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BIRDS v3.1 Tutorial for Low Energy Residential Database

Joshua Kneifel
Eric O'Rear
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Applied Economics Office
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U.S. Department of Commerce
Wilbur L. Ross, Jr., Secretary

National Institute of Standards and Technology
Kent Rochford, Acting NIST Director and Under Secretary of Commerce for Standards and Technology

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Abstract

Building stakeholders need practical metrics, data, and tools to support decisions related to sustainable building designs, technologies, standards, and codes. The Engineering Laboratory of the National Institute of Standards and Technology (NIST) has addressed this high priority national need by extending its metrics and tools for sustainable building products, known as Building for Environmental and Economic Sustainability (BEES), to whole buildings. Whole building sustainability metrics have been developed based on innovative extensions to life-cycle assessment (LCA) and life-cycle costing (LCC) approaches involving whole building energy simulations. The measurement system evaluates the sustainability of both the materials and the energy used by buildings over time. It assesses the “carbon footprint” of buildings as well as 11 other environmental performance metrics, and integrates economic performance metrics to yield science-based measures of the business case for investment choices in high-performance green buildings.

Building Industry Reporting and Design for Sustainability (BIRDS) applies the sustainability measurement system to an extensive whole building performance database NIST has compiled for this purpose. Based on the NIST Net Zero Energy Residential Test Facility (NZERTF), the BIRDS low energy residential building database includes energy, environmental, and cost measurements for 480 000 residential building designs for Gaithersburg, MD for study period lengths ranging from 1 year to 40 years. Focusing on a single location allows for the consideration of incremental building energy efficiency measures, both those specified in most recent editions of the International Energy Conservation Code (IECC) as well as those adopted in the NZERTF design that lead to net-zero energy performance. The sustainability performance of buildings designed to meet current energy codes can be compared to a number of alternative building designs to determine the impacts of improving building energy efficiency on overall sustainability performance. The initial version of this database was introduced in BIRDS v3.0 and has been expanded in BIRDS v3.1 to include additional metrics related to indoor environmental quality (thermal comfort of occupants and indoor air quality) and an additional exterior wall finish option. The BIRDS interface now includes additional graphing features not available in previous versions of BIRDS.

This document is a tutorial to assist BIRDS users in understanding and using the BIRDS Low Energy Residential Buildings Database Web Interface, including detailed definitions for and explanation of the purpose of each input and output option.

Keywords

Building economics; economic analysis; life-cycle costing; life-cycle assessment; energy efficiency; low-energy buildings; residential buildings

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Preface

This documentation was developed by the Applied Economics Office (AEO) in the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST). The BIRDS low-energy residential database web interface is designed to assess the sustainability performance (energy, environmental, and cost impacts) of the adoption of new residential building designs. The intended audience is users of BIRDS, such as researchers and decision makers in the residential building sector, and others interested in building sustainability.

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Disclaimers

The policy of the National Institute of Standards and Technology is to use metric units in all of its published materials. Because this report is intended for the U.S. construction industry that uses U.S. customary units, it is more practical to include U.S. customary units as well as metric units. Measurement values in this report are therefore stated in metric units first, followed by the corresponding values in U.S. customary units within parentheses.

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List of Acronyms

Acronym	Definition
ACH50	air changes per hour at 50 Pa
AEO	Applied Economics Office
BEES	Building for Environmental and Economic Sustainability
BIRDS	Building Industry Reporting and Design for Sustainability
CO2e	carbon dioxide equivalent
EIS	Environmental Impact Score
EL	Engineering Laboratory
FAQ	Frequently Asked Questions
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IECC	International Energy Conservation Code
I-P	Imperial units
LCA	Life-Cycle Assessment
LCC	Life-Cycle Cost
NIST	National Institute of Standards and Technology
NZERTF	Net-Zero Energy Residential Test Facility
PV	Present Value

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1 Introduction

A wave of interest in sustainability gathered momentum in 1992 with the Rio Earth Summit, during which the international community agreed upon a definition of sustainability, which remains one of the most cited to this day, in the Bruntland report: “meeting the needs of the present generation without compromising the ability of future generations to meet their own needs” (Brundtland Commission 1987). In the context of sustainable development, needs can be thought to include the often-conflicting goals of environmental quality, economic well-being, and social justice. While the intent of the 1992 summit was to initiate environmental and social progress, it seemed to have instead brought about greater debate over the inherent conflict between sustainability and economic development, which has continued up to today.

This conflict is particularly apparent within the construction industry. Frequently, well-intentioned green development plans are not executed for economic reasons, and economic development plans fail to materialize over concerns for the environment and public health. Thus, an integrated approach to sustainable construction—one that simultaneously considers both environmental and economic performance—lies at the heart of reconciling the conflict. For this reason, building stakeholders need practical metrics, data, and tools to support decisions related to sustainable building designs, technologies, standards, and codes that consider both the environmental protection and economic growth dimensions of sustainability.

The Engineering Laboratory (EL) of the National Institute of Standards and Technology (NIST) has addressed this high priority national need by extending its metrics and tools for sustainable building products, known as Building for Environmental and Economic Sustainability (BEES) (National Institute of Standards and Technology (NIST) 2010) at the whole building level to address building sustainability measurement in an integrated manner that considers complex interactions among building materials, energy technologies, and systems across dimensions of performance, scale, and time. Whole building sustainability metrics have been developed based on innovative extensions to life-cycle assessment (LCA) and life-cycle costing (LCC) approaches involving whole building energy simulations, and evaluates the sustainability of both the construction materials and the energy used by a building over time. It assesses the “carbon footprint” of buildings as well as 11 other environmental performance metrics, and integrates economic performance metrics to yield science-based measures of the business case for investment choices in high-performance green buildings. This approach does not consider the social equality dimension of sustainability due to the current lack of rigorous measurement methods.

Building Industry Reporting and Design for Sustainability (BIRDS) applies the sustainability metrics to an extensive whole building performance database NIST has compiled for this purpose (NIST 2014, NIST 2015, NIST 2016, NIST 2017). The energy, environment, and cost data in BIRDS measure building operating energy use through detailed energy simulations, building materials use through life-cycle material inventories, and building costs over time.

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BIRDS v1.0 included energy, environmental, and cost measurements for 11 building prototypes in 228 cities for a total of 12 540 new commercial and non-low rise residential building designs across all U.S. states for 9 study period lengths. See Lippiatt et al. (2013) for additional details. BIRDS v2.0 included both the commercial and residential database that included the energy, environmental, and cost measurements for 9120 residential buildings, covering 10 single family dwellings (5 one-story and 5 two-story of varying conditioned floor area) in 228 cities for study period lengths ranging from 1 year to 40 years. See Kneifel and Lavappa (2015) for additional details related to the underlying assumptions, data sources, and approaches implemented to develop the BIRDS new residential database. All the variables shown in Figure 1-1 are accounted for in the BIRDS database.

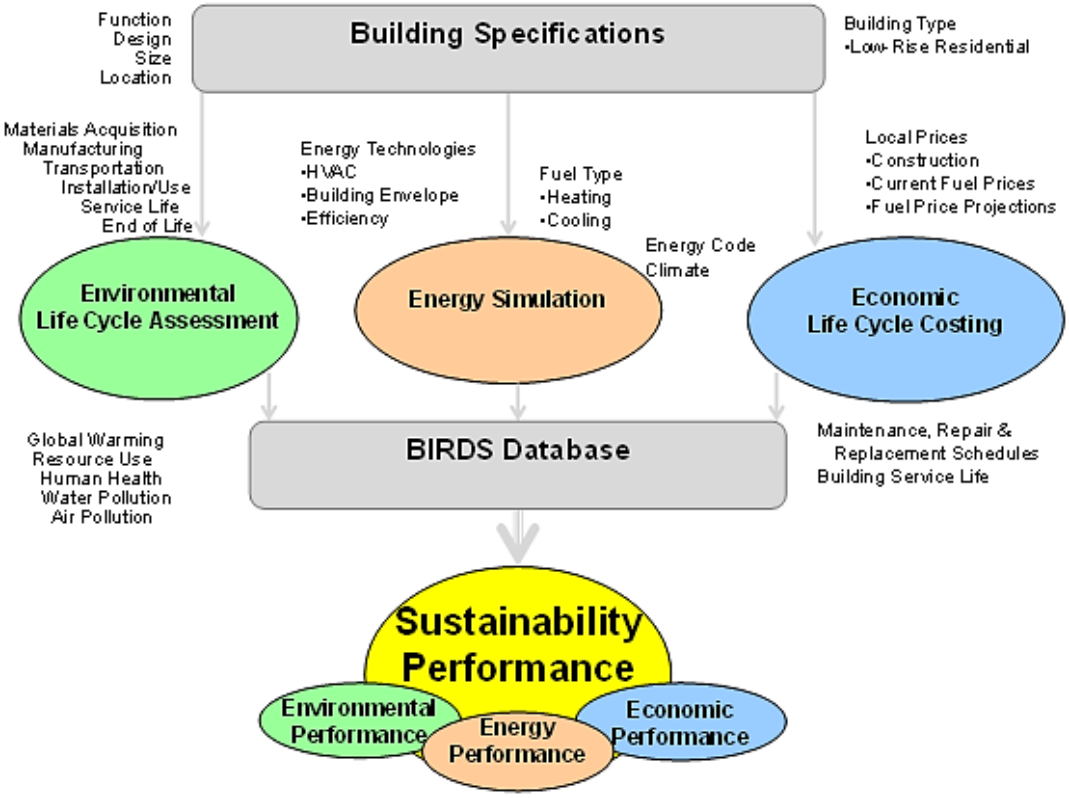

Figure 1-1 BIRDS Sustainability Framework

Similar to the previous databases, the low-energy residential database incorporated into BIRDS v3.0 includes the energy, environmental, and cost measurements. However, instead of considering locations across the country with minimal building design options, BIRDS v3.0 allows for detailed incremental energy efficiency measure analysis for a single location (Gaithersburg, MD, USA): 240 000 residential building designs based on the NIST Net-Zero Energy Residential Test Facility (NZERTF) specifications and varying requirements across International Energy Conservation Code (IECC) editions.[1] Again, study period lengths from 1

[1] BIRDS has been designed to allow for additional locations to be incorporated in future versions.

