COMPUTER-AIDED TRAINING
OF BIOCLIMATIC ARCHITECTURAL DESIGN
Experience with Teachware for Building Performance Prediction

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ABSTRACT

"Bioclimatic Architecture" offers adequate inner thermal comfort for human. use, while, responding to the climatic outdoor conditions with reduced heating and cooling loads. This demand. asks for prediction. and preevaluation of thermal performance of architectural design. solutions. The new German building-regulation sets legal limits to precalculated. yearly heating-loads / m2, considering solar gains through transparent building elernents. The paper compares the manual and computer based calculation methods for building performance prediction, exemplified by student-work of the seminar "New Chances for Solar Architecture" and the ongoing developrnent "Interactive Learning System - Bioclimatic Architecture" for training and life-long learning.

INTRODUCTION

Air pollution in Central Europe results from 80% CO_2-emmission of waste-gases of fuel combustion, by heating buildings to the adequate thermal comfort. As implemented architectural design concepts have demonstrated, it is possible under uropean climatic conditions, to cover most of the heating-demand for thermal comfort in buildings, by using the potential of solar radiation, falling on their exterior surfaces. Replacing fuel combustion in buildings by passive and active use of the renewable energy source of solar radiation, represents an substantial potential of reducing both European environment-pollution and economic dependency on energy imports.

The introduction of renewable energy in architecture is obstructed mainly by the lack of confidence of designers, caused by the unsatisfactory access to the growing information-flood. Most of the actually avaiable information material is based on theoretical studies of the thermal performance of buildings, lacking an efficient parallel of practical design experience. Renewable energy in architecture calls for collaboration of designers / engineers in early project stages and the readiness for life-long learning. Missing European infrastructures for organisation and dissemination of training, with steps oriented towards designers, count for the weakness of market for renewable energy products, equipment and services.

The issues of energy-savings in buildings, have been vividly debated in Germany, during the last three years. Starting in 1995, the revised federal regulation for reduction of heating loads for buildings, has gained legal force. For every new or redesigned building, an energy-certificate must be issued, proving that heating-load/m^2 (manual or computer calculation) does not exceed the legal maximum. The manual calculation takes into account the thermal impact of building orientation, solar gain through transparent building components, shading devices, venting modes. Numerous publications and workshops presented the background and consequences of the new regulation, students and practitioneers learning about the goals, contents, calculation methods and the implications of the new regulation.

The Union of Founders of German Science in Essen / Germany (Stifterverband für die Deutsche Wissenschaft) announced in 1994 a competition, for ideas supporting the ongoing study reform and the reduction of college days. The jury selected projects promoting the introduction of new media in university educationl. Of the 102 entries submitted by 38 German universities, the selection committee awarded 14 initiatives, to be granted generous financial support, during the next three years, including the author's proposal of a model-project "Interactive Learning - Bioclimatic Architecture", encompassing the development of a computer-based, interactive system for teaching, training and life-long learning, in the domains of architecture, building-construction, HVAC, introducing CAD, simulation and database retrieval.

TEACHING BIOCLIMATIC ARCHITECTURAL DESIGN

Renewable energy in architecture, as new field of knowledge and research, is still the domain of specialists, allthough interested students, planners and designers are willing to learn about and apply theses new technologies. As expriences at university level and workshops with practicing professional demonstrate, students and designers are extremely interested to bring their contribution to reduction of air pollution, towards a cleaner environment.

Bioclimatic architectural design, introducing renewable energy in buildings, claims for an early, intensive cooperation of designers and specialists for building physics, engineering, statics, as the early decisions in the design process (building orientation, internal zoning, transparent surfaces, construction materials, etc.) have a decisive influence on the thermal response of the building in real climate-conditions. Future-oriented architectural education and life-long learning concepts have to respond to this imperative in a didactically efficient ways.

