Quality Assurance

BEEP
BUILDING ENERGY EFFICIENCY PROJECT

Ministry of POWER
GOVERNMENT OF INDIA

ENERGY IS LIFE
BEE
CONSERVE IT

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
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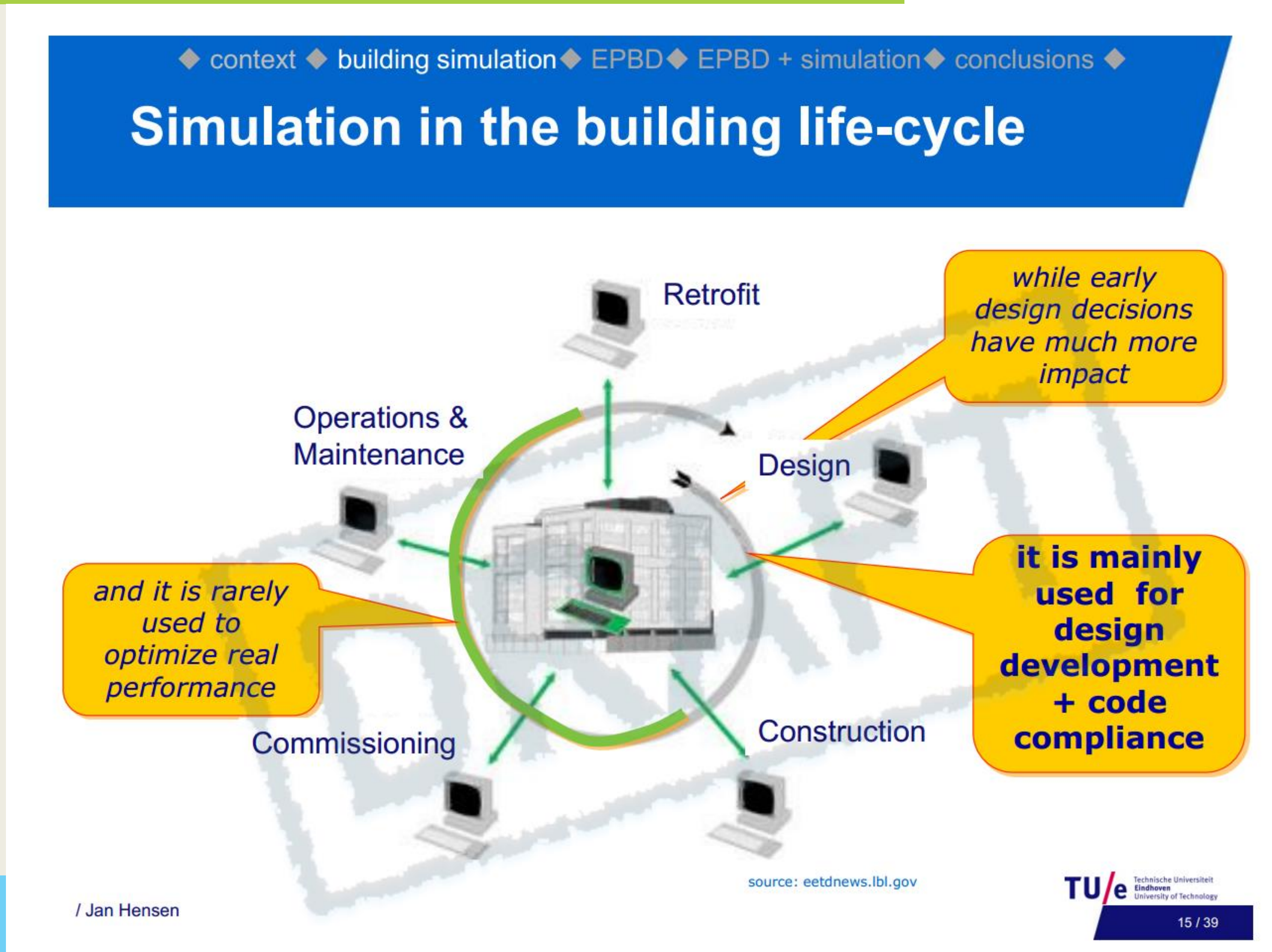
Embassy of Switzerland in India

Preliminary remark

- This presentation about Quality Assurance aims at actual building performance simulation and not at label or regulation compliance, which is often far from the real world

Simulation during the design process: Too often used later in the design



Example of the role of the user in the building simulation: IEA 21

Reports published by BRE and other bodies have conclusively demonstrated that 90% of all building failures have their origin in faults in design and construction (design faults being responsible for 50% of all failures), Fig. 2.1, [I, PSA, 19861.

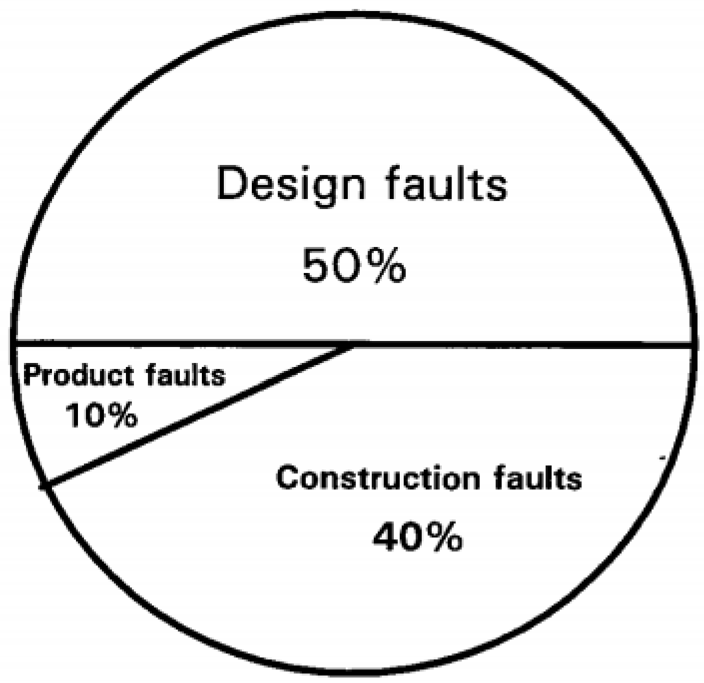


Fig. 2.1- **Breakdown of building failures on basis of their origin**

ENERGY ANALYSIS TESTS FOR COMMERCIAL BUILDINGS

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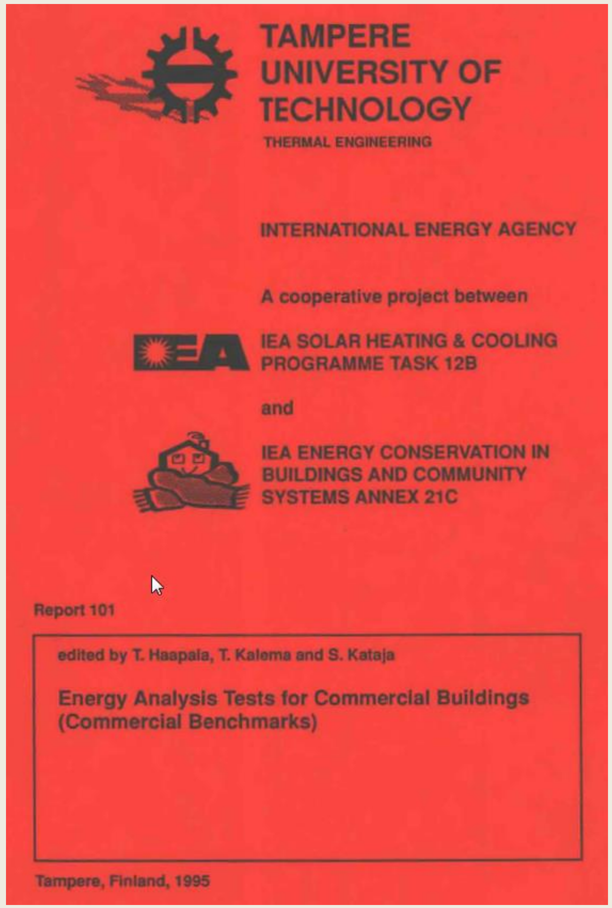
- Six energy analysis programs, BLAST, ESP, SERI-RES, S3PAS, TASE and TRNSYS, participated in this study



