw – EnergyPlus weather files
- *.wea - Weather Data File
- *.dat - plain text file
- WYEC and WYEC2 data files
- Test Reference Year (TRY)
- Typical Meteorological Year (TMY)
- Design Summer Year (DSY)

Reference year (RY)

Should represent mean values of main climate parameters that are as close as possible to long-time mean values (average conditions) and therefore are not appropriate for the assessment of performance under extreme conditions.

Main requirements for RY

- True frequencies, i.e., as near as possible to true mean values over a longer period, e.g., a month, and a natural distribution of higher and lower values for single days.
- True sequences, i.e., the weather conditions must have a duration and follow each other in a similar manner to often-recorded conditions for the location.
- True correlation between different parameters, i.e. temperature, solar radiation, cloud cover and wind.

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Climate data

Climate data for energy calculations:

- Multi-year datasets: they are fundamental and include a substantial amount of information for a number of years.
- Typical years: a typical or reference year is a single year of hourly data selected to represent the range of weather patterns that would typically be found in a multi-year dataset. The definition of a typical year depends on how it satisfies a set of statistical tests relating it to the parent multi-year dataset.
- Representative days: they are hourly data for some average days selected to represent typical climatic conditions. Representative days are economical for small-scale analysis and are often found in simplified simulation and design tools.

Selection of weather data format driven by the modelling objective. E.g.:

- ❖ Sizing of cooling/heating plant => design weather year
- ❖ Estimation of overheating risk for naturally ventilated spaces (percentage of hours over a certain temperature) => near extreme summer and mid-season
- ❖ Annual energy use prediction=> typical weather year

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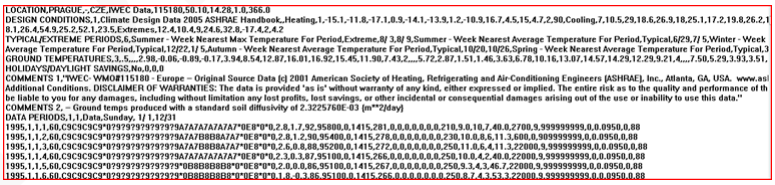
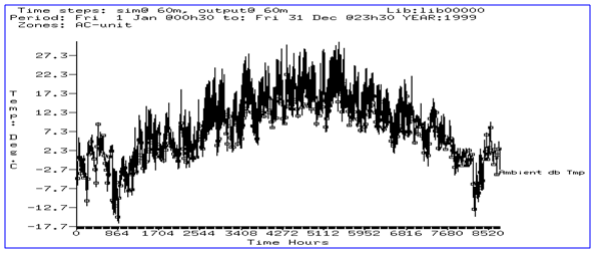
Climate data

PRG iwec





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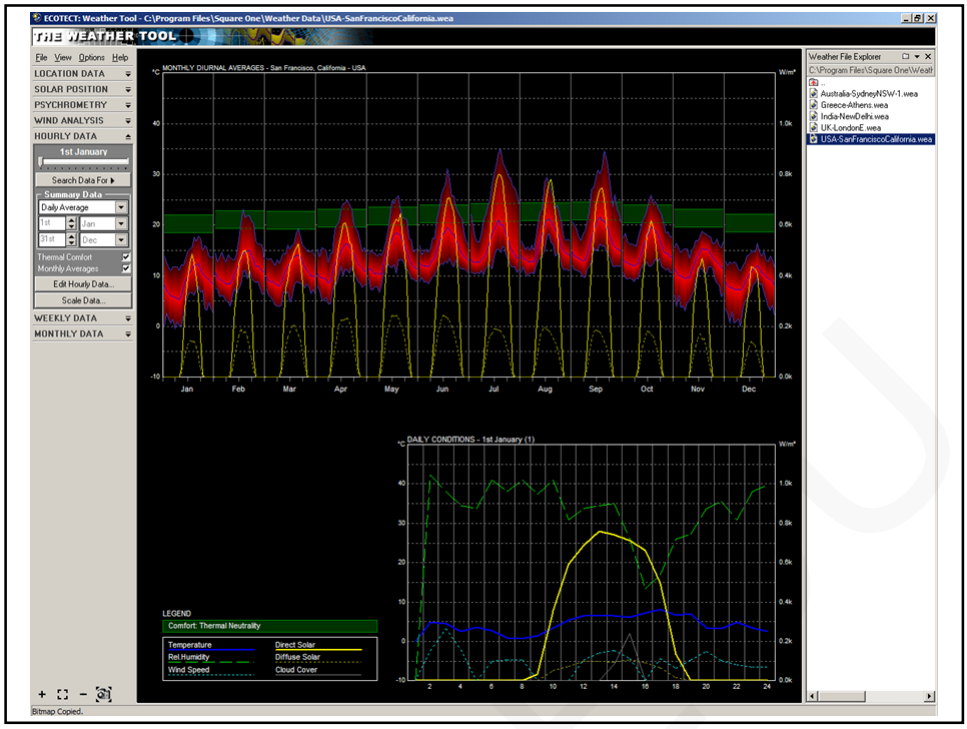

