

LearnHPB and eLAD – Two Related Online eLearning Platforms for High Performance Buildings

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ABSTRACT

Saving energy in buildings involves more than developing new technologies. High-efficiency equipment that is not properly installed, calibrated, operated, or maintained will typically save far less energy than estimated. Thus, there is a critical need today and in the future to train people skilled in the design, construction, operation, and maintenance of increasingly complex buildings and systems.

Currently, there are very few software resources that can provide both system-level and building-level integrated experiences, especially for use in education. Most existing software have issues that seriously compromise their potential use as learning vehicles including: limited to a single building component or package¹, prohibitively steep learning curves, extensive time needed to build models in order to test them, or difficulty in cross platform/system comparisons and intersystem dependency modeling.

Learn High Performance Buildings (LearnHPB) and eLearning for Lighting and Daylighting (eLAD) are two eLearning platforms that are currently being developed in parallel that address these issues. LearnHPB and eLAD use Problem-Based Case Study (PBCS) scenarios supported by 3D visualizations and game-based approaches to address real life situations found in key phases of an office building's life cycle. LearnHPB integrates four building systems - envelope, HVAC (heating, ventilation, and air-conditioning), lighting, and daylighting – that use Modelica, EnergyPlus, and Radiance to conduct short-term and real-time simulations. eLAD uses precalculated simulation results only for lighting and daylighting.

Compared to more traditional forms of learning, LearnHPB and eLAD immerse the user into a learning experience of virtual 3D, interactive environments providing cut-aways views of the building systems. Users can change building systems and components and then directly see the performance and energy results; they can choose their own sequence of actions to explore system performance and energy use. This is to encourage users to explore systems thinking for problem solving and for improving energy-efficiency in building design, construction, and operations.

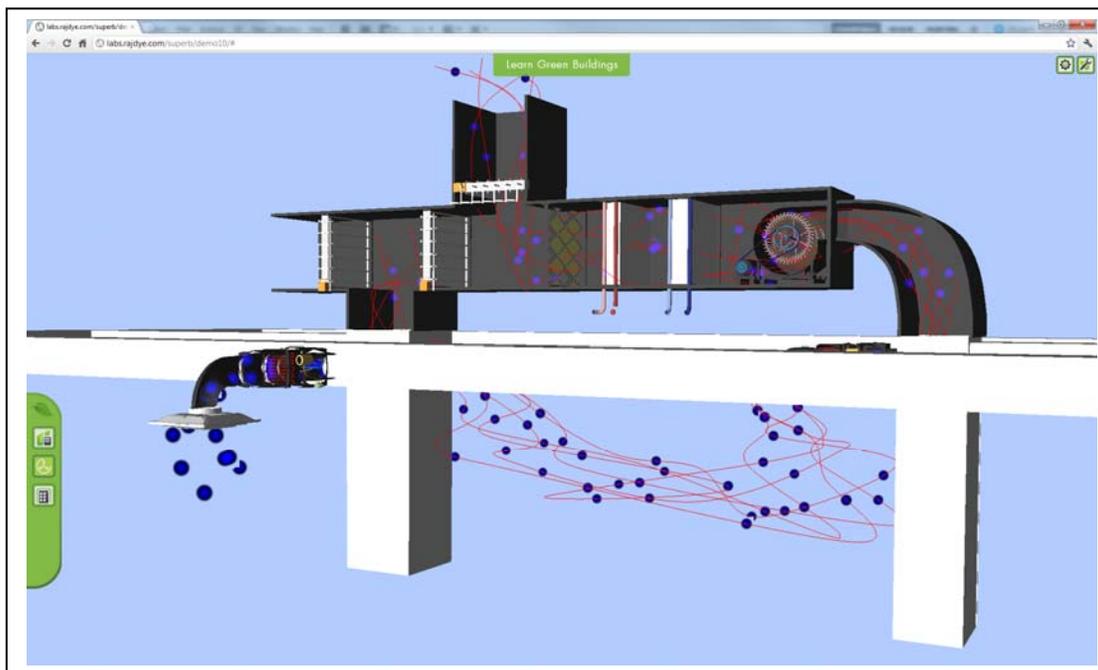
¹ There are number of simulators available for HVAC education and training; one company in this market is Simutech (www.simutechsystems.com). The simulators have some nice features. However, these simulators mainly treat residential and small commercial equipment such as air conditioners and heat pumps, in particular, they do not treat complete HVAC systems or equipment for the 'built up' HVAC systems found in larger commercial buildings. COMFEN is a useful design tool for architects during early design phases, but has limited application to trouble shooting situations or to later stages of building delivery.