TAMPERE UNIVERSITY OF TECHNOLOGY
THERMAL ENGINEERING

INTERNATIONAL ENERGY AGENCY

A cooperative project between

IEA SOLAR HEATING & COOLING PROGRAMME TASK 12B

and

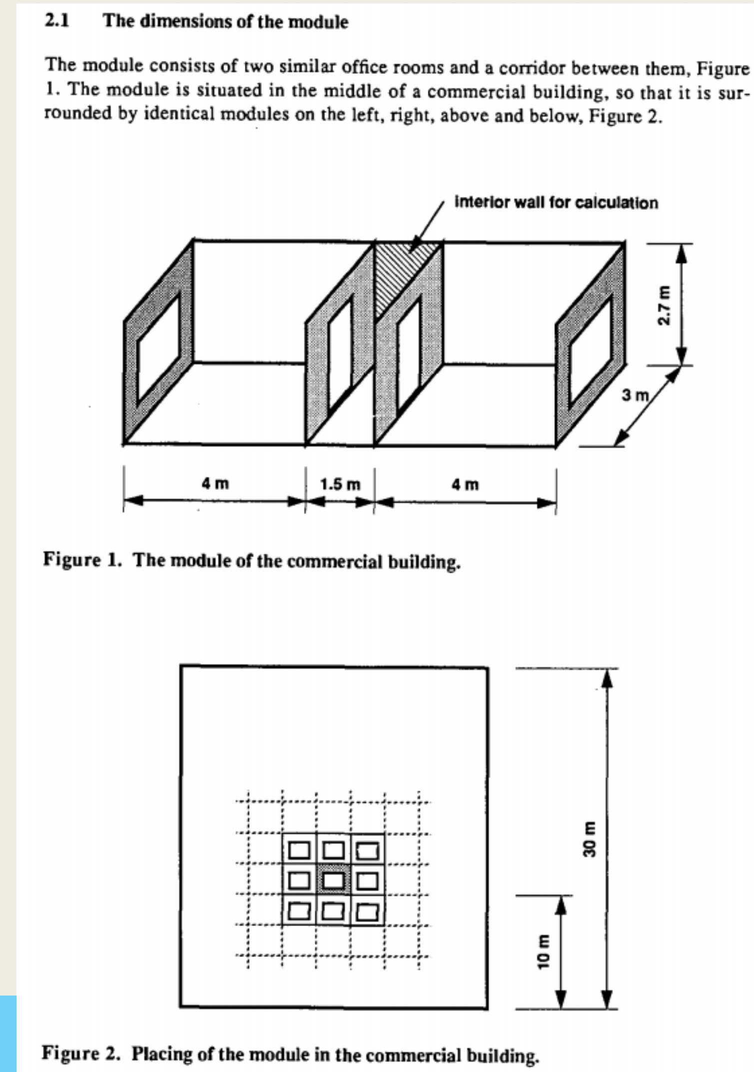
IEA ENERGY CONSERVATION IN BUILDINGS AND COMMUNITY SYSTEMS ANNEX 21C

Report 101

edited by T. Haapala, T. Kalema and S. Kataja

Energy Analysis Tests for Commercial Buildings (Commercial Benchmarks)

Tampere, Finland, 1995



2.1 The dimensions of the module

The module consists of two similar office rooms and a corridor between them, Figure 1. The module is situated in the middle of a commercial building, so that it is surrounded by identical modules on the left, right, above and below, Figure 2.

Figure 1. The module of the commercial building.

Figure 2. Placing of the module in the commercial building.

ENERGY ANALYSIS TESTS FOR COMMERCIAL BUILDINGS

Maximum annual air temperatures for each space in case 3a. Test case 3a: north-south, unshaded, unheated

The indoor volume weighted maximum air temperature of the whole module calculated by the various programs differs less than -2.3 ... +2 OC from the mean value of all programs, which was approximately 28.5 °C. The greatest difference between the results of two programs for a room is between the temperatures of TASE and SERI-RES. TASE gives approximately a 4.5 OC greater maximum temperature for the south-facing room than SERI-RES. The minimum temperatures of the corridor calculated by the various programs differ less than -2 ... +2.6 °C the lowest.

Table 9. The operating schedules and the set point temperatures for heating and cooling for case 3.

Time interval	Rooms 1 and 2		Corridor
	heating	cooling	heating
h	°C	°C	°C
0700 ... 1700	20	25	-100
1700 ... 0700	18	100	-100

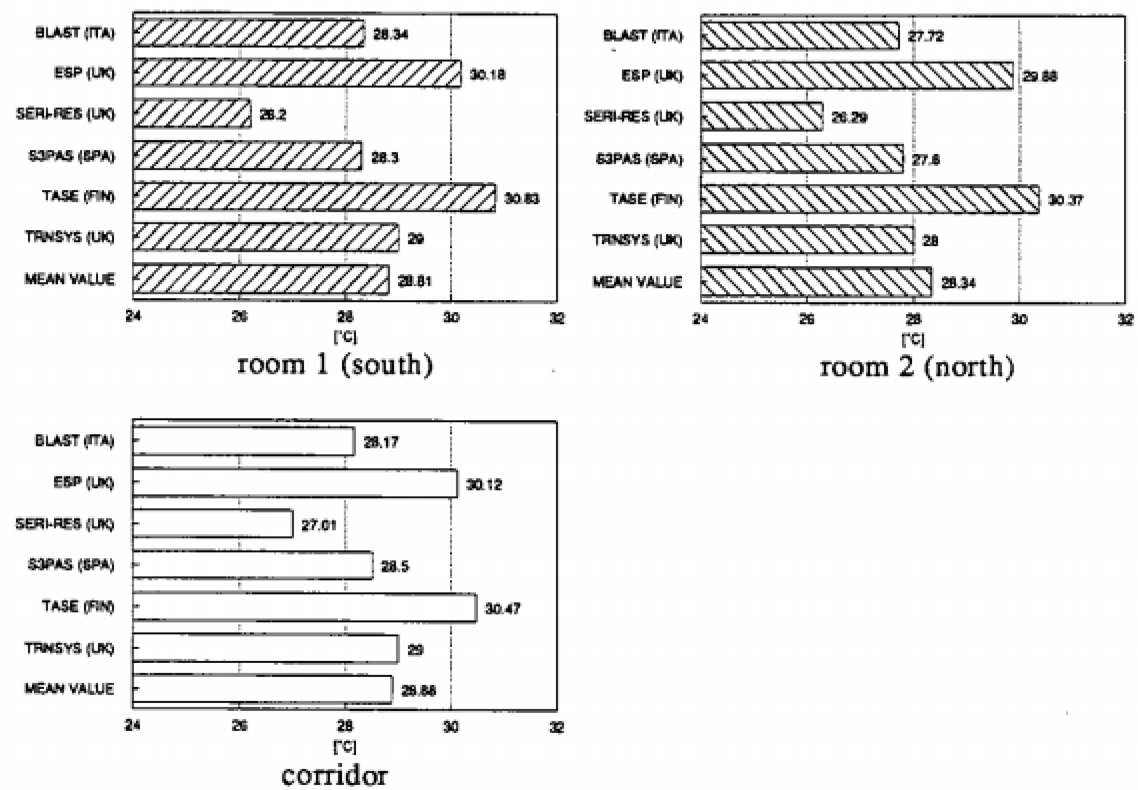


Figure 11.3a **Maximum annual air temperatures for each space in case 3a.**

Example of the role of the user in the building simulation: IEA 21

4.3 Evaluation methodology

4.3.1 Benchmark tests

The computer software packages being used within the Performance Assessment Methods (PAMs) were tested and compared, using the Cases 9 to 12 'benchmarks' developed in IEA Solar Task WI [4.1].

These cases include both simple lightweight and heavyweight constructions, with mechanical heating and cooling and free-float conditions. The main aim of this exercise was to quantify the differences between the programs used within the documented Performance Assessment Methods (PAMDOCs) so as to aid in interpreting the comparison of results from different PAMs. Five countries took part: Belgium, Germany, The Netherlands, Switzerland and the United Kingdom.