The author's teaching concept is based on the assumptions of designing a built environment which combines optimal indoor-conditions for human use, considering the dynamic outdoor-conditions of the climate. The goal is to enable students to design architectural-solutions offering an adequate functional, spacial, thermic, optical, acoustic and hygienical comfort for the user. As the indoor conditions, guaranteeing the thermal comfort, are measurable and precalculable, the contentment of future user is estimable. The teaching practice, based on the knowledge of building physics, introduces the foresighted calculation of heat-flows, thermal impact of solar rediation, air-temperature, heating-, venting- and cooling-loads, aiming towards energy-efficient architectural design.

The teaching concept aims towards creation of a strong consciousness among the students, for the factors that influence the thermal response of an inhabited building in real-climate conditions. Understanding the importance and implications of developing an energy-concept for building-design and the complex impact of all elements that form the design and use of bioclimatic architecture, is a main goal of the teaching-practice, leading to an open and complex view of architectural design-connections. The teaching is integrated in the curriculum of architectural education at Stuttgart University, starting at primary-level with courses on basics of bioclimatic architecture and manual calculation of heating-loads and -costs for buildings. At upper study-level, parallel to design-studios are offered seminars on bioclimatic architectural design, heating-load regulation, application of computer-tools like energy-calculation, -simulation, databases, interactive learning. Precalculation of heating- loads, heat-flows, solar gain, temperatures of indoor-air, walls and windows surfaces, are optimisation-parameters for energy-efficient, bioclimatic design- or redesign-solutions. [1]

The teaching of bioclimatic architectural design proved to be most efficient effectuated in form of project-oriented seminars, tought parallel to design-studios. Thus, the students learn the principles of bioclimatic architecture, the content and application of German regulations regarding reduction of heat-loads for buildings, the manual and computer-aided calculation of building costs, the application of dynamic energy simulation and computer-aided data retrieval, beeing able to apply the required knowledge and skills, while elaborating an architectural design solution. Following arepresented "packages" of courses (seminars and sesign-studios) tought parallel during one semester.

- "Energetical optimization of architectural design-solutions with dynamic simulation", "Building-costs of bioclimatic architecture" (manual and computer-based methods) and "Design of an ecological, low energy, low cost Kindergarten in Stuttgart".
- "Dynamic energy simulation - as computer tool for thermal building evaluation" and "Thermo-energetical analyse of historic German frame timber houses".
- "Dynamic energy simulation, thermal comfort analysis in sunspace additions" and "Bioclimatic redesign of residential houses built in 1960ies".
- "Sun and architecture - energetical pre-evaluation of bioclimatic architectural design", "Databases in architecture" and "Design of a Solar Architecture Studio - Living and Working with the Sun".

During the ongoing design-class "Solar Architecture Studio" students of the first year, second term (summer 1995) successfully effectuated dynamic energy-simulation, at their own request, in order to verify the energy-efficiency of their proposed design solutions. The teaching methods and results were recently presented by the author at international exhibitions and conferences in Stuttgart, Lyon, Weimar and Corfu. [2] [3] [4] [5]

TEACHING PROJECTS BIOCLIMATIC ARCHITECTURE

The teaching-praxis regards training as a flexible, open education, able to prepare students for life long-learning in a dynamically changing profession. The teaching goals and implementation maintain an experimental approach, with methods beeing gradualy improved according to evaluations. Architecture training at university level offers the chance to introduce and develop new computer-tools in research projects, like ADELINE [6] and to test their efficient use by students as future architects. The implementation of the experimental teaching, introducing new media, requires substantial additional preparation time, needing supplementary funding for the aquisition of hardware, software and for adequate tutoring assistance, like the following projects, made possible by generously granted funding.

Awarded financial support by the Union of Founders of German Science in Essen / Germany, the goals of the pilot-project "Interactive Learning - Bioclimatic Architecture" encompasses the development and implementation of a new training method, by introduction of new media and the implicit realisation of a change in the direction of teaching-orientation, by methods of individual study and knowledge aquisition. The aim is to develop a learning and teaching system with a wide-spread field of subjects, as model for other architecture colleges, building the bridge from research to practice. The topic is related to the European efforts to reduce the environment pollution by fuel combustion and on the actual German debate raised by the new heating-load reduction regulation and on the interests of energy efficient architecture.