Introduction

Learn High Performance Buildings (LearnHPB)

This is a \$2-million, three-year eLearning project funded by the California Energy Commission (CEC). The platform will provide users with the ability to learn about the energy performance of each of four building systems: exterior envelope, HVAC (heating, ventilation, and air-conditioning), lighting, and daylighting. Working alpha software products are scheduled to be available by mid to late 2012. LearnHPB proof-of-concept interactive models, demos (see Figure 1), videos, and related information may be viewed at: <http://www.LearnHPB.org>.

Figure 1. Early Concept of LearnHPB GUI – Demo 10



Source: <http://learngreenbuildings.org/demos/demo.php>

eLearning for Lighting and Daylighting (eLAD)

Running parallel to LearnHPB, eLAD is a \$1.5-million grant-supported project through Lawrence Berkeley National Laboratory (LBNL) for the US Department of Energy (DOE). eLAD focuses on developing an eLearning platform exclusively for these two building systems. In the Phase 1 effort that is currently funded, eLAD is focusing primarily on daylighting.

The LearnHPB and eLAD project teams have been informally collaborating for some time. The intent is to allow many platform elements -- the graphic user interface (GUI), data structures, 3D models, and Radiance scripting -- to be compatible across the platforms (see Figure 2). LearnHPB is combining and extending the GUIs and data structures from Learn HVAC and from eLAD in order to provide users with a whole-building integrated environment.

The eLAD project has produced a wiki that includes descriptions of many project features. It is located at: <http://elad.lbl.gov>.