Nine computer packages were used: BLAST, BREADMIT, ENERGY2, ESP, SERI-RES, TAS, TRNSYS, VA114 and a code written in-house by a BRE contractor from Tsinghua University, China.

Some packages were run by more than one participant, giving an insight into the effect of variations in personal interpretation of input data. Details of special features and problems found when running each package are documented. Comparative results have been plotted and are discussed.

Example of the role of the user in the building simulation: IEA 21

Sixteen sets of results were obtained. These showed clear variations between users for ESP, SERI-RES, TAS and TRNSYS and indicates the difficulties of interpretation even for a clearly defined simple building. This user effect can cause greater differences in results than that of using different programs. Typical results for annual heating loads have a range of 7988 to 9403 kwh for the lightweight building, while cooling loads have a wide range from 411 to 1299 see Figure 4.1. The range of results is smaller for the heavyweight case. Many programs predicted loads outside the target ranges established within IEA Task VIII. For the lightweight building annual heating loads, 6 results were above the maximum and 3 below the minimum of Task Vm; for cooling loads, none was above the maximum but 9 were below the minimum. For the heavyweight building heating loads, 8 results were above the maximum and 5 below the minimum of Task VIII; only one cooling load was above the Task VIII maximum but 11 out of the 16 were below the minimum

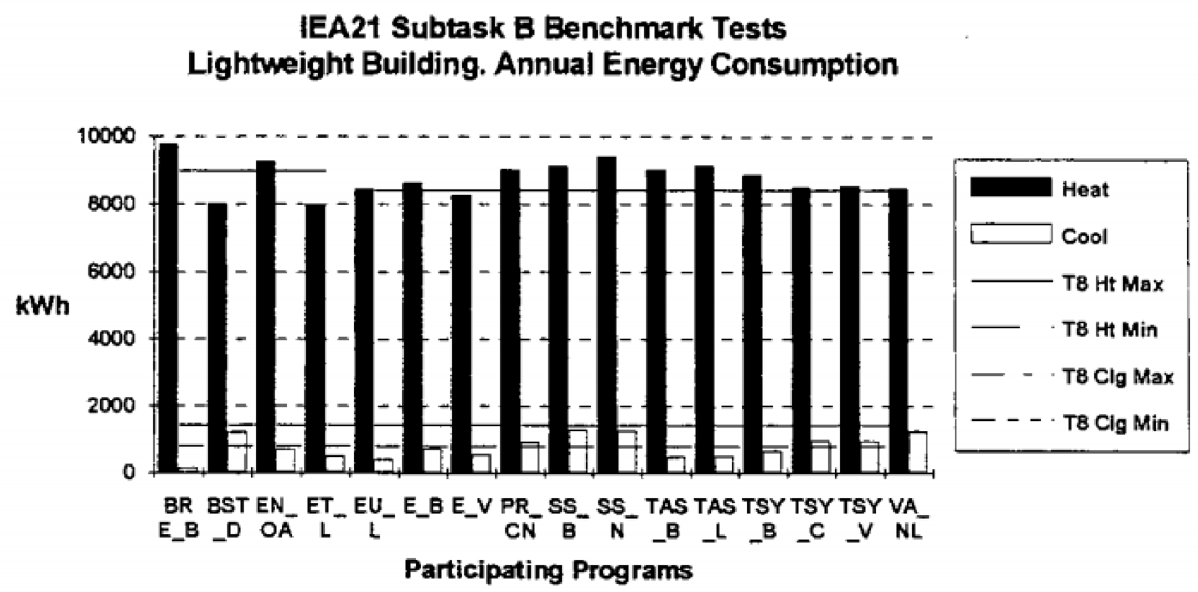
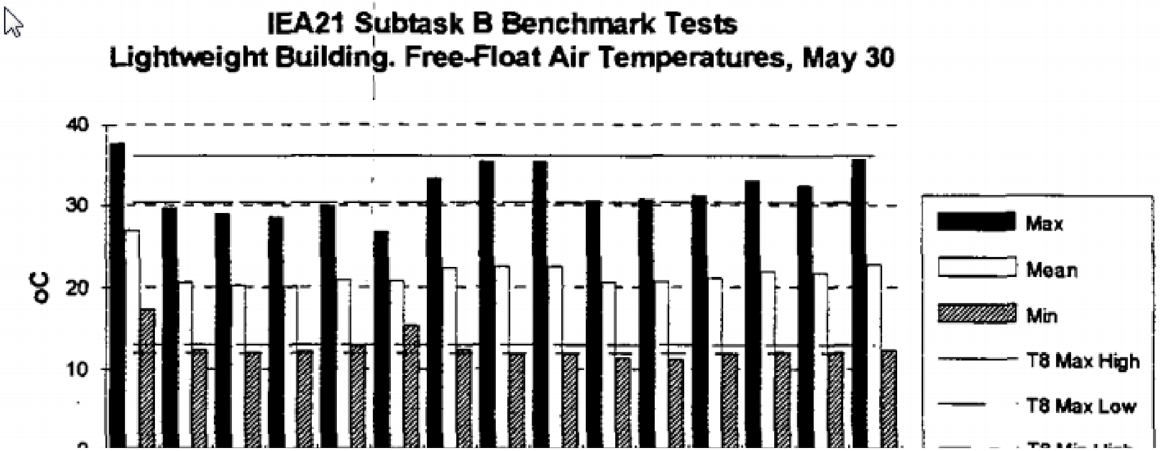


Fig 4.1

EXAMPLE OF THE ROLE OF THE USER IN THE BUILDING SIMULATION: IEA 21

A good indicator of how a program treats the thermal mass, or storage of the building can be gained by looking at the predicted range in temperature over a day. Most of the programs gave similar results but with a few outliers, at least one of which seemed likely to be due to user rather than program errors. As some of the PAMs use the accumulated frequency of temperature as a criterion for overheating, this parameter was calculated. The predicted number of hours for which a temperature was exceeded varied widely between programs. For example, 25°C was exceeded between approximately 100 and 180 hours for the calculated cases.



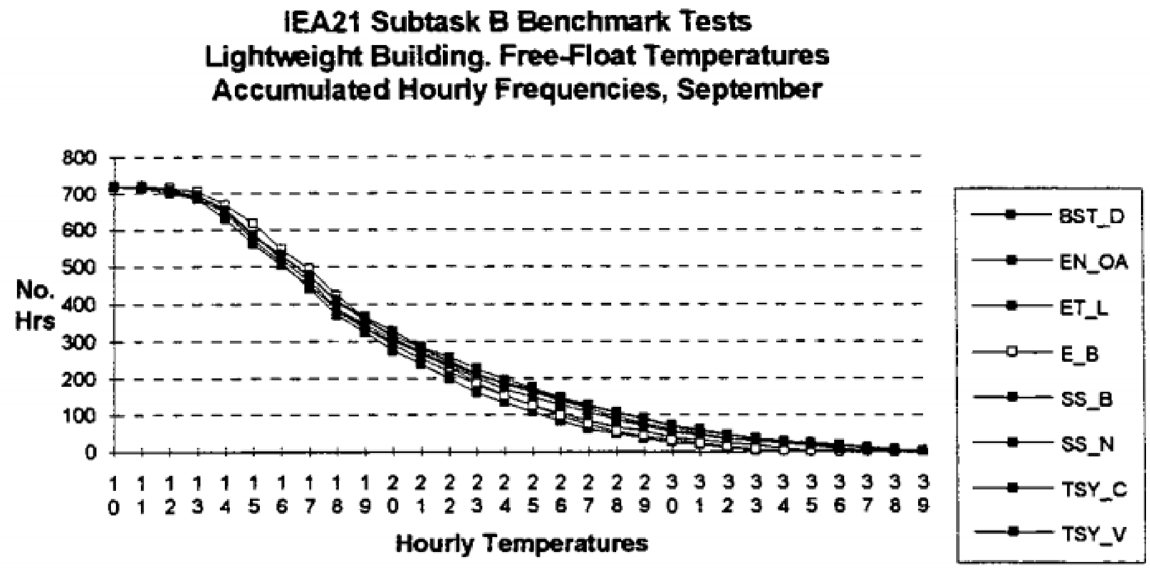


Fig. 4.3

Example of the role of the user in the building simulation: IEA 21

- Comparison of users influence on the results of overheating risk assessment

- Stage 1: only physical and operational description of the building occupation description
- Stage 2: use of a Performance Assessment Method documentation (PAMDOC)