The methodical approach of the pilot project is founded on the author's experience of teaching "Bioclimatic Architectural Design", with introduction of computer-aided tools of calculation and energy-simulation and on the experience of the pilot project "Databases in Architecture". The envisaged learning-system is meant to allow users to aquire basic and profound knowledge of the topic, by asking informations on design principles of bioclimatic architecture, by analyse of existing buildings and design solutions of the new database and by using the interactive- helping system for the introduction of CAD, daylight- and energy-simulation for the energetical optimization of existing buildings and for the design of new bioclimatic architecture.

As prospective result, the project-outcome will encompass an interactive multi-media learning system, for use in university training of architecture and in later phases also in the fields of building construction and HVAC, as well as for life-long-learning of practicioneers in the domains of design, implementation, funding and supervision of buildings. Preparation and implementation of the model-project is set to a time-frame of three years, starting 1994. Time is needed for introduction to use of the authorware MultiMedia ToolBook 3.0 [7], to the CAD-system acadgraph [8], to the Window-version of the energy simulation software SUNCODE.PC [9] and TRNCAD [10], with parallel collection and selection of information material. Further on, the learning system will be implemented, tested in courses, evaluated, improved and updated while used as teachware. [11]

At the Institute of Building Economy, the author teaches at first study-level the manual calculation of heating-cost for buildings, using a procedure similar to the new German heating-load-regulation calculation-method. At secondary study-level, computer-aided calculation is introduced, for the energetical analysis and the gradual optimization of architectural-design and redesign. Starting 1993, Stuttgart University supported finacially the implemetation of the project "Computer-Aided Energy Economy" allocating funds for equipment for a computer-pool (hardware, software and tutoring-funding) for introduction of new media in training. The goal of the project is to experimentally introduce software relevant to energy economy for different hardware platforms:

• PC-IMB	ADELINE	[6]
	EPASS	[12]
	LESOSAIX	[13]
	SUNcode.PC	[14]
• MacIntosh	COMFIE	[15]
	ENERGY SCHEMING	[16]
• UNIXSolaris	MUSES	[17]
	RADIANCE	[18]

The plan is to develop criterias for the applicability of computer-programs in university teaching and to analyse the time and effort needed for learning the efficient use of the software, as to bring the experience into life-long learning, for designers and engineers willing to energetically evaluate their future projects during the design process. The programs will be intgrated into the Interactive Leaning System - Bioclimatic Architecture.

TOOLS FOR PREDICTION OF THERMAL BUILDING PERFORMANCE

A future-oriented training has to prepare students for practicing in the next millenium in a dynamically changing profession. Teaching an actual topic and introduction of new computer-tools, in the context of energy-efficient bioclimatic archtectural design, were the goals of the seminar "New Chances for Solar Architecture?", tought by the author in winter-term 1994/95. The course offered an introduction of the actual (old - valid since 1984 till Dec. 31, 1994) and the revised edition (starting Jan. 1, 1995) of the German heating load-reduction regulation for buildings.

A comprehensive reader and computer-aided information-retrieval in the literature-database RSWB, served as input for discussions and students' papers on the consequences, goals and implications of the new regulation, from different and contradictory points of view (energy-aware versus energy-reluctant architect, optimistic versus pessimistic building physicist, industry producing solar building-components versus traditional handcraft, a. o.) organised in form of a debate having as guests compenent administration-officials of the Land Baden-Württemberg.

As practical excercises, the students calculated afterwards in team-work the heating-loads for existing or designed buildings, using first the manual calculation method of the new heating regulation, second they used the computer-calculation of the energy-certificate program EPASS and third, they effectuated dynamic simulations using SUNCODE.PC. Finally, the students compared the calculated results and elaborated conclusions of the relevance of building performance prediction of the calculation methods.