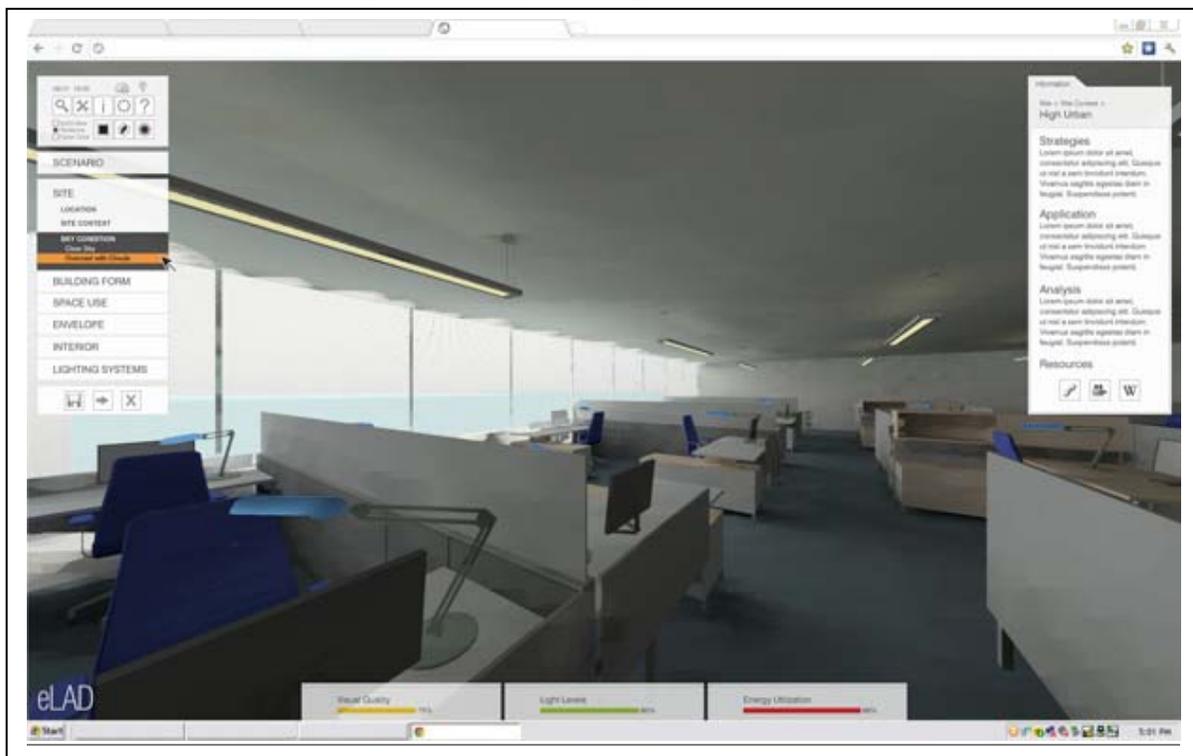
Mission

The mission of LearnHPB and eLAD is to improve the ability of the building industry to design, build, operate, maintain, and fix high performing energy-efficient commercial buildings. The approach is to enhance the education and training of key decision makers and participants, including architects, mechanical designers, commissioning providers, service technicians, and building operators. The intent is to improve their understanding of ways to improve how to design, document, install, commission, operate, and maintain buildings

eLAD addresses just the daylighting and electrical lighting components. LearnHPB has a broader scope, and addresses:

- HVAC system operation, controls, and troubleshooting
- Envelope design, maintenance, and troubleshooting
- Lighting design and controls
- Daylighting design, installation, controls, and troubleshooting
- Whole building integrated design and operation of low-energy, sustainable buildings

Figure 2. Early Concept of eLAD GUI



Source: http://elad.lbl.gov/index.php/eLAD_Overview

The Problem

It is common for buildings to underperform compared to the energy savings potential identified during design. Sometimes such underperformance is significant. To allow the energy-efficiency potential from early design to be realized in the building during operation, a life-cycle

approach is needed to ensure that design concepts and high-efficiency equipment are properly installed, calibrated, tested, operated, and maintained. This discussion is applied to commercial buildings, but many aspects also extend to residential buildings.

Several major trends are increasing the complexity and difficulty of properly operating and maintaining buildings:

- Climate change priorities require a stronger focus on very low energy and zero net energy solutions as quickly as possible.
- As buildings attempt to innovate to achieve higher performance, the risk of failures increases.
- Digital control technology is becoming common in both new and existing building systems. Thus, building operators and technicians must master a new set of computer-related skills (e.g., hardware, software, database management, and local area networking) in addition to their traditional skills of building system management and repair.
- Regulations and policies are increasingly involved, including new commissioning and sustainability factors.
- Energy performance monitoring, commissioning and retro commissioning together address the increasing cost of energy but require advanced capabilities to be effective.
- Security is increasingly important since 9/11, and operators must monitor advanced security systems, initiate emergency response plans, and shut down complex systems in the event of environmental attacks.

To learn about the separate performance of individual building systems is not enough as changes to one system can significantly affect other systems. LearnHPB provides an integrated and accurate whole building, cross-system approach to learning about building efficiency.

Approach

The LearnHPB and eLAD eLearning platforms now being developed can be used in either individual or group-learning situations. These software platforms are open source and are designed for use on web-based public domain delivery platforms, thus facilitating their widespread use and their potential extension and modification by others. All tools and resources developed are intended to be available at no cost to users.

Learn HVAC

A key predecessor to LearnHPB and eLAD is Learn HVAC (www.LearnHVAC.org). Learn HVAC development began in 2004, with major software products published in 2008 (Version 1) and 2010 (Version 2). It uses a strong problem-based case study approach.² Its main intended audience has been technicians being trained in community colleges. It has been viewed as a virtual hands-on environment that is similar to very expensive equipment. We know of only two such full-scale lab setups in California, one at Laney College and the other at Sacramento City College. Learn HVAC has been refined via testing in community college classrooms. It is

² Learn HVAC development was partly funded by NSF. During its development, there was strong informal collaboration with work on problem-based case studies funded in part by another NSF grant. See www.makinglearningreal.org.

available online at no cost and has been downloaded by over four thousand people worldwide. We have received very positive feedback about it. It is a simulation-driven, highly interactive, immersive eLearning tool that addressed the building's HVAC system. Learn HVAC explores the operations and control dynamics of a typical VAV system.

LearnHPB builds on previous collaborations among SuPerB, LBNL and others funded by the NSF Advanced Technological Education program and CEC. LearnHPB will replace and expand upon Learn HVAC and will build upon the capabilities of eLAD to create an integrated eLearning experience teaching users how the exterior enclosure, lighting, daylighting, and HVAC systems interact with one another. eLAD deals with daylighting and treats electric lighting in an introductory way.