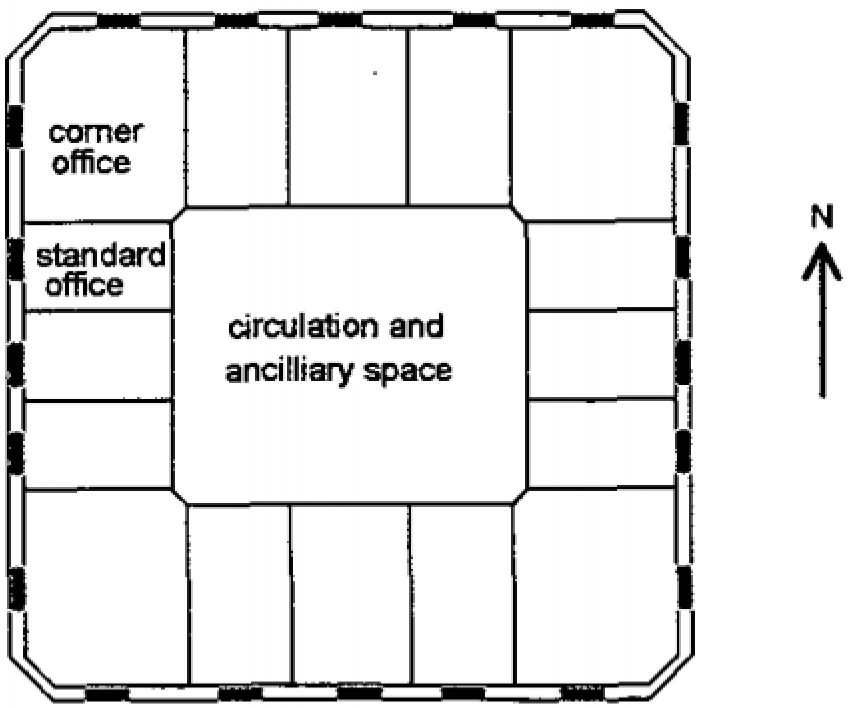


Fig. 4.4 Basic floor plan

Example of the role of the user in the building simulation: IEA 21

Other building information was provided at a level expected to be the case in practice as

follows:-

. layers of materials with thicknesses, but without thermophysical properties

glazing description with basic characteristic data, but no detailed description of physical

properties which is not normally available.

type, level and time schedules for occupation and equipment to enable values for internal

gains to be determined, but no rdiative/convective split

verbal description of lighting system and its control

0 verbal description of ventilation strategy

This leads to the necessity for the users to make assumptions on data which is not available

from the building description nor from the program manual. Information obtained from the

PAMDOCs is supposed to fill the gaps.

Example of the role of the user in the building simulation: IEA 21

The users were asked to calculate 2 cases:

-A base case with a minimum hygienic ventilation rate provided through open windows during occupancy time and infiltration only during non-occupied periods.

-A 'night ventilation' case, with enhanced window ventilation for cooling purposes during non-occupied periods with inkormation being provided by a sketch of the window opening pattern.

Some of the participants also considered measures such as blinds for solar protection. The problem description was initially supplied to the prospective users for comment. The comments received from the participants after the first distribution of the specification almost exactly addressed items where incomplete information had been intentionally given and where assumptions would normally have had to be made. These should have been available from the PAMDOCs. They asked for radiative-convective splits, detailed glazing descriptions, thermophysical properties etc.

Room	Case	User: / Program:	TNO / VA114	Newcastle / SERI-RES	Sorane / TRNSYS	EMPA / DOE-2
south center	Base case		1060	1493	1089	1068
	with blinds		692		788	38
	open windows night, no blinds		849	706	200	507
	open windows night, with blinds		36		4	34
south-east corner	Base case		1060	1480		1248
	with blinds					36
	open windows night, no blinds			688		782
	open windows night, with blinds					34

Table 4.1: Number of hours with room temperatures > 25 °C (occupancy time only)

Example of the role of the user in the building simulation: IEA 21

Room	Case	User: / Program:	TNO VA114	Newcastle SERI-RES	Sorane TRNSYS	EMPA DOE-2
south center	Base case		1037	1447	1089	913
	with blinds		182		210	0
	open windows night, no blinds		394	290	14	94
	open windows night, with blinds		0		0	0
south-east corner	Base case		969	1451		919
	with blinds					0
	open windows night, no blinds			328		156
	open windows night, with blinds					0

Table 4.2: Number of hours with room temperatures > 28 °C (occupancy time only)

4.14

Room	Case	User: / Program:	TNO VA114	Newcastle SERI-RES	Sorane TRNSYS	EMPA DOE-2
south center	Base case		41.6	45.4	<= 41	38.6
	with blinds		30.8		<= 31	26.2
	open windows night, no blinds		35.7	34.5	<= 29	31.0
	open windows night, with blinds		26.2		<= 29	26.1
south-east corner	Base case		39.2	44.2		37.7
	with blinds					26.1
	open windows night, no blinds			33.8		30.9
	open windows night, with blinds					26.1

Table 4.3: Maximum calculated room temperatures during run period, °C (occupied period only)

Example of the role of the user in the building simulation: IEA 21

In the Netherlands 4 users were asked to do calculations on the IEA Annex 21 'Base Case' with the Dutch simulation program VAI 14 in 2 stages: without and with the use of the VA114 related PAM developed by TNO-Bouw.
To obtain maximum informatibn from this test some extra work was done:
Before the 4 users started witki stage 1 they were asked to provide information about how they would do the zoning and about how they would present the results. After they had delivered this information sdge 1 was started with a prescribed way of zoning and a prescribed way of presenting the results.
After the 4 users had completed the simulations a fifth user studied their input and output files. This was done to search for errors, differences in assumptions made, differences in input data, differences in nbdelling. This fifth user also carried 0111 the BaseCase simulation.
In this way important information for PAM development was collected.

Example of the role of the user in the building simulation: IEA 21

The Dutch work resulted in:
completed questionnaires about the way of zoning
. completed questionnaires about the way of presenting the results
. list with findings from checking the input files and a documented print out of the input values.
. influence of the use of a PAM (together with a check by a second person).
Figure 4.5 gives the results without the use of a PAM and without check by a second person, Figure 4.6 gives the results with the use of a PAM and with a check by a second person. The check by a second person was shown to be essential.

Example of the role of the user in the building simulation: IEA 21

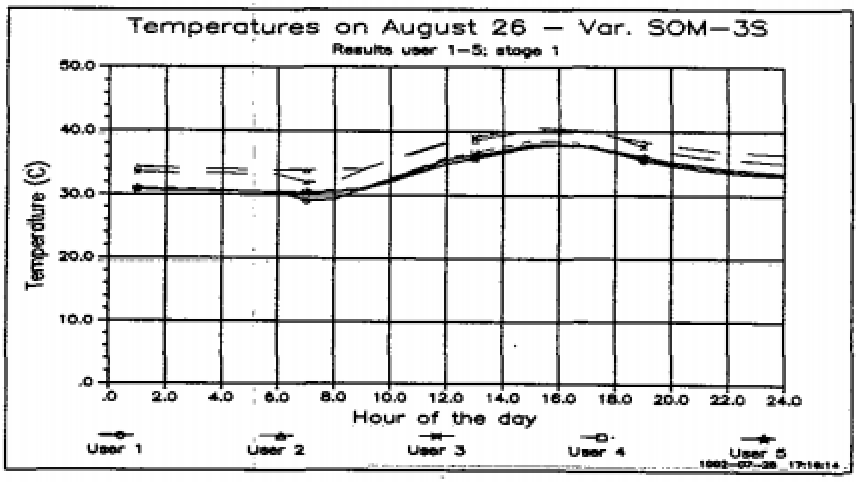


Fig.4.5(a)