Project Site

Input data

- Location (e.g. latitude, longitude, altitude)
- Solar and wind exposure
- Ground reflectance and temperature

Data Sources

- Client
- Architect
- Photographic material
- Weather file
- Google Earth
- Topographic maps
- Site visit
- Inherent program database

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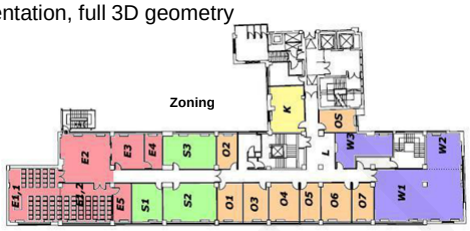
Building Geometry

Input data

- Single- or two-zone simulation programs→ orientation, space volumes, opaque and transparent surface areas
- Whole-building simulation programs→ orientation, full 3D geometry



Data Sources

- Drawings and specifications
- CAD geometry import

Zoning

- Increased complexity has a significant negative impact on calculation time (for program) and on modelling time (for user) especially for large projects with the benefits in the simulation output from this more "realistic" representation of the building being only minimal.
- Spaces should be grouped into one zone when similarities exist in:
  - Free-running environmental performance
  - Conditioning (HVAC) characteristics
  - Internal and solar gains.

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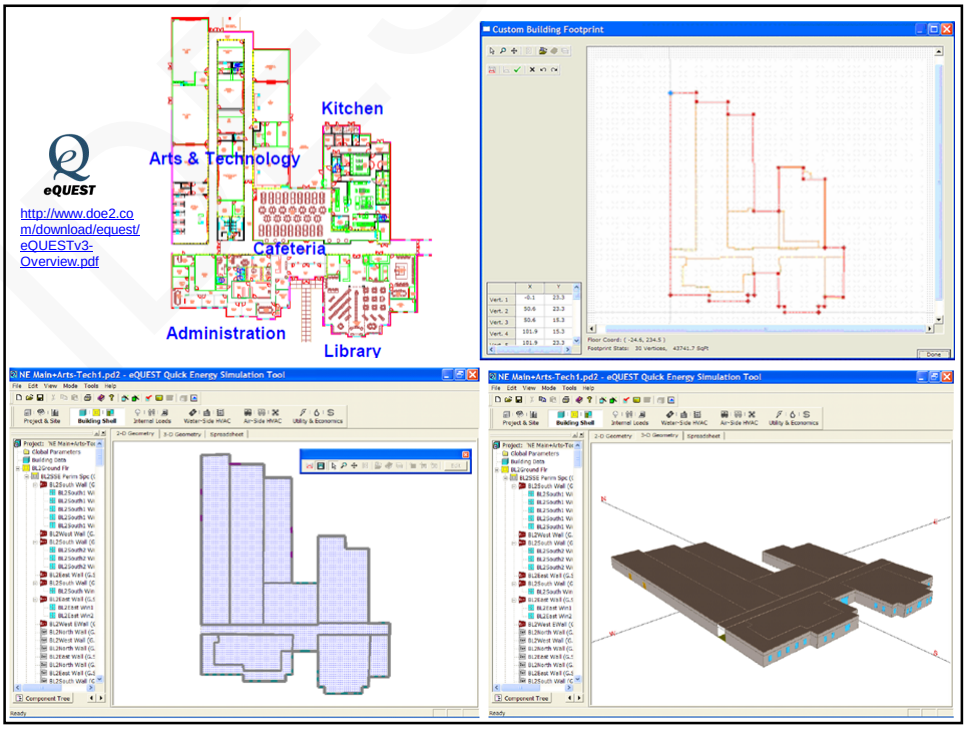
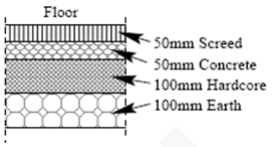
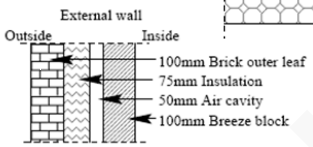


