COMFEN 3.0 – Evolution of an Early Design Tool for Commercial Facades and Fenestration Systems

Stephen Selkowitz
Lawrence Berkeley National Laboratory

Robin Mitchell
Lawrence Berkeley National Laboratory

Maurya McClintock
McClintock Façade Consulting LLC

Daniel McQuillen
McQuillen Interactive LLC

Andrew McNeil
Lawrence Berkeley National Laboratory

Mehry Yazdanian
Lawrence Berkeley National Laboratory

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STEVE SELKOWITZ
Lawrence Berkeley National Laboratory, Building Technologies Department, Berkeley, CA

ROBIN MITCHELL
Lawrence Berkeley National Laboratory, Building Technologies Department, Berkeley, CA

MAURYA MCCLINTOCK
McClintock Façade Consulting LLC, Walnut Creek, CA

DANIEL MCQUILLEN
McQuillen Interactive LLC, Santa Cruz, CA

ANDREW MCNEIL
Lawrence Berkeley National Laboratory, Building Technologies Department, Berkeley, CA

MEHRY YAZDANIAN
Lawrence Berkeley National Laboratory, Building Technologies Department, Berkeley, CA

ABSTRACT

Achieving a net-zero energy building cannot be done solely by improving the efficiency of the engineering systems. It also requires consideration of the essential nature of the building including factors such as architectural form, massing, orientation and enclosure. Making informed decisions about the fundamental character of a building requires assessment of the effects of the complex interaction of these factors on the resulting performance of the building. The complexity of these interactions necessitates the use of modeling and simulation tools to dynamically analyze the effects of the relationships, yet decisions about the building fundamentals are often made in the earliest stages of design, before a 'building' exists to model.

To address these issues, Lawrence Berkeley National Laboratory (LBNL) has developed an early-design energy modeling tool (COMFEN) specifically to help make informed decisions about building facade fundamentals by considering the design of the building envelope, orientation and massing on building performance. COMFEN focuses on the concept of a "space" or "room" and uses the EnergyPlus, and Radiance™ engines and a simple, graphic user interface to allow the user to explore the effects of changing key early-design input variables on energy consumption,

peak energy demand, and thermal and visual comfort. Comparative results are rapidly presented in a variety of graphic and tabular formats to help users move toward optimal façade and fenestration design choices.

While COMFEN 1.0 utilized an Excel™-based user interface, COMFEN 3.0 has been reworked to include a simple, more intuitive, yet powerful Graphic User Interface (GUI), a broader range of libraries for associated system and component choices and deliver a wider range of graphic outputs and options.

This paper (and presentation) outlines the objectives in developing and further refining COMFEN, the mechanics of the program, and plans for future development.

1 INTRODUCTION

Lawrence Berkeley National Laboratory (LBNL) developed the energy modeling and simulation tool, COMFEN, to address the three key issues discussed below pertaining to early building design phases.

First, improving overall building energy efficiency by 20-30% over 'baseline' ASHRAE targets can often be achieved by making engineering systems more efficient so designers usually initially target HVAC, lighting, plug-load, etc. To increase overall energy efficiency by 50% or more, however, requires consideration of the essential nature of the building including factors such as architectural form, massing, orientation and façade enclosure. Making informed decisions about the fundamental character of a building requires assessment of the effects of the complex interaction of these factors on the resulting performance of the building. The complexity of these interactions necessitates the use of modeling and simulation tools to dynamically analyze the effects of the relationships yet decisions about these fundamentals design elements often must be made in the earliest stages of design, before a well defined 'building' exists to model.

Second, the building envelope, particularly it's fenestration systems, must be designed to optimize building thermal loads while achieving desired visual and thermal building occupant comfort levels. In addition most buildings will seek to maximize the use of daylight, creating a further challenges with tradeoffs for solar gain and glare. Therefore, such tools need to appropriately model and simulate envelope interactions with the other building systems such as lighting.

Third, today's energy-efficient windows can dramatically lower the heating and cooling costs associated with the building envelope while increasing occupant comfort. Manufacturers' product information typically provides window properties such as U-factors or R-values, Solar Heat Gain Coefficients or Shading Coefficients. Such properties are, however, based on static evaluation conditions that ignore the vital effects of dynamically varying exterior environmental conditions and the interactive effects of shading systems, lighting systems and interior environmental conditions. Designers are consequently often unsure how to account for these dynamic impacts in selecting the most efficient window design for a commercial building.