Manual calculation conform to the new German heating-load regulation

In 1977 as a reaction to the shock of the mineral-oil crisis, Germany adoped a new federal law, for reduction of heating-losses of buildings (WärmeSchutz-VerOrdnung), demanding for every new building to presend at least double-glazed windows and maximal mean U-values for exterior walls and windows, set in relation to the ratio of the area of the exterior surface to the heated volume of the building. The thermal losses of walls towards lofts, basements and unheated rooms were taken into consideration by fractional coeeficients.

In 1984 the regulation was replaced by more severe demands and 1992 started the preparation for the actual regulation. The novella of the heating load regulation introduced 1995 the new principle of reducing the heating-loads of buildings, by setting a maximum of yearly KWH/ sm (heated area), in relation to the ratio of the area of the exterior surface to the heated volume of the building. Thus, passive solar gains through transparent building elements were taken into account, by calculating with an equivalent U-value for transparent building elements, considering their transparency, orientation, tilt and shading.

The calculation method of the heating load of buildings, raised vivid scepticism among building physicists. The outdoor conditions like climate, solar radiation, heating-degreed days and other influences of the building site, are reduced by this calculation method for the whole country to the heating-degree value of Würzburg, city situated in the center of Germany. The indoor conditions of the buildings like internal gains, infiltration rates, heating or venting loads are to be defined with static values, reported to the heated volume of the building. The users' behavior over the day or over the seasons can not be considered. The calculated yearly heating load / sm (heated area) is to be considered mainly as a measure tool for thermal response of different buildings. [21]

- *Computer-aided calculation of heating-load with energy-certificate software EPASS*

With the computer based method of Hauser / Hausladen, it is possible to elaborate the energetic profile of a building or building design, to judge the relative and absolute energy consumption, to find specific points of departures for energy reducing measures, to develop energy concepts and to estimate the effect of different packages of energetical improvement measures. Detailed analyse of the heat loss through exterior building elements is possible, as well as an evaluation of heating equipment, of venting equipment with heat recovery, of orientation of the building, of solar gains, thermal bridges and special building systems like sunspaces, solar collectors, a. o. At the end, the program assignes to every analysed building an energy consumption number, considering it's thermal losses and gains. The figure acts as orientation measure for energy conscious building owners, buyers or tenants.

The program EPASS combines static calculation methods with the possibility of variation of different parameters, taking into consideration the climatic conditions of different building sites, allowing the introduction of optional values for heating degree days. Other variable parameters are temporary shading and blinding for windows, different infiltration rates and internal gains. The users' behavior, the different conditions changing over days and seasons, may be represented by fractional values. In addition, the heating equipment and the method of warm water heating may be defined. The calculated equipment energy allows a classification of the building on a measure scale rating from 0 to 400 KWH, issued as "Energy Certificate" for the building. [12]

Computer-aided calculation using dynamic energy-simulation with SUNCODE.PC

The program was developed for thermal analysis of residential or small commercial buildings. It is the microcomputer version of SERI/RES, a mainframe program written for the Solar Energy Research Institute. The method of analysis used in the program is simulation. A thermal model is created by the user and transformed into mathematical form by the program. For simulation, the mathematical equations are solved repeatedly at time intervals of one hour, usually for a year. The program has an interactive editor for creating building descriptions. It also checks for the validity of the input and reports errors as soon as possible. It also provides facilities for storing and referencing several types of building description files.

The dynamic energy simulation takes into account the weather datas of TRY (test reference years for 13 different climate regions in Germany) for the building site, including air temperature, normal and horizontal solar radiation and wind speed. Shading by neighboring buildings and vegetation, reflexion and temperature of the ground may be defined by static values or varying in time conform to defined schedules. The simulation considers the different thermal zones of the building, the heat flows between zones and the heat storage of relevant building elements, by physically defined building materials of wall layers. The dynamic thermal use of the buildings by its users, like varying values for setpoints for heating, venting and cooling, may also be scheduled in hourly steps.