Materials & Constructions

Input data

- Material properties (conductivity, density, specific heat, short-wave absorptivity, long-wave emissivity, moisture diffusion resistance)
- Thickness of individual element layers





Data Sources

- Opaque building elements:
  - Architect
  - Inherent program library
  - User personal database
  - Published databases from recognized institutions and associations (e.g. ASHRAE, CIBSE)
- Transparent building elements:
  - Facade specialist
  - Manufacturer data
  - Output from specific programs (e.g. WIS and WINDOW)

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Lighting and equipment internal gains

Input data

- Gains may be inputted in the form of: W/m2, number of units in space, or W for entire space
- Radiative and convective components for each source
- Sensible and latent components for each source
- Load schedules (hourly, daily, weekly, seasonal etc)
- Lighting sensor location (name of space and distance from façade), type (e.g. On/Off), activation threshold and interaction (if any) with shading system operation

Data Sources

- Electrical engineer, lighting specialist
- Inherent program database
- Published databases from recognized institutions and associations (e.g. ASHRAE, CIBSE)

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Sensible heat from lights

Heat transferred to the room from the lights can be calculated as

$H_l = P_{inst}\, K_1\, K_2$

where

H_l = *heat transferred from the lights (W)*

P_{inst} = *installed effect (W)*

K_1 = *simultaneous coefficient*

K_2 = *correction coefficient if lights are ventilated. (= 1 for no ventilation, = 0.3-0.6 if ventilated)*

Installed effect W/m²	Illumination lux				
	200	400	600	800	1000
Incandescent lamp	38	75	110	145	180
Fluorescent tubes	15	25	36	48	60

Office Activity	Illumination lux
Normal work	200
PC work	500
Archive	200
Drawing work, normal	500
Drawing work, detailed	1000

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Sensible heat from electric equipment

Heat transferred from electrical equipment can be calculated as

- $H_{eq} = P_{eq}\, K_1\, K_2$

where

- H_{eq} = *heat transferred from electrical equipment (W)*
- P_{eq} = *electrical power consumption (W)*
- K_1 = *load coefficient*
- K_2 = *running time coefficient*

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Sensible heat from machines

When machines runs heat can be transferred to the room from the motor and/or the machine.

If the motor is in the room and the machine is outside

$H_m = P_m / h_m - P_m$

If the motor is belt driven and the motor and belt is in the room and the machine is outside

$H_m = P_m / h_m - P_m h_b$

If the motor and the machine is in the room

$H_m = P_m / h_m$

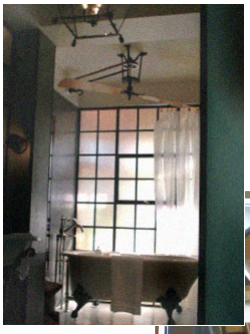
- In this situation the total power is transferred as heat to the room.
- **Note!** If the machine is a pump or a fan, most of the power is transferred as energy to the medium and may be transported out of the room.

If the motor is outside and the machine is in the room

$H_m = P_m$

If the motor is belt driven and the motor and belt is outside and the machine is in the room

$H_m = P_m h_b$



where

H_m = heat transferred from the machine to the room (W)

P_m = electrical motor power consumption (W)

h_m = motor efficiency

h_b = belt efficiency

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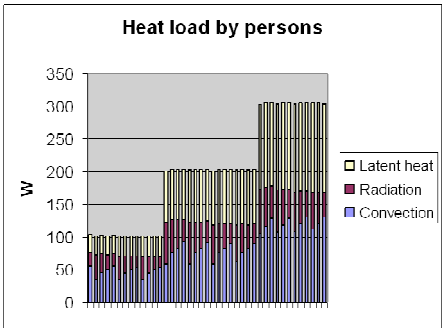
Occupancy

Input data

- Gain input in any format of: W/m2, number of occupants in space, W for entire space
- Activity level or Sensible and Latent component
- Occupancy profiles (hourly, daily, weekly, seasonal etc)



Data Sources

- Client
- Architect
- Inherent program database
- Published databases from recognized institutions and associations (e.g. ASHRAE, CIBSE)

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CO_2 production

- Carbon dioxide (CO_2) concentration in "clean" air is 575 mg/m^3.
- Huge concentrations can cause headaches and the concentration should be below 9000 mg/m^3.