COMFEN is designed to help address these issues by using EnergyPlus, WINDOW, Radiance™ and a simple user interface to:

- Facilitate easy comparison of the effects of altering building fundamentals on the energy consumption, peak energy demand and thermal and visual comfort performance of the building,
- Assess the impact of emerging fenestration, shading and daylighting technologies on envelope and building energy and cost performance,
- Assist a design team to design an "optimum" building envelope consistent with internal and external constraints.

Released in 2008, COMFEN 1.0 was a prototype tool that provided a simplified Excel™-based user interface to access the sophisticated analysis engine EnergyPlus™ to dynamically simulate the effects on building performance of the choices made in key areas. Base on feedback from users LBNL has enhanced the functional capabilities and improved the software interface so that the newly developed COMFEN 3.0 now utilizes:

- A simplified but powerful user-friendly graphic front-end interface with drag-and-drop capabilities,
- Extended libraries of façade-system components and weather-data locations,
- Greatly enhanced output capabilities with easy-to-select graphics and tables that illustrate side-by-side comparisons of the effects of different façade choices,
- Automatic connectivity to WINDOW to create glazing, framing and shading systems, and
- Automatic connectivity to Radiance™ to generate graphic daylighting and glare results.

This paper outlines 1) the evolution of COMFEN 3.0 by highlighting the goals of the development project, 2) the mechanics and operation of the program, 3) the new input, output and simulation functionality, and 4) plans for future development.

2 BACKGROUND

There are several existing tools with similar objectives and features to COMFEN including EFEN (DesignBuilder), Daylight1-2-3 (NRC), SPOT (AEC), Ecotect (Autodesk), and the MIT Design Advisor (MIT). The limitations of each of these tools was reviewed with users and the functionality of COMFEN designed to address those limitations, expanded to provide new features desired and these key functionalities package into a single, simple-to-use tool.

COMFEN development is planned to be iterative, building on feedback from users at each stage of its development. To keep focus COMFEN is intended to clearly center the users' attention on a limited set of variables specific to façade and fenestration design, variables that are considered at the earliest stages of the design. Some of the above tools offer additional user controlled input (e.g. more complex and complete building forms, different HVAC alternatives, etc.) and therefore additional analysis variables. In contrast, COMFEN intentionally focuses on a 'room' rather than complete building designs, and provides limited building-type and opaque envelope variation alternatives

At the same time, while COMFEN's developers intentionally limited the range of non-fenestration user controlled variables, it is intended to provide much richer user control over envelope and particularly fenestration-specific variables and is currently developing additional fenestration impact related choices such as detailed thermal comfort assessment, additional daylighting features and the impact of low-energy HVAC systems that depend on fenestration design/control choices. The intent is to provide direct links to the most sophisticated façade and fenestration analysis options available through today's simulation tools.

3 COMFEN TARGET USERS AND OBJECTIVES

Clearly identifying the intended user groups for a software tool and defining their product requirements is critical to determining the appropriate functionality of a tool. Additionally, tailored versions of such a tool may need to be developed to address the specific needs of different user groups.

The primary target user group for COMFEN is architects since decisions about a building's orientation and façade configuration made early in the design process, have a fundamental impact on the performance of the building. Key decisions include:

- The ratio of glazed façade areas to total wall area,

- Glazing, framing and daylight penetration and control selections that allow energy impacts to be optimized and which balance aesthetic, energy, and occupant comfort goals,
- The shading devices, controllable or otherwise, appropriate for specific building orientations and transparency goals.

In the absence of a user-friendly yet sophisticated tool for evaluating the impact of such design decisions on energy and occupant comfort, market assumptions and aesthetic considerations have often dictated the choices made by architects. The intent is for COMFEN to help balance and inform this decision-making process.

For COMFEN to be useful to architects, it needs four key features. First: a user-friendly interface. Second: a focus on key façade design options with the means to easily vary these parameters. Third: a sophisticated simulation engine(s), hidden from view, to analyze the interactive impacts of design choices. Fourth: a readily interpretable results display to facilitate easy comparison of the selected design alternatives and understanding of the implications of the choices.