Audiences and the Building Life Cycle

Key intended users for both platforms are students in two-year and four-year college programs. Two other key audiences are building facility managers and O&M personnel. Other secondary audiences encompass a wide range of players within the building industry including building operators, maintenance technicians, commissioning providers, and building design professionals.

LearnHPB and eLAD are not design tools (although they can be used in learning about design issues). They are eLearning tools intended to allow users to master system thinking in (1) understanding how buildings function and (2) addressing and solving problems that can occur at each stage of a building's life cycle including: pre-design, design, construction document preparation, construction, occupancy, operations and maintenance, retrofit.

While we will need to develop sufficient structural detail in the building systems to address key design decisions and trade-offs, for several building systems we will focus initially on scenarios that can occur in the later stages of building delivery, namely, construction document preparation, construction, occupancy, operations and maintenance.

Educational Settings and Levels

Both the LearnHPB and eLAD platforms and their scenarios are intended for use in a number of educational settings:

- As part of classroom lectures
- For individual and team problem-solving classroom exercises
- As part of seminars and workshops at energy centers
- As part of instructor-assisted or directed online or hybrid courses
- As part of online "virtual" team problem-solving exercises, where team members are either in the same location or are in different locations
- For individual self-directed learning situations that can be customized by the instructor

The platforms are intended for potential use by the following educational levels:

- Continuing education programs
- Two-year programs in community colleges and technical schools
- Four-year college and university, and post-graduate programs

- High School students

The software development teams include active participation of representative users and user groups, from experts in academia and design to educational institutions such as community colleges, universities, and continuing education centers.

Key Features

Learning Objectives

Both the LearnHPB and eLAD platforms emphasize game-based approaches (Prensky 2001) and Problem-Based Case Study (PBCS) scenarios as key pedagogical approaches (Boud & Feletti 1997) (Bransford et al. 2000) (Cheaney & Ingebritsen 2005). Both platforms also focus primarily on the educational objectives and on the needs of technicians, operators, and designers addressing key building life cycle phases.

Key eLearning and Technical Features

The key features of LearnHPB and eLAD platforms include:

- A solid pedagogical framework that establishes the software foundation.
 - Extensive use of Problem-Based Case Study scenarios that can be tailored by domain experts or by faculty to address current and emerging building industry problems. Such scenarios make excellent exercises that can be added to existing curricula. Once these platforms and scenarios are completed, we plan to develop online interactive curricula built upon these platforms. We plan to develop the curricula as Open Educational Resources (OER).³
 - Scenarios that present building systems that perform normally or that show signs of stress or failure from one of more faults or problems.
 - Use of videos to present complex, real world problems.
 - Use of a well-developed, stepped learning process that promotes simultaneous learning of business, communication, and technical skills as part of team or individual problem solving exercises.
 - Assistance in trouble-shooting methods.
- A graphical user interface (GUI), refined from the previous Learn HVAC GUI, presents users with easy-to-understand immersions into a virtual building environment. The interface includes behind-the-scenes energy simulations that present pictures and animations of how a building and its systems operate.
- Dynamic 3D techniques, similar to those used in a gaming environment to allow flexible user interactions with a building and the operation of its systems.
- Simulation-driven animations that make it easy for a user to quickly grasp the performance, energy, and comfort impacts of building system selection and operation.
 - Modelica, EnergyPlus, and Radiance are the key simulation engines being used.

³ See: http://en.wikipedia.org/wiki/Open_educational_resources

- These simulations run in the background in the “cloud” and hide the complexity of the simulations from the average user.
- The capacity for more advanced users to access increasingly detailed layers of information and to view the underlying model structures, building descriptions, equations, and concepts.
- With the ability to create multiple scenarios from a single Use Case, the learning process allows players to apply principles to different situations.
- A web-based “administration” capability enables domain experts and course instructors at each institution to edit and create PBCS scenarios. For example, instructors may select one or more “faults” that impair component and system operation, hide the faults from students, and create “problem” videos that describe the impact of the faults that the students must then identify and solve.
- A long-term objective is to allow changeable time scales and intervals to enhance learning objectives. In the short term:
 - eLAD explores selectable fixed points in time.
 - LearnHPB focuses on a learning experience within 24-hour diurnal pattern, with longer-term energy impacts also available.
- Web-based community-building approaches are being incorporated in the software development process to facilitate remote sharing and development of resources, solutions, and PBCS scenarios and to enable potential remote teaming on solving problems and generating tool enhancements.