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year to 40 years are included in the low-energy residential database. The sustainability performance of buildings designed to meet current energy codes can be compared to a number of alternative building designs to determine the impacts of improving building energy efficiency as well as varying the investor time horizon and other assumptions on overall sustainability performance. See Kneifel et al. (2016) for additional details on the BIRDS v3.0 low-energy residential database.

BIRDS v3.1 expands the low-energy residential database by including metrics related to indoor environmental quality (thermal comfort of occupants and indoor air quality) and an additional exterior wall finish option, doubling the building designs to 480 000. In addition to the expansion of the BIRDS low-energy residential database, the BIRDS interface now includes additional graphing features not available in previous versions of BIRDS. Kneifel et al. (2017) provides additional details on the BIRDS v3.1 low-energy residential database.

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2 BIRDS New Residential Buildings Database Tutorial

This tutorial will walk a user step-by-step through using the BIRDS Low-Energy Residential interface. There will be some guidance and recommendations included in the explanation to assist a user in better understanding their selections and how to view and interpret results comparisons. The interface can be used for a range of purposes, including identifying key building designs that meet certain goals (e.g., minimize life-cycle costs) and comparing the performance of these key design across a range of sustainability metrics, comparing different IECC editions, and analyzing the impacts of incremental efficiency improvements to a specific building component (e.g., windows).

The example in this tutorial will compare the performance of a house based on the NZERTF, but built to minimally meet Maryland code requirements (2015 IECC), to alternative building designs using the following approaches:

(1) Constructing to meet requirements in different editions of the IECC relative to current Maryland code requirements
(2) Changing the thermal performance of the exterior wall assembly relative to current Maryland code requirements
(3) Considering different combinations of building components using current Maryland code requirements and the specifications of the NZERTF

A user begins on the BIRDS main webpage, which is a “one-stop shop” for information related to BIRDS. In the center of the webpage, there is an introduction to the purpose and capabilities of the BIRDS databases (highlighted in Figure 2-1).

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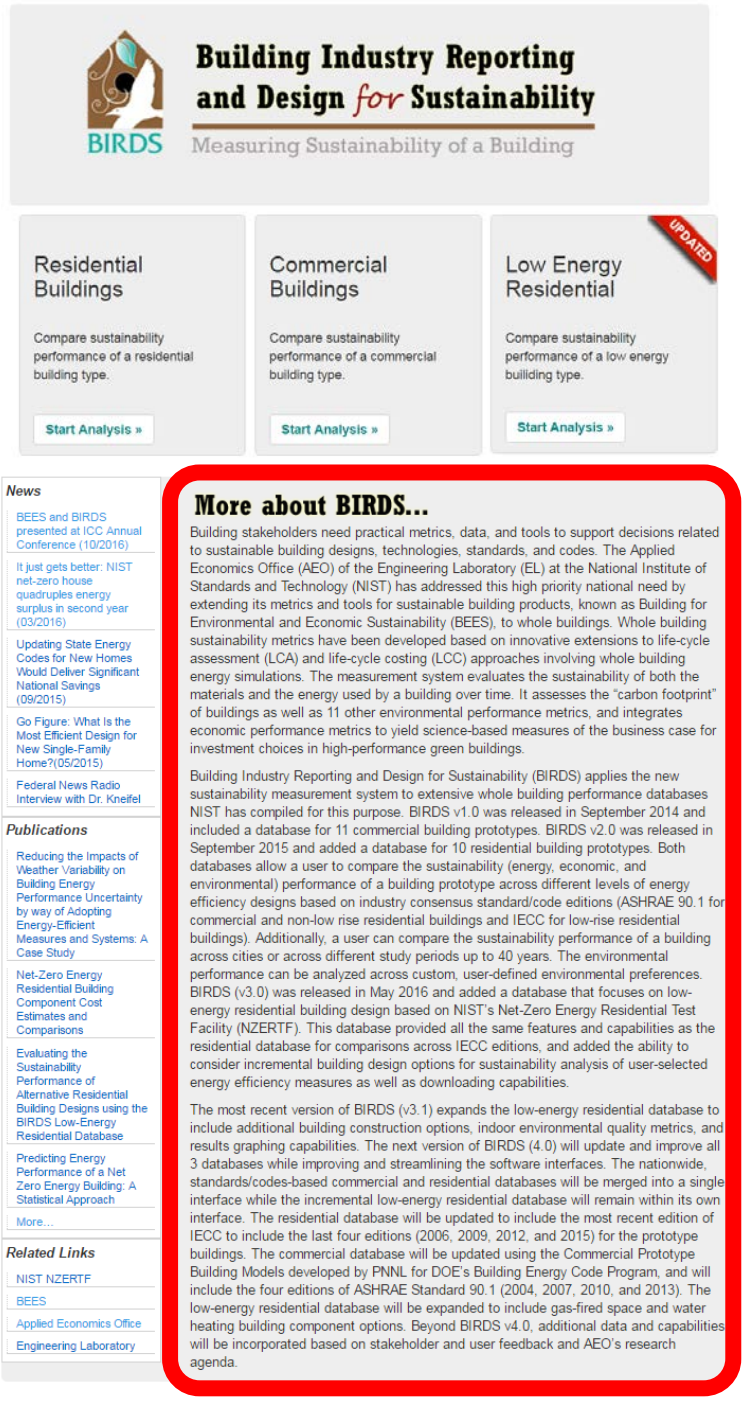

Figure 2-1 BIRDS Main Webpage - Introduction

On the left hand side of the main page, a user can access information related to BIRDS, including recent news, related publications, and other related links (highlighted in Figure 2-2). Recent news will include news articles, press releases, and announcements related to BIRDS. The most recent and/or most downloaded BIRDS-related publications are shown, which link to the NIST publication database to allow for a complete search of BIRDS publications. Related

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links include BIRDS's "sister software" – BEES – that allows for comparison of individual building products and the NIST Net Zero Energy Residential Test Facility (NZERTF) main page as well as access to the Applied Economics Office (AEO) and the Engineering Laboratory (EL) at NIST.

If the user is interested in additional information not available from the BIRDS main page or has comments to improve BIRDS, NIST can be contacted at either birds@nist.gov or joshua.kneifel@nist.gov.

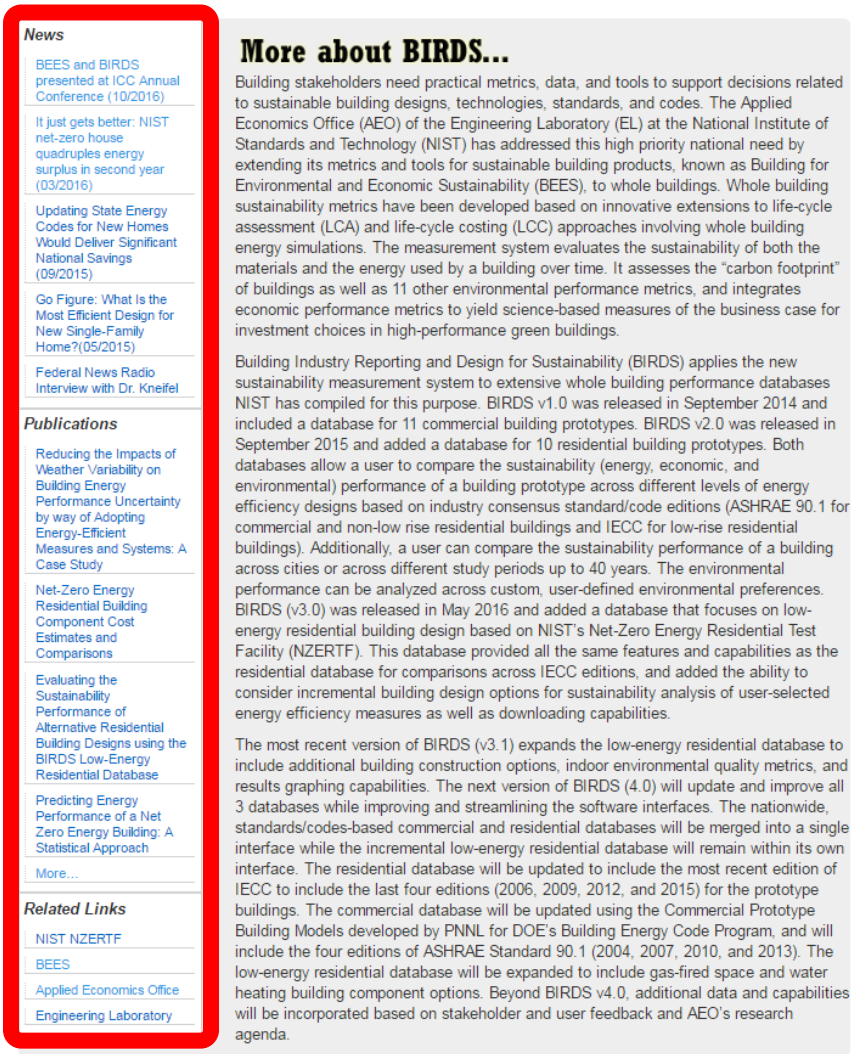

Figure 2-2 BIRDS Main Webpage – Related Links

Above the introduction are links directing you to each of the BIRDS databases (highlighted in Figure 2-3). The Residential Buildings and Commercial Buildings "Start Analysis >>" links direct you to the new residential database and new commercial buildings database, respectively. Each database allows the user to compare the sustainability performance of various reference building designs built to various editions of the IECC across different locations. The Low-

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Energy Residential "Start Analysis >>" link directs the user to the low-energy residential buildings web interface, which will allow a user to compare the sustainability performance of incremental changes in energy efficiency measures adopted in a single-family dwelling based on energy-efficiency measures incorporated into the NZERTF. The new database also allows for sustainability performance comparisons of the NZERTF design across multiple editions of the IECC (2006, 2009, 2012, and 2015) but adds the possibility of exceeding the energy performance of the minimum efficiency code.

Figure 2-3 BIRDS Main Webpage – Database Links

For this tutorial, the user selects the Low-Energy Residential "Start Analysis >>" link and is directed to the BIRDS Low-Energy Residential database web interface (highlighted in Figure 2-4).

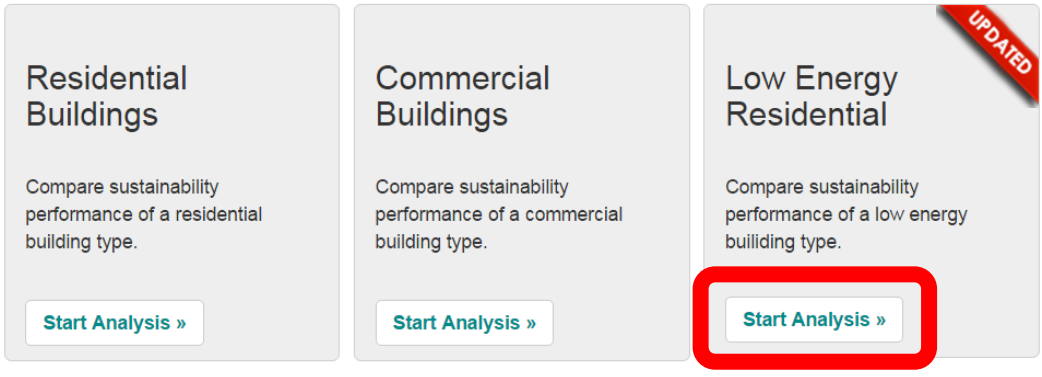

Figure 2-4 BIRDS Main Webpage – Start Analysis

The **Low Energy Residential** web interface defaults the user to Step 1 as shown in Figure 2-5. There are four steps in completing and viewing sustainability comparisons.

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1. Select your general assumptions, location, and baseline building design.
2. Select alternative building component properties to be compared to the baseline building design.
3. Select weighting preferences for environmental performance.
4. View results graph(s) and data.

At any step in the process, the user can access the BIRDS Home webpage, BIRDS Low Energy Residential database documentation, this tutorial, and FAQ at the top-right corner of the page as shown in Figure 2-5. Note that the successful computation of database results is contingent upon proper selection by the user of all parameters inputs. If any of the general assumptions, baseline building design components, alternative building component properties, and/or weighting preferences are not defined by the user at any point, no results will be displayed and input parameters that have not been defined or defined incorrectly will be noted in red text.

Figure 2-5 BIRDS New Residential Interface – Initial View

The remainder of this tutorial will walk the user through a detailed example and the resulting comparisons available to the user. Note that there are a variety of values that the user must select in order to view results, but BIRDS v3.1 includes further information (by clicking on the information icons noted later in the manual) and default values (where determined necessary) to assist a user in making those selections. The documentation and tutorial for the BIRDS Residential Buildings database (Kneifel et al 2015, Kneifel and Lavappa 2015) and BIRDS Commercial Buildings database (Lippiatt et al. 2013) can be accessed in their respective links shown in Figure 2-4 or through the DOI links in the References section of this document. To compare the changes made to the BIRDS Low-Energy Residential database and interface, see Kneifel et al (2016a) and Kneifel et al (2016b).

2.1 Step 1: Selecting Your Baseline Assumptions

The user completes the first part of "Step 1: Select Your Baseline Assumptions" by selecting the assumptions to be used in the analysis from the eight drop-down menus shown in Figure 2-6. Selections are made based on the preferences of the user. The user first selects the Building Type, which currently allows only for the selection of the **NZERTF** (based on the NIST

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NZERTF). For the second and the third assumptions, the user selects the **State** and **City** locations for the baseline building. These selections must be made sequentially. The only state and city options currently available are **Maryland** and **Gaithersburg**, respectively.[2] The Discount Rate (the rate at which the user discounts future dollars) is the fourth assumption selected by the user. Two options are available: **3 %** and **8 %**.[3] Next, the user selects the assumed financing method using the Financing dropdown menu. Again, two options are available for selection: **Cash Only** and **80/20** (80 % financing/20 % down payment). Construction Quality (e.g., architecture and finishes) is the sixth assumption selected by the user. He/she can choose either **Average** or **Luxury** construction quality (e.g., quality of interior finishes). Exterior wall finish is the seventh assumption selected by the user. He/she can choose either **wood siding** or **brick veneer**. Lastly, the user selects the length of the Study Period over which the analysis is conducted. Study period options range from **1 year** to **40 years** in one year increments. For further information on the assumptions, click the blue information icon next to "Select Analysis Assumptions". For the example used in the remainder of this tutorial the selections for the eight drop down menus are as follows: **Maryland**, **Gaithersburg**, **3 %**, **80/20**, **Average**, **Wood Siding**, and **30 years**.

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[2] Simulations have been run solely for this location at present because it is where the NZERTF is located. Additional locations will be added in future updates of BIRDS.

[3] These two options were selected to represent two different investment alternatives, 3 % for individuals that would invest in a less risky asset such as treasury bills and 8 % for those that would invest in riskier asset such as stocks. Additional options will be added in future updates of BIRDS.

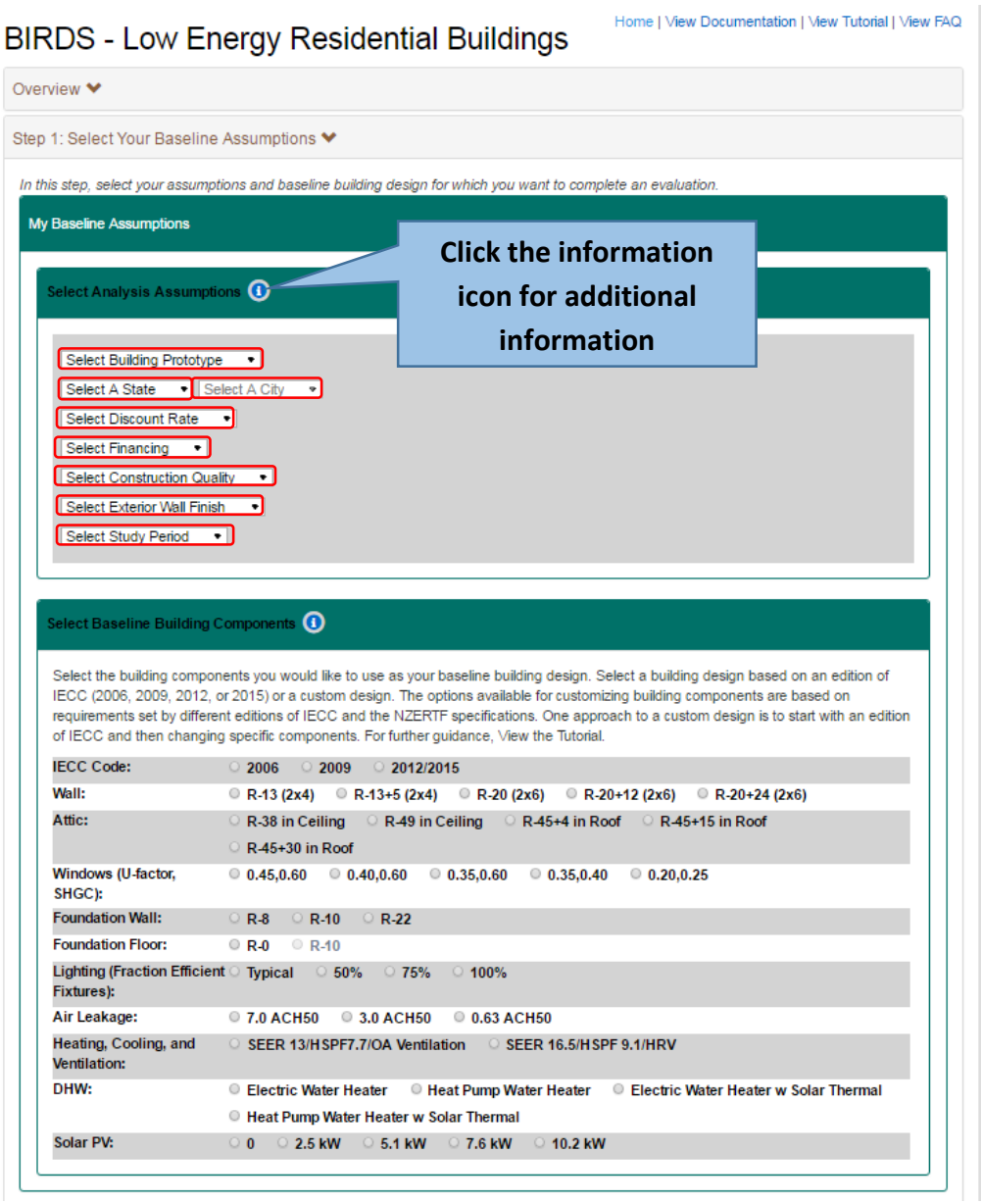

Figure 2-6 Baseline Assumptions – Analysis Assumptions

To complete the second part of "Step 1: Select Your Baseline Assumptions," the components of the baseline building must be selected (Figure 2-7). The user has the option of either choosing a building design based on an edition of the IECC (2006, 2009, 2012, 2015) or a custom design. Note that the requirements for the assemblies selected for the baseline design are identical for both the 2012 IECC and 2015 IECC, and are combined for this version of BIRDS. Options available for building customization are based on the requirements of different editions of IECC and the NIST NZERTF specifications. These custom design options are categorized according to 10 primary building components: Wall, Attic, Windows, Foundation Wall, Foundation Floor, Lighting, Air Leakage, Heating, Cooling, and Ventilation (HVAC), Domestic Hot Water (DHW), and Solar photovoltaic (PV). I-P units are displayed throughout BIRDS because the tool

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is designed for U.S.-related activities. As shown in Figure 2-7, five options are available for wall and attic insulation.[4] There are also five options available for window specifications that are expressed in terms of U-Factor and Solar Heat Gain Coefficient (SHGC). Building foundation characteristics (Wall and Slab) are described in terms of insulation R-values. Three options are available for the Foundation Wall, while two are available for the Slab (Foundation Floor). Expressed as a fraction of efficient fixtures (compact florescent light or light emitting diode), four options are available for lighting. The four Air Leakage rates available are described in terms of air changes per hour at 50 Pa (ACH_{50}). Two options are available for the baseline Heating, Cooling, and Ventilation system. The first is based on the federal minimum efficiency requirements. The other is based on the efficiency specifications of the system installed in the NIST NZERTF, which includes a separate dedicated outdoor air system with a heat recovery ventilator. The four options available for the Domestic Hot Water configuration are based on the federal minimum efficiency requirements and the specifications of the system installed in the NIST NZERTF, including the solar thermal system. Five options are available for the solar photovoltaic system, ranging from no solar photovoltaic system to a 10.2 kW system. For further details on the building components, click the information icon next to “Select Baseline Building Components”.

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[4] For more information on the wall and attic assemblies, see the BIRDS v3.1 documentation.

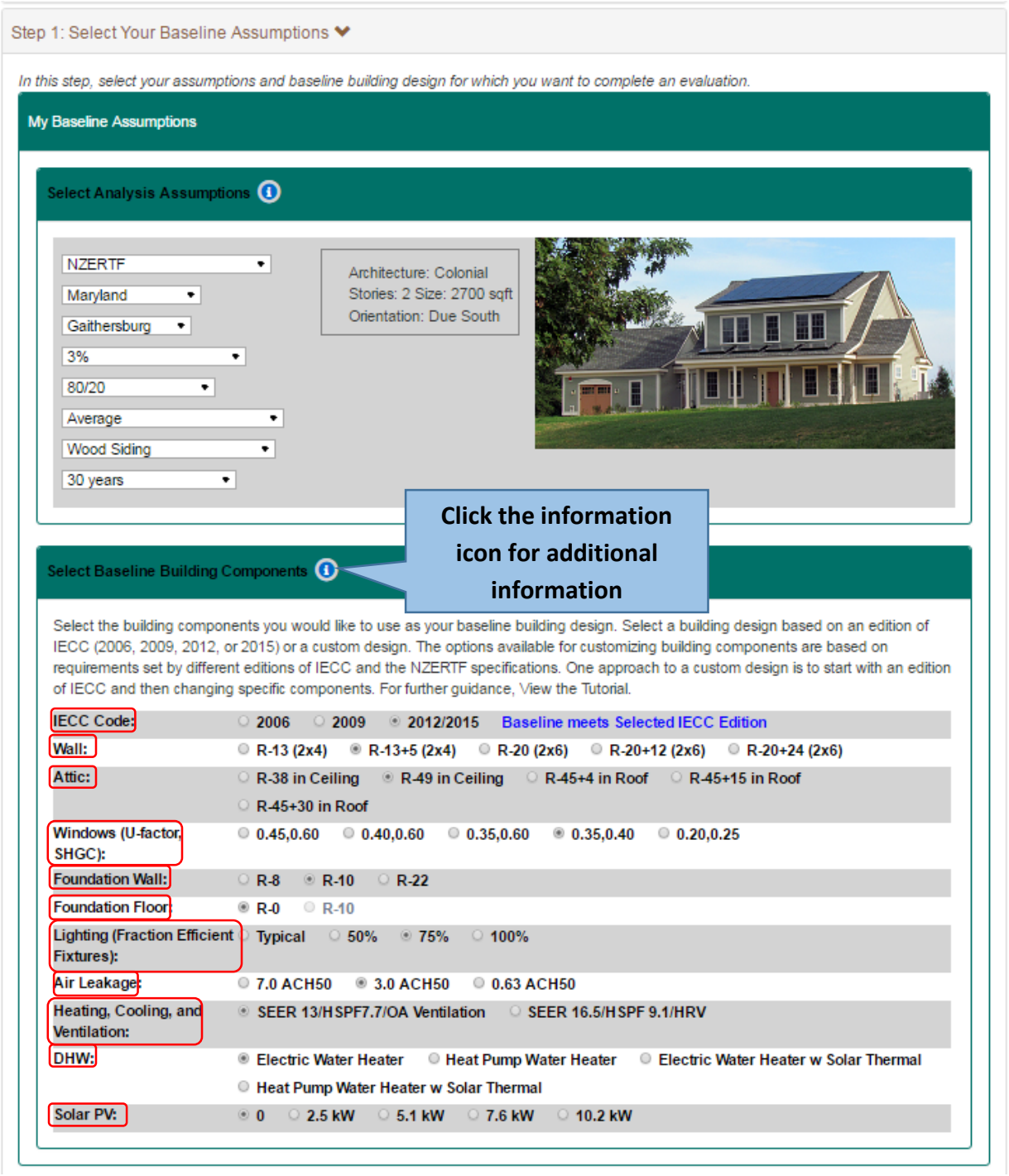

Figure 2-7 Baseline Assumptions –Building Components

If the user would like their baseline building to meet the specifications of an edition of the IECC, he/she must select their desired edition. The building component specifications associated with an IECC edition will automatically populate in the cells below following the selection of that edition (Figure 2-8). If the user would like to customize their baseline design, they can take one

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of two approaches: (1) manually select each of the 10 individual building components; or (2) select an edition of the IECC and manually change specific building components.

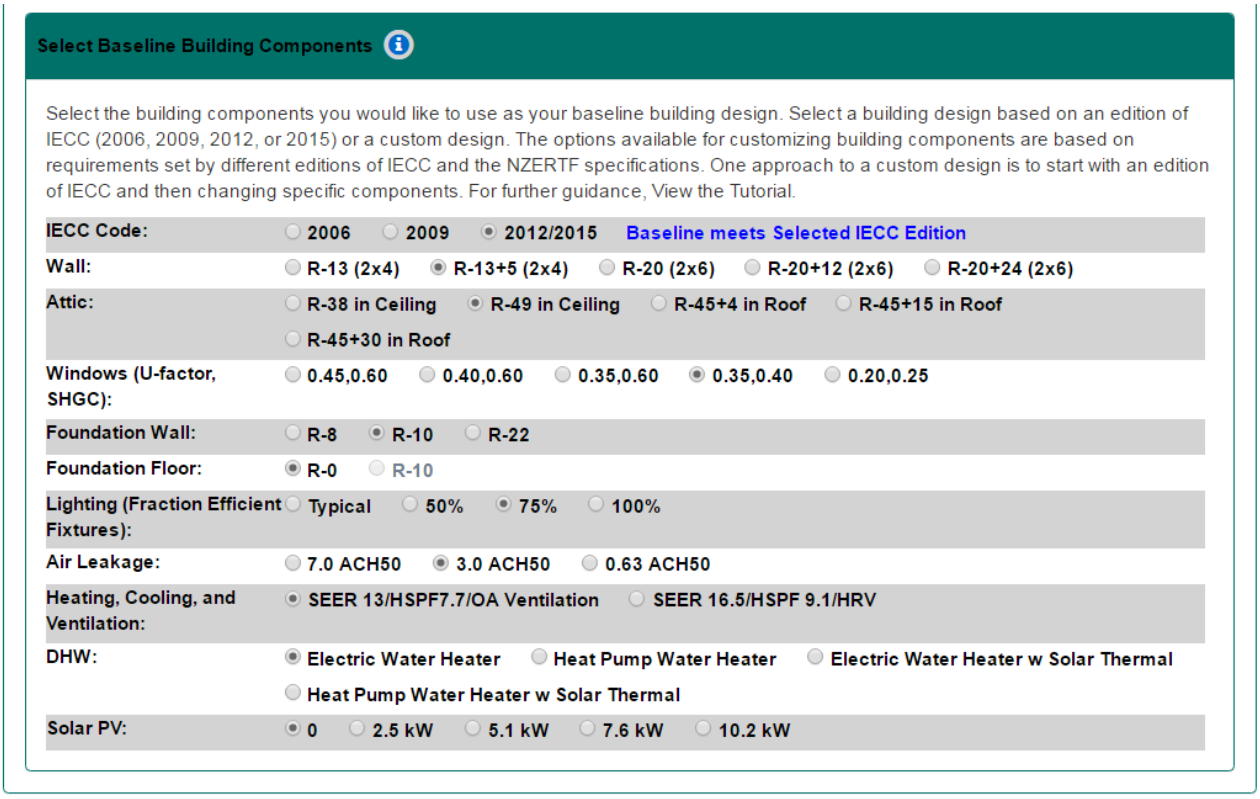

Figure 2-8 Building Component Specifications

For this tutorial, assume that the user is considering building a two-story home located in Gaithersburg, MD and constructed according to the specifications of the **2015 IECC** as shown in Figure 2-9. The user assumes a **3 %** discount rate, loan with 20 % down payment (**80/20**) financing, **Average** construction quality, and a 3**0-year** study period. Notice that after selecting the **NZERTF** as the building type, a picture of the building and its characteristics are displayed to the right. The default selection for the building components is 2012/2015 IECC because the Maryland building code is comparable to the 2015 IECC as of early 2017.[5] Note that if an edition of the IECC is selected, blue text stating "Baseline meets Selected IECC Edition," is displayed to the right of the IECC Code row. If a custom design is selected, red text stating, "Custom Baseline Selections," will be displayed in the same location. Current state energy codes can be found at https://www.energycodes.gov/adoption/states. Following the selection of the above assumptions, the user selects the desired comparisons.

[5] The 2012 IECC and 2015 IECC are grouped together because the requirements in 2012 IECC and 2015 IECC are the same for the building characteristics of the NZERTF.

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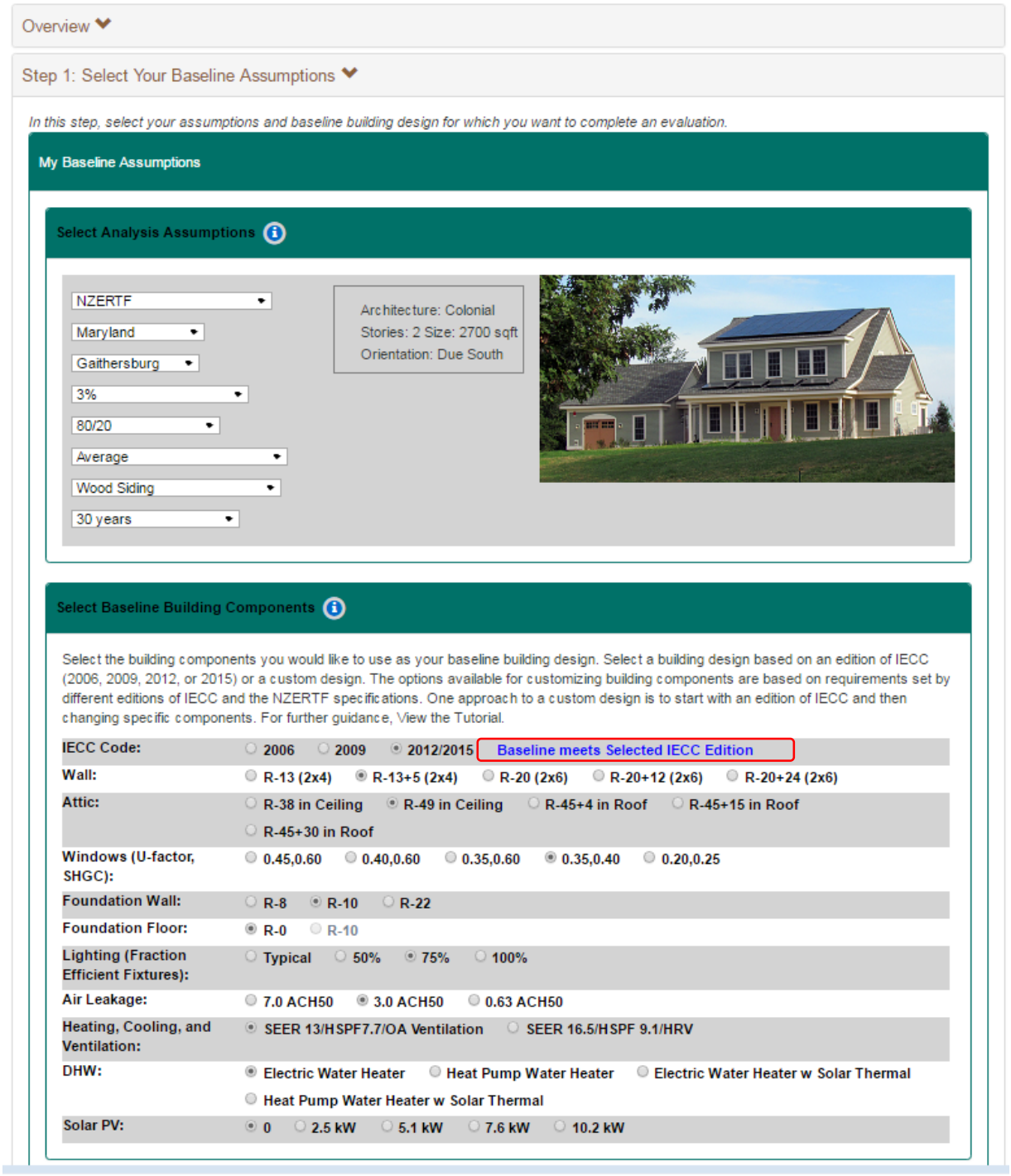

Figure 2-9 Baseline Building Details

2.2 Step 2: Selecting Your Comparisons

As shown in Figure 2-10, clicking on the “Step 2: Select Your Building Comparisons” tab displays two question prompts by which comparisons can be made (highlighted in red). The first question states, “Do you want to compare IECC editions?” The second question states, “Do you

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want to compare user-defined building alternatives?" The user has the option of selecting yes (**Y**) or no (**N**) for either or both of the two questions.

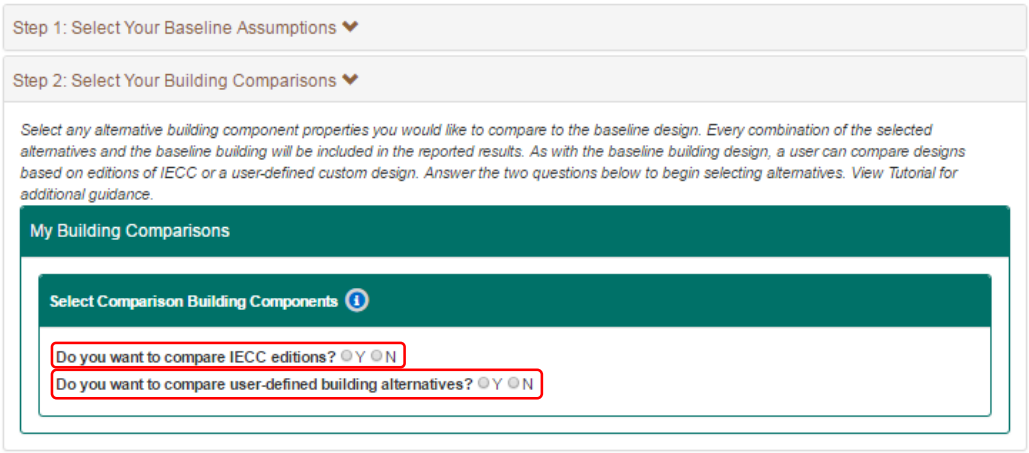

Figure 2-10 Selecting IECC Editions for Comparison

Should the user be interested in comparing across IECC editions, he/she must select "**Y**" for the first question and the IECC editions will appear below (Figure 2-11). The user will then select the alternative IECC edition(s) by checking the boxes corresponding to each. Note that if the assumed baseline building is constructed according to an IECC edition, that edition will not be available for selection. Since the baseline building in this tutorial uses 2015 IECC, it can no longer be selected as shown in Figure 2-11.

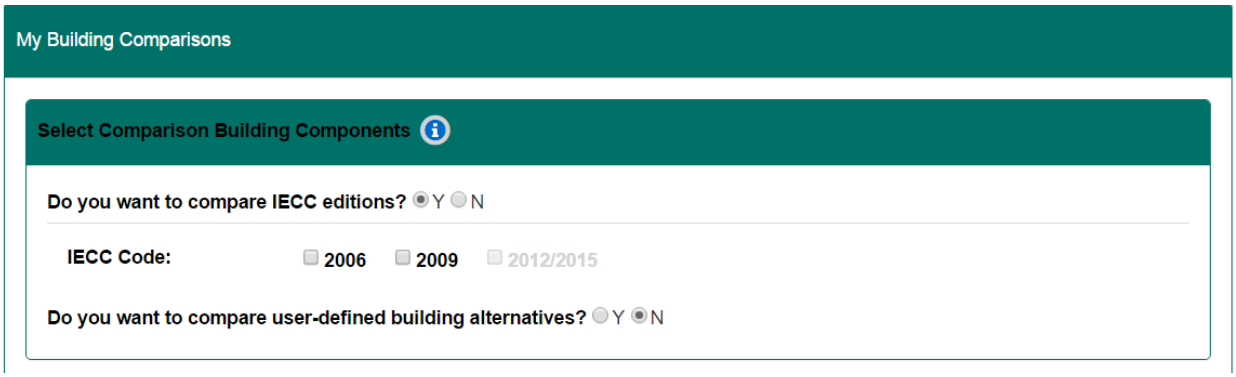

Figure 2-11 Comparison across IECC Editions

Should the user be interested in comparing a user-defined custom design to the baseline, he/she must select "**Y**" for the second prompt and the tab will expand, listing the options for the 10 major building components (Figure 2-12). It is here that the user selects the building component alternatives. Note that all of the building component specifications associated with the baseline building can no longer be selected. The user has the option of comparing their baseline design to

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alternative IECC editions AND user-defined custom designs, which could include up to the entire set of 240 000 building design options. All combinations of the baseline building components and the alternative component selections will be reported. For example, if a user selects “Foundation Wall” = **R-22** and “Solar PV” = **10.2 kW** as alternatives, then BIRDS will report results for

(1) the baseline building as defined (foundation insulation of R-10 and no solar PV system)
(2) baseline building with ONLY the foundation insulation increased to R-22
(3) baseline building with ONLY the 10.2 kW solar PV system added to the roof
(4) baseline building with BOTH the foundation insulation increased to R-22 and the solar PV system added to the roof

“**Y**” must be selected for both prompts. In this case, the alternative building components defined in all selected IECC editions will have automatically been selected. Each combination of the baseline building and the alternative selections will be available for analysis in Step 4. The information icon next to “Select Building Comparison Components” includes information on each of the 10 building components.

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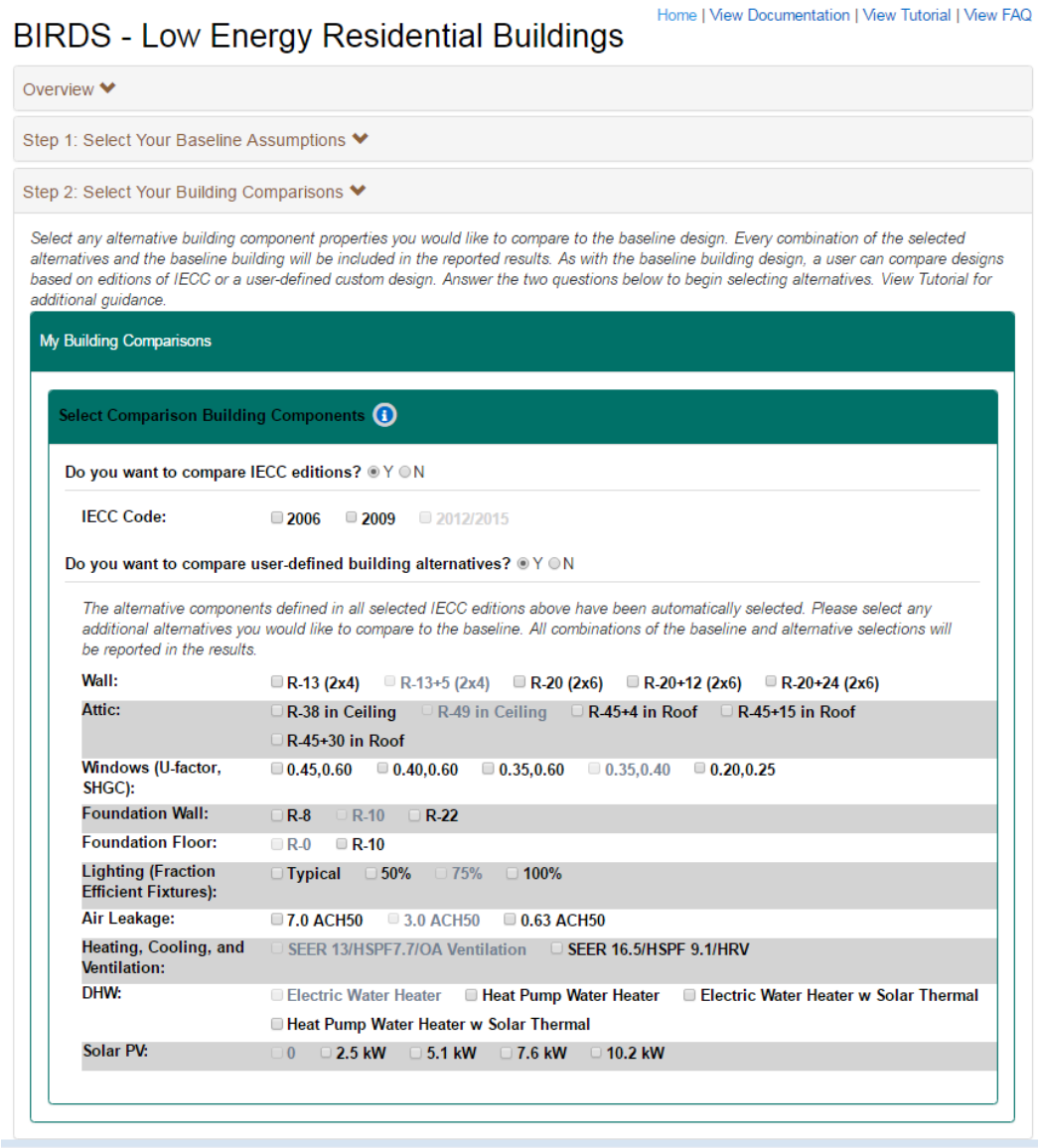

Figure 2-12 Selecting User-Defined Building Alternatives for Comparison

For this tutorial, assume that the user is interested in three analyses: (1) evaluate the current Maryland code requirements (2015 IECC) to previous versions of IECC (2006 and 2009) (2) evaluate the NIST NZERTF design to current Maryland code requirements, and (2) evaluate the impacts of improving the thermal integrity of the baseline building's wall assembly by switching to advanced framing (**2x6** wall assembly) and increasing wall insulation levels (**R-20**, **R-20+12**, and **R-20+24**). To do this, the user would check the boxes **R-20**, **R-20+12**, and **R-20+24** for the incremental wall assembly analysis and the more efficient option for each of the other building components: Attic = **R-45+30 in Roof**, Windows = **0.20,0.25**, Foundation Wall = **R-22**, Foundation Floor = **R-10**, Lighting = **100 %**, Air Leakage = **0.63 ACH50**, Heating, Cooling, and Ventilation = **SEER16.5/HSPF 9.1/HRV**, DHW = **Heat Pump Water Heater w/ Solar Thermal**, and Solar PV = **10.2 kW** (Figure 2-13). The user would also select the **2006** and **2009**

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IECC codes. BIRDS will report the results for all combinations of the baseline characteristics selected in Step 1 and Step 2, allowing for incremental analysis of each building component option selected.

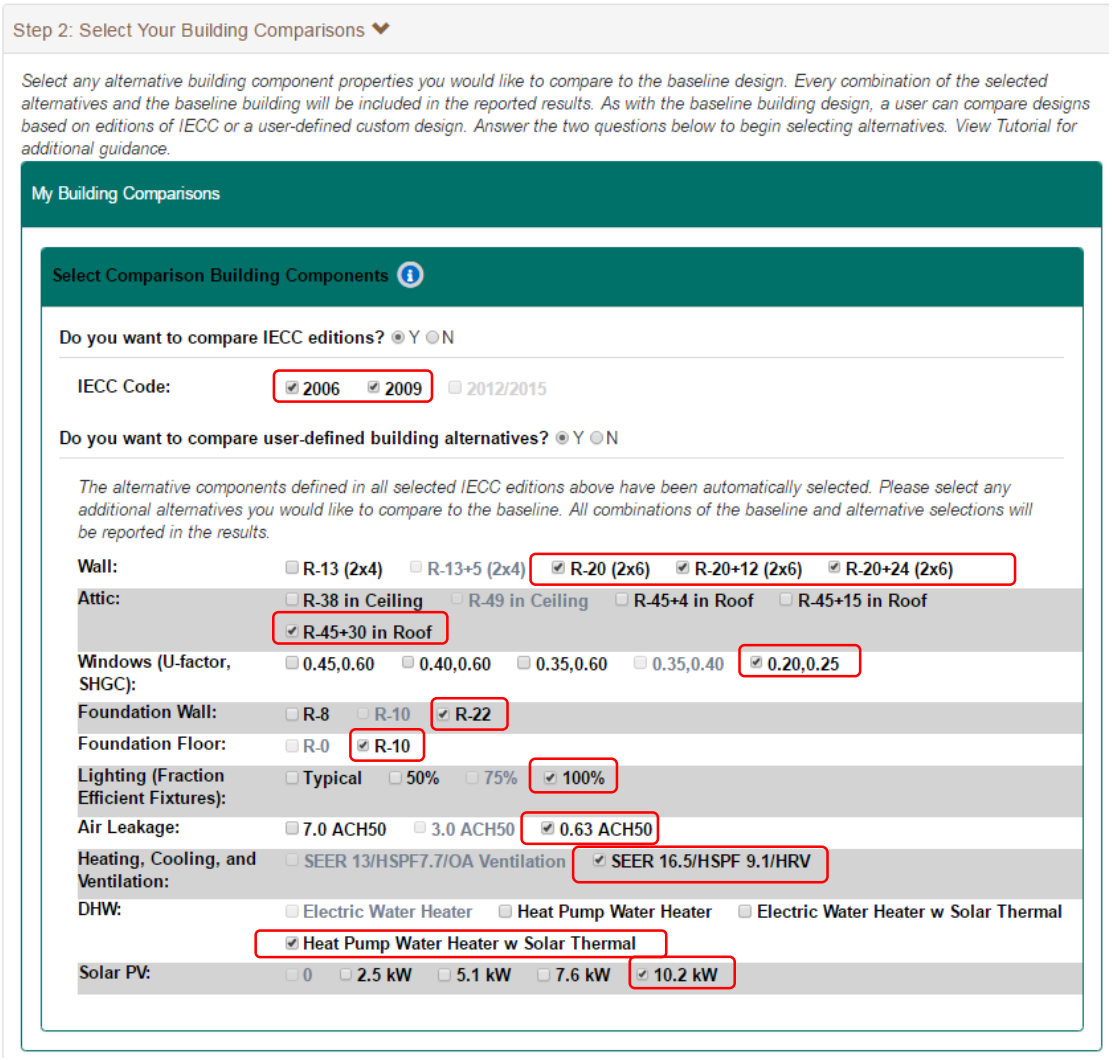

Figure 2-13 Selected Design Alternative to be compared to the Baseline

2.3 Step 3: Selecting Environmental Weighting Preferences

Clicking on the "Step 3: Select Your Environmental Preferences" displays an introductory paragraph that describes how the 12 environmental impact categories are used to compute the Environmental Impact Score (EIS). For further explanation of each of the environmental impact categories, please see the documentation. The user must define their preferences regarding the relative importance of each environmental impact. They can either select one of the pre-defined weight sets or create their own. If using a pre-defined weight set, the user must start by selecting their Environmental Weighting Approach from the dropdown menu, which includes 4 pre-defined options as shown in Figure 2-14 (highlighted in red). Note that selection of "My

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Weights" for a user-defined weight set is not available in the drop down. The following paragraph will explain how to get "My Weights" added to the drop down menu. The user can view the weights for each of the four pre-defined approaches on the right-hand side of the screen. For information on the environmental weighting approach or pre-defined weight sets, click the appropriate information icons.

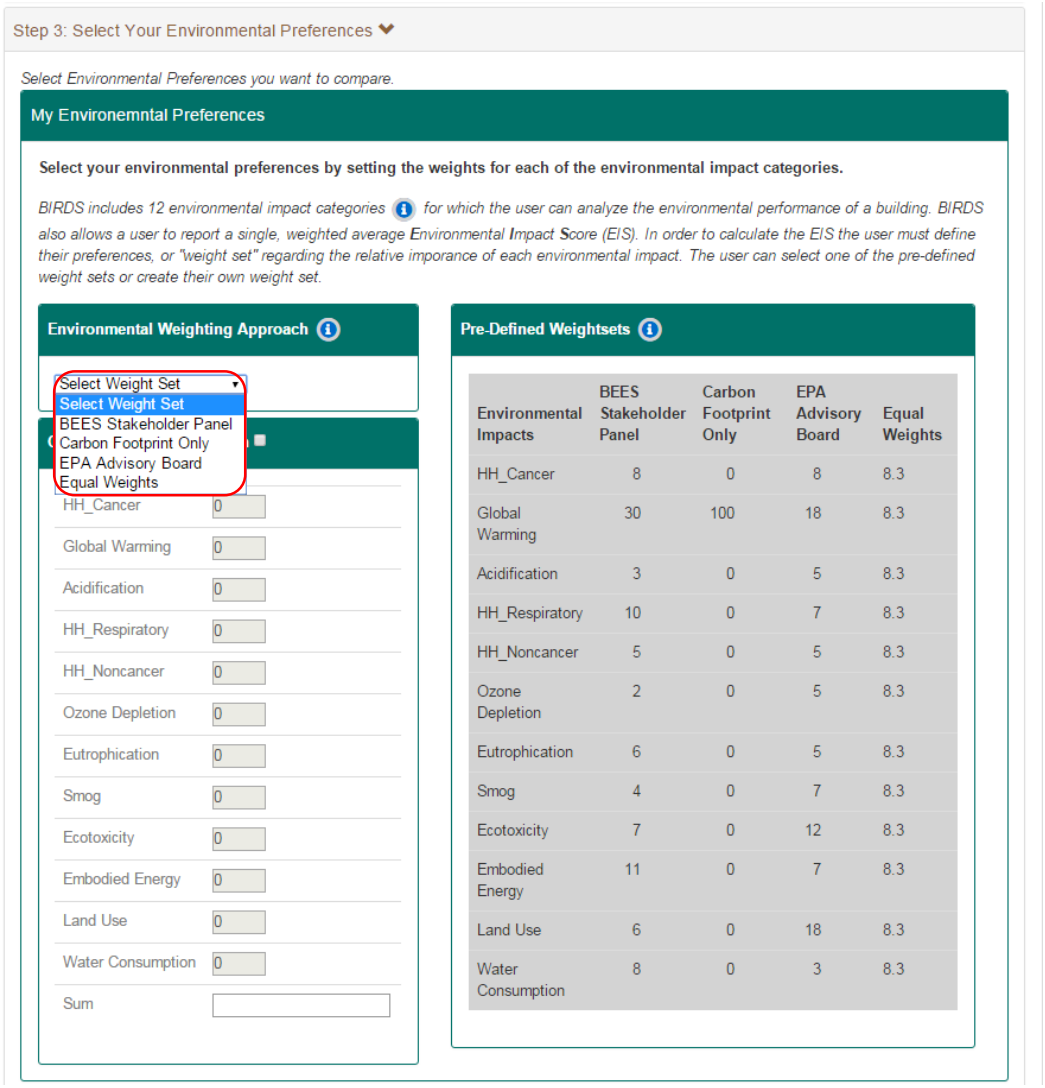

Figure 2-14 Selecting Environmental Weighting – Pre-defined Weighting Approach

Should the user choose to create their own series of weights, they must check the "Create Weighting Approach" box. They will then assign a weight ranging from 0 to 100 to each of the 12 impact categories. The sum of the weights must total 100. For this tutorial, assume that only four environmental impacts are important to the user (**Climate Change**, **Acidification** (i.e., acid rain), **Ozone Depletion**, and **Water Consumption**) and choose to place an equal weight on these categories (25) while ignoring the other impacts. They will check the "Create Weighting Approach" box, and assign a weight of **25** to these categories (Figure 2-15). Once the **My**

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Weights approach has been created with the weights adding up to 100, it can be selected in the drop down menu.

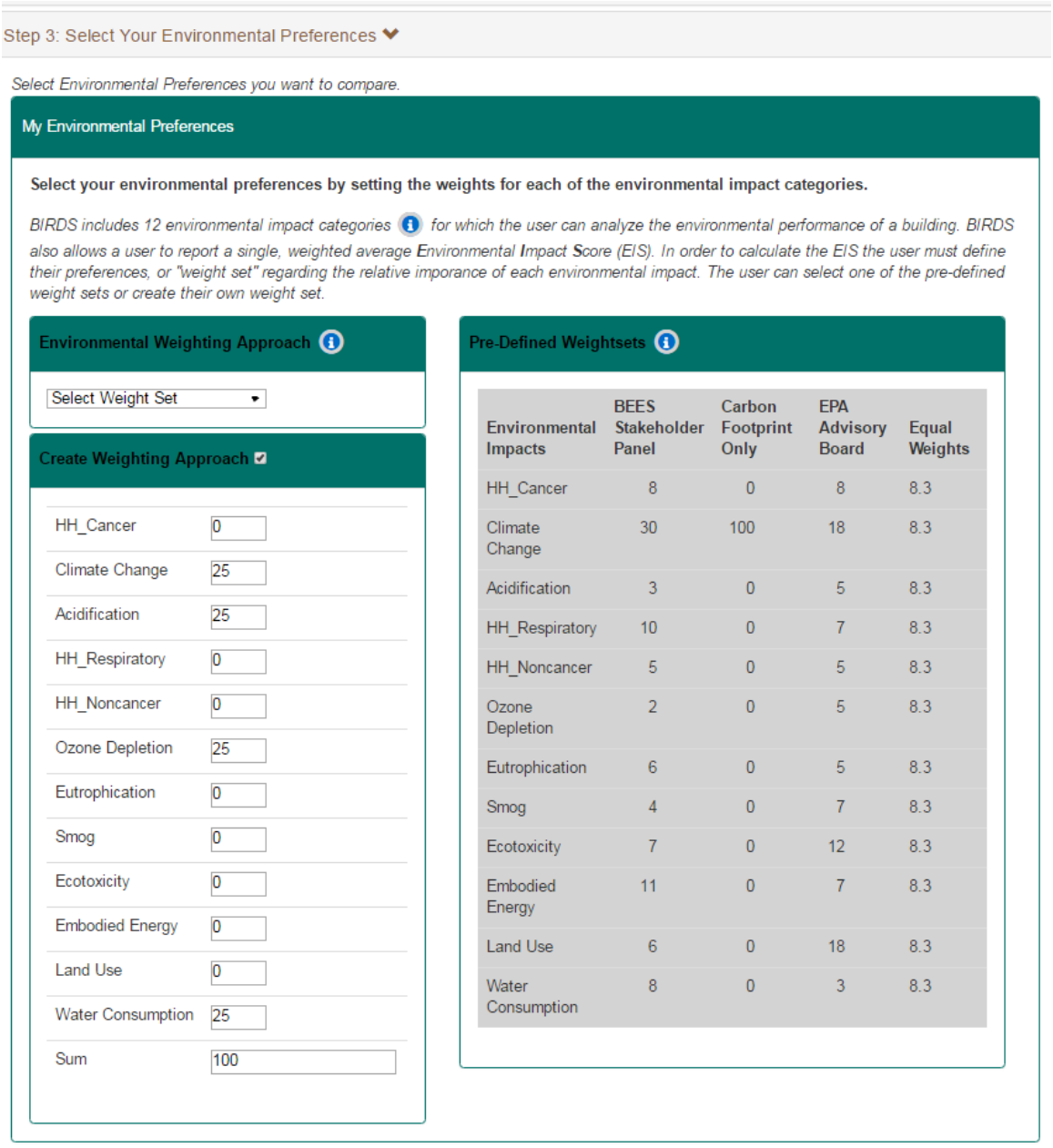

Figure 2-15 Selecting Environmental Weighting – Custom Weighting

Successful computation of database results is contingent on the proper selection of all the inputs discussed up to this point. If any of the general assumptions, baseline building design components, building component properties, and/or weighting preferences are not defined by the user at any point, no results will be displayed and any incorrect input parameters will be noted in red text.

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2.4 Step 4: Viewing Results

Clicking on the "Step 4: View Results" tab will display five results options: **Download Data**, **Summary Table**, **Scatter Plots**, **Radial Charts**, and **Line Charts**. A brief description of each option is available in the information icon to the right of the Results heading as shown in Figure 2-16. This section will discuss the data displayed, the types of comparisons that can be made, and how to interpret the results for each tab. Note that depending on the number of alternatives you select, it may take 10 to 20 seconds for the data to load. The results are defaulted to the Download Data tab. There will be a "thinking icon" while the loading is in process as shown in the top image of Figure 2-16.

2.4.1 Download Data

The **Download Data** tab allows BIRDS users to download all results data for all selected building design options in CSV format (BIRDSRawData.txt) for the purpose of conducting their own analysis, such as comparisons that cannot currently be displayed in BIRDS' graphing features. The user can download the data by clicking the "Download" button (bottom image in Figure 2-16). Units for the variables reported in the BIRDSRawData.txt file can be found in the BIRDS v3.1 Technical Manual (Kneifel et al. 2017).

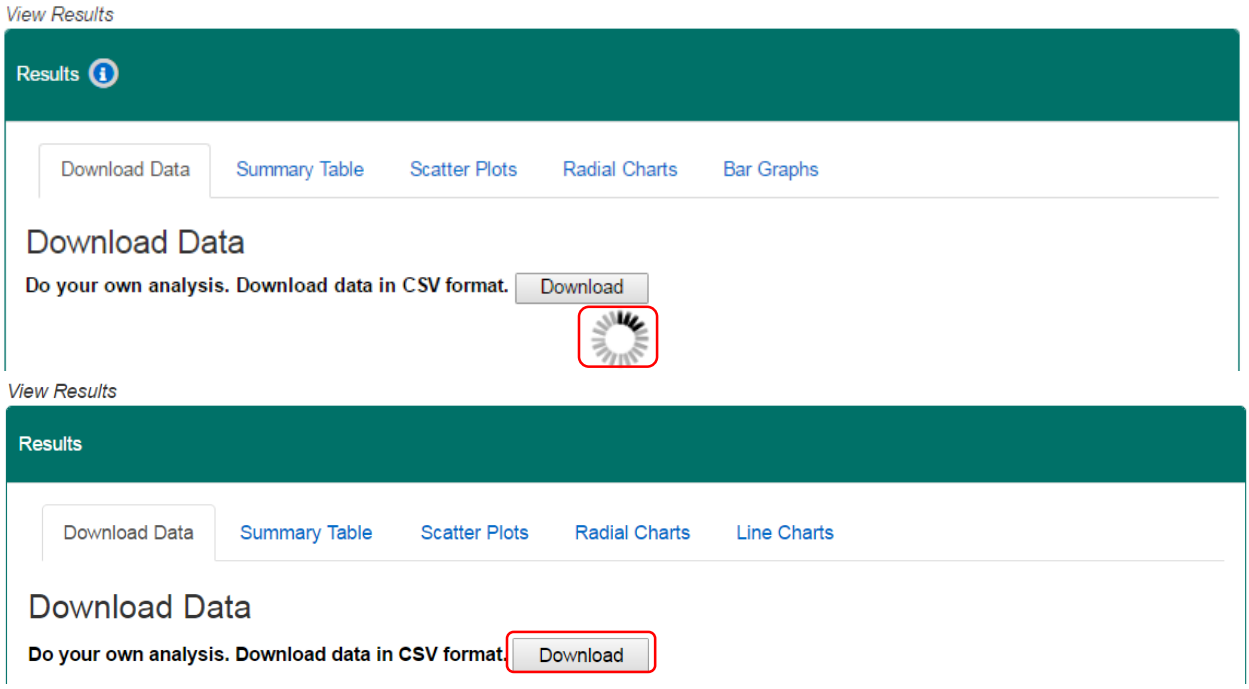

Figure 2-16 Downloading Data

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2.4.2 Summary Table

Clicking on the **Summary Table** tab will display two tables of data as shown in Figure 2-17. The top table displays the building characteristics for up to 6 key building designs from the subset selected in Step 1 and Step 2 above, which are defined as follows:

A = baseline design.
B = design that leads to the lowest LCC
C = design that leads to the lowest energy consumption for the same LCC as the baseline design
D = design that reaches net-zero energy performance at the lowest cost
E = design that reaches the lowest energy consumption
F = design that leads to the lowest EIS

Of these 6 key building designs, only one may not have a value reported in the table. Design D only exists in the user's subset if there is at least one building design that reaches net-zero energy consumption.

The bottom table displays the reported sustainability performance metrics for each of the key building designs defined above: LCC, initial investment cost, percentage change in energy consumption compared to baseline, percent change in EIS compared to baseline, percent change in climate change potential compared to baseline, hours not comfortable, hours CO_2 above 750 ppm, and hours CO_2 above 900 ppm. These results will be available to be displayed visually in the **Radial Charts** tab.

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