IEA Task 31

Daylighting Buildings in the 21st Century

Prepared by:

Nicolas Morel and Jean-Louis Scartezzini

Laboratoire d'Energie Solaire et de Physique du Bâtiment (LESO-PB)

Ecole Polytechnique Fédérale de Lausanne (EPFL)

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Laboratoire d'Energie Solaire et de Physique du Bâtiment (LESO-PB)
Ecole Polytechnique Fédérale de Lausanne (EPFL)

Authors:

Prof. Dr Jean-Louis. Scartezzini, LESO-PB/Ecole Polytechnique Fédérale de Lausanne
Dr Nicolas Morel, LESO-PB/Ecole Polytechnique Fédérale de Lausanne
Dr Marilyne Andersen, LESO-PB/Ecole Polytechnique Fédérale de Lausanne
(now at Building Technology Programme/Massachusetts Institute of Technology)
David Lindelhöf, LESO-PB/Ecole Polytechnique Fédérale de Lausanne

Steering Group:

A. Eckmanns, Programmleiter Bundesamt für Energie
M. Zimmermann, Programmleiter, Bundesamt für Energie

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Bundesamt für Energie BFE
Worblentalstrasse 32, CH-3063 Ittigen • Postadresse: CH-3003 Bern
Tel. 031 322 56 11, Fax 031 323 25 00 • office@bfe.admin.ch • www.admin.ch/bfe

Vertrieb: ENET, Egnacherstrasse 59. 9320 Arbon, enet@temas.ch, www.energieforschung.ch

1. IEA Task 31 Objectives and Methodology

1.1 Objectives

The SHC IEA Task 31 is seeking to make daylighting the typical and preferred design solution for lighting buildings in the 21st Century by integrating human response with daylighting systems, shadings and electric lighting control strategies (cf. Figure 1). Two key issues, requiring further research to accomplish substantial energy savings, have been identified for that purpose :

- The assessment of occupant response toward the luminous and thermal environment in buildings involving the use of daylighting systems and daylight responsive controllers.
- The integration of daylighting systems, electric lighting and shading control strategies which take occupant response into account in order to optimize energy savings.

The knowledge transfer to building design professionals, building owners and manufacturers made up the third objective of IEA Task 31 *Daylighting Buildings in the 21st Century*.

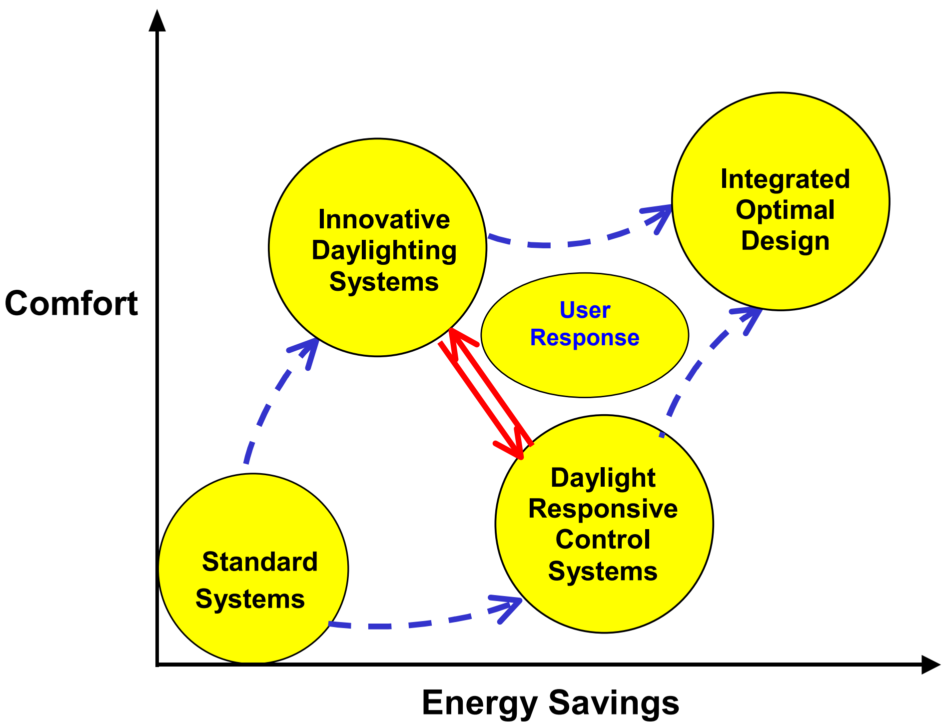

Figure 1 : Schematic representation of objectives of IEA Task 31 regarding user response toward daylighting and electric lighting systems.

The focus during the duration of IEA Task 31 from 2001 through 2006 was placed both on new and existing non-residential buildings (commercial and institutional buildings), such as office and retail buildings, as well as schools. Twenty-four research institutions, representing fifteen countries of Europe, North America, Asia and Oceania collaborated for that purpose in a worldwide research network.