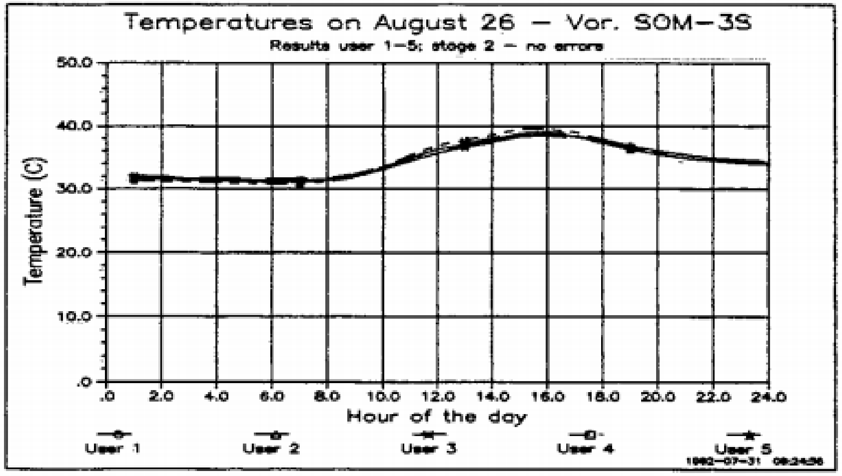


Fig. 4.6(a)

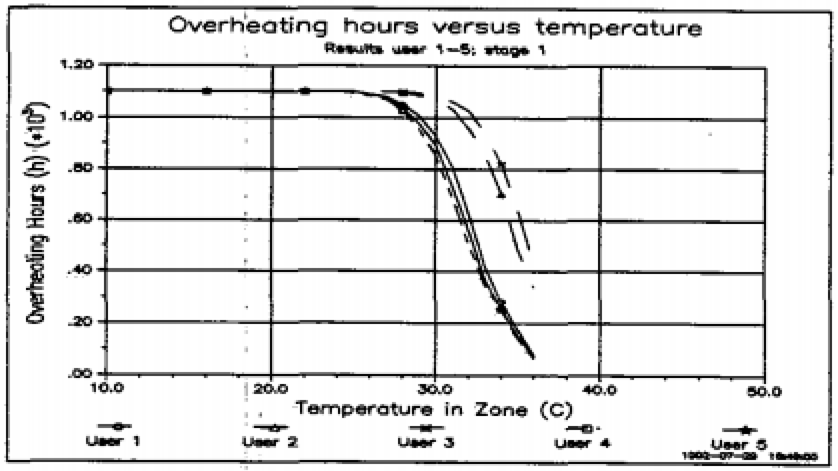


Fig.4.5(b)

Figure 4.5a and b: Results after stage 1
(without PAM and without check by second person)

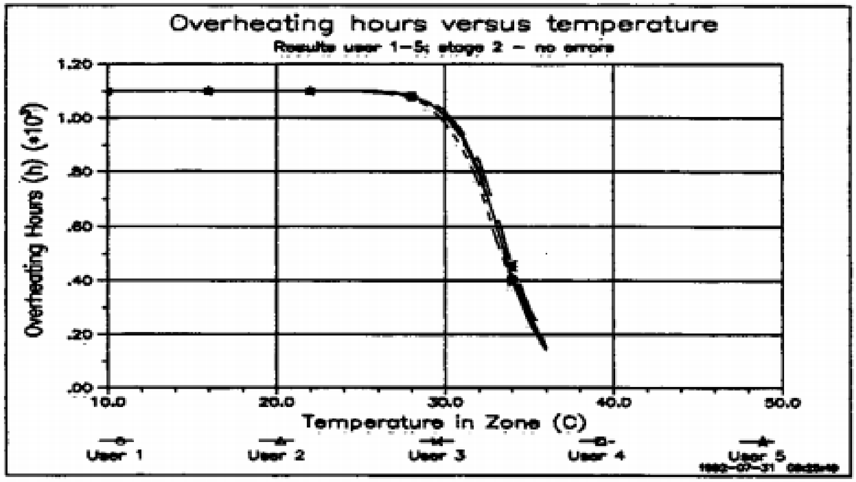


Fig. 4.6(b)

Figure 4.6a and b: Results after stage 2
(with PAM and with check by second person)

Example of the role of the user in the building simulation: IEA 21

In Switzerland, 3 users with different knowledge levels: highly experienced, medium experienced and a beginner were selected from the community of the companies equipped with the simulation program DOE-2.

They were asked to perform an overheating risk assessment on the IEA Annex21 case study building for 4 different cases with blinds and different assumptions for internal heat gains and ventilation.

This was done the first time without any aids, according to the practice of the respective company, and a second time with the tool developed in the' framework of this project. This was not the PAMDOC, nor any other paperwork, but a 'standard DOE-2-input for this application, formed by a transformation of the PAMDOC content. The users were unaware of the differences.

An important aspect of this test was that the level of information provided was not in such detail as would be necessary to achieve very close results. It's intention was to provide as much information as would be expected in a practical case at the stage of a project where the question of overheating has to be treated, and which is usually available for the products in use. No information was given on the zones to be selected, except that for comparison reasons they were asked to treat at least the center office module in the south and the west facade. The location of the building was given and the users were asked to follow the regional requirements and to provide nr leus~ any results to meet the.

Example of the role of the user in the building simulation: IEA 21

		1st Stage				2nd Stage			
Zone	**Case**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
South	**User 1**	1147.2	960.4	*17.2*	398.8	*0.2*	*18.0*	*0.0*	75.4
	User 2	82.2	82.2	*6.3*	*0.0*	33.4	33.4	*0.0*	101.9
	User 3	71.1	60.7	*24.7*	960.2	*3.5*	*5.0*	*0.0*	*16.6*
West	**User 1**	*0.0*	*0.0*	*0.0*	*0.0*	---	---	---	---
	User 2	216.7	216.7	33.7	*0.0*	102.3	102.3	*0.2*	219.8
	User 3	38.9	31.6	*15.0*	893.4	82.5	94.5	*0.0*	139.0
East *	**User 1**	2735.0	2641.0	103.0	1727.0	1572.7	---	50.7	---
Corner SW	**User 2**	67.0	67.0	*4.0*	*0.0*	*2.2*	*2.2*	*0.0*	*14.5*

Table 4.4: Results of the Swiss user test, in the form of overheating Degree-hours (Kh)
* Own assumptions from stage 1 partly kept in stage 2 to show differences.
Italics: No overheating

EXAMPLE OF THE ROLE OF THE USER IN THE BUILDING SIMULATION: CLIM 2000 1

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- Simulation of the energy demand for a single family house