Online Educational Resources

Several online resources are potentially usable from within the platforms. Examples are:

- IBPSA-USA’s BEMBook wiki: this is an emerging body of knowledge about building energy modeling (bembook.ibpsa.us).
- eLAD Body of Knowledge: As a part of eLAD’s educational resources, a wiki Body of Knowledge was developed and can be found at <http://elad.lbl.gov/>. This wiki aims to increase the range and depth of available open educational resources on energy-related aspects of lighting and daylighting. The Body of Knowledge is a basic set of public educational content that can be shared and remixed under the Creative Commons Attribution-Share Alike 3.0 License, unless otherwise noted.

Scenario Builder and Scenario Player

The eLAD and LearnHPB platforms are built around the use of a Scenario Builder and Scenario Player. The Builder is a user interface where instructors or professionals can customize options to create problem-based scenarios specific to their educational objectives. These scenarios can then be exported to the Scenario Player, where students, guests to the platform, or others can explore the concepts and procedures presented within the scenario.

The Scenario Player is being developed with three modes of use:

- **Guided Learning:** The user receives a range of hints and guidance as they explore the scenario.

- **Exploration:** The user can freely explore the scenario, but is not given hints or feedback in the process.
- **Assessment (or Testing):** As in the exploration mode, the user does not receive feedback, but scoring occurs in the background based on the Measurements of Success defined in the Scenario Builder. The user hits a “submit” button to receive the test results.

Graphical User Interface

LearnHPB and eLAD use the same GUI structure. Information is presented using progressive disclosure to simplify the user interface. Motivational tactics used in video game design are also implemented, such as experience bars to measure progress, immediate feedback, and the ability to create different difficulty levels. In a non-linear fashion, the students can learn by exploring and solving the problems posed in the scenario.

Data Structures for Nine-Zone Analysis

The LearnHPB is being designed with a data structure to permit examination of any one of nine zones (spread along the North, East, South, West, and Core zones) on one floor of a multi-story building. This allows users to switch from zone to zone, or to compare system behaviors across zones. For example, both HVAC and daylighting behaviors at 3 pm on a sunny summer afternoon can be expected to vary considerably by orientation and zone.

Example LearnHPB and eLAD Use Cases

- Gaming Challenges, e.g., starting with a code-compliant building, change building features, controls and operations to get as close to a net zero building as possible.
- Troubleshoot an installed non-functioning daylighting system.
- Troubleshoot an installed daylighting system in which the sensors and controls are out of calibration.
- Troubleshoot a faulty installed HVAC system.
- Troubleshoot problematic zonal airflows and pressures caused by air leakage in the exterior envelope.
- Troubleshoot problems with construction documents (HVAC, lighting, or exterior).
- Explore impacts on building energy performance, thermal comfort, and visual comfort from significant changes, after design and before occupancy, in window-to-wall ratios and effective apertures.
- Explore a Tenant Improvement for a low quality open office.

Development Process

Switch from Flash to WebGL

Learn HVAC, developed from 2005-2011, has been a basic building block of LearnHPB. Learn HVAC uses 3D images within a 2D animation engine developed in Adobe Flash⁴ and

⁴ For multiple reasons, it appears as if Flash is now being slowly phased out and replaced by HTML5 and CSS3.

simulations in EnergyPlus and Modelica that were downloaded to a user's local computer. The simulations could run only in an MS Windows environment.

Very recently, innovative web-based resources have become available, and the eLAD and LearnHPB projects are early adopters of these new technologies, which include:

- WebGL is a cutting-edge JavaScript-based functionality with the ability to render 3D assets natively in a web browser. Unlike previous frameworks like Flash or Java applets, no browser plug-in is required for WebGL, and 3D animations can be viewed as seamlessly as viewing a website.⁵ In addition, eLAD and LearnHPB are built partly in Kuda, an authoring environment for WebGL developed by SRI International.
- Both eLAD and LearnHPB use pre-calculation of data and images when simulations cannot keep up with the user experience.
- Phase 1 of eLAD does not use any real-time simulations, whereas LearnHPB makes extensive use of real time second-by-second simulations to allow the user to experience short-term dynamic building behavior and control dynamics.
- LearnHPB has migrated the simulation engines from the user's local computer into the "cloud," with direct two-way communications between simulation engines and the GUI and animations in the WebGL-based browser.