1.2 Methodology

In order to achieve an efficient organization, the IEA Task 31 was subdivided into four different Subtasks, which can be described as follows :

- Subtask A : User Perspectives and Requirements
- Subtask B : Integration and Optimization of Daylighting Systems
- Subtask C : Daylighting Design Tools
- Subtask D : Performance Tracking Network and Design Support Groups

Among the achievements expected to be reached within IEA Task 31 over the years 2001 - 2006, one can mention :

- Generic descriptions of daylighting requirements for building codes
- Daylighting technology roadmaps for designers with performance targets
- Guidelines for control systems interface design to account for user response
- User friendly computer tool releases with working documents on plug-in specifications for sky models and complex fenestration systems
- Guidelines on appropriate use of computer tools
- Demonstration of solutions appropriate to commercial and institutional buildings
- Transfer of practical results to architects, engineers and industry (workshops, regional support groups, Website including data sets of user preferences, building performance targets and case studies).

2. IEA Task 31 Research Activities

2.1 Subtask A : User Perspectives and Requirements

Lighting conditions in buildings are important factors that affect the well-being and comfort of users. While it is commonly agreed that daylighting strategies have significant potential to reduce energy consumption and produce better quality work environments, little fundamental knowledge exists about the behavior of occupants regarding the control of integrated daylighting systems. Without reliable data on such behavior, as well as on users preferences, potential energy savings are difficult to reach.

Objectives

Subtask A investigated current knowledge on human response to daylighting systems and electric lighting control strategies in order to understand the role of user perceptions and visual and thermal comfort on the control of energy saving daylighting strategies. The overall intent is to provide benchmarks, performance metrics and improved computer simulation and design tools to effectively optimize daylighting solutions and reduce energy consumption in buildings, while at the same time maximizing the benefits of daylighting for their occupants. Subtask A included the development of databases of important literature on the topic and appropriate case study buildings. In addition, human subject studies in daylit buildings in various countries were planned to complement and expand existing scientific knowledge.

***Subtask Leader* :** Christoph Reinhart, National Research Center, Canada

Projects

Subtask A comprised the following research projects:

- Project A1: Literature survey (Project Leader: Michael Donn, New-Zealand)
- Project A2: Methods for the assessment of visual comfort (Project Leader: Anna Pellegrino, Italy)
- Project A3: Application of user assessment methods for visual comfort (Project Leader: Anna Pellegrino, Italy)
- Project A4: Modeling (Project Leader: Christoph Reinhart, Canada)
- Project A5: Guidance (Project Leader: Christoph Reinhart, Canada)

Outcomes

- Practical methods to assess visual and thermal indoor environment quality
- Descriptions on daylighting requirements for inclusion in standards and building codes
- Rules of thumb for daylighting office spaces
- Computer models to predict user response for designing daylighting and electric lighting and shading control systems
- Guidelines on the use of these algorithms in daylighting and energy simulation software

The outcomes resulting from Subtask A will directly support designers and manufacturers by improving their understanding of user perspectives and/or requirements. It will also contribute to the achievements of potential energy savings by providing architects, designers, lighting professionals and energy simulation specialists with more reliable data, guidelines and tools. Governments, building code authorities, standards boards and professional bodies will be able to update existing documents to further enhance occupants well-being, while contributing at the same time to a more sustainable future.

2.2 Subtask B : Integration and Optimization of Daylighting Systems

Energy efficiency strategies based on the use of more efficient lighting components, have helped many countries to achieve reductions in building energy use. Larger energy savings with greater cost effectiveness can be reached, when systems integration strategies such as daylighting, are skillfully designed and deployed. Successful daylighting solutions are beyond the grasp of most design professionals: they require a high level of expertise and familiarity with new design and evaluation tools, as well as the understanding of design approaches leading to successful solutions. They also require the integration of novel technologies encompassing glazing, shading and electric lighting, as well as smart controls, in a manner that optimizes overall performance including human factors. These are essential challenges, if daylighting is to become the preferred option in buildings in the 21st century.

Objectives

The objective of Subtask B is to enable building designers to successfully address system performance and integration issues in the design and evaluation of daylighting strategies. The aim is to achieve economical design solutions that minimize energy use and electric demand for lighting and HVAC (using only 30% of the lighting energy required in non-daylighted buildings). The overall effort will be applicable to different building types, locations and climates.

In order to meet this need, a review project and three research projects were carried out in this Subtask. Although the intent of the work is to be broadly applicable to any building type, Subtask B initially focused its efforts on two common building categories represented in every member country: office and educational buildings. Within these building types a range of building sizes and space functions can be addressed.

Subtask Leader **:** Stephen Selkowitz, Lawrence Berkeley National Laboratory, USA.

Projects

Subtask B comprised the following research projects:

- Project B1: State of the Art Review (Project Leaders: Steve Coyne, Australia; Steve Selkowitz, USA)
- Project B2: Design Solutions Roadmap (Project Leader: Mark Luther, Australia)
- Project B3: Optimizing Control and Operation of Daylighting Systems in Buildings (Project Leader: Nicolas Morel, Switzerland)
- Project B4: Field Studies (Project Leader: Lars Bylund, Nils Svendenius, Sweden)

Outcomes

- A design process roadmap that identifies key issues to be addressed by a building design team
- Database of performance benchmarks that quantify potential savings with daylighting strategies
- Procedures to calibrate and commission key daylighting control systems
- Measured control system operational data that will enhance confidence in control system performance
- Measured total system performance data to increase building owner confidence
- Test room and building performance data for tool validation.

- Building performance data to improve optimization hardware and software.

Subtask B advanced to further daylighting implementation. As there is no critical mass of R & D currently underway in any country, this collaborative work will accelerate development of new design approaches, control algorithms and performance data. It provided designers with performance targets for use in the design process and a roadmap to achieve better results at a lower cost. It will give manufacturers a clearer sense of the improvements needed in existing products and a vision of how new products might provide new market opportunities. It will also provide building owners with quantifiable expectations for systems performance and reduce the perceived and real risk of undertaking a day lit building.

2.3 Subtask C : Daylighting Design Tools

Daylighting design tools like ADELINE, developed through international collaboration within the last decade, helped designer to quantify the energy savings potential by using natural lighting resources. A wide range of different graphical, analytical and simple computer-aided tools, useful in the early and the detailed design phase, are available for practical use. However the use of these tools has mainly been restricted in the past by a lack of algorithms for novel technologies and new research results. There is a continuing need for algorithms, tool development and extensions that reflect these novel technologies, such as performance prediction methods, new sky models and user-friendly interfaces. New methods and updated design tools also have to be continuously validated to ensure correct results and give practitioners confidence in tool application. In Subtask C, new developments made available modular plug-ins to be used in multiple tools, thereby reaching a larger number of users.

Objectives

The objectives of Subtask C is to improve the knowledge and quality of lighting tools to enable building designers to predict the energy performance and visual comfort conditions of complex fenestration systems in their daily working environment. This Subtask will make a link between industry, designers and software developers and promote the tools to the practitioners. The research work in this subtask concentrated on four topics:

- Evaluation on tool users expectations of daylighting design tools
- Development of new algorithms for complex fenestration systems and their implementation in different design tools
- Setting-up of a Web based and target groups oriented information and promotion platform
- Validation of new functionalities and benchmarking procedures of daylighting design tools

***Subtask Leader* :** Hans Erhorn, Fraunhofer Gesellschaft, Germany

Projects

Subtask C comprised the following research projects:

- Project C1: User Interactions (Project Leader: Fawaz Maamari, France)
- Project C2: Algorithms and Plug-Ins (Project Leader: Jan de Boer, Germany)
- Project C3: Promotion of Tools & Engines (Project Leader: Bill Carroll, USA)
- Project C4: Validation (Project Leader: Fawaz Maamari, France)

Outcomes

- Concepts for improvement of user expected interfaces and data bases
- Models and libraries for complex fenestration systems
- New Algorithms for sky models
- Plug-in specifications for advanced visual comfort and user behavior algorithms
- Enhanced validated tools and engines (e.g. ADELINE 4.0)
- Plug-ins for complex fenestration systems and sky models extending the capability for use in standard lighting tools
- Internet based catalogue of computer tools describing their capabilities
- New data sets for integrated systems
- Extended validation data sets
- Online CIE approved benchmark procedure for tools and engines.

Subtask C advanced acceptance of daylighting tools in the design process. It emphasized improved tool quality and integration aspects, occupant response and use of plug-ins to enable their use in a standard way. It created a platform as a link between industry, designers and software developers by the way of the Internet.

Subtask D: Performance Tracking Network and Design Support Groups

This Subtask has the responsibility to disseminate the results of Subtasks A, B and C in a manner that facilitates widespread use of daylit buildings in IEA member countries. The Subtask has three primary audiences: Building owners (making critical decisions about the nature of new investments in buildings); building design teams (providing the solutions) and window component manufacturers (developing solutions to meet the market demand).

Objectives

The main objective is to record benefits of daylighting technology by providing the necessary facts and figures demonstrating all possible gains related to the use of efficient daylighting strategies. The performances concern energy savings in buildings as well as improved well-being, comfort, and building value.

Subtask Leader **:** Marc Fontoynont, Ecole Nationale des Travaux Publlics de l'Etat, France

Projects

The objectives have been addressed by the following activities:

- Project D1: Development of a Web Server Structure (Project Leader: Michael Donn, New-Zealand)
- Project D2: Content of Data Base #1 - Record Benefits of Daylighting Techniques (Project Leader: Marc Fontoynont, France)
- Project D3: Content of Data Base #2 - Noteworthy Examples (Project Leader: Pascale Avouac-Bastie, France)
- Project D4: Material for Support Groups (Project Leader: Marc Fontoynont, France)

Outcomes

- Development of a Web server restricted for access to participants and supporters of the Task
- Establishment of databases demonstrating the benefits of daylighting techniques through fully documented examples accessible through the web
- List of benefits of daylighting techniques, such as financial benefits of investing in daylighting systems, building added value, cost of daylighting options, electrical energy savings, users productivity, daylighting solutions and monitoring results
- Database on noteworthy examples providing access to case study buildings (real and virtual), as well as long-term performance data
- Establishment of an international network of daylight design support groups that provide guidance of appropriate levels of design assistance.
- PowerPoint presentations for support groups

Since owners and designers are risk averse, the greatest need is a convincing documentation on successful daylit buildings to be available for inspection by owners. The most powerful argument to support daylighting in buildings is to be able to walk through a well daylit space and to compare to other similar buildings. In Subtask D, a network of buildings with measured performance data was created that will be available for direct inspection or available to others as a virtual building on the World Wide Web.

3. Swiss contributions to IEA Task 31

The Swiss contributions to IEA Task 31 were built around the participation of LESO-PB/EPFL, whose involment was essentially focused on Subtasks A and B. Although a minimal participation was also planned for the other Subtasks, limitation of funding impeded further contributions to Subtasks C and D since the beginning of IEA Task 31. As a consequence, only specific outcomes of Subtasks A and B are presented in this report.

3.1 Contribution to Subtask A

The projects A1 (Literature survey), A2 (Methods for the assessment of visual comfort), A3 (Application of user assessment methods for visual comfort), A4 (Modeling) and A5 (Guidance) are all closely related to research projects carried out at LESO-PB/EPFL, especially the Swiss National Foundation project *Visual comfort and* *lighting needs at visual display units*. A participation of LESO-PB/EPFL to these projects was planned, as a consequence.

3.2 Contribution to Subtask B

The project B3 (Optimizing Control and Operation of Daylighting Systems in Buildings) is the main core of LESO-PB/EPFL contribution (Project Leader : Nicolas Morel); a significant work was also planned for project B4 (Field Studies). Both projects are strongly related to other research projects carried out at LESO-PB/EPFL, especially the EPFL internally funded project AdControl *Elaboration and experimentation of an adaptive control systems for heating, electric lighting and solar shadings*, as well as the EC funded project Ecco-Build *Advanced control strategies for complex shading devices*.

4. Main achievements due to Swiss contributions

4.1 Results of Subtask A

Since LESO-PB/EPFL was not a leading participant in Subtask A : the corresponding results of this Subtask are not available as a specific national report. Instead of this, Subtask A and project leaders made final documents available. The list of these documents is given below; the later can be obtained on request.

Monitoring Protocol for the Assessment of Occupant Usage of Lighting and Shading Controls

This report presents a monitoring protocol for the assessment of occupant interactions with lighting and shading controls in real buildings. Different techniques showing how to monitor user occupancy, the use of light switches and Venetian blinds, as well indoor environmental conditions such as work plane illuminances in occupied spaces, are reviewed. The document further suggests a number of techniques and graphical representations showing how to extract user behavior patterns from collected data. The resulting graphs provided moreover a common reporting format for human subject studies within IEA Task 31 *Daylighting Buildings in the 21st Century*. The document is an extension of previous CIE and IEA Task 21 monitoring protocols.

Research Literature Database

This document provides a summary of daylighting topic sheets to which contributed the IEA Task 31 participants. Topic sheets identify research documents for the collaborative work, which have been reviewed by the contributing members and found to be relevant for the support of ongoing international research. A brief introduction is provided to give readers an overview of the topic areas and highlight important aspects. Topics discussed are:

- Measurement and Modeling of Sky Luminance and Daylight Availability in the Southern Hemisphere
- Radiance-Based Annual Daylight Simulations
- Advanced Daylight System Control Algorithms and User Acceptance
- Discomfort Glare from Daylighting
- Visual Comfort Assessment Methods
- Daylighting in School Buildings
- Daylighting in Atrium Buildings
- Light Pipes for Daylighting Applications

Energy & Buildings Special Issue

IEA Task 31 proposed the elaboration of a Special Issue of the international Journal *Energy and Buildings.* The final content of this issue includes 10 papers from various contributors, including a contribution from LESO-PB/EPFL - *Typical Patterns of User Behavior Under an Advanced Automatic Control System for Blinds and Electric Lighting* written by David Lindelöf and Dr Nicolas Morel. The issue will be available during the first semester of 2006 and will contribute to the dissemination of the scientific knowledge gathered by IEA Task experts to a wider audience.

4.2 Results of Subtask B (Project B3)

The main outcome from Project B3 is a design guide for advanced control systems, entitled *Advanced Daylight and Electric Lighting Control Systems Design Guide.* This guidebook is essentially targeted at designers of control systems, control system manufacturers and professionals, such as consultant engineers involved in building integration of control systems.

A short outline of this report is given here; the document is also available as an appendix of the present report.

Requirements for control algorithms

- Integration: Daylighting and electric lighting issues are not independent from thermal and air quality concerns; a control system should, as a consequence, integrate all these different aspects in order to operate in an optimal way.

- Priority of user preferences: In general, the users should be given the absolute priority when they require a modification of systems setting instead of those provided by an automatic controller. There are nevertheless exceptions, such as the case of an unoccupied room (thermal considerations should then have the priority), or when safety reasons apply (for instance rolling up the external blinds when the wind velocity is too high and would possibly damage them). User preferences should be taken into account in a different way for spaces with a large number of people (conference rooms, open space offices, etc) compared to spaces occupied by a small number of persons (office rooms with less than 2 or 3 persons).

- Avoid user disturbance: A control system should not cause a high level of disturbance for users. For instance, if the solar shading movements are noisy, the system should avoid too frequent movements. The issue is especially critical with devices that need to be moved stepwise and cannot go unnoticed by users (e.g. on/off control of electric lighting or up/down movements of blinds).

- Adaptivity to user preferences: In order to avoid rejection by users, a control system should progressively adapt its parameters to the user preferences, which may be very different from one user to another. Building services, which do not fulfill this condition, for instance a fixed temperature set point or a non-movable window, are primary causes of the well-known "Sick Building Syndrome". Of course, the situation is not similar for spaces with a large number of people compared to spaces with a small number of occupants.

- Adaptivity to boundary conditions: This characteristics, involving self-adaptation to building characteristics and weather data for instance, leads to "self-commissioning" control systems and can reduce the overall system cost.

- Sensors, redundancy and reliability: The control system should still operate satisfactorily even when a reduced set of measurement is available, due for instance to sensor failure. The control system itself should be implemented in a reliable way, avoiding algorithms which provide an unsound output in some special conditions.

- Optimal comfort: The first priority of a control system is to provide optimal comfort to building users : energy savings is worthwhile but can only be a second priority. Related to that point, the issue of understanding discomfort mechanisms needed further research, especially concerning visual comfort, which was investigated in Subtask A.

Practical design and implementation of advanced control systems

- Design steps: The design of an advanced control algorithm should include three steps: (i) the elaboration of a rule base gathering the expert and "common sense" knowledge about the building services to be controlled and the user's comfort; (ii) the elaboration of the full control algorithm, taking into account the knowledge gathered during the first step and including the required descriptive models and user interface; (iii) the test of the elaborated system by simulation or with real people (whole building or mock-up).

- Building management bus: A building bus allows an easy access to all sensors and actuators, making the integration of controllers easier. Choosing a well-supported standard, such as EIB or LonWorks provides a wider choice of sensors and actuators produced by various manufacturers : they should be freely interoperable. The building bus also helps to reduce the cabling work between sensors, actuators and controllers and improve the flexibility when redefining the use of spaces.

- Reliability and serviceability: The long-term reliability of a control system is important, as well as the serviceability. The reliability of the whole system can be improved by the use of redundant sensors, the use of a stable real-time operation system for the controller, or the appointment of a well-trained responsible person checking for the appropriate system operation.
- User interface: With complex control systems, the user interface plays an important role: it must be simple to understand, unambiguous, and should provide explanations for control actions.

- Control system architecture: Daylight-responsive control systems for electric lighting usually exhibit a simple structure, with a single closed-loop controller and a set-point luminance or illuminance. On the opposite side, advanced control systems, with the requirements given above need to account for several building services; they take advantage of more elaborated architectures, distinguishing between different control "levels" (designing the different levels separately can help to keep a well-organized structure). In particular, cascaded control algorithms are advisable for a complex system, because they allow dividing the system into several levels (cf. Figure 2).

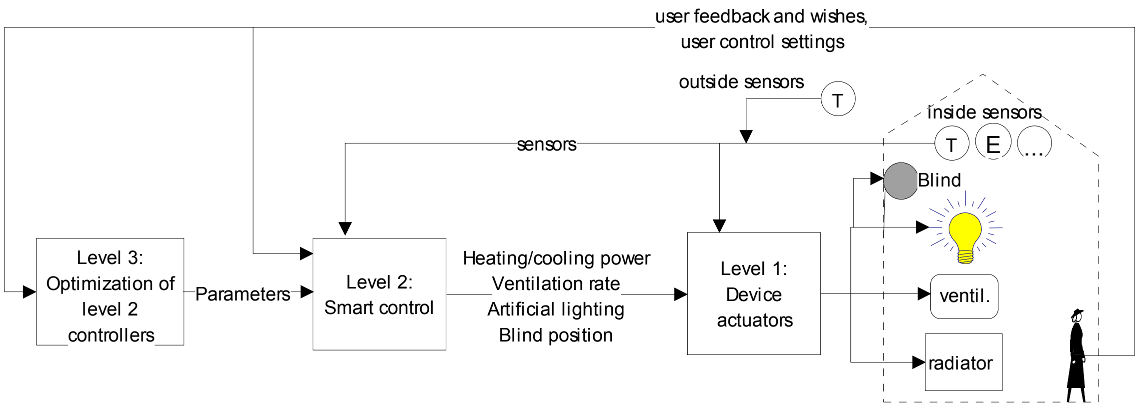

Figure 2 : Architecture of a complex control system involving cascaded control levels.

Three different levels are considered in this case: i) Level-1 control block allows the direct control of
building services considered in this specific case, translating the physical variables (for instance a blind position) into actuators commands ("blind up"/"blind down"); ii) Level-2 control block includes a knowledge base and provides the desired set-points for building services taking into account the information provided by sensors, as well as a predicted future system behavior; iii) Level-3 control block allows a continuous adaptation of control parameters for the lower loops, taking the users reactions into account.

Biomimetic Control Strategies

Bio-inspiration: The terms «bio-inspiration» or «bio-mimetic» control strategies and algorithms can characterize several requirements concerning the control algorithm. Advanced control systems may be considered as a living organism. Although the environmental conditions (i.e. meteorological conditions) and the activity (i.e. the building use) may vary significantly, the control system allows providing optimal conditions, as a living organism would do. In order to reach that goal, the controller needs many information from the surrounding world and from the building itself by the way of sensors and acts to keep optimal conditions by the way of actuators.

Practical examples from research projects

The Advanced Control System Design Guide is completed by a number of practical examples issued from research projects. The examples focus on the algorithms used and not their practical implementation. Following projects carried out at LESO-B/EPFL were considered :

DELTA (LESO-PB/EPFL, TU-Wien, Zumtobel Licht, Landis & Gyr): Illustration of use of Fuzzy Logic for a blind controller.

AdControl (LESO-PB/EPFL): An automatic control for heating, electric lighting and solar shadings adaptive to the user preferences.

Ecco-Build (EC project involving LESO-PB/EPFL): An advanced algorithm for the control of electric lighting and complex solar shading devices.

Auto-adaptive system (Technical University of Berlin): Control of electric lighting and daylight device by a flexible adaptive control algorithm.

4.3 Results of Subtask B (Project B4)

Two field studies carried out by LESO-PB/EPFL were considered as a Swiss contribution to Project B4: the AdControl project, funded internally by EPFL, and the EC project Ecco-Build, funded by the Swiss Federal Office of Education and Science (OFES). For the latter project, experimental results will be available in March 2006 at the end of the experimental campaign.

Project AdControl – Executive Summary

The project AdControl ("Adaptive Control: Bio-Mimetic Building Control Strategy Using Genetic Algorithms to Account for Human Wishes"), carried out at LESO-PB/EPFL, aimed at the investigation of control algorithms adapting to human wishes by the way of genetic algorithms. It was started in January 2002 and essentially concerned individual office rooms (one or two persons per room).

Bio-mimetic control strategies of building services (heating, cooling, ventilation and lighting) were recently subject to significant advances, using algorithms such as fuzzy logic and artificial neural networks. The AdControl project was based on this knowledge and investigated the use of a novel approach – genetic algorithms - to implement adaptability for building services controllers. Its capabilities, regarding energy savings and human comfort, were deeply examined in relation with:

- The adaptation to human wishes;
- The adaptation to changing building features and building use.

The adaptation to human wishes was investigated in a new way. Users have different requirements for set points of building services, regarding for instance lighting conditions, indoor temperatures or indoor air quality. Control systems which do not adapt their operation to user behavior, even if they take into account several factors and apply smart strategies, have an important drawback: the users may either switch the control system off, because they are unsatisfied, with a very high risk to get uncomfortable situations if forgetting to act on the system and increasing energy consumption (for instance, by letting the electric lighting on when leaving the room); if they have no access to the system control, they become unsatisfied and frustrated. A very common cause of the "Sick Building Syndrome" is the fact that users cannot adjust his/her close environment, by modifying set-point temperatures, moving blinds or opening windows.

Therefore, the utilization of control strategies, which allow an adaptation to the human wishes, is an important step, which follows the elaboration of smart control strategies for building services. Based on the results of previous research projects, these adaptive characteristics were provided through the use of genetic algorithms.

The comparison between a manual control, an automatic control without adaptation to user preferences and an automatic control with adaptation to user preferences, has shown that comparable energy savings can be achieved by a smart control algorithm in comparison to a standard manual control : this performance was preserved by the user-adaptive control algorithm but with a lower rejection rate and with an improved indoor comfort.

Project AdControl - Experimental results

In a second phase, measurements were carried out on the LESO experimental building, involving the monitoring of 14 occupied office rooms (mostly occupied by one or two persons), during nine months. The monitoring results confirmed the interest of new user-adaptive algorithms, as illustrated in Table 3.

Controller type	Energy savings (vs. manual)	Thermal comfort satisfaction	Visual comfort satisfaction	Rejection rate after 4 weeks
Manual	-	84 %	86 %	-
automatic, without adaptation to user's preferences	- 26 %	84 %	88 %	25 %
automatic, with adaptation to user's preferences	- 26 %	86 %	89 %	5 %

Table 3 : Comparison of energy performance and user comfort achieved by different building control strategies (manual, automatic with and without adaptation to users preferences).

Table 3 shows clearly that the substantial energy savings achieved by an automatic controller compared to the manual control of building services were not altered by the implementation of an adaptation to user's preferences : at the same time the rejection rate after 4 weeks of utilization was reduced from 25 % down to 5 %.

Project Ecco-Build – Executive Summary

The objective of project ECCO-BUILD is to develop a novel generation of controllers for solar shadings, glare control systems, electric lighting and HVAC equipment optimizing simultaneously the building energy consumption and users comfort. Another important goal of the project was the development of a novel glare index for windows and daylighting systems, which can be used for control purposes, as well as the development of a new luminance-meter.

The project comprised seven different work packages:

WP1 Coordination
WP2 User assessment: Development of new criteria for glare rating to be used for building management systems. The basis for the selection of these criteria is the user acceptance studies carried out in different countries.
WP3 Measurement facility: Design and setting-up of a novel luminance-meter in order to be able to characterize different facade systems.
WP4 Control device: Development of new control algorithms and setting-up of a new controller.
WP5 Design tool: Development of an information package for building planners, as well as modeling tools to predict the energy impact of different control

strategies designed for glare management and solar shading.

WP6 Pilot buildings: Test of the algorithms developed in WP4 in an occupied multi-rooms building and other pilot cases.

WP7 Dissemination: Results transfer to scientists, standardization bodies, component and facade manufacturers, architects and building planners, as well as a setting-up an Internet service.

The project was started in November 2002 for three years duration. Work packages 2 and 4 have been allocated the most significant activities. Preliminary results show that the pupil illuminance represents a sound index for visual comfort, together with the usual horizontal work plane illuminance. An exploration work was undertaken, considering a novel control strategy for Venetian blinds based on a Bayesian algorithm and different alternatives for the assessment of Solar Shading Coefficient of blinds. In the framework of WP 6 (main contributors are LESO-PB/EPFL and ISE), the monitoring has been initiated, but no data is available for the moment.

Regarding the control algorithm, the research activities started on the basis of the scientific knowledge acquired during previous projects carried at LESO-PB/EPFL, in particular the project AdControl devoted to the elaboration and experimentation of a user-adaptive control algorithm for blinds (fabric roll-down), electric lighting and HVAC equipment. Since more complex shading systems are considered in the ECCO-BUILD project (Venetian blinds), the control algorithm was elaborated further in order to be able to handle a more complex Bidirectional Transmission Density Function (BTDF).

More information is available on the dedicated Ecco-Build open Web site:
http://www.ingelux.com/ecco_build

Technical reports are also available and were disseminated among the partners.

5. CONCLUSION

The SHC IEA Task 31 is seeking to make daylighting the typical and preferred design solution for lighting buildings in the 21st Century by integrating human response with daylighting systems, shadings and electric lighting control strategies. Two key issues, requiring further research to accomplish substantial energy savings, have been identified for that purpose :

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The Swiss contributions to IEA Task 31 was built around the participation of Laboratoire d'Energie Solaire et de Physique du Bâtiment of Ecole Polytechnique Fédérale de Lausanne (LESO PB/EPFL), whose involment was essentially focused on Subtasks A and B. A minimal participation was planned for the other Subtasks due to the limitation of funding.

Contributions to several projects of Subtask A were based on the results of the Swiss National Science Foundation project *Visual comfort and lighting needs at visual display units,* to which participated the LESO-PB/EPFL. Main achievements obtained in this framework contributed to the elaboration of documents published by IEA Task 31, such as :

- Monitoring Protocol for the Assessment of Occupant Usage of Lighting and Shading Controls
- Research Literature Database
- Special Issue of Energy and Building International Journal

Contributions to Subtask B were strongly related to the EPFL project AdControl *Elaboration and experimentation of an adaptive control systems for heating, electric lighting and solar shadings*, as well as the EC project Ecco-Build *Advanced control strategies for complex shading devices*. The main outcome obtained thanks to the Swiss participation was the elaboration of the reference book *Advanced Daylight and Electric Lighting Control Systems Design Guide,* which comprises the following main items :

- Requirements for control algorithms
- Practical design and implementation of advanced control systems
- Biomimetic control strategies

Field studies carried out at EPFL, using the LESO solar experimental building as a test platform, made up a significant contribution to IEA Task 31 : they allowed to investigate the performance of biomimetic control strategies adapting to human wishes by the way of genetic algorithms. Comparisons of performance with manual control and non-adaptive control systems demonstrated the adequacy of this novel approach, which achieved a very low rejecting rate by users in conjunction with significant energy savings. A novel controller generation for solar shadings, glare control systems, electric lighting and HVAC equipment were implemented and experimented on the same building, contributing to the field studies presented within IEA Task 31.

6. REFERENCES

Scientific publications issued from IEA Task 31 presented at Lux Europa 2005

Andersen, M., De Boer, J., *Experimental and simulation based approaches to assess bidirectional properties of complex fenestration systems*, Proceedings Lux Europa 2005, pp 201-204.

Fontoynont, M., *Long term assessment of costs associated with lighting and daylighting techniques*, Proceedings Lux Europa 2005, pp 227-230.

Maamari, F., Andersen, M., De Boer, J., Carroll, W. OL., Dumortier, D., Greenup, *Experimental validation of daylighting simulation methods for complex fenestration systems*, Proceedings Lux Europa 2005, pp 245-248.

Morel, N., Lindelof, D., *Bayesian optimization of user visual comfort*, Proceedings Lux Europa 2005, pp 120-124.

Ruck, N.C.,*The Outcomes of IEA SHC Task 31: Daylighting buildings in the 21st century,* Proceedings Lux Europa, pp 108-112.

Selkowitz. S., Lee, Eleanor, *Daylightiing Buildings: Integrated optimized systems for energy efficiency and comfort*, Proceedings Lux Europa 2005, pp 105-107.

Serra, V., Pellegrino, *Experimental assessment of daylighting and artificial lighting control systems*, Proceedings Lux Europa 2005, pp 149-153.

Wienold. J., Christoffersen, J., *Towards a new glare rating*, Proceedings Lux Europa 2005, pp 157-161.

Technical reports issued from IEA Task 31 available in the year 2006

Christoph Reinhart, *LIGHTSWITCH model to determine the impact of user behaviour on energy* use, NRC/Canada.

Christoph Reinhart, *Subtask A Overview*, NRC/Canada.

Steve Coyne and Steve Selkowitz, *Framework for a design guide*, Queensland University of Technology/Australia, Lawrence Berkeley National, Laboratory/USA.

Nicolas Morel, C*ontrol Design Guide*, Ecole Polytechnique Fédérale de Lausanne/Switzerland.

Martin Butcher, *Commissioning guide including procedures to calibrate and commission key daylighting control systems,* Lighting Consultant/Australia.

Anna Pellegrino, Valentina Serra, Steve Selkowitz, *Case studies energy savings and occupant response*, Politecnico di Torino/Italy, Lawrence Berkeley National, Laboratory/USA.

Steve Selkowitz , *Subtask B Overview*, Lawrence Berkeley National, Laboratory/USA.

Marilyne Andersen and Jan de Boer, *Goniophotometry and assessment of bidirectional photometric properties of complex fenestration systems,* MIT/USA, IBP Fraunhofer Institute for Building Physics/Germany.
Fawaz Maamari, *Experimental validation of simulation methods for bidirectional transmission properties at the daylighting performance level* Ecole Nationale des Travaux Publics de l'Etat, France.

Jan de Boer, *Modeling indoor illumination by complex fenestration systems based on bidirectional photometric data,* Fraunhofer Institute for Building Physics/Germany.

Fawaz Maamari, *Application of the CIE test cases to assess the accuracy of lighting computer programs*, Ecole Nationale des Travaux Publics de l'Etat, France.

Fawaz Maamari, *A reliable database to assess the accuracy of lighting computer programs*, Ecole Nationale des Travaux Publics de l'Etat, France.

Yasuko Koga, *All Sky Model validation and implementation into Radiance*, Kyushu University/Japan.

Jan de Boer, *Subtask C Overview*, Fraunhofer Institute for Building Physics/Germany.

All reports available on the IEA Task 31 Website : http://www.iea-shc.org/task31

Energy and Buildings Refereed Journal – IEA Task 31 Special Issue available in 2006

Guest Editors: Christoph Reinhart, NRC/Canada and Steve Selkowitz, Lawrence Berkeley National, Laboratory/USA.

Swiss contribution : David Lindelhöf and Nicolas Morel, *Typical Patterns of User Behaviour Under an Advanced Automatic Control System for Blinds and Electric Lighting*, accepted for publication.

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7. ANNEX

IEA SHC TASK 31 NATIONAL CONTACT PERSONS

Operating Agent
Nancy Ruck
School of Architecture, Design Science and Planning
University of Sydney
Sydney NSW 2006

Australia
Stephen Coyne
Centre for Medical, Health Environment Physics
School of Physics & Chemical Sciences
Queensland University of Technology

Brisbane, Queensland 4001

Phillip Greenup
Ove Arup and Partners
Sydney

Mark Luther
Built Environment Research Group
Deakin University
Geelong, Victoria

Belgium
Magali Bodart
Université Catholique de Louvain
Architecture et Climat
Place de Levant 1
1348 Louvain-la-Neuve

Arnaud Deneyer
Belgian Building Research Institute
Avenue P. Holoffe 21
B-1342 Limelett

Canada
Christoph Reinhart
National Research Council,
Canada Institute for Research in Construction
1500 Chemin Montreal Road
Ottawa, Ontario KIA OR6

Denmark
Kjeld Johnsen, Jens Christoffersen
Danish Building and Urban Research
Energy and Indoor Climate Division
Postboks 119
DK-2970 Hørsholm

Finland
Liisa Halonen
Helsinki University of Technology
Otakaari 5 A
02150 Espoo

Jorma Lethovaara
Helsinki University of Technology
Lighting Laboratory
PO Box 3000
FIN-02015 HUT

France
Marc Fontoynont, Fawaz Maamari
ENTPE/DGCB
Rue Maurice Audin
69518 Vaulx-en-Velin, Cedex

Germany
Jan de Boer, Hans Erhorn
Fraunhofer-Institut für Bauphysik
Nobelstrasse 12
70569 Stuttgart

Alexander Rosemann
Technical University of Berlin
Strasse des17. Juni 135
10623 Berlin

Italy
Valentina Serra, Anna Pellegrino
Dipartimento di Energetica-
Facolta di Architettura-
Politecnico di Torino
Viale Mattioli 39
10125 Torino

Japan
Koga Yasuko
Dept. of Architecture and Urban Design
Kyushu University
Japan

New Zealand
Michael Donn, Werner Osterhaus
Victoria University of Wellington
Centre for Building Performance
P.O. Box 600
Wellington 1

Norway
Barbara Matusiak
Norwegian University of Science and Technology
Faculty of Architecture, Planning and Fine Arts
7034 Trondheim

Sweden
Helena Bülow-Hübe, Lund University
Division of Energy and Building Design
Department of Construction and Architecture
P.O. Box 118
S-221 00 Lund

Nils Svendenius
Lund University
Department of Atomic Spectroscopy
Sölvegatan 14
S-223 62 Lund

Lars R Bylund
PELK Design Group
Drottningsgatan 71 C
SE-11136 Stockholm

Switzerland
Nicolas Morel, Jean-Louis Scartezzini,
David Lindelhof, Marilyne Andersen
Solar Energy & Building Physics Lab.
École Polytechnique Fédérale de
Lausanne
1015 Lausanne

United Kingdom
John Mardaljevic
Institute of Energy & Sustainable Development
Leicester
UK LE7 9SU

United States
William Carroll
Lawrence Berkeley National Laboratory
Mail stop 90 - 3111

Berkeley, California 94720

Steve Selkowitz , Eleanor Lee
Lawrence Berkeley National Laboratory
Building 90-Room 3111
Berkeley, CA 94720