The second group of target users for COMFEN are glazing/framing system manufacturers and façade sub-contractors. This group is critical to bringing new, high performance fenestration components and systems to the market. To facilitate this function, this group needs COMFEN to enable manufacturers and architects to analyze the effects of new materials and components on the performance of the system as a whole. This requires powerful simulation engines and the rapid inclusion of emerging technologies into COMFEN's database.

The third user group for COMFEN are other early design team members such as façade consultants, HVAC engineers and energy modelers. This group additionally requires COMFEN to facilitate the export (ideally directly) of façade design solutions to 'populate' a simple (and possibly later a more complex) whole-building energy model.

COMFEN is intended to address the requirements of the groups described above to promote the design and deployment of high performance fenestration systems by making complex simulation comparisons of alternative fenestration design choices accessible to a wide audience of users. Since these choices are made on the early stages of design, there is little detail on the rest of the building. To minimize complexity, COMFEN currently limits room and building geometry choices and uses constant default values for HVAC system components and details, internal loads and scheduling. (In the future, COMFEN will include more detail on some of these topics and selective control over other key variables).

4 COMFEN STRUCTURE

COMFEN was designed to simulate façade energy/performance appropriate for the very early design phases, typically before a 'building' exists with the level of detail needed to develop a 'total building energy model'. COMFEN provides feedback on how combinations of orientation, massing and enclosure systems affect building performance. This focuses the user on fenestration and external wall variations by minimizing attention on other building systems and detail. Simulation results are based on comparative analysis of 'scenarios' each consisting of: a rectangular room with a single exterior façade wall and adiabatic ceiling/roof, floor and interior walls. The scenario is conditioned by a packaged single zone HVAC system that is automatically sized for the façade plus interior loads. (Eliminating the effects of interactive variations in whole-building designs, e.g. thermal exchange between adjacent thermal zones and varying HVAC components and system,) highlights the relative impacts of façade variations).

The performance of up to four different façade systems i.e. four scenarios, can be compared in the detailed 'comparison' analysis output screens. This comparative approach is central to the design of COMFEN. This approach is appropriate for early design options exploration but later detailed design must consider whole-building issues as well.

4.1 COMFEN Project Input

The main project screen (Figure 1) is divided into 3 sections; 1) the Project Browser on the left, 2) the Scenario graphic representation in the upper right, and 3) the Results tabs in the lower right .

A project is defined as a collection of scenarios. Each project can contain as many scenarios as needed to explore the desired design solutions. Scenarios can be differentiated by geometry, orientation, glazing systems, shading systems, framing systems, lighting controls, and occupancy and plug load values. Using this approach, the user can explore a range of façade design issues such as the relative impacts of changing orientation for the same façade design or various configurations of window, glazing systems, frames, shading surfaces, and daylighting controls.

More than one project can be created and stored in a COMFEN database. Each project is defined by a name, location, building type, vintage, and project orientation. The project location identifies the weather data used for the EnergyPlus simulation. Building type controls the occupancy, lighting, and equipment schedules and can be set to Office, Mid-Rise Residential, Hotel, Hospital (patient room), Retail and School (classroom). Vintage is currently limited to new ASHRAE 90.1-2004, but may be extended in the future. Project orientation allows the user to rotate the complete set of scenarios.

4.2 COMFEN Scenarios

Defining COMFEN scenarios is done in the Scenario Edit screen (Figure 2). First, the user creates the room geometry by defining height, width and depth. This generates a graphic representation of the exterior façade. The user then defines orientation in terms of cardinal coordinates and the scenario can be offset using the Project North input value in the Project definition.

COMFEN then generates default input values for lighting controls (based on daylighting levels), lighting and equipment loads, and number of people. The user may modify these values.

This Scenario Edit screen also contains a graphic representation of the exterior façade. Window geometry is user-defined either ‘numerically’ (values are input for height, width, distance from left wall, and sill height) or ‘graphically’ (by selecting from the Window Library tab in the Project Browser and ‘dragging’ with the mouse onto the graphic representation of the scenario façade). When a window has been placed on the façade, it can be repositioned or resized either graphically (by moving, shrinking, or stretching it with the mouse) or through the numeric input screen (by double clicking on the graphic of the window and changing the values in the pop-up input screen).