The output data of the dynamic simulation with SUNCODE.PC allow several strategies for thermal evaluation of buildings: analyse of energy efficiency, by comparing heating, venting, cooling loads and heat flows through walls and windows, analyse of solar impact, by checking the solar gains, analyse of thermal comfort by looking at inner air temperatures and surface temperatures of walls and windows. The output encompasses data describing the ambient, the building, each thermal zone, window, wall, surface etc. The values may be calculated for yearly, monthly, dayly or hourly time-periods. [14]

EXAMPLE OF STUDENT WORK

The following paragraphs present one excercise effectuated during the seminar-course "New Chances for Solar Architecture"? in winter-term 1994/95. The authors are upper-level students, cand. arch.: Matthias Fürlinger, Axel Nething and Achim Pilz. They analysed the precalculated heating load for an Ecological Kindergarten in Karlsruhe, situated in the Land Baden-Württemberg, Germany.

The figures 1, 2 and 3 illustrate the building design. The text-description was selected from informations furnished by the designing architect and the engineering firm. The building was concieved as an ecologically oriented kindergarten, with walls constructed in a special mud-technique. Half of the building rests on an unheated ground-floor. It offers room for ca. 50 children and it's paedagogy, as Waldorf Kindergarten, is influenced by Rudolf Steiners educational and life philosophy. A substantial part of the construction was effectuated by parents and children, reducing building costs, while increasing their identification with the new building.

The student-work encompassed two phases: comparison of building heating-loads using manual and computer-methods (Fig.4) and preevaluation of energetically relevant redesign-solutions, in order to reduce the actual heating load (Fig. 5). The effect of each redesign-feature was calculated separately, in order to compare the thermal relevance of each of the proposals. Thus, conform simulation results, - Simul 4. (mechanical controlled ventilation with heat recovery - L_W= 0,5 1/H) has the greatest impact in terms of heating-load reduction. The students used the precalculated results for energy-efficient hypothetical redesign-propsals.

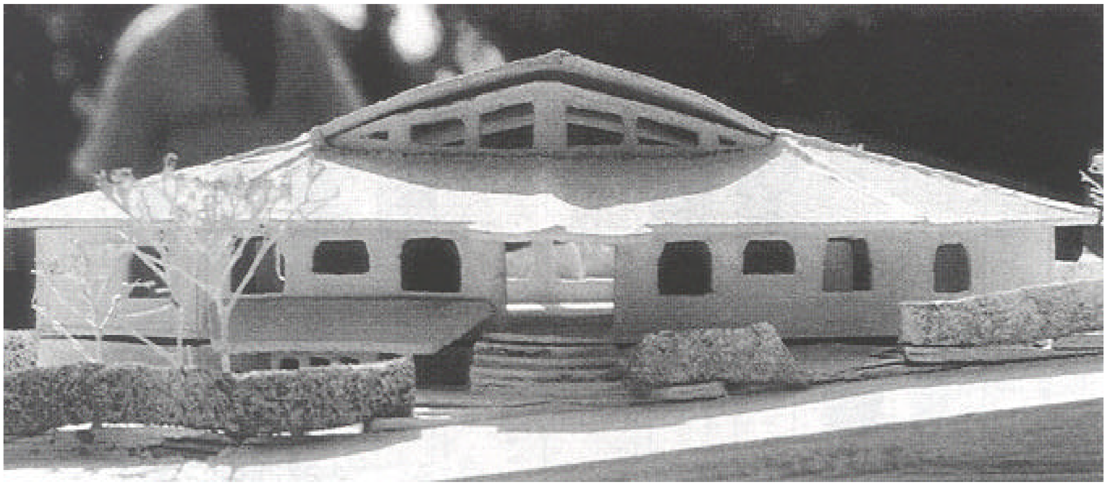
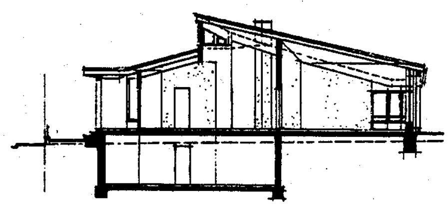


