# Final Task Management Report

**IEA – SOLAR HEATING & COOLING PROGRAM, TASK 34**

**IEA – ENERGY CONSERVATION IN BUILDINGS AND COMMUNITY SYSTEMS PROGRAM, ANNEX 43**

## TESTING AND VALIDATION OF BUILDING ENERGY SIMULATION TOOLS

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**Prepared by Operating Agent on behalf of United States Department of Energy**

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## IEA SHC Task 34/IEA ECBCS Annex 43: Testing and Validation of Building Energy Simulation Tools

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**IEA SHC Task 34/ IEA ECBCS Annex 43: Testing and Validation of Building Energy Simulation Tools**

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## TASK DESCRIPTION

Title: Testing and Validation of Building Energy Simulation Tools
Commencement Date: October 1, 2003
Completion Date: December 31, 2007

## 1. REVIEW OF ACTIVITIES

### 1.1 Task Initiation

The main activities during the planning phase were:

- Preliminary task definition meeting: Bordeaux, France, June 2002
- Concept paper for new task, approved (by SHC) November 2002
- Second task definition meeting: Fontainebleau, France, December 2002
- Task Definition Workshop: Delft, Netherlands, April 2003
- Draft Annex submitted, May 2003
- Annex Document approved (SHC & ECBCS), June 2003
    - ECBCS requested additional planning meeting
- 2nd planning meeting/1st experts meeting, Duebendorf, Switzerland, September 2003
- Draft Work Plan submitted, October 2003
- Work Plan approved, November 2003
- Revised Annex Document and Work Plan submitted, April 2004
- Revised Annex Document approved (SHC & ECBCS), June 2004
- Revised Work Plan approved (SHC & ECBCS), June 2004
- Extension of Task through Dec 2007 approved: June 2004 (ECBCS), Nov 2004 (SHC)

The duration of the task was initially planned for October 2003 through December 2006. However, a one-year extension of the project to December 2007 was requested to better accommodate addition of ECBCS participants. The project definition phase was organized by Ron Judkoff, National Renewable Energy Laboratory (NREL) and Joel Neymark, J. Neymark & Associates (under contract with NREL). Ron Judkoff served as Operating Agent during the task.

The original number of participating countries was 12: Australia, Belgium, Canada, Czech Republic, France, Germany, Japan, Netherlands, Sweden, Switzerland, United Kingdom, United States. Czech Republic withdrew in 2004 because of funding issues. However, we finished with 13 participating countries as Denmark joined the task in 2004, and Ireland joined the task in 2006. Project F (Virtual Simulation Center) was dropped because of lack of funding.

## 1.2 Experts Meetings

1. 29-30 September 2003, Swiss Federal Materials Research Laboratory (EMPA), Duebendorf/Zurich, Switzerland.
2. 5-7 April 2004, Fraunhofer Institute for Building Physics, Holzkirchen, Germany.
3. 6-8 October 2004, Czech Technical University, Prague, Czech Republic.
4. 11-13 April 2005, University of Liège, Liège, Belgium.
5. 3-5 October 2005, Aalborg University, Aalborg, Denmark.
6. 10-12 April 2006, Iowa Energy Center, Ankeny/Des Moines, Iowa, United States.
7. 4-6 October 2006, Lund University, Lund, Sweden.
8. 26-28 March 2007, National Renewable Energy Laboratory, Golden, Colorado, U.S
9. 24-26 October 2007, University of Strathclyde, Glasgow, United Kingdom

## 1.3 Project Leaders

***Project A: Ground-Coupled Heat Transfer with respect to Floor Slab Constructions***
Joel Neymark, J. Neymark & Associates (under contract with NREL); Ron Judkoff, NREL, United States

***Project B: Multi-Zone Buildings and Air Flow***
*Project B1: Multi-Zone Non-Airflow Tests*
Joel Neymark, J. Neymark & Associates (under contract with NREL); Ron Judkoff, NREL, United States
*Project B2: Airflow Tests Including Multi-Zone Airflow*
Yasuo Utsumi, INCT, Japan

***Project C: Shading/Daylighting/Load Interaction***
*Project C1: EMPA Shading/Daylighting/Load Interaction*
Peter Loutzenhiser and Heinrich Manz, EMPA, Switzerland;
*Project C2: ERS Shading/Daylighting/Load Interaction*
Peter Loutzenhiser and Greg Maxwell, Iowa State University, United States

***Project D: Mechanical Equipment and Controls***
Clemens Felsmann, Dresden University of Technology, Germany

***Project E: Buildings with Double-Skin Facades***
*Project E1: Double-Skin Façade Literature Review*
Harris Poirazis, Lund University, Sweden
*Project E2: Double-Skin Façade Empirical Validation Tests*
Per Heiselberg, Olena Kalyanova, Aalborg University, Denmark
*Project E3: Double-Skin Façade Comparative Tests*
Per Heiselberg, Olena Kalyanova, Aalborg University, Denmark

***Project G: Web Site Consolidation for Tool Evaluation Tests***
Ron Judkoff, NREL; Joel Neymark, JNA (under contract with NREL), United States

## 1.4 Description of Task 34/Annex 43:Validation of Building Energy Simulation Tools

The goal of this Task was to undertake pre-normative research to develop a comprehensive and integrated suite of building energy analysis tool tests involving analytical, comparative, and empirical methods. These methods provide for quality assurance of software, and some of the methods will be enacted by codes and standards bodies or other regulatory agencies to certify software used for showing compliance with building energy standards, tax credits, or other building energy incentive programs. This goal was pursued by accomplishing the following objectives:

- Create and make widely available a comprehensive and integrated suite of IEA Building Energy Simulation Test (BESTEST) cases for evaluating, diagnosing, and correcting building energy simulation software. Tests address modeling of the building thermal fabric and building mechanical equipment systems in the context of innovative low-energy buildings.
- Maintain and expand as appropriate analytical solutions for building energy analysis tool evaluation.
- Create and make widely available high quality empirical validation data sets, including detailed and unambiguous documentation of the input data required for validating software, for a selected number of representative design conditions.

***Scope***

This Task investigated the availability and accuracy of building energy analysis tools and engineering models to evaluate the performance of innovative low-energy buildings. Innovative low-energy buildings attempt to be highly energy efficient through use of innovative energy-efficiency technologies or a combination of innovative energy efficiency and solar energy technologies. To be useful in a practical sense such tools must also be capable of modeling conventional buildings. The scope of the Task was limited to building energy simulation tools, including emerging modular type tools, and to widely used innovative low-energy design concepts. Activities include development of analytical, comparative and empirical methods for evaluating, diagnosing, and correcting errors in building energy simulation software. The audience for the results of the Task/Annex is building energy simulation tool developers, and codes and standards (normes) organizations that need methods for certifying software. However, tool users, such as architects, engineers, energy consultants, product manufacturers, and building owners and managers, are the ultimate beneficiaries of the research, and will be informed through targeted reports and articles.

***Means***

For the purpose of describing the work, it is useful to define the terms “comparative tests” and “empirical validation.” In comparative testing, a BESTEST-type comparative/diagnostic evaluation test procedure is written and software programs are compared to each other. Advantages of comparative tests include ease of testing many parameters, and that simple building descriptions may be used; the major disadvantage is lack of any truth standard for cases where analytical solutions are not possible. In empirical validation, software is compared with carefully obtained experimental data. The advantage of empirical tests is that true validation of the models may be accomplished within the uncertainty of the experimental data; disadvantages are that gathering high quality experimental data is expensive and time consuming, making it difficult to test the individual effects of many parameters.

Comparative tests included:

- BESTEST ground-coupled heat transfer with respect to floor slab construction (Project A)
- BESTEST multi-zone heat transfer, shading and internal windows (Project B1)
- BESTEST airflow, including multi-zone airflow (Project B2)
- Chilled-water and hot-water mechanical systems and components (Project D)
- Buildings with double-skin facades (Project E3).

Within the comparative test cases, analytical verification tests for evaluating basic heat transfer and mathematical processes in building energy analysis tools were included where possible. Analytical verification tests are comparisons with closed-form analytical solutions or with generally accepted numerical solutions performed outside of the environment of whole-building energy simulation software. Such closed-form analytical solutions and numerical solutions represent a “mathematical truth standard” and “secondary mathematical truth standard”, respectively, based on the underlying physical assumptions given in the test specifications.

Empirical validation tests include:

- Shading/daylighting/load interaction (Project C)
- Chilled-water and hot-water mechanical systems and components (Project D)
- Buildings with double-skin facades (Project E2).

When a number of building energy simulation programs are tested against the same empirical data set, comparative tests are also possible. Such comparative tests can help identify deficiencies in the empirical experiment if they exist, or broad-based deficiencies in the current modeling state of the art.

To effectively disseminate the results of the Task a single web site consolidates IEA tool evaluation tests from SHC Task 12 / ECBCS Annex 21, SHC Task 22, and SHC Task 34 / ECBCS Annex 43.

## 2. ACCOMPLISHMENTS/TECHNOLOGY ADVANCES: TASK 34/ANNEX 43

Six IEA Technical Reports were produced containing four empirical validation test suites, four comparative test suites, and several analytical verification test cases as part of the comparative test suites. In addition a comprehensive literature review on Double Façade buildings was also published as an IEA Technical Report. 24 computer models were tested among the various projects (see Table 1) identifying 106 results disagreements leading to 80 software, documentation, or modeling repairs. These fixes have led directly to improvements in software tools used for evaluating the impacts of energy efficiency and solar energy technologies commonly applied in innovative low-energy buildings.

Brief descriptions of the newly developed test procedures are included below. Technical conclusions from each of the projects are summarized in Section 6.

***Project A: Ground Coupled Floor Slab Comparative Tests (Leader: US/NREL)***

The objective of these in-depth test cases is to determine the causes for disagreements among detailed ground heat transfer model results found in preliminary test cases developed during SHC Task 22. The cases are divided into “a”-series, “b”-series and “c”-series cases. The “a”-series test cases are for checking proper implementation of detailed 3-d numerical ground heat transfer models run independently of whole-building simulations. They include a steady-state 3-d analytical verification test case, and two other idealized steady-state and periodically-varying comparative test cases. The less idealized “b”-series and “c”-series cases compare ground heat transfer models integrated with whole-building simulations to the independent numerical models. Parametric variations in these cases include: periodic ground surface temperature variation (versus steady-state), floor slab aspect ratio, slab size, deep ground temperature depth, and interior and exterior convective coefficients (realistic versus high values to test the effect of surface temperature uniformity).

**Table 1. Models Tested during IEA SHC Task 34 / ECBCS Annex 43**

| Model Tested | Participating Country | Project |
|---|---|---|
| BASECALC | Canada | A |
| BSim | Denmark | E |
| CODYRUN | France | B1 (MZ320 only),B2 |
| COMFIE | France | B1 (MZ320 only) |
| COMIS 3.2 | Japan | B2 |
| DOE-2.1E | Switzerland | C |
| EES | Belgium | D |
| EnergyPlus | Switzerland | C |
| EnergyPlus | United States | A,B1,D |
| ESP-r | United Kingdom | B1,B2,C,E |
| ESP-r/BASESIMP | Canada | A |
| FLUENT* | Kuwait | A |
| HELIOS | Switzerland | C |
| HTB2 | United Kingdom | B1,B2 |
| IDA-ICE | Sweden | E |
| IDA-ICE | Switzerland | C |
| KoZiBu | France | B1 (MZ320 only) |
| MATLAB* | Ireland | A |
| MATLAB-Simulink | Germany | D |
| SUNREL-GC/GHT | United States | A |
| TRNSYS-TUD | Germany | B1,B2,C,D,E |
| TRNSYS-16* | United States | A |
| TRNSYS-16 | Belgium | B1,C |
| VA114 | Netherlands | B1,D,E |
| VA114/ISO-13370 | Netherlands | A |
| VentSim | Japan | B2 |

* Used as platform for developing detailed 3-D numerical model

***Project B1: Multi-Zone Non-Airflow Tests (Leader: US/NREL)***
These cases test: a) models' ability to correctly keep account of inter-zonal conduction heat transfer, b) the ability of programs to account for multi-zone shading by a single shading object and self-shading of the building by zones that shade other zones, and c) the ability to model internal windows between zones. Shading and internal window test cases employ idealized glazing and building zones designed as calorimeters for testing shading and solar gains effects.

***Project B2: Airflow Tests including Multi-Zone Airflow (Leader: Japan/INCT)***
The airflow cases emphasize flows driven by natural ventilation, buoyancy, wind, temperature-difference, and mechanical fan. Cases have been developed in 1-zone and 3-zone configurations. The test cases are based on the geometry of the multi-zone non-airflow conduction cases, are simpler (potentially more diagnostic) than the ECBCS Annex 23 (COMIS airflow) cases, and allow use of nodal, zonal, and CFD models (not possible with COMIS cases).

***Project C1: EMPA Shading/Daylighting/Load Interaction Empirical Tests (Leader: Switzerland/EMPA)***
This project accomplished:

- Collection of empirical data in the Swiss Federal Laboratory for Materials Testing and Research (EMPA) test cells for the validation of building energy simulation models of windows with and without shading devices
- Comparison of simulation results with empirical data.

The suite of eight experiments includes: 1) Overall test cell conductance, 2) Overall test cell internal capacitance, 3) Glazing only, 4) Glazing with external textile shading screen, 5) Glazing with internal textile shading screen, 6) Glazing with external Venetian blinds, 7) Glazing with internal mini-blinds, and 8) Window, i.e. glazing with frame. The simulations for the solar gain experiments were designed to predict the cooling power required to maintain the constant zone temperature.

***Project C2: ERS Shading/Daylighting/Load Interaction Empirical Tests (Leader: US/Iowa)***
The work done at Iowa Energy Resource Station (ERS) in the United States created an empirical validation data set for daylighting controls. Equipment used includes: dimmable ballasts, fabric shades, mini-blinds, exterior shading fins, and equipment for scheduled internal gains. Electric lights are controlled to maintain a minimum illuminance level; when enough natural daylight is available electric lighting is reduced.

***Project D: Mechanical Equipment and Controls Empirical Validation Tests (Leader Germany/TUD)***
This work developed procedures for testing and validating energy simulation software related to chilled- and hot-water building energy systems. The tests are separated into several sub-exercises to focus on single components as shown in Table 2 below. Beside a set of comparative tests, the experimental and measurement facilities at the Iowa Energy Resource Station were used for empirical studies.

The work includes comparative test cases for the coils (both cooling and heating coil) and the hot water boiler. The coil comparative tests are designed to predict coil performance to maintain a given leaving air temperature when temperature and humidity of entering air and water are given. Two different types of coil control strategies (variable water mass flow vs. variable water inlet temperature) are used for comparative test cases.

**Table 2: Components of the building systems related to Project D**

| Test case | Simulation Exercises |
|---|---|
| Chilled water system | - Chiller (two scroll compressors)<br>- cooling coil (dry / wet regime with condensing water flow rate measurement)<br>- hydronic network (pipes, pump, valve) |
| Hot water system | - Boiler (Condensing atmospheric natural gas boiler with variable firing rate)<br>- Heat exchanger (terminal re-heat)<br>- hydronic network (pipes, pump, valve) |

***Project E: Buildings with Double-Skin Facades***
The work within Project E assessed suitability and awareness of building energy analysis tools for predicting heat transfer, ventilation flow rates, cavity air and surface temperatures and solar protection effect and interaction with building services systems in buildings with a double facade.

*Project E1: Double-Skin Façade Buildings Literature Survey (Leader: Sweden/Lund University)*
This project developed a review of available literature on double-skin façade (DSF) buildings regarding typologies, modeling approaches, measurements, tools, etc. The literature review final report covers: building energy consumption, thermal and visual comfort, acoustics, environmental impacts during construction and operation, application of new technologies, and modeling

approaches and methods for DSF. The report also documents the study of several categories of double-skin building construction types; advantages and disadvantages of DSF; and modeling issues including airflow, thermal and daylighting simulations. The literature review found roughly 50 case studies.

*Project E2: Double-Skin Façade Empirical Tests (Leader: Denmark/Aalborg University)*
This project developed a test facility and an empirical validation test suite for DSF models including description of test facility and test cases, and documentation of the empirical data sets and simulation results. Test cases include the following configurations:

- All façade openings closed
- Openings are open to the outside
- Bottom opening open to outside; top opening open to inside

Within the test cases are a number of variations to check the influence of various parameters, including:

- Driving force of airflow (buoyancy, wind, mechanical fan, combined forces)
- Internal (thermal)/External (thermal, solar, wind) boundary conditions
- Opening area (fully opened, opening area controlled by temperature and/or airflow rate)

*Project E3: Double-Façade Comparative Tests (Leader: Denmark/Aalborg University)*
This project developed a comparative validation test procedure for DSF models. The following three comparative test cases were defined:

- All façade openings closed
- Openings are open to the outside
- Bottom opening open to outside; top opening open to inside

The Project E3 test procedures were not published; they will be included in a Working Document.

### *Project G: Web Site for Consolidation of Tool Evaluation Tests (Leader: Operating Agent [US/NREL])*
Creation of a single location for obtaining all tool evaluation tests developed in IEA SHC Task 12 / ECBCS Annex 21, SHC Task 22, and SHC Task 34 / ECBCS Annex 43, including a note identifying IEA procedures that have been adapted into ANSI/ASHRAE Standard 140, and a link to the Standard-140 web page. This will be coordinated with the SHC webmaster at the June 2008 Executive Committee meeting. Task 12/Annex 21, Task 22 and Task 34/Annex 43 reports that do not include test procedures (e.g., methodology studies, literature surveys, etc.,) will not be included with this web page.

## 3. DEGREE TO WHICH OBJECTIVES WERE ACHIEVED

Task 34/Annex 43 achieved all but one of its initially planned projects (that project was not funded), and produced three additional "bonus" deliverables that were not initially planned. Section 3.1 (below) describes the planned results listed in the Task 34/Annex 43 "Annex Document". Section 3.2 discusses degree of achievement.

## 3.1 Planned Results

*Projects A and B: Comparative Tests*

(a) *Usable BESTEST-type test specifications* – including equivalent inputs that can accommodate a variety of computer programs – that can be incorporated into codes and standards used for certifying building energy simulation computer programs. Analytical solutions will be included where possible.

(b) Along with the test specifications described in "(a)", final reports will also include: benchmark simulation results, modeler reports, enumeration of bugs found and/or corrected in simulation software, and improvements to the test procedure resulting from international field trials.

*Project C, D, and E: Empirical Validation Tests*

(a) An expanded set of empirical validation test procedures and data sets based on highly instrumented test facilities or buildings.

(b) A report or series of reports on the results of evaluating widely used building energy simulation tools with the empirical data sets.

*Project F: Building Simulation Centre Proposal*

(a) Proposal for development of Building Simulation Centre to be submitted to the ECBCS and SHC Executive Committees.

*Project G: Web Site for Consolidation of Tool Evaluation Tests*

(a) Web site consolidating the tool evaluation tests from SHC Task 12 / ECBCS Annex 21, SHC Task 22, and SHC Task 34 / ECBCS Annex 43.

Products of all Projects, except Projects F and G, will also include technical papers or articles presented at international congresses or in professional journals throughout the course of Task 34/Annex 43. Such papers will include assessments of the impact of improved building energy analysis tools in the areas being studied.

## 3.2 Degree of Achievement

*Projects A and B: Comparative Tests*

- Three test procedures were developed for Projects A and B as described in Section 2
- All three of these test procedures utilized analytical solutions where possible
- All three final reports provide usable BESTEST-type test specifications, benchmark simulation results, modeler reports, and enumeration of bugs found
- All of the test procedures were improved during the course of the field trials.
- Project A was originally intended to cover both slab-on-grade and basement configurations, however, limited resources restricted the work to slab-on-grade configurations only.

*Project C, D, and E: Empirical Validation Tests*

- Three final reports were developed, which include four empirical validation test suites for Projects C1, C2, D and E2 as described in Section 2; this expands the set of available empirical validation test procedures and data sets based on highly instrumented test facilities or buildings.
- All three final reports provide usable test specifications, benchmark simulation results, modeler reports, and enumeration of bugs found.

*"Bonus" Items:*

- Preliminary to the development of empirical validation test procedures, Projects D and E developed comparative tests.
    - The comparative test cases for Project D are included with the Project D final report.
    - The comparative test cases for Project E (designated as Project E3) will not be formally published, but will be included in a working document during Summer 2008.
- A literature review on Double-Skin Façade buildings was also developed.

*Project F: Building Simulation Centre Proposal*
A proposal for development of a Building Simulation Centre (requested by the Swiss Executive Committee member) to be submitted to the ECBCS and SHC Executive Committees was not funded. The project was dropped.

*Project G: Web Site for Consolidation of Tool Evaluation Tests*
This will be a single location for obtaining all tool evaluation tests developed in IEA SHC Task 12 / ECBCS Annex 21, SHC Task 22, and SHC Task 34 / ECBCS Annex 43, to be coordinated with the SHC webmaster at the June 2008 Executive Committee meeting.

## 4. EFFECTIVENESS OF NATIONAL PARTICIPATION

There was an active and productive core group of participants that either attended meetings regularly or participated in test specification field trials without regularly attending meetings, consisting of **53 participants** from **32 organizations** located in the following **13 countries**: Australia, Belgium, Canada, Denmark, France, Germany, Ireland, Japan, the Netherlands, Sweden, Switzerland, the United Kingdom, and the United States. **24 computer programs/models were tested** by the participants as listed in Table 1 above. More than 33 person-years of effort were expended by the participants over the course of the task. A list of participants is included in Appendix B.

A relevant quote from the authors of the Project A and Project B1 final reports:

> "… the authors wish to acknowledge that the expertise available through IEA and the dedication of the participants were essential to the success of this project. Over the 4-year field trial effort, there were several revisions to the BESTEST specifications and subsequent re-executions of the computer simulations. This iterative process led to the refining of the new BESTEST cases, and the results of the tests led to improving and debugging of the simulation models. The process underscores the leveraging of resources for the IEA countries participating in this project. Such extensive field trials, and resulting enhancements to the tests, were much more cost effective with the participation of the IEA SHC Task 34 / ECBCS Annex 43 experts."

As the work for the other projects is of similar nature, this quote is likely relevant for all of the test suites developed by Task 34/Annex 43.

## 5. INDUSTRY INVOLVEMENT

### 5.1 Software Developer and Other Industry Participants in Task 34/Annex 43

- CANMET Energy Technology Centre (developer of BASECALC and BASESIMP)
- Cardiff University (developer of HTB2)
- CSTB (developer of SIMBAD)
- Dresden University of Technology (developer of TRNSYS-TUD)
- EMPA (developer of COMIS)
- GARD Analytics (representative of EnergyPlus development team)
- Ecole des Mines de Paris (developer of COMFIE)
- JNLOG (developer of KoZiBu)
- NREL (developer of SUNREL)
- Sanko Air Conditioning Co., Ltd. (support for Japan’s participation)
- Sumitomo-Mitsui Construction Co., Ltd. (support for Japan’s participation)
- Thermal Energy Systems Specialists (developer of TRNSYS-16)
- University of Reunion Island (developer of CODYRUN)
- University of Strathclyde (developer of ESP-r)
- VABI Software BV (developer of VA114)

#### *5.1.1 Noteworthy Quotes from Industry Participants/Software Developers*

Jeff Thornton, President of Thermal Energy System Specialists (TESS), Madison, Wisconsin, U.S. published the following comment in his modeler report for Project A:

> “Without this IEA subtask for ground coupling, we would have had no means to check the results from our model, nor had a reason to make improvements to our model. There should be no question that the IEA subtask has improved the TRNSYS ground coupling model and, in doing so, has also provided energy modelers a greatly increased sense of confidence when modeling heat transfer to the ground.”

Aad Wijsman, VABI Software BV, Delft, The Netherlands published the following in his modeler report for Project B1:

> “Bestest and IEA-34/43 tests brought a number of new errors to the surface. This shows the importance of these test [cycles]!! And still there will be errors in the software!! Development of new, specific test cases is of big importance!!”

### 5.2 Links with Industry

The primary audiences for the IEA tool evaluation research are building energy analysis tool authors and national and international building energy standard (norme) making organizations. Activities of SHC Task 34/ECBCS Annex 43 and previous related SHC Task 22 and SHC Task 12/ECBCS Annex 21 research are linked to the needs and recommendations of the world's leading building energy analysis tool developers. For example, a recent study comparing 20 whole building energy simulation tools indicates that 19 of the 20 tools reviewed had been tested with at least one of the IEA BESTEST procedures; 10 of the tools had been tested with more than one of the BESTEST procedures. The study also indicates that test procedures developed by the IEA dominate the set of available tests. (Crawley, D., Hand, J., Kummert, M., Griffith, B. [2005]. *Contrasting the Capabilities of Building Energy Performance Simulation Programs.* Washington, DC: U S

Department of Energy ; Glasgow, Scotland, UK : University of Strathclyde ; Madison, WI : University of Wisconsin. http://gundog.lbl.gov/dirpubs/2005/05_compare.pdf)

Industry links for this work are well founded. Activities related to the propagation and adoption of the IEA BESTEST procedures, described below, include codes and standards activities, non-English language translations of test procedures, publication of papers and news articles, and so forth.

### 5.3 Codes and Standards Activities

A key audience and link to industry for the research undertaken within this Task is national and international building energy standards organizations. These organizations have been adopting the test cases developed in this task, along with those developed in previous IEA tasks, to create standard methods of tests for building energy analysis tools used for national building energy code compliance.

The American National Standards Institute (ANSI) and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) continue to adopt SHC work into their standards. **ANSI/ASHRAE Standard 140-2007** includes adaptations of earlier SHC work (posted at http://www.iea-shc.org/task22/index.html):

- **IEA Building Energy Simulation Test and Diagnostic Method (BESTEST)** – building thermal fabric comparative tests, developed by National Renewable Energy Laboratory (NREL), US, in joint *SHC/ECBCS Task 12/Annex 21*, *Solar Building Analysis Tools*
- **HVAC BESTEST Volume 1** – unitary cooling equipment analytical verification tests, developed by NREL in *SHC Task 22*, *Building Energy Analysis Tools*
- **Fuel-Fired Furnace BESTEST** – analytical verification tests, developed by Natural Resources Canada in *SHC Task 22*
- **HVAC BESTEST Volume 2** – unitary cooling equipment comparative tests, developed by NREL in *SHC Task 22*.

There is a several year time lag between development of new test suites and their incorporation into ASHRAE standards because of the ANSI/ASHRAE consensus standards process. The Operating Agent has been acting as liaison with, and is the Chair of, ASHRAE SSPC 140 (the ASHRAE project committee responsible for ANSI/ASHRAE Standard 140). Future revisions of Standard 140 will consider adaptation of additional test suites, including those recently developed under joint *SHC Task 34/ECBCS Annex 43*, *Testing and Validation of Building Energy Simulation Tools*.

Standard 140 and/or the reports that comprise the test suites contained therein are being referenced and used by a growing number of code promulgation authorities throughout the world. ASHRAE Standard 90.1-2007, which is used for regulating energy efficiency in commercial and non-low-rise residential buildings requires use of Standard 140-2004 for testing software used in building energy efficiency assessments. Software used for calculating energy savings for purposes of the energy-efficient commercial building tax deductions in the U.S. must be tested with Standard 140-2007. The International Energy Conservation Code is also referencing Standard 140. These citations are important because they mandate software evaluation using test procedures developed under IEA research activities. For example, because of the ASHRAE Standard 90.1 requirement to test software using ASHRAE Standard 140, two of the largest suppliers of building HVAC equipment in the world, Carrier and Trane Corporations, regularly test their respective software packages HAP and TRACE with Standard 140. Also, EnergyPlus, the USDOE's most advanced simulation program for building energy analysis, maintains their Standard 140 validation results on their website.

The Netherlands (TNO) has developed their Energy Diagnosis Reference (EDR) based on BESTEST. TNO has developed the EDR to satisfy the European Performance Directive (EPD) of the European Union. The EPD emphasizes performance-based standards and requires certification of software used to show compliance with energy performance standards (normes). Portugal is also using BESTEST as their basis for software quality control under the EPD. As part of their building energy performance assessments under the EPD, Austria, Denmark, Greece and The Netherlands are using a new software tool that includes algorithms that have been checked with BESTEST. Also, CEN has utilized BESTEST to check their reference cooling load calculation general criteria of prEN ISO 13791 and simplified methods of prEN ISO 13792. Elsewhere, IEA BESTEST has been referenced in codes and standards in Australia and New Zealand. Furthermore, NREL's overall validation methodological framework has been included in the *2005 ASHRAE Handbook of Fundamentals* and is being updated for the *2009 ASHRAE Handbook of Fundamentals*. As a result of these and other activities, many major building energy software providers worldwide are using BESTEST and ASHRAE Standard 140.

The UK's Chartered Institute of Building Services Engineers (CIBSE) is compiling tests (CIBSE TM33) for software accreditation and verification. The tests address "a need for UK regulators to have a mechanism for the technical accreditation of detailed thermal models as part of their formal approval for use in the [UK] National Calculation Methodology." CIBSE notes that the TM33 tests are primarily meant to instill confidence in users rather than to provide comprehensive validation of a program. For those intending more detailed program validation, CIBSE TM33 cites tests and benchmarks available from ASHRAE Standard 140, IEA, ASHRAE Research, and CEN. For example, papers recently published by U. Strathclyde, UK, describe how many of the BESTEST suites have been directly integrated within ESP-r for automated testing of revisions to the software.

### 5.4 Non-English Language Translations of IEA BESTEST

The popularity and utility of the BESTEST procedures developed within various SHC Tasks is also evident from language translations undertaken within various countries using their own resources, including translations into Japanese, Dutch and German. Japan distributed a recently completed Japanese-language translation of HVAC BESTEST Volume 1 (NREL/SHC Task 22). This translation and an earlier translation of IEA BESTEST (NREL/SHC Task 12/ECBCS Annex 21) have been distributed to over 30 researchers and engineers in Japan. Several Japanese papers have already been published that refer to these BESTEST translations. Translations of HVAC BESTEST Volume 2 (NREL/SHC Task 22) and Fuel-Fired Furnace BESTEST (NRCan/SHC Task 22) into Japanese are planned for the future. The Netherlands (TNO) has developed their Energy Diagnosis Reference (EDR) based on the IEA BESTEST building thermal fabric test suite, which was revised for Netherlands-specific buildings, and is written in Dutch. A journal article on HVAC BESTEST Volume 1 was translated into German and published in a German HVAC engineering journal.

# 6. TECHNICAL CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

BESTEST analytical verification and comparative test cases have been extended to cover:

- Ground-coupled heat transfer with respect to floor slab constructions (Project A)
- Multi-zone conduction, multi-zone shading and internal window models (Project B1)
- Airflow including multi-zone airflow (Project B2)
- Hydronic mechanical equipment and controls (Project D)

Empirical validation test procedures and detailed data sets have been extended to cover

- Shading, daylighting and load interaction (Project C)
- Hydronic mechanical equipment and controls (Project D)
- Double-Skin Façade buildings (Project E2)

The work has led directly to improvements in software tools used for evaluating the impacts of energy efficiency and solar energy technologies commonly applied in innovative low-energy buildings. 24 computer models were tested among the various projects. **So far among all projects, the work has identified 106 results disagreements that have led to 80 software or modeling fixes.** Table 3 indicates by project the number of model errors that were identified and fixed so far. This indicates the utility of both empirical validation (Projects C, D and E) and analytical verification and comparative testing (Projects A and B) to identify disagreements that lead to corrections. Detailed technical conclusions for each project follow.

### Table 3. Model Fixes Attributable IEA SHC 34 / ECBCS Annex 43

| | | **Disagreements** | | **Models** |
|---|---|---|---|---|
| **Project** | **Leader** | **Fixed** | **Identified** | **Tested** |
| **A. Ground Coupled Slab-on-Grade**, | US/NREL | **19** | 24 | 9 |
| **B1. Multi-Zone Non-Airflow** | US/NREL | **32** | 48 | 9 |
| **B2. Airflow** | Japan | **1** | 1 | 6 |
| **C. Shading/Daylighting/Load Interaction** | Switz., US/Iowa | **14** | 14 | 7 |
| **D. Mechanical Equipment and Controls** | Germany | **8** | 10 | 5 |
| **E2. Double-Skin Facade** | Denmark | **6** | 9 | 5 |
| **IEA SHC 34/ ECBCS 43 TOTAL** | | **80** | 106 | 24 |

### *Project A: Ground Coupled Floor Slab and Basement Comparative Tests (Leader: US/NREL)*

The IEA BESTEST cases have been extended to include in-depth analytical verification test cases for slab-on-grade heat transfer models. **An important achievement of this project was the development of a formal methodology to facilitate using and verifying numerical models to develop quasi-analytical solutions.** This allows for greatly enhanced diagnostic capability when comparing results of other simplified and mid-level-detailed modeling methods that are typically used with whole-building energy simulation programs, because the range of disagreement among quasi-analytical solutions is typically much narrower than the range of disagreement among simulation results that may be applying other modeling methods. This also allows quasi-analytical solutions to be developed for more realistic (less constrained) cases than exact analytical solutions allow. The methodology applies to both the development of the test cases as well as to implementation of the numerical models. **The work resulted in diagnosis of 24 software issues resulting in 19 improvements to 7 of the simulation models, including: EnergyPlus, ESP-r/BASESIMP, BASECALC, SUNREL-GC, TRNSYS-GC, VA114, and DIT's model executed within MATLAB.** The detailed 3-D numerical-methods models of TRNSYS-GC, FLUENT, and MATLAB are able to produce results in agreement within 1% for the analytical solution case, and within 4% of each other for the remaining cases. These models provide a secondary numerical mathematical truth standard for the other cases.

***Project B1: Multi-Zone Non-Airflow Tests (Leader: US/NREL)***

The IEA BESTEST cases have been extended to include an in-depth analytical verification test case for multi-zone conduction and diagnostic comparative test cases for multi-zone shading and internal window models. **This project has resulted in diagnosis of 48 modeling issues related to conduction, shading, and internal windows, resulting in 32 improvements to 6 of the simulation programs including: CODYRUN, EnergyPlus, ESP-r, HTB-2, TRNSYS-TUD, and VA114.** For the multi-zone conduction case, all but one of the tested simulation programs agree within 0.3% of the analytical solution. For the shading cases, results indicate the programs are properly accounting for multi-zone and building-self shading after a number of disagreements were diagnosed and fixed, and that shading models for both direct beam and diffuse radiation are working in a multi-zone context. The improved shading diagnostics for the revised cases allowed identification of software errors that have reduced ranges of disagreement to about one third of the disagreement range evident at the beginning of the project. For the internal window cases, agreement among results has also improved substantially as a result of model improvements during the project.

***Project B2: Airflow Tests including Multi-Zone Airflow (Leader: Japan/INCT)***

IEA BESTEST has been extended to include analytical verification test cases for airflow models, including tests for the effects of natural ventilation, buoyancy, wind driven, and temperature-difference driven flows, and the effects of mechanical fan driven flows. Analytical solutions given in the final report provide a mathematical truth standard for the test cases. **This project has resulted in diagnosis of 1 modeling issues related to an input error in VentSim, which was corrected.**

***Project C1: EMPA Shading/Daylighting/Load Interaction (Leader: Switzerland/EMPA)***

Empirical validation test cases were developed to test models related to shading, daylighting and load interaction related to shading of solar gains. **This project has resulted in diagnosis of 14 modeling issues, resulting in 14 improvements to 5 of the simulation programs including: HELIOS XP, EnergyPlus, ESP-r, TRNSYS-TUD and IDA-ICE.** Overall uncertainty in various input parameters causes roughly ±3% uncertainty in simulated cooling load results. Experimentally determined cooling loads have similar uncertainty. EnergyPlus simulations are within 95% credible limits of the empirical data and the propagated error for the experiment with glazing and internal mini-blinds. It is therefore believed that the experiments are well suited for empirical validation.

***Project C2: ERS Shading/Daylighting/Load Interaction (Leader US/Iowa)***

Additional empirical validation test cases were developed to test models related to shading, daylighting and load interaction related to shading of solar gains. Simulation results were received from ISU/EMPA, US/Switzerland (EnergyPlus, DOE-2.1E). Conclusions are that overall predictions for daylighting performance were within acceptable ranges, and that uncertainty in the ERS – a real building – is greater than in a controlled laboratory experiment. This is a good exercise to see how accurate predictions for a real building can be.

***Project D: Mechanical Equipment and Controls Empirical Validation Tests (Leader Germany/TUD)***

Empirical validation test cases were developed to test models related to hydronic mechanical system equipment and controls. Empirical data for both the hot-water and the chilled-water systems were obtained from several experiments conducted at the ERS. After several iterations of test specification and model improvements, model agreement with experimental data was greatly improved. **This project has resulted in diagnosis of 10 modeling issues related to hydronic equipment and controls, resulting in 8 improvements to 3 of the simulation programs including: TRNSYS-TUD, VA114, and U. Liège's model executed within EES.**

***Project E2: Double-Façade Empirical Tests (Leader: Denmark/Aalborg University)***

Empirical validation test cases were developed to test models related to double-skin façade (DSF) buildings. The authors concluded that, while night-time modeling results were good, it is difficult to model naturally driven flow in a DSF cavity during periods with intensive solar radiation. To achieve better modeling (and avoid underestimating cavity air temperatures), it is suggested to consider applying variable surface coefficients to models to obtain better predictions of cavity air temperatures. Additionally, none of the existing models consider recirculation flows in the DSF cavity. It is recommended to develop empirical and comparative tests cases for testing sensitivity of the following: wind pressure coefficients, discharge coefficients, spectral properties of glazing, DSF geometry *in the model*, and presence of a shading device in the DSF cavity. **This project has resulted in diagnosis of 9 modeling issues related to modeling double-skin facades, resulting in 6 improvements to 3 of the simulation programs including: BSim, TRNSYS-TUD and VA114.**

## 6.2 Recommendations

As a result of Task 34/Annex 43, the content of the status of the Tool Evaluation Test Matrix has progressed, as shown in Table 4. This table also includes test procedures developed under SHC Tasks 8, 12 and 22. While representing a useful suite of basic tests, the existing suite of test cases do not address a sufficiently broad enough cross-section of topics to represent a comprehensive evaluation of building energy analysis tools. Additional work should focus on filling missing or only partially covered areas of the matrix.

Continued support of model development and validation activities is essential because occupied buildings are not amenable to classical controlled, repeatable experiments. The few buildings that are truly useful for empirical validation studies have been designed primarily as test facilities. The energy, comfort, and lighting performance of buildings depend on the interactions among a large number of transfer mechanisms, components, and systems. Simulation is the only practical way to bring a systems integration problem of this magnitude within the grasp of designers. There is a growing body of literature and activity demonstrating the importance of the use of simulation tools for greatly reducing the energy intensity of buildings through better design. As building energy simulation programs are more widely used – such as, in the U.S. for establishing LEED ratings and federal tax deductions, in Europe to comply with the European Performance Directive, in Australia to comply with greenhouse gas emission ratings, etc. – the design and engineering communities must continue to have confidence in the quality of these programs. Such confidence and quality is best established and maintained by combining a rigorous development and validation effort with user-friendly interfaces.

The work described here represents a good start in the effort to develop carefully validated building energy simulation tools. Continued development and validation of whole-building energy simulation programs is one of the most important activities meriting the support of national energy research programs. The IEA Executive Committees for Solar Heating and Cooling and for Energy Conservation in Buildings and Community Systems should diligently consider what sort of future collaborations would best support this essential research area.

**Table 4. Validation Test Matrix**

| | ***Building Fabric*** | ***HVAC*** | ***On-site Generation Equipment*** |
|---|---|---|---|
| ***Analytical Verification*** | • Working Document of Task 22 Subtask A.1 Analytical Tests<br>• ASHRAE RP-1052<br>• Slab-on-Grade ground-coupling, IEA 34/43<br>• Airflow, IEA 34/43 | • HVAC BESTEST (E100-E200), Task 22<br>• Furnace BESTEST, Task 22<br>• ASHRAE RP-865 | |
| ***Comparative Tests and Diagnostics*** | • IEA BESTEST, IEA 12/21<br>• HERS BESTEST (NREL)<br>• Expanded ground coupling test cases. Task 22<br>• Multi-Zone Non-Airflow, IEA 34/43 | • HVAC BESTEST (E300-E545), Task 22<br>• RADTEST, Task 22<br>• TUD Hydronic Equipment and Controls, IEA 34/43 | • Residential Cogen, Annex 42 |
| ***Empirical Validation*** | • ETNA/GENEC Tests, Task 22<br>• BRE/DMU Tests, IEA 12/21<br>• ETNA BESTEST (EDF/NREL)<br>• EMPA Shading/ Daylighting/Load, IEA 34/43<br>• ERS Shading/ Daylighting/Load, IEA 34/43<br>• AAU DSF Tests, IEA 34/43 | • Iowa ERS – VAV, Task 22<br>• Iowa ERS – Daylighting HVAC I, Task 22<br>• Iowa ERS – Economizer Control, Task 22<br>• TUD/ERS Hydronic Equipment and Controls, IEA 34/43 | • Residential Cogen, Annex 42 |

## 7. DISSEMINATION ACTIVITIES

### 7.1 Consolidated Website

Currently test procedures are posted or listed at: IEA SHC Task 22 website (www.iea-shc.org/task22/deliverables.htm), SHC Task 12 (http://www.iea-shc.org/publications/category.aspx?CategoryID=17 [also include "Task12-Lomas-et-al-Part4.zip", which was not previously posted], ECBCS Annex 21 (www.ecbcs.org/annexes/annex21.htm), and SHC Task 34/Annex 43 (http://www.iea-shc.org/task34/publications/index.html). We will consolidate (with links) PDF reports and accompanying data files containing procedures currently listed at the Task 22 and Task 12/Annex 21 websites with the new procedures to come from Task 34/Annex 43.

### 7.2 Codes and Standards Activities

The work of Task 34/Annex 43 is expected to become an integral part of codes and standards activities as described in Section 5.3 above

### 7.3 Conferences where Task 34/Annex 43 Work Was or Will Be Presented

- Affordable Comfort Conference, 2008, Pittsburgh, United States (2 sessions)
- AIVC2008, 14-16 Oct 2008, Kyoto, Japan
- Architectural Institute of Japan, Annual Conference, 2004, Japan
- ASHRAE Annual Meeting, June 2006, Quebec City, Canada
- SimBuild, IBPSA-US, Berkeley, California, USA, July 2008: Session on Validation and IEA 34/43 work
- Building Simulation 2009, 27-29 Jul 2009, Glasgow, UK (planned/invited session(s) on IEA 34/43 testing and validation projects)
- EPIC2006AVIC, 22-24 Nov 2006, Lyon, France
- Greenbuild, 2007, Chicago, United States
- IAQVEC, 2007, Sendai, Japan
- Schweizerisches Status-Seminar Energieforschung im Hochbau, Eidgenössische Technische Hochschule, 7-8 September 2006, Zürich, Switzerland
- SHASE Annual Conference, 2005, Japan
- Third International Building Physics Conference, 2006, Montreal, Canada
- TRNSYS User Day, 2006, Stuttgart, Germany
- 12$^{th}$ Symposium for Building Physics, 2007, Dresden, Germany

### 7.4 Papers, Journal Articles and Other Articles

See Appendix A.

Additionally, the Operating Agent has written regular news articles in the ECBCS Newsletter and SHC Solar Update to publicize SHC Task 34/ECBCS Annex 43 reports as they are published, and to provide updates on codes and standards activities related to this work. The ECBCS Executive Secretary, with input from the Task 34/Annex 43 Operating Agent, wrote an article on the early ECBCS Annex I connection to BESTEST and Standard Methods of Test including Standard 140, ISO CEN tests, etc.

## 8. UNRESOLVED TECHNICAL ISSUES

Project E2 for developing double-skin façade empirical validation test cases involved the most complicated building physics (most interaction of a variety of physical phenomena) of all the test cases developed for Task 34/Annex 43. The Project E2 leaders made a number of recommendations for both improving models and developing additional test cases, as indicated in Section 6.2 (above), and in their final report.

## 9. MANAGEMENT RECOMMENDATIONS FOR OTHER TASKS

- **Keep the scope of the Task as narrow as possible.** Task 34/Annex 43 was planned to solely focus on developing testing and validation procedures. The degree of focus generated a lot of cross-communication, with many participants working on more than one project. This high level of common interest also seemed to make meetings more efficient and interesting – plenty of relevance for a majority of the participants.

- **Invite as many colleagues as possible to the planning meetings, and especially industry participants.** Invitations emphasized software developers and institutions known for doing high quality building energy simulation modeling work. The initial planning meetings for Task 34/Annex 43 were very well attended, with 42 different attendees for the first three meetings (including the two planning workshops conducted in 2003). A strong core group developed out of this initial pool, which further attracted additional key participants as the Task progressed. **Working with two Executive Committees helped to expand the pool of potential participants.** Although reporting to two Executive Committees was sometimes cumbersome, the benefit of expanding the number of participants justified the additional administrative cost.

- **During the planning phase, be wary of addressing ideas that come from sources that do not demonstrate any funding commitment.**

- **Be clear to task leaders, and repeat often, about expected final outcomes.** This helped the task leaders to produce usable test suites, where the value of such test suites has been documented by the number of software modeling issues found and fixed for each test suite. All of the final reports for the test procedures developed in Task 34/Annex 43 document at least one modeling correction, and all but one of those reports documented 6 or more corrections.

- **Have individual project leaders directly submit to the Operating Agent the required material for reporting on their project in the Task Status Reports.** That facilitated assembly of the Task Status Reports, and allowed the reporting to be more accurate. This also gave the technical participants some appreciation for the administrative effort required.

## APPENDIX A: TASK 34/ANNEX 43 PUBLICATIONS

**Project A: Ground Coupling Comparative Tests**
To be published final report, *IEA BESTEST In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-on-Grade Construction* (Joel Neymark, Ron Judkoff, et al.)

- Status: Approved by SHC and ECBCS, Apr 2008; final publication expected Sep 2008
- Related published articles:
    - *Model Validation and Testing: The Methodological Foundation of ASHRAE Standard 140*, Ron Judkoff and Joel Neymark, ASHRAE Transactions, Volume 112, Part 2. August 2006.

**Project B: Multi-Zone and Air Flow Comparative Tests**
To be published final report, *IEA BESTEST Multi-Zone Non-Airflow In-Depth Cases: MZ320-MZ360* (Joel Neymark, Ron Judkoff, et al.)

- Status: Distributed to IEA-34/43 Experts for Approval and Comments, May 2008; final publication expected Sep 2008
- Related published articles:
    - *Zur Bilanzierung der solaren Einstrahlung in Gebauden*, Joachim Seifert and Clemens Felsmann, Gesundheits Ingenieur, Jahrgang 2006

To be published final report, *BESTEST Airflow Cases Including Multi-zone* [preliminary title], (Yasuo Utsumi, Teruaki Mitamura)

- Production Schedule
    - Distribute to Task experts for Approval and Comments: May 2008
    - Distribute to SHC and ECBCS reviewers for Approval and Comments: Jun 2008
    - Final publication expected Sep 2008
- Related published articles:
    - *On the Situation of Thermal and Ventilation Simulation Tool and its Development in Abroad*, **in Japanese**, UTSUMI Yasuo, MITAMURA Teruaki, Annual Conference of AIJ (Architectural Institute of Japan), 2004
    - *The Trend of Research and Development Activity of IBPSA and Related Institutes in Japan*, **in Japanese**, Yasuo Utsumi and Hisaya Ishino, Annual Conference of SHASE (Society of Heating, Air-conditioning and Sanitary Engineering, 2005
    - *On the Significance of Thermal Simulation*, **in Japanese**, Yasuo Utsumi, The Journal of Building Equipment and Plumbing, Vol. 44, No.6, March 2006
    - *HVAC BESTEST Volume 1: Part I : Cases E100 – E200*, NREL/TP-550-30152, J. Neymark and R. Judkoff : January 2002 : committee material of IBEC (Institute of Building Energy Conservation), Japan, **translated into Japanese** June 2006
    - *HVAC BESTEST Volume 1 : Part II and III*, NREL/TP-550-30152, J. Neymark and R. Judkoff : January 2002 : committee material of IBEC (Institute of Building Energy Conservation), Japan, **translated into Japanese** September 2007
    - Will appear in the proceedings of AIVC2008 (14 Oct –16 Oct 2008, Kyoto, Japan): 1 paper from Institute of National Colleges of Technology (Utsumi)

**Project C: Shading/Daylighting/Load Interaction Empirical Validation Tests**
Final Report: *Empirical Validations of Shading/Daylighting/Load Interactions in Building Energy Simulation Tools*, (Peter Loutzenhiser, Greg Maxwell, Heinrich Manz)

- Status: Fully approved final report posted on SHC web site Aug 2007 (completed)
- Related published articles:
    - Manz H, P Loutzenhiser, T Frank, PA Strachan, R Bundi, G Maxwell. Series of experiments for empirical validation of solar gain modeling in building energy simulation codes—Experimental setup, test cell characterization, specifications and uncertainty analysis. *Building and Environment* 41 (2006) 1784-1797

  - Loutzenhiser PG, H Manz, C Felsmann, PA Strachan, T Frank, GM Maxwell. Empirical validation of models to compute solar irradiance on inclined surfaces for building energy simulation. *Solar Energy* 18 (2007) 254-267
  - Loutzenhiser PG, H Manz, PA Strachan, C Felsmann, T Frank, GM Maxwell, P Oelhafen. An empirical validation of modeling solar gains through a glazing unit using building energy simulation programs. *HVAC & R Research* 12 (2006) 1097-1116
  - Loutzenhiser PG, H Manz, C Felsmann, PA Strachan, and GM Maxwell. An empirical validation of modeling solar gain through a glazing unit with external and internal shading screens. *Applied Thermal Engineering* 27 (2007) 528-538
  - Loutzenhiser PG, GM Maxwell, and H Manz. An empirical validation of the daylighting algorithms and associated interactions in building energy simulation programs using various shading devices and windows. (Accepted for publication in *Energy* on February 23, 2007)
  - Loutzenhiser PG, H Manz, S Carl, H Simmler, GM Maxwell. Empirical validations of solar gain models for a glazing unit with exterior and interior blind assemblies (Accepted for publication in *Energy and Buildings* and available online March 3, 2007 at www.sciencedirect.com)
  - Loutzenhiser PG, H Manz, S Moosberger. An empirical validation of window solar gain models and the associated interactions. (Submitted for publication to the *International Journal of Thermal Sciences* on May 16, 2007)
  - Manz H, PG Loutzenhiser, T Frank, R Steiner, G Reber, and P Oelhafen. Empirical validation of solar gain modeling in building energy simulation codes using test cells in IEA Task 34/Annex 43. *Proceedings of the Third International Building Physics Conference*, Concordia University, Montreal, Canada (2006) 595-601
  - Loutzenhiser PG and H Manz. 2006. Empirical Validation of Solar Gain Modeling, 14. Schweizerisches Status-Seminar Energieforschung im Hochbau, Eidgenössische Technische Hochschule, Zürich, Switzerland (7-8 September 2006) 301-308
  - Frank T, H Manz, P Loutzenhiser. Validation procedures for transient temperature, load and energy calculations in building simulation codes. *Conference Proceedings of 12th Symposium for Building Physics*, Dresden, Germany, 2007

**Project D: Mechanical Equipment and Control Strategies Comparative and Empirical Validation Tests**

To be published final report, *Mechanical Equipment & Control for a Chilled Water and a Hot Water System* (C. Felsmann)

- Production Schedule
  - Distributed to Task experts for Approval and Comments: May 2008
  - Distribute to SHC and ECBCS reviewers for Approval and Comments: Jun 2008
  - Final publication expected Sep 2008
- Related published articles appear in the proceedings of EPIC2006AVIC (22-24 Nov 2006, Lyon, France): 2 papers from University of Liège (Lebrun, Andre, Adam, Lemort), 1 paper from Technical University of Dresden (Felsmann)

**Project E: Double Façade Building Comparative and Empirical Validation Tests**

Final report***:*** *Double Skin Facades; A Literature Review* (T. Poirazis)

- Status: Fully approved final report posted on SHC web site Aug 2007 (completed)

To be published final report: *Double-Skin Façade Empirical Validation Tests at Aalborg University, Denmark* [preliminary title] (Olena Kalyanova, Per Heiselberg)

- Production Schedule
  - Distribute to Task experts for Approval and Comments: May/Jun 2008
  - Distribute to SHC/ECBCS reviewers for Approval and Comments: Jun/Jul 2008
  - Final publication expected Sep/Oct 2008

Working Document: *Double-Skin Façade Comparative Tests* (Olena Kalyanova, Per Heiselberg)

- Status: To be completed Sep/Oct 2008

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