Once the window geometry has been entered, the user defines the glazing system, frame, and shading system associated with it by double clicking on each window graphic representation and selecting the appropriate choices in the popup input screens.

External building-shading devices such as rectangular overhangs and fins can be located and sized in the Scenario Edit screen/Wall Shades tab. The default scenario façade view is an Elevation, but Section and Plan views can also be displayed (although editing can only be done in Elevation view).

4.3 COMFEN Libraries

COMFEN 3.0 has richer and more flexible libraries, providing default values for many input parameters, and in some cases allowing the user to create custom entries. The libraries included in COMFEN 3.0 consist of:

Glass Library: derived from the International Glazing Database (IGDB 2010) which contains over 3,500 glass layers.

Glazing System Library: contains a set of sample glazing systems that can be used to define façade systems. It also allows custom glazing systems to be created based on layers from the Glass Library and Gas Library. These glazing systems are imported into EnergyPlus as material layer objects using full spectral data to maximize analysis accuracy.

Frame Library: contains a default set of frames which can be used to define the façade systems. It also allows users to add custom frame data which affords the exploration of very high-performance window systems using highly insulated frames.

Location Library: contains a set of US and international locations. It also allows the user to add to the project any location with a USDOE EnergyPlus weather file.

Shading System Library: contains a default set of shading systems which can be applied to a glazing system and allows users to create new shading systems. Venetian blinds or fabric roller shades, located inside, outside, or between layers of each window and sunscreens can currently be modeled. This library allows the user to select from a variety of shading control options (e.g., based on exterior incident solar or interior daylight illuminance levels).

4.4 COMFEN Analysis Output

Having created a set of scenarios, to analyze each scenario the user clicks on the 'Calculate' button (the yellow lightning bolt) in the tool bar at the top of the screen. COMFEN automatically generates an EnergyPlus input data file for each scenario and exports the data to EnergyPlus which then performs the required calculations. EnergyPlus creates a numerical output data file for each scenario and generates the results that COMFEN then graphically displays in the lower right hand side of the screen.

The three main Results tabs, Overview, Climate and Comparison, are located at the top of the screen, above the scenario graphics. Each graphic in any of these tabs can be saved as a separate PNG image using the icon in the upper right of the graphic. The PNGs can be then be used in reports, Powerpoint™ presentations and other presentation media. The EnergyPlus output data file can also be saved as a CSV file to allow users to re-organize or re-graph data if desired.

4.4.1. Overview Tab

Overview graphically shows the summary energy usage results for up to 200 scenarios. This result presentation has proven particularly helpful for educational research users and fenestration manufacturing industry professionals. (Figure 3)

4.4.1. Climate Tab

Climate graphically represents weather data for the location. It includes a number of sub-tabs with graphics that illustrate different attributes (temperatures, sky-illuminance, wind-speed and direction, etc.) of the daily, monthly, seasonal and annual average outdoor climate for the project currently being evaluated. (Figure 4)

4.4.2. Detailed Comparison Tab

Comparison allows four scenarios to be compared at a time and contains the most detailed set of results. A number of sub-tabs located under the scenario input graphics allow the user to drill down to more detail.

The 'Summary' sub-tab graphically illustrates a comparison of the effects of four scenario design-choices on Annual Scenario Energy Use, Monthly Solar Heat Gain (through the windows), Daylight Penetration and Annual Average Thermal Comfort. These inter-related façade performance measures were historically difficult to assemble into a single display since their calculation required the use of multiple software packages. COMFEN assembles this data in a single graphic and also allows an easy side-by-side comparison of scenarios that greatly assists in helping to make balanced performance design decisions. (Figure 3)

Other sub-tabs afford access to graphics illustrating energy consumption and peak energy, façade and window loads, thermal comfort, daylight illuminance and penetration, and discomfort glare. Sub-sub-tabs under each of these headings access graphics at an increasing level of detail (based on the hourly results data generated by EnergyPlus). The graphics show annual, seasonal and monthly averages as well as results for each hour in a given day. There is also a new function that automatically exports input data to Radiance™ which created hourly simulation graphics for daylight and glare that can then be displayed in COMFEN. Details of this function are outlined below. (Figure 4)