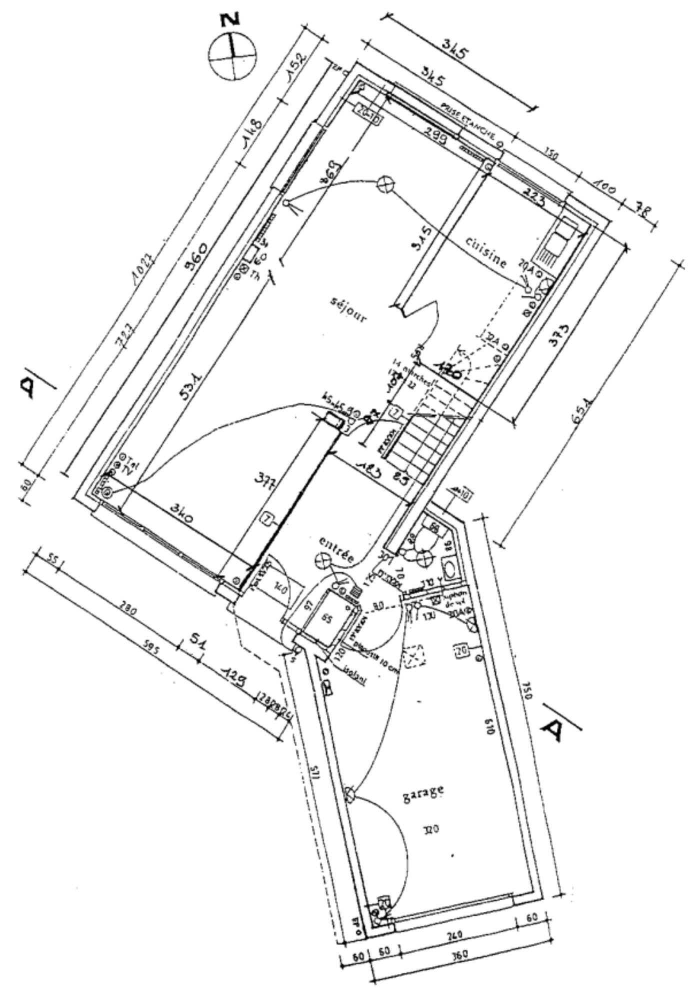
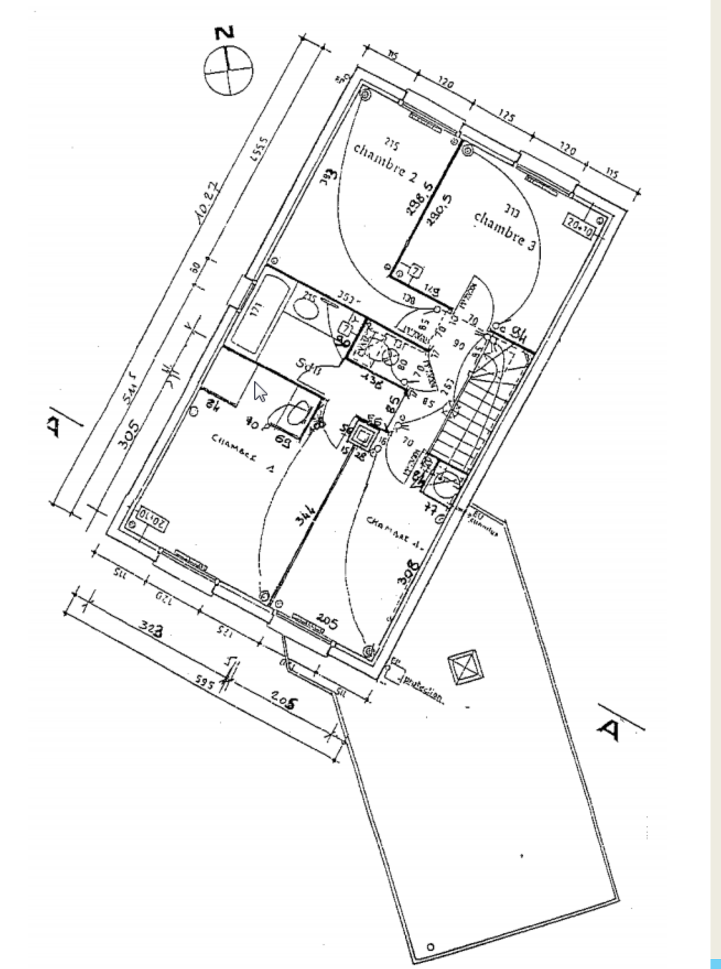


Figure 2 : Drawing of Valeriane first floor



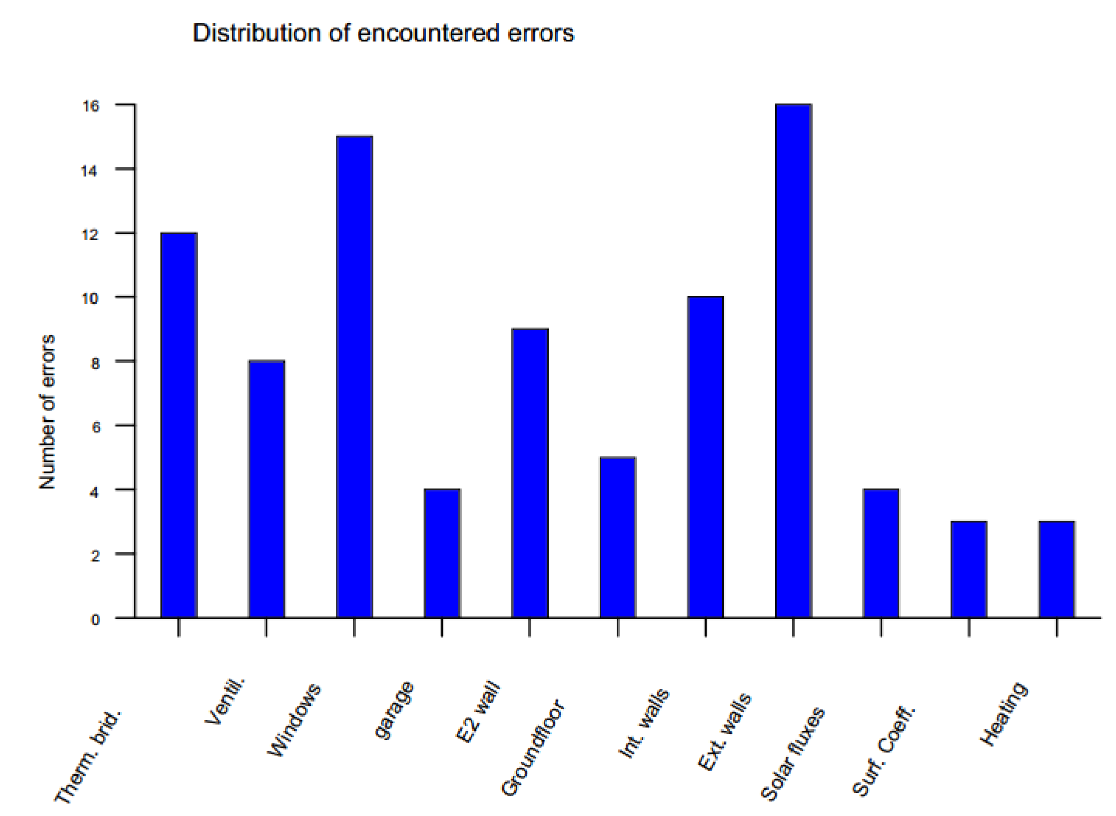
ROLE OF THE MODEL USER IN RESULTS OBTAINED FROM SIMULATION SOFTWARE PROGRAM, Gilles GUYON, Electricité De France, DER/AEE/ADEB, Site des Renardières, 77818 Moret sur Loing Cedex, France E-Mail : Gilles.Guyon@der.edfgdf.fr

Example of the role of the user in the building simulation: CLIM 2000 1

many categories of errors were identified :

- thermal bridges,
- ventilation,
- windows and French windows,
- constitution of wall between entrance and garage,
- modelling of ground floor,
- constitution of external walls,
- surface coefficients,
- heaters,
- solar fluxes transmitted in the room