Figure 1: Ecological Kindergarten - view of model



ECOLOGICAL KINDERGARTEN IN KARLSRUHE - GERMANY

• Project:
Ecological Kindergarten in Karlsbad-Langenstein
For two groups of children, of ca. 25 each

• Building-owner:
Association for Promotion of Waldorf Paedagogy

• Designing architect:
Manfred Pilz, Dipl.-Ing. Freier Architect
Sperberweg 15, D - 76199 Karlsruhe, Germany

• Energy concept and heating technology:
Büro für angewandte Bauphysik, Dipl.-Ing. Z. Vasarek
Heideweg 19, D-76332 Bad Herrenalb, Germany

• Construction year:
Planning - start 1989
Construction - start 1991
Kindergarten functioning - start 1992

• Building site:
Karlsbad, Karlsruhe, Baden-Württemberg, Germany

• Construction:
Exterior walls: Timber-frame, mudd, straw
Interior walls: Timer-frame, massive brick
Insulation: Woodfibre, cork, reed
All biologically non-toxic building materials

• Building cost: 770.000,- DM + 160.000 DM self-built

• Heating load:

Precalculated:		18,70 kWh/a m^3
Measured	March 1993	37,16 kWh/a m^3
	June 1995	25,80 kWh/a m^3

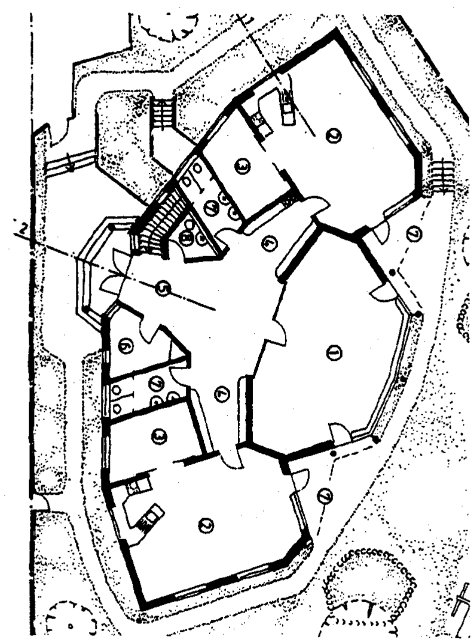
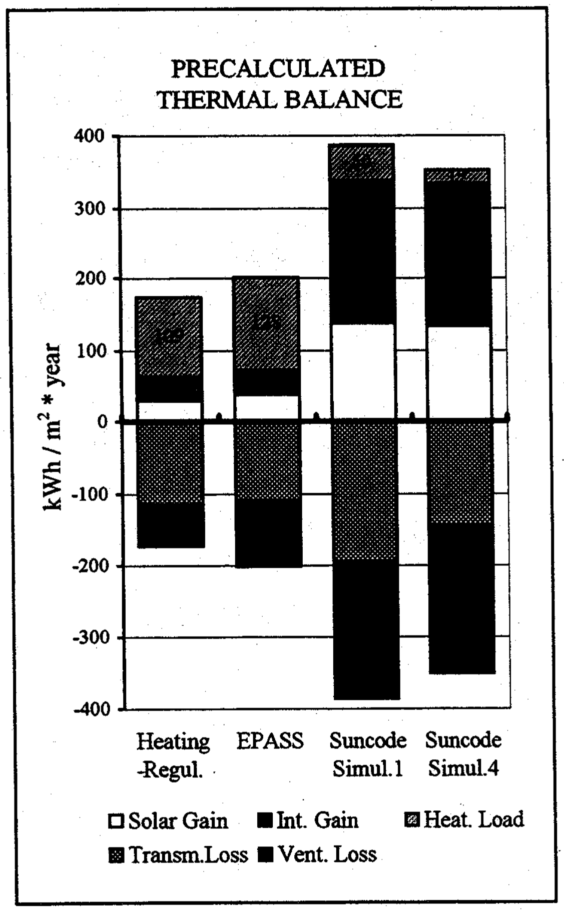