5 IMPLEMENTATION METHODS

5.1 A New User Interface

Making the program user-friendly and introducing 3-D visualization were primary goals for COMFEN 3.0. The objective was to present the user with a clear, simple and visually rich interface that facilitates easy navigation and simplifies both the process of building simulations and accessing meaningful results. The team selected Adobe's Flex framework as the Graphic User Interface (GUI) application to achieve this objective. Flex is a free and open-source software development kit that enables highly interactive applications with rich and detailed data visualization, including a specialized charting function. Although the Flex framework is open-source, it requires Adobe's proprietary Flash Player to run.

Flex is well established as a robust platform for enterprise web applications, enabling COMFEN 3.0 to link to desktop-based simulation engines such as LBNL's EnergyPlus, Radiance™ and WINDOW 6. These applications run locally on user's machines, so COMFEN 3.0 is packaged as a desktop application using the Adobe AIR runtime. Adobe AIR allows Flex applications to run on a user's desktop with access to SQLite databases and the ability to read and write files and launch native processes.

COMFEN 3.0 is written as a typical Model/View/Controller application, with visual classes separated from control or persistence layers. The excellent open-source SWIZ library was used to create an 'Inversion of Control' approach to managing the dependencies and event propagation between the different parts of the application.

COMFEN 3.0 is currently a Microsoft Windows™ application, but because it is built on the cross-platform Flex/AIR frameworks, the program has the potential to be ported to other operating systems or as a web application with little change to the GUI or the user experience.

5.2 Links to EnergyPlus Simulation Engine

As described above, EnergyPlus is the simulation engine behind most of the results calculated in COMFEN. Data is exported from COMFEN to EnergyPlus using parameterized input files, i.e. pre-defined ASCII files with EnergyPlus macros, to generate an EnergyPlus input macro file (IMF). COMFEN then runs Energy Plus using this IMF file to generate the results, which are then exported to COMFEN to generate the graphical displays described above.

5.3 Links to Radiance™

While EnergyPlus is used to generate graphical daylighting and glare results, Radiance™ is the simulation engine behind the more-detailed renderings of daylighting and glare in COMFEN 3.0.

Radiance™ is a physically based lighting simulation program which is widely regarded as the best software for daylight simulation. Radiance™ does not have a graphical user interface, instead commands are entered at the command line and models are written in ascii text files. The lack of a graphical interface makes Radiance™ difficult to use for casual users.

COMFEN uses Radiance™ in the background to render interior views of COMFEN models. Input values which describe the room geometry and fenestration are converted into Radiance™ input, where the program then runs and generates the renderings that are displayed in the daylighting and glare results sub-tabs. COMFEN uses the Radiance™ mkillum program, with WINDOW 6 Bi-directional Scattering Function files to generate false-color images which represent the fenestration system as an illuminance source.

Once rendered users can select view points and view directions inside their model as well as time of day and day of year for the renderings. COMFEN uses the Radiance™ programs findglare and glarendx to calculate Daylight Glare Index (DGI) for each rendering. The DGI for a rendering is correlated to a subjective glare scale ranging from just perceptible to intolerable glare. Reporting DGI allows COMFEN users to understand the glare implications of their facade design choices.

6 FUTURE DEVELOPMENT PLANS

COMFEN development continues and plans for additional feature are being developed and defined. Early user feedback has been invaluable in determining potential near and longer term development plans.

6.1 Near Term Enhancement Plans

COMFEN 3.0's strength is its capacity to present complex data in easily comprehensible and comparative formats. The design team consequently continues to explore graphic and informational output improvements. Additional features under development include:

- Supplementary Radiance™ false-color and contour-plot graphics.
- More graphs and charts of EnergyPlus daylight and glare information such as daylight illuminance profiles, useful daylight and daylight autonomy.
- Complementary graphic illustration of results such as sun-path diagrams, shading-masks, and psychrometric climate-data plots.

The next generation of energy-saving and energy-producing window technologies employs detailed bi-directional scattering (i.e., transmitting and reflecting) distribution properties. A Complex Glazing Data Base (CGDB) similar in nature to the IGDB for glazing is being developed by the WINDOW simulation team. Once the CGDB is complete COMFEN will be modified to access these more optically complex glazing and shading materials.