Figure 3 : Distribution of encountered errors



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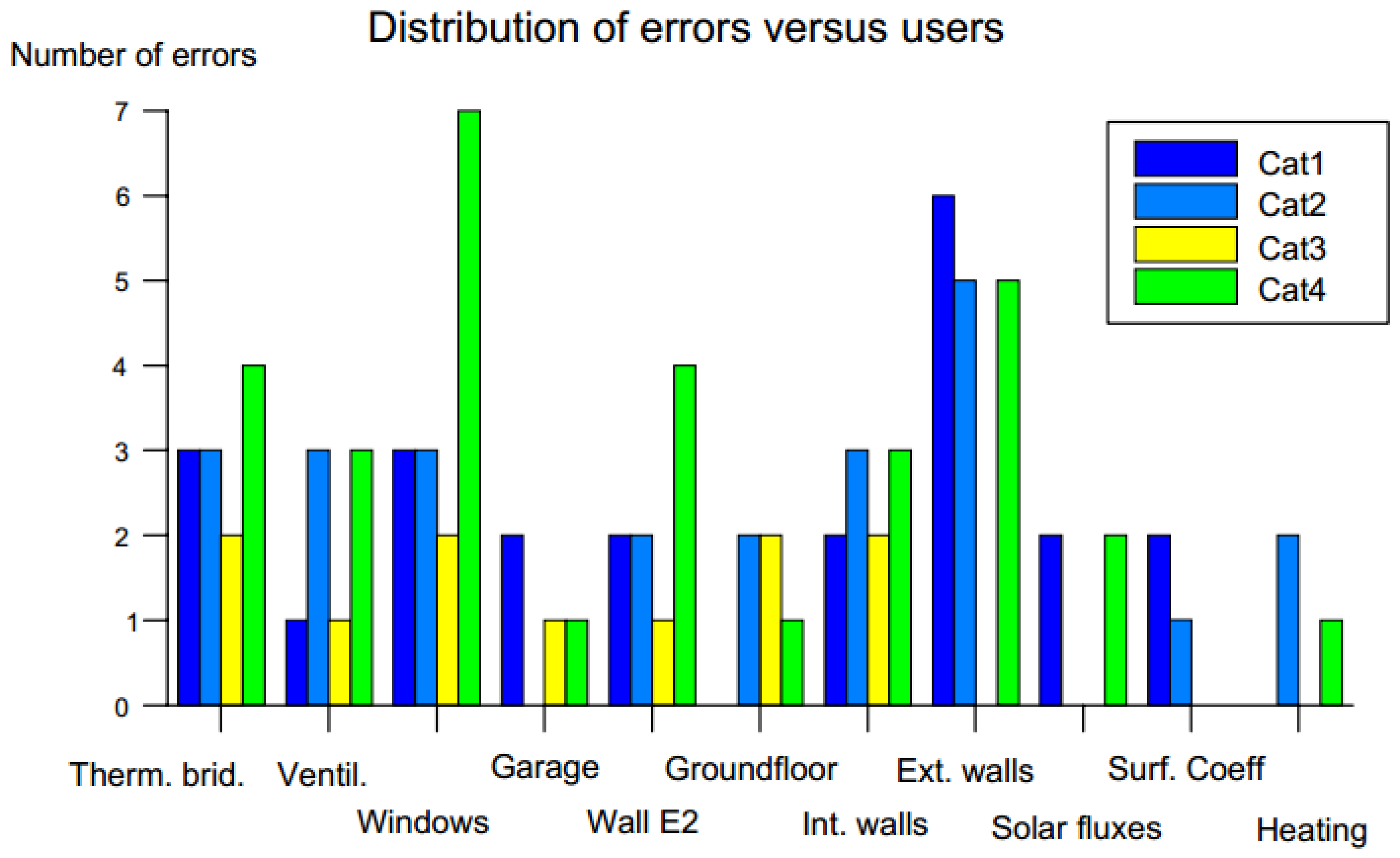
Example of the role of the user in the building simulation: CLIM 2000 1

Figure 4 : Distribution of errors versus users



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Example of the role of the user in the building simulation: CLIM 2000 3

Table 1 : Panel of participants

Reference	Description	Number
Cat 1	EDF people accustomed to CLIM2000 use for studies	3
Cat 2	EDF people accustomed to CLIM2000 use but not for studies	3
Cat 3	Students with the help of people accustomed to CLIM2000 use for studies	2
Cat 4	Exterior consultants accustomed to CLIM2000 use	4

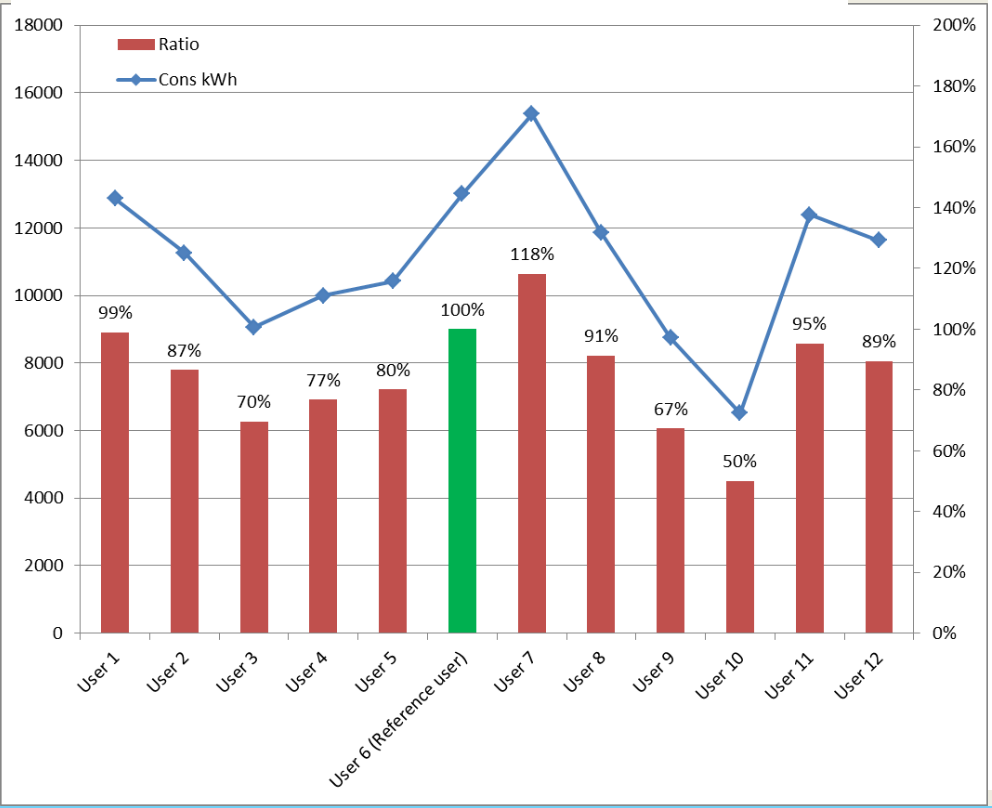

Table 2 : Results obtained and comparison with the average value

Average value : 11090 kWh
Standard deviation = 2235 kWh

	User1	User2	User3	User4	User5	User6	User7	User8	User9	User10	User11	User12
Cons. kWh	12862	11256	9060	9987	10419	13000	15367	11861	8744	6510	12392	11626
variat^{n}/ avg	+16%	+1.5%	-18%	-10%	-6%	+17%	+39%	+7%	-21%	-41%	+12%	+5%

Table 3 : Comparison with the « reference modelling »

	User1	User2	User3	User4	User5	User6	User7	User8	User9	User10	User11	User12
Cons. kWh	12862	11256	9060	9987	10419	13000	15367	11861	8744	6510	12392	11626
variat^{n}/ ref. val.	-1%	-13%	-30%	-23%	-20%	0%	+18%	-9%	-33%	-50%	-5%	-11%

Table 4 : Participants distribution

Reference	Description	Users	Variation/ mean value	Variation/ reference
Cat 1	EDF people accustomed to CLIM2000 use for studies	1, 8, 12	+5 to +16%	-11 to -1%
Cat 2	EDF people accustomed to CLIM2000 use but not for studies	9, 10, 11	-41 to +12%	-50 to -5%
Cat 3	Students with the help of people accustomed to CLIM2000 use for studies	4, 5	-10 to -6%	-23 to -20%
Cat 4	Exterior consultants accustomed to CLIM2000 use	2, 3, 6, 7	-18 to +39%	-30 to +18%

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Accuracy, reliability and real world compliance of simulation results

- Quality of the design brief
  - Occupation scenario
  - Specifications for comfort
- Quality robustness of software
- Quality of data
- Quality of the simulation user

Quality of the design brief

– Occupation scenarios

– Specifications for comfort

Quality/robustness of the software

- Modelling capability
  - HVAC
  - Advanced components
  - Natural ventilation
  - Adiabatic, evaporative cooling
  - Possibility do add specific capability ?
    - Source code well described ? Accessible ?
    - Co-simulation capabilities
- Environment for parametric studies
  - Inside
  - Outside
- Validation stage
- Technical support, user's club, etc

Quality of data

- Weather data availability
  – Careful about synthetic data
- Possibility to build data from other sources than the software itself ?
- Data base for components ?
    - New materials, systems performances

Quality of the simulation user

- Knowledge and understanding of the building physics, HVAC
- Good common sense
  - Ability to relate results to physical understanding, memory of previous situations
  - Ability to analyse the results and question them
- Ability to make quick parallel calculations
  - Simple back of the envelope
  - Equation based models
  - Books, abacus, ….
- Representation of results data for coherent checking
- Ability to identify important parameters upfront
  - Define relevant parametric studies
- Willingness to discuss inputs and results with others

How to improve or acquire common sense ?