Activity	Respiration per person m^3/h	Carbon dioxide generation per person m^3/h
Sleeping	0.3	0.013
Sitting, relaxed	0.5	0.02
Working, moderate	2 - 3	0.08 - 0.13
Working, heavy	7 - 8	0.33 - 0.38

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Activity	W/m^2
Reclining	46
Seated relaxed	58
Standing relaxed	70
Sedentary activity (office, dwelling, school, laboratory)	70
Graphic profession - Book Binder	85
Standing, light activity (shopping, laboratory, light industry)	93
Teacher	95
Domestic work - shaving, washing and dressing	100
Standing, medium activity (shop assistant, domestic work)	116
Washing dishes standing	145
Domestic work - washing by hand and ironing (120-220 W)	170
Volleyball	232
Gymnastics	319
Aerobic Dancing, Basketball, Swimming	348
Sports - Ice skating, 18 km/h	360
Skiing on level, good snow, 9 km/h, Backpacking, Skating ice or roller, Tennis	405

1 Met = 58 W/m^2 , 58 W/m^2 x 1.8 m^2 = 104 W

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Lighting

Input data:

- Optical properties (i.e. SHGC, solar optical transmittance, inward flowing fraction) of glazing systems
- Room surface properties (i.e. reflectance)
- Sky luminance data
- Electric lighting fixtures type and characteristics
- Site obstructions

Data Sources

- Lighting specialist
- Façade specialist
- Manufacturer data
- Inherent program library
- Published databases from recognized institutions and associations (e.g. IESNA, CIBSE)

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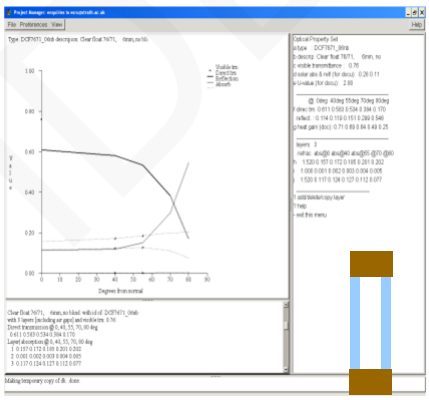
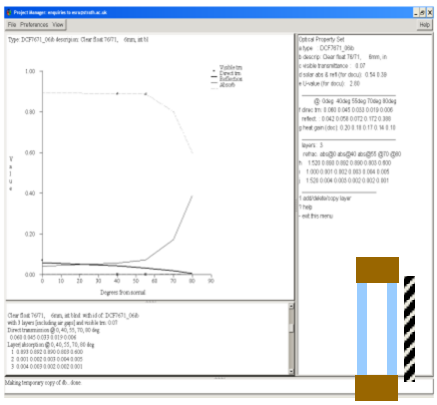
Glazing



Clear float 76/71, 6mm, no blind
id: DCF7671_06nb



Clear float 76/71, 6mm, internal blind
id: DCF7671_06i

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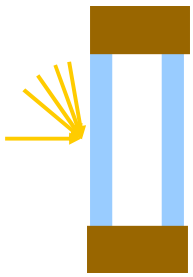
Optical properties ESP-r

Documentation

- Visible transmittance
- Solar absorptivity and reflectivity
- U-value

Calculation

- Incident angle (0-80°)
- related values
- Direct transmittance
- Reflectivity
- Heat gain
- Absorptivity



```
Optical Property Set
a type   : DCF7671_06nb
b descrip: Clear float 76/71,     6mm, no
c visible transmittance :   0.76
d solar abs & refl (for docu):  0.28 0.11
e U-value (for docu):   2.80
_____________________________________
         @  0deg  40deg 55deg 70deg 80deg
f direc trn: 0.611 0.583 0.534 0.384 0.170
  reflect. : 0.114 0.119 0.151 0.299 0.546
g heat gain (doc): 0.71 0.69 0.64 0.49 0.25
_____________________________________
  layers:  3
   refrac. abs@0 abs@40 abs@55 @70 @80
h    1.520 0.157 0.172 0.185 0.201 0.202
i    1.000 0.001 0.002 0.003 0.004 0.005
j    1.520 0.117 0.124 0.127 0.112 0.077
_____________________________________
1 add/delete/copy layer
? help
- exit this menu
```