6.2 Longer Term Development Plans

Additional enhancements either currently under development or under consideration include:

- Natural ventilation and mixed-mode analysis and results capabilities.
- Modeling different HVAC systems (both more traditional and also low-energy systems such as under-floor, radiant floors, radiant ceilings, chilled beams, etc.).
- Link to the Berkeley Radiant Thermal Comfort simulation.
- Cost and simple payback analysis.
- Benchmarking capabilities (envelope-only prescriptive, envelope-only tradeoff and whole building analogy).
- Links to green building rating tools such as LEED
- Life-cycle-cost, CO_2 and embodied energy financial calculations.
- Modeling of BIPV and other façade-related energy-generation technology – including inclusion in financial analysis
- Non-rectangular room and shading geometries.
- Compatibility with alternative graphic input platforms such as Google-SketchUp™, Autocad-Revit™ etc. to improve the flexibility of easy user input

7 ACKNOWLEDGMENTS

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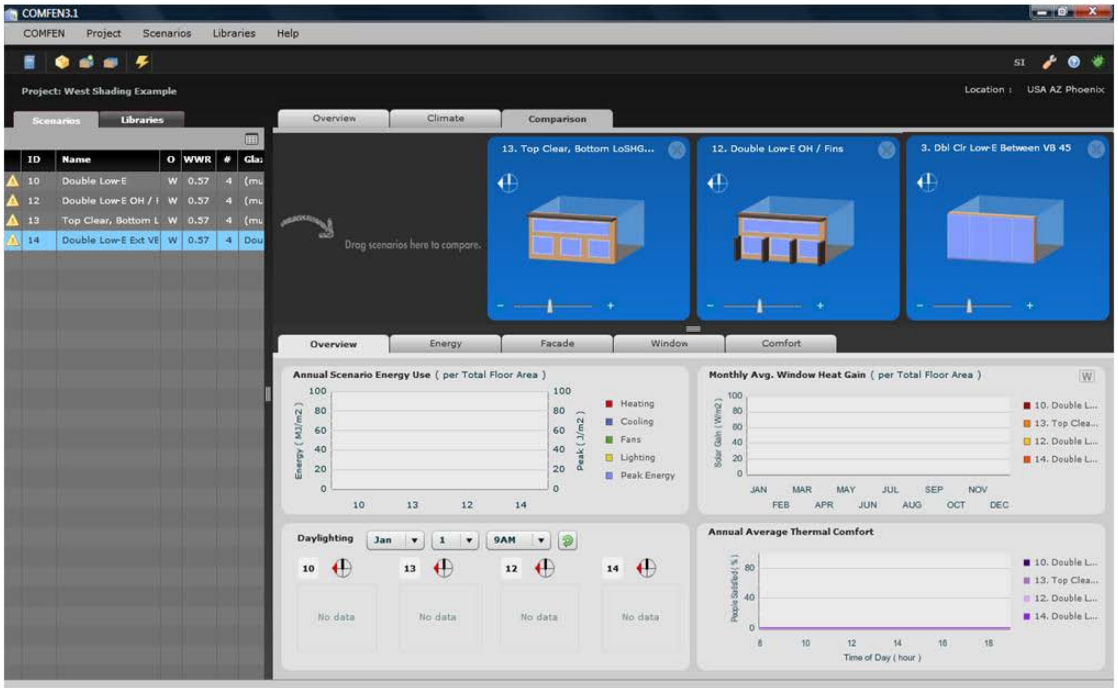