- "So let's seek common sense and apply it to everything, because knowledge plus common sense is wisdom, **but knowledge minus common sense is nonsense**"
- "Engineering is the art of applying scientific and mathematical principles, experience, judgment, and **common sense** to make things that benefit people"
- "**Common sense means paying attention to the obvious**. This is not as easy as it sounds, because we all have vivid imaginations, and we tend to get lost in our fantasies"
- Practical matters (including science) will always need to be considered though the filter of common sense, otherwise the application of science will be compromised
- Common sense is practical intelligence ?
- To reduce common sense down to domain-specific expertise or knowledge is to miss the point. It extends far beyond that, recruiting both meta-knowledge and a discerningability to know which rules and judgements apply in vastly differing circumstances.
- "Common sense is the most widely shared commodity in the world, for every man is convinced that he is well supplied with it." ― René Descartes
- "Common sense is in spite of, not the result of, education." ― Victor Hugo
- "Common sense is not so common." ― Voltaire
- Common sense knowledge(CSK) is the knowledge we use in everyday life without necessarily being aware of it. Panton et al. (2006) of the Cyc project, define common sense as "the knowledge that every person assumes his neighbors also possess

How to improve or acquire common sense ?

- Learn from mistakes- they are bound to happen, so make them a positive experience. Nobody is perfect! Besides, life's greatest lessons are learned through mistakes. Some mistakes are so horrific that you'll never forget them (and therefore you'll never make them again).
- People who are book smart are usually pointed out to lack common sense. Why you may ask? Well, people who are book smart tend to need answers to everything from out of a text book. In life, suprises arrive and most often than not you have to use previous experience to get through it. Don't over analyze things, you will complicate simple things.
- Common sense plays a role in science. If there are two possibilities that could both be true, it is accepted by science that the most simple, most "common sense" answer is the place to start, and until or unless it is disproved or "wobbly,"[3] it should be given more weight than an answer that breaks common sense until more evidence can be gathered.

Limits of common sense

- Common sense is often confused with rational thought, being that people often believe common sense must be true and act incredulously to rational or scientific ideals that contradict common sense. This is due to the fact that the human brain can easily work with ideas like common sense and rules of thumb but can't quite cope with physics and statistics

Choice of the tools for given issues, problems, definition of modelling

- Don't use a sledgehammer to kill a fly
- Use the fastest and reliable method to answer the questions
- Get hold of the important parameters before going into a very detailed model where too many parameters will be involved

Choosing a proper tool for the design issues at this stage

- At what stage do we need a dynamic building simulation programme ?
- What level of modelling do we need ?
  - Complete building ?
  - Only part of the building ?

Using simulation software at very early stage

- Quality assurance ?
  - At early stage, design decision making for the project
  - Later in the design process, refine results and check specifications compliance
- What to simulate ?
  - Simulate in detail a small portion of the building ?
    - E.g. a portion of an office building
  - Simulate with less detail the whole building ?
    - Look at global orientations, facades, solar gains
  - Simulation of specific parts or features ?
    - consider a specific model for down-draft evaporative cooling ? (CFD ?, thumb rule ?)

What is the objective

- At early stage
  - Check feasibility of different options
  - Check extreme conditions
  - Focus on extreme conditions to check feasibility of different option
  - Check rapidly energy performance for comparison
- Later
  - Focus on energy performance with more detailed and more complete modeling for the zones

Preparation of the model for the early stage simulations

- Check and validate the design brief
- Create the model
- Validate the model with colleagues, and performance assessment documentation if available
- If using weather data for the first time in a location, plot the data to be sure that they are consistent
  – Compare the data with similar sites in terms of temperature, solar radiation, humidity, wind

Checking physical parameters before simulation

- Building envelope
- Structure, mass
- Raised floor, false ceiling
  - Coupling with thermal mass or not ?
- Shading systems
  - Fixed
  - Movable external devices

Checking control parameters for the simulation

- Typical errors in setting the simulation
  - Heating on then natural ventilation is also on
  - Cooling on simultaneous to heating
  - Hysteresis overlapping
  - Strategy not actually in operation
    - Levels for natural ventilation on/off not in tune with the conditions
  - Sequence of strategies not properly ordered or wrong parameters

Setting energy balance checks

- Make sure to avoid «numerical energy» generation
- Prepare outputs that allow to check the consistency of the results
- Trace hourly results in winter, mid-season and summer, represent the physical parameters like natural ventilation air-change, evaporative cooling on, chiller on, ….
- Select representation of values which you can relate with (e.g. W/m2 of floor area)

Verifications before simulation Systems configuration

- Location, weather data
- Orientation
- Geometrical data
- Building envelope (cross-section)
  - Checking of radiative and convective modelling options
- Shading strategies
  - Fixed shading geometry
  - Movable blinds caracteristics
- HVAC system
  - Zone level cooling equipement
    - Avoid duplication of systems (parameters for fan-coil, slab cooling, radiant panels all presents,
  - Cooling system
  - Ventilation systems
    - Heat recovery
    - Evaporative cooling
    - Desiccant wheel
    - Enthalpy wheel
- Natural ventilation settings if applicable

Verifications before simulation Parameters

- Building envelope tightness
- Internal gains scenarios
  - Occupancy schedules
  - Equipment density
- Ventilation rates
  - Fresh air
  - Recirculation if any
- Movable shading settings
- Artificial lighting control

Identify parametric study to perform

- Windows to wall ratio
- Glazing caracteristics
- Shading strategies
- Thermal mass
- Natural ventilation air change rate
- Evaporative cooling options
- Active cooling system with
  - Air coolers
  - Cooling towers
  - Hybrid systems
  - Radiant or all air systems

Choose the extreme conditions

- Select the hottest week
- Select the most humid week
- Select the coldest week
- Prepare outputs to compare the results of different runs on these weeks on the same plot (post treatment might be needed)

Perform simulation with relevant parametric variations

- Results
  - At zone level (gross energy balance)
  - At system level (EPI)
- Trace
  - Temperature
  - Air change
  - Control strategies state
  - Cooling load

Common sense checking

- Look at the hourly profiles
  - Check if the strategies do actually happen as expected
    - Logical sequence (example)
      - Natural ventilation
      - Evaporative cooling
      - Active cooling
    - Movable blinds are operated
    - There is no oscillation in the controls

Special means to rapidly check the consistency of the simulation

- Add an interface for the graphical representation of the output with co-simulation tools
  - E.g. TRNSYS + EES

Quantitative checking

- Check the extreme conditions by hand calculation
  - Choose a very hot period at a precise moment
  - Check the physical values of different parameters (in W/m2 of floor area)
    - Solar incident on the facade
    - Solar transmitted inside
    - Internal gains
    - Cooling power

Strategies for saving time and keep quality

- Prepare typical templates which have been previously validated for similar kind of buildings
- Add incrementally the new features needed, check simulation more thoroughly for the new features
- Document carefully the different runs
  - Keep trace of all the inputs files which should be uniquely identifiable by a number, this will help at a later stage

Documentation for modelling preparation

- Performance assessment methods
  - As seen earlier in this presentation, PAM (performance assessment methods documentation) have been developed in the frame of the IEA Annex 21. Such documents can serve as a basis for the development of specific documentation to be used in house

When not to simulate

In the context of building airflow simulation it isalso relevant to remember the 10 Banks and Gibson (1997) rules when not to simulate:

1. The problem can be solved using "common sense analysis".
2. The problem can be solved analytically (using a closed form).
3. It's easier to change or perform direct experimentson the real.
4. The cost of the simulation exceeds possible savings.
5. There aren't proper resources available for the project.
6. There isn't enough time for the model results to be useful.
7. There is no data-not even estimates.
8. The model can't be verified or validated.
9. Project expectations can't be met.
10. If system behavior is too complex, or can't be defined.

Conclusions

- Quality assurance is very boring, but it is necessary
- The user of the software needs to be knowledgeable, have common sense and have experience to be able to ensure reliable results
- Multi disciplinary knowledge is a must for whole building simulation (building physics, HVAC, …)

THANK YOU