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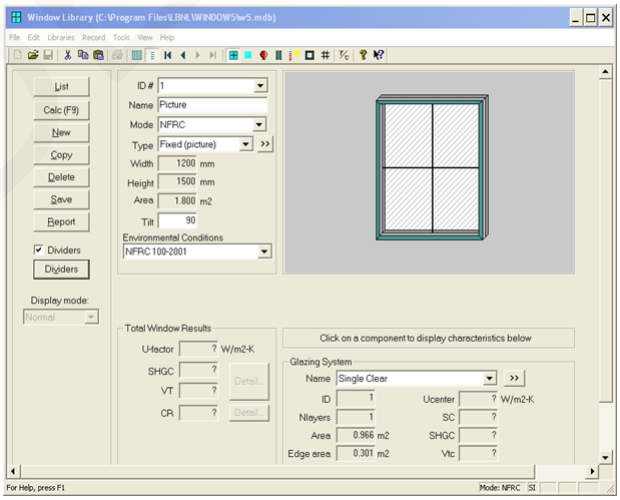
WINDOW 6.3



http://windows.lbl.gov/

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Ventilation

Input data

- Mechanical ventilation rates
- Infiltration rates
- Mechanical ventilation schedules (hourly, daily, weekly, seasonal etc)
- Controls
- Characteristics of fans and ducts
- External pressure coefficients and characteristics of natural ventilation openings (size, operation schedule etc) and
- In case of CFD also define geometry, grid, boundary conditions and turbulence model.

Data Sources

- o Building services engineer
- o Published databases and guidelines from recognized institutions and associations (e.g. ASHRAE, SMACNA, AIVC)

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Plant & Systems

Input data

- System types (e.g. VAV, CAV) and specifications (e.g. efficiency, capacity)
- Plant specification for each system component (e.g part load performance curves, full load efficiency, stand-by losses etc)
- System and plant components control characteristics (e.g. thermostat set points, sensor types and locations, operational characteristics such as: On/Off, proportional only, etc)

Resources

- o Building services engineer
- o Inherent program library
- o Published databases from recognized institutions and associations (e.g. ASHRAE, CIBSE)

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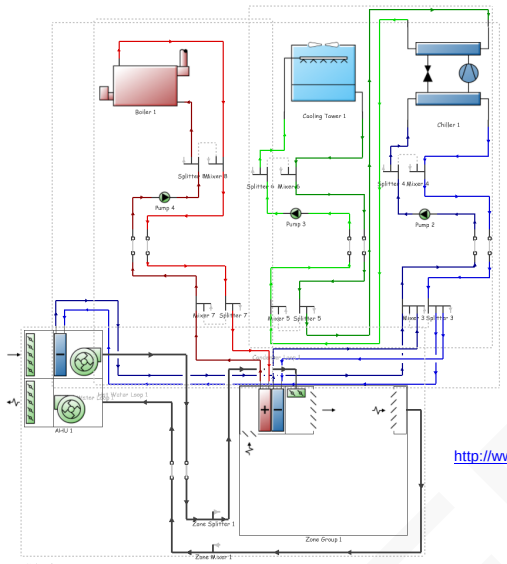
Graphical definition of HVAC plant and components



http://www.designbuilder.co.uk/content/view/115/182/

DesignBuilder Software

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Case study

Low-energy office building

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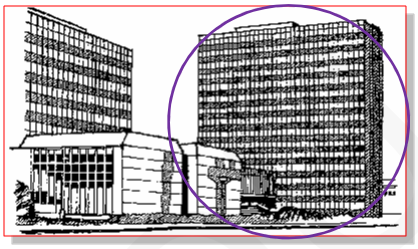
Case Study Description

Architect's request:

- low-energy sustainable office building
- comfort indoor environment
- office rooms for 1-3 persons, oriented south-north



Architect's question:

- What is the best U-value for building envelope ???

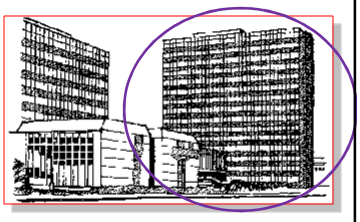
Kabele, Dvořáková 2006

Case Study Description

Czech building regulations

Building envelope requirements

	Alternative	U wall [W/m²K]	U window [W/m²K]
1	DEM (Demanded)	0,38	1,7
2	REC (Recommended)	0,25	1,2
3	LE (Low-energy)	0,15	0,8



Indoor environment requirements

Indoor resultant temperature

winter 18-24 ℃

summer 20-28 ℃

Relative humidity 30-70%

What is the best tool to handle the question ?

Kabele, Dvořáková 2006

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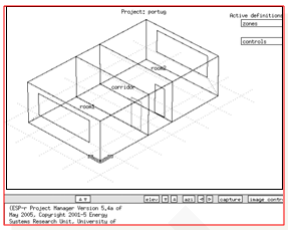
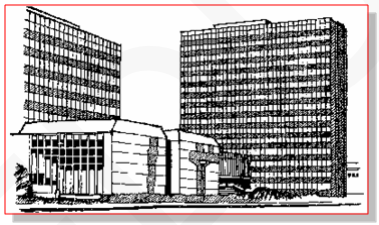
Computer modelling

- ***ESP-r 3 zones model***
  - *2 office rooms 4 x 6 x 3 m*
  - *Corridor 2 x 6 x 3 m*
- ***Heating and cooling system***
  - *heating 0 - 500W,*
  - *cooling 0 - 2500W*
  - *mix of 75 % convection, 25% radiation*
  - *pre-heat and pre-cool controller sensing*
  - *mix of zone db temperature and MRT set points: heating 20℃; cooling 26℃*
- ***Ventilation system***
  - *working hours 1 ac/hr*
  - *non-working hours 0,2 ac/hr*
- ***Casual gains (working time 8-17)***
  - *Occupancy 140 W/per*
  - *Equipment 200W/comp*
  - *Lighting (500 lx): 35 W / m²*



Geometry of simulation model



Kabele, Dvořáková 2006

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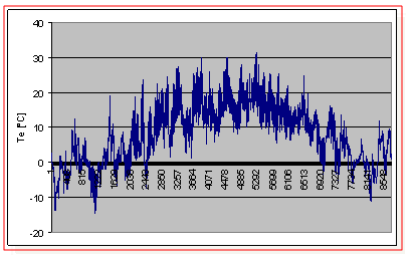
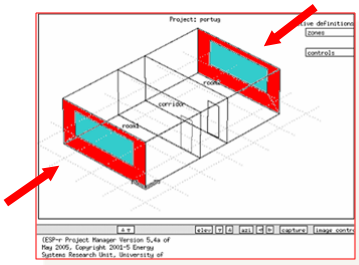
Simulation

	Alternative	U wall [W/m²K]	U window [W/m²K]
1	DEM (Demanded)	0,38	1,7
2	REC (Recommended)	0,25	1,2
3	LE (Low-energy)	0,15	0,8

- *Annual simulation in Czech climate conditions*
- *Building energy and environmental performance*





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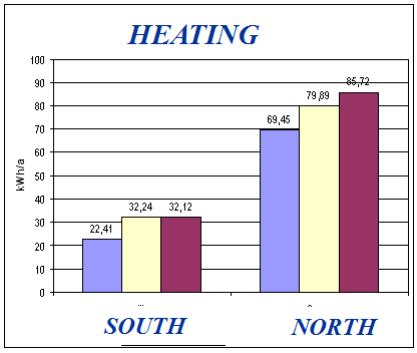
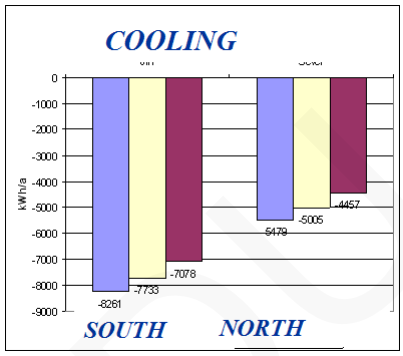
Results

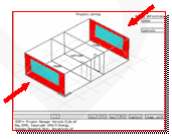
Annual energy consumption





Office

DEManded	
RECommended	
Low-Energy	



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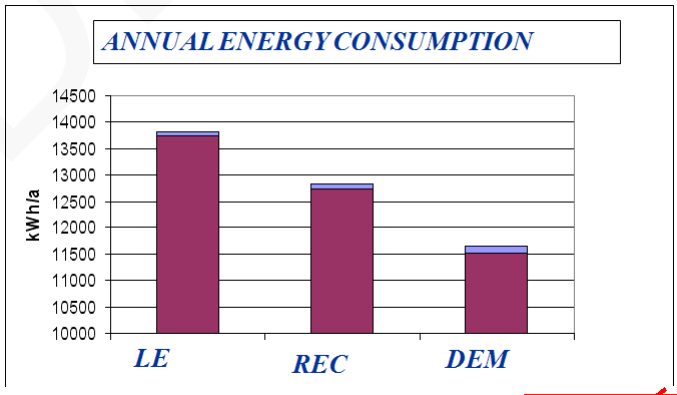
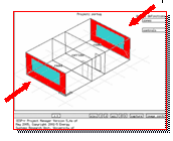
Results

- Total energy consumption



Cooling	
Heating	



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Results

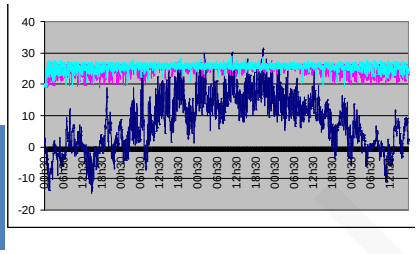
- Indoor temperature

Tair max

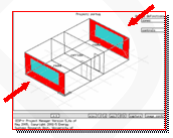
Alternative	Room 1	Corridor	Room 2
LE	27,52	30,84	29,08
DEM	27,54	30,78	29,08
REC	27,76	30,79	29,05

Tair min

Alternative	Room 1	Corridor	Room 2
LE	19,07	18,92	19,11
DEM	19,07	18,66	19,19
REC	19,01	18,81	19,12



Tair Room 1
Tair Room2
Te



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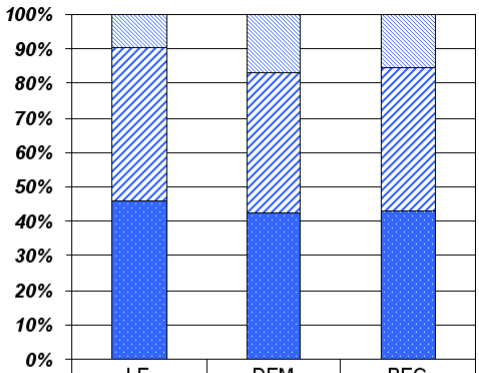
Results

Thermal comfort analysis

- **Annual distribution of PMV during working time according to ČSN EN ISO 7730**
- **Comfort -0,5<PMV<0,5**
- **Acceptable -1<PMV<1**
- **Discomfort PMV<-1 or PMV>1**



	LE	DEM	REC
Comfort	9,7%	16,9%	15,6%
Acceptable	44,3%	40,5%	41,3%
Discomfort	46%	43%	43%

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Conclusion

- Presented case study has shown a possible utilization of integrated simulation supporting the early conceptual design phase
- The recommendation based on this approach is to continue in designing alternative DEM - **demanded U-values**
- The reason, why the results of the thermal comfort evaluation are so unsatisfactory (more than 40% of working time is PMV>1) is due to the relatively high summer temperature set point (+26°C) in connection with settled clothing value and activity of the occupants.

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Case study

Low energy cooling of historical library hall

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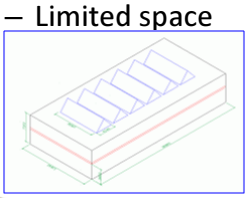
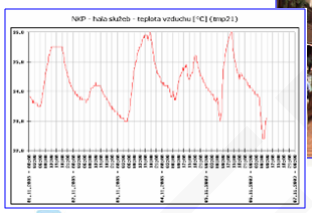
Problem description

- Library services hall
  - Heat gains cca 140 kW
  - Strict requirements on indoor environment
  - No air-conditioning
  - Overheating
  - Historic building
  - Limited space





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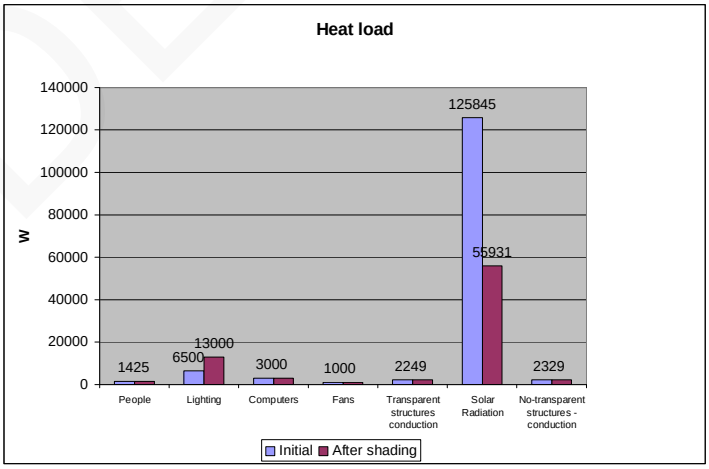
Step 1: Heat load decrease



skylight – shading s =0,9 → 0,4:

140k → 70 kW (standard design calculation)

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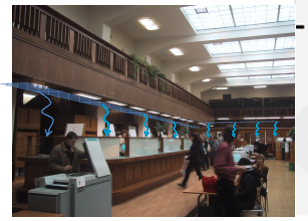
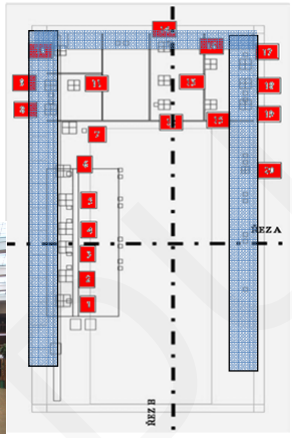
Step 2: Heat load elimination

Air or water system?

space restriction,
operational costs…

Local cooling – ceiling radiant cooling panels





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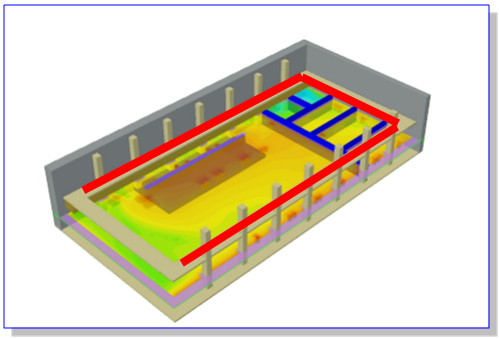
Model

- CFD – Flovent
  - Aim: prediction of indoor working environment with radiant cooling panels
  - 2 alternatives of cooling panels location



Alternative 0 – initial situation
Alternative 1 – 2 sides
Alternative 2 – 3 sides

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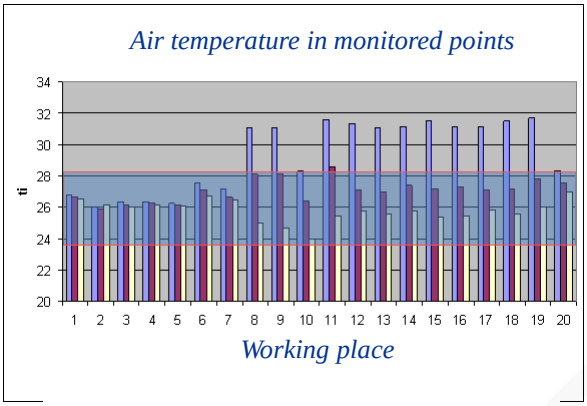
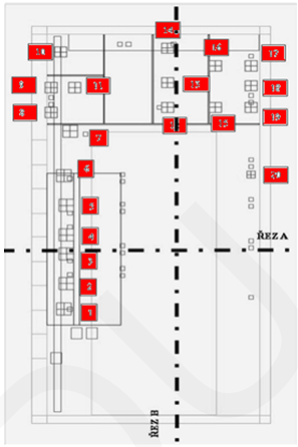
Results





Working places

Initial *2 sides* *3 sides*

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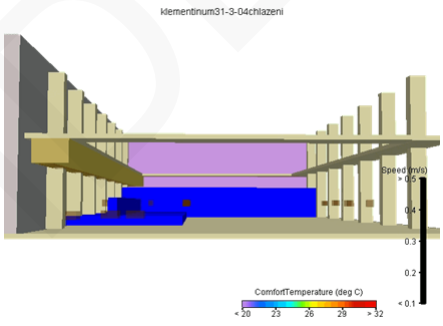
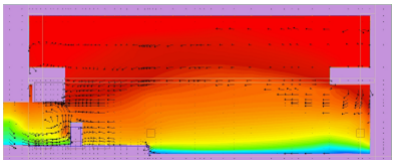
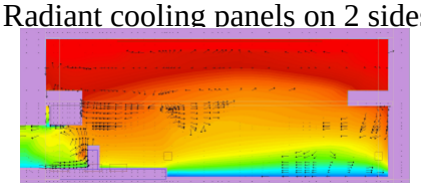
Operative temperature

Initial state

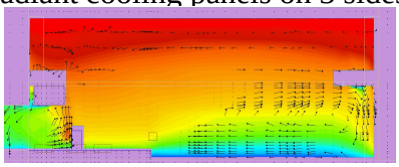




Radiant cooling panels on 2 sides



Radiant cooling panels on 3 sides



Legend					
<20°C	22,4°C	24,8°C	27,2°C	29,6°C	>32°C

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Conclusions

Technical solution

- Cooled ceiling system is advisable for local cooling
- Using this principle is possible to reduce cooling load from 70 kW to 6 kW
- Principle does not solve indoor environment in entire hall

- Modelling and simulation
  - Basic standard heat gain calculation
  - CFD for prediction of temperature distribution
  - Problem of boundary conditions a turbulence modell

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