Figure 1: Sample primary input screen

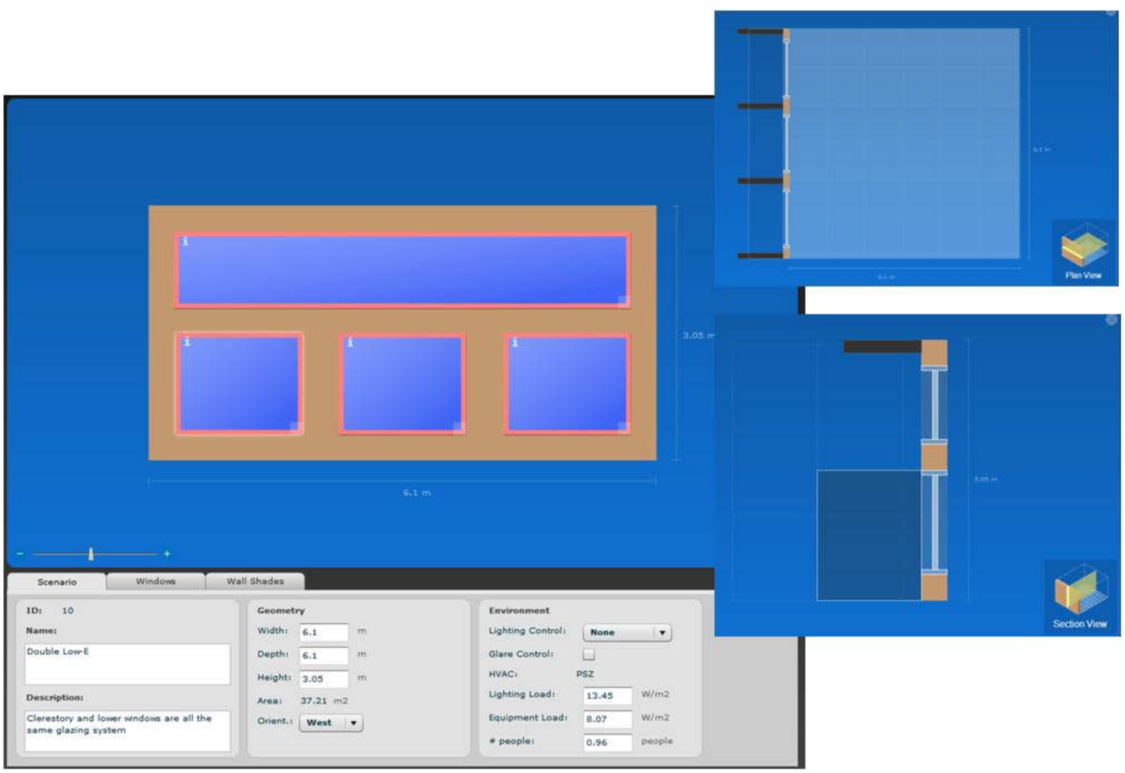

Figure 2 : Sample edit screens

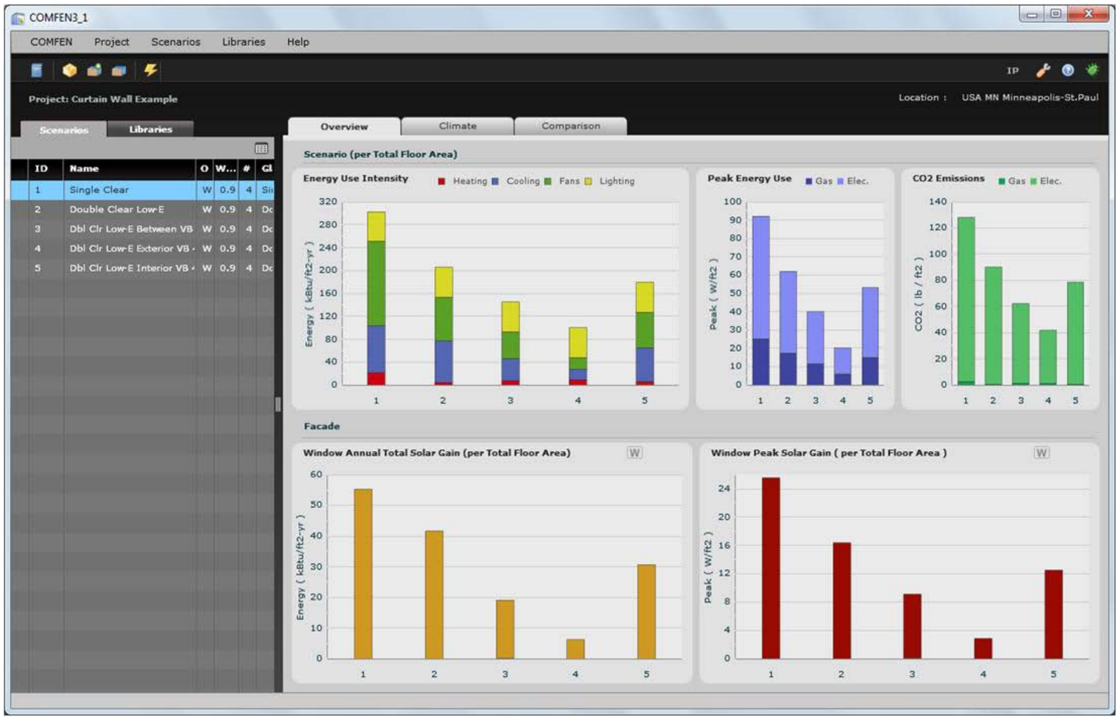

Figure 3 : Sample ‘Overview’ output