Figure 2: Section through the entrance

Figure 3: Plan of ground floor

Source of picture, description and drawings:
Manfred Pilz, Dipl.-Ing. Freier Architekt,
Sperberweg 15, 76199 Karlsruhe, Germany



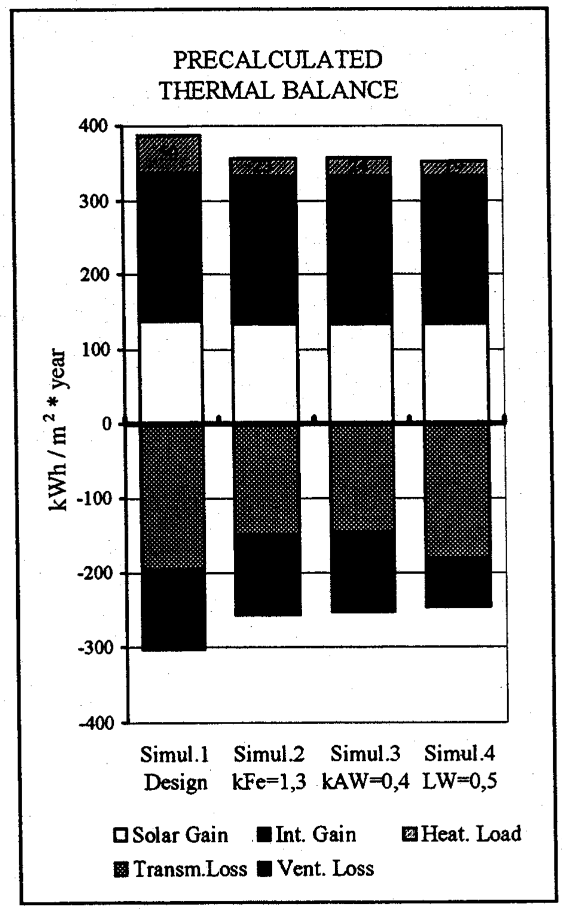


Figure 4:
Overview of thermal building-response, calculated with manual method (heating regulation 1995), compututer aided Energy-Passport (EPASS) and dynamic energy simulation (SUNcode.PC). Simul.1 is based on a building description similar to the existing building. Simul.5 is related to a hypothetic energy-efficient redesign, with better insulated exterior walls (U-value 0,48 kWh/m^2K), windows (U-value 1,3 kWh/m^2K) and mechanical controlled ventilation with heat recovery (L_W= 0,5 1/H).

Figure 5:
Overview of the results of dynamic energy simulations, based on the building description of the designed / existing kindergarten (Simul.1) and with integrated proposals for energy-efficient redesign solutions. Each simulation integrates one single improvement, like following: Simul.2 - thermal-insulating windows (U-value 1,3 kWh/m^2K), Simul.3 - better insulated exterior walls (U-value 0,48 kWh/m^2K), Simul.4 - mechanical controlled ventilation with heat recovery (L_W= 0,5 1/H).

CONCLUSIONS

Bioclimatic Architectural Design - stands for increased awareness of planners, towards the energetical impact of building design. Dynamic energy simulation, as validated method, closely related to the real performance of buildings, used successfully as teachware, fosters the knowledge of parameters, measurements and scale, of energetical consequences of building design decisions.

The applications bring together architects with building physicists, creating a common vocabulary, towards a better understanding and cooperation. Integrated into an interactive learning system, the programs will enhance the learning process in training and life-long learning. International programs on EU-level, like ALTENER or LEONARDOS have to disseminate this experiences.

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