Simulation - Driven Animations, FMUs and Middleware

Such cloud-based simulations greatly simplify the distribution of the LearnHPB software. Several years ago, the Learn HVAC tool had to be downloaded and installed onto a user's computer, including the program's simulation engines, creating issues of system incompatibility, and making it difficult to upgrade and roll out new features. Today, with WebGL, LearnHPB simulations can be run on demand in the "cloud" and all a user will have to do is visit a website to start learning. This workflow offers several advantages:

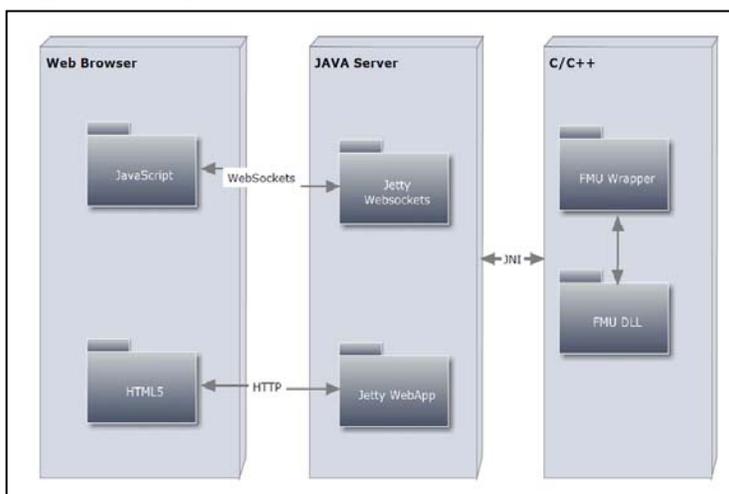
- Upgrades to the system can seamlessly be applied to the web server and require no action by the end user.
- System incompatibility issues with the user's computer, particularly with the simulation engines, will not exist if everything is transmitted through a standard web browser.
- In academic environments, administrators do not need to install the software on school lab computers, which greatly simplifies access for students.
- As a web based platform, LearnHPB it permits multiple, simultaneous instances of browser client and simulation servers.

The three simulation programs used in LearnHPB – Modelica, EnergyPlus and Radiance – provide a mix of short-term and real-time simulations (minutely and hourly), and longer-term simulations (monthly and annual).

Two-way data flows between the browser "client" and the simulations are handled by a set of middleware routines that are complex but are hidden from the user. At the simulation location, the data exchange to and from the actual simulation engines are simplified by a Functional Mockup Unit (FMU) (See Figure 3).

⁵ Currently, Internet Explorer is the only major modern browser that still requires a plug-in for WebGL.

Figure 3. Key Elements of the Middleware and FMUs



Source: Raj Dye, Pacific Coast Digital Inc.

eLAD a Phase 1 Product

Due to limited funding, Phase 1 of eLAD has narrowed the use case domain from seven use cases to just one, and has also limited the number of building component variables and options being examined. The selected use case deals with resolving a serious glare issue. Radiance is used to perform lighting analysis. The desire to try to display real-time Radiance renderings was moved to LearnHPB or to a future eLAD phase. eLAD does display multiple pre-rendered images, allowing the user quickly view high quality visualizations of consequences of actions, and to switch from a photorealistic High Dynamic Range image to false color images. Radiance measures the simulated light levels that describe the lighting quality of the space and highlight possible glare problems. Numerical data containing information on the illuminance and luminance levels provides output information for the metrics that is used to grade the student.

eLAD Phase 2 and LearnHPB

Phase 1 of eLAD has produced a basic structure for the daylighting and lighting eLearning platform to be built upon in later phases of development. With funding for Phase 2 uncertain at this time, a number of elements planned for eLAD Phase 2 will likely be implemented in LearnHPB.

These include integrating other background software and other features to make the platform more robust including Modelica, for short-term, real-time simulations, EnergyPlus for energy system simulations, Radiance for real-time simulations, visualizing of light rays, and measuring instruments.

To increase user-friendliness, LearnHPB's GUI is being developed to allow the user to perform the same action using different means, such as changing an option by using the toolbar or selecting from the model. Building upon eLAD's motivational tactics based on gaming techniques, LearnHPB is implementing (1) faults for elements of uncertainty, (2) long- and short-term aims, and (3) rewards for effort.

Normal Operations and Faults/Problems

An important component of LearnHPB is that a user can view the systems either operating normally or operating with one or more "faults" or "problems" that cause a building energy system to operate outside of normal conditions. Faults will be system specific and illustrate common issues within a system, such as stuck valves in HVAC heating or cooling coils, dirty heating or cooling coils, improper installation of envelope components allowing excess infiltration, or misaligned to improperly calibrated lighting sensors.

LearnHPB will expand upon techniques that have been developed over the past seven years with Learn HVAC. For example, when a scenario is started, the user can interact with the animated simulations in one of three basic ways:

- **View normal operation:** The user can observe the system behaving normally, with no faults or problems activated. In this mode, the user can explore system operation through a variety of variables, including season, time, occupancy conditions, compare design strategies, and other various settings.
- **Activate known faults:** The user can activate one or more known faults or problems to mild or severe levels and can observe how they impact building and system behavior. This is an excellent educational-use mode allowing the user to explore the impact of various faults and trademark signs to diagnose the fault in the future.
- **Troubleshoot a scenario with unknown faults:** An instructor can create scenarios with single or multiple faults or problems that are hidden from the user; the challenge to the student is to find the faults and propose corrective action. Such Problem-Based Case Study scenarios can range from being simple and quickly solvable to difficult and complicated. In either case, this troubleshooting mode puts the user's skills to the test and simulates situations they will face in real buildings.

Faults and problems can also highlight the integrated nature of building systems. For example, a fault in the envelope allowing excess infiltration can illustrate how the HVAC system will respond to compensate.

Project Teams

The project development teams include energy researchers, energy experts, pedagogy experts, instructional designers, professional software developers, 3D modelers and animation specialists, and managers with solid experience in both energy research and software development. The software development process has been designed to include the active participation and feedback of representatives of California educational institutions and organizations.

Successful software gains depth, relevance and richness from a collaboration of a team of experts with diverse skills. Our development team has years of experience in producing easy-to-use, effective, and relevant educational software. Descriptions of the project teams for these two related projects may be found at the following locations:

- For the LearnHPB team description see <http://www.learnhpb.org>.
- For the eLAD team description see <http://elad.lbl.gov>.

Conclusion

LearnHPB and eLAD are important emerging eLearning resources that can be very helpful in providing the in-depth education to many players in the building community. These platforms can provide the education resource to assist high-performance buildings to actually achieve their potential. Browser-based online education and training has the reach and scale to allow such effective training to reach a broad audience. eLAD and LearnHPB fill a void in current educational resources. Together they:

- Build upon seven years of successful implementation and user testing of Learn HVAC.
- Emphasize system thinking in learning about energy performance throughout the life cycle of commercial buildings.
- Emphasize well-developed game-based learning pedagogy that not only makes the learning experience more interesting, but also increases comprehension and retention through practice.
- Are early adopters of a set of innovative WebGL 3D browser-based technologies.
- Are open source and free, thus facilitating their widespread use and their potential modification and extension by others.

These platforms hide the complexity of using full version simulation engines by wrapping them in an easy-to-use GUI, instead of using less accurate simplified simulation engines. Thus, the eLAD and LearnHPB platforms can directly address sophisticated integrated high performance building solutions and problems. Learn HPB accesses the simulation engines via the “cloud,” making the software more accessible, easier to maintain, and easier to update.

eLAD Phase 1 will be completed by June 30, 2012. LearnHPB Phase 1 will be completed by late 2013, but working alpha versions of the software should be available by mid to late 2012. Future planned development for both platforms would add additional software features and address new innovative building systems. Also, the plans call for adding substantial curricula to help flesh out the eLearning platforms and the problem-based scenarios.

References

- Boud, David, and Grahame Feletti, Editors. 1997. *The challenge of Problem-Based Learning, Second Edition*. Kogan Page Limited, London.
- Bransford, John D. ... [et al.], editors. *How people learn: brain, mind, experience, and school: Expanded Edition*. 2000. Committee on Developments in the Science of Learning and Committee on Learning Research and Educational Practice, Commission on Behavioral and Social Sciences and Education, National Research Council. National Academy Press, Washington, D.C.
- Cheaney, James, and Thomas S. Ingebritsen. 2005. *Problem-based Learning in an Online Course: A case study*. Iowa State University, USA.
- Prensky, Marc. 2001. *Digital Game-Based Learning*. McGraw-Hill.