Figure 4: Sample climate data output

Figure 5: Sample ‘Comparison-Summary’ output

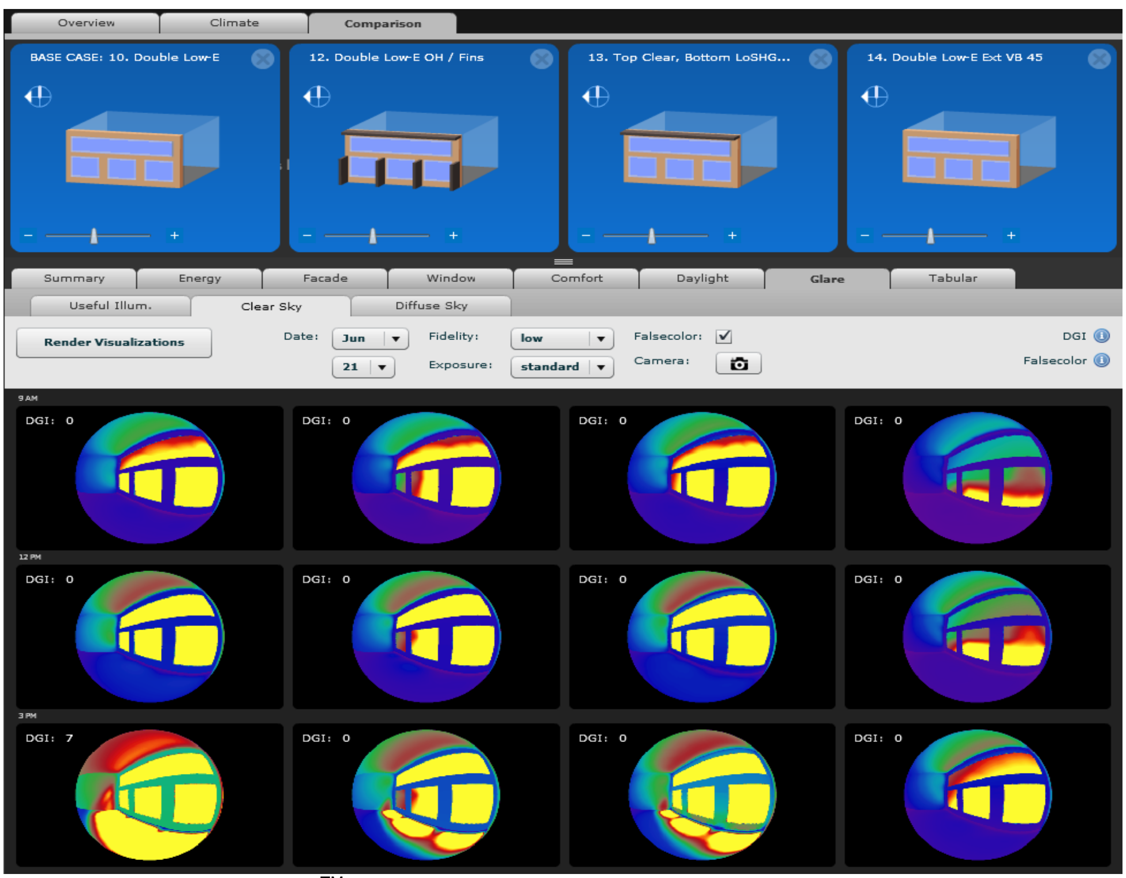

Figure 6: Sample Radiance^{TM} hourly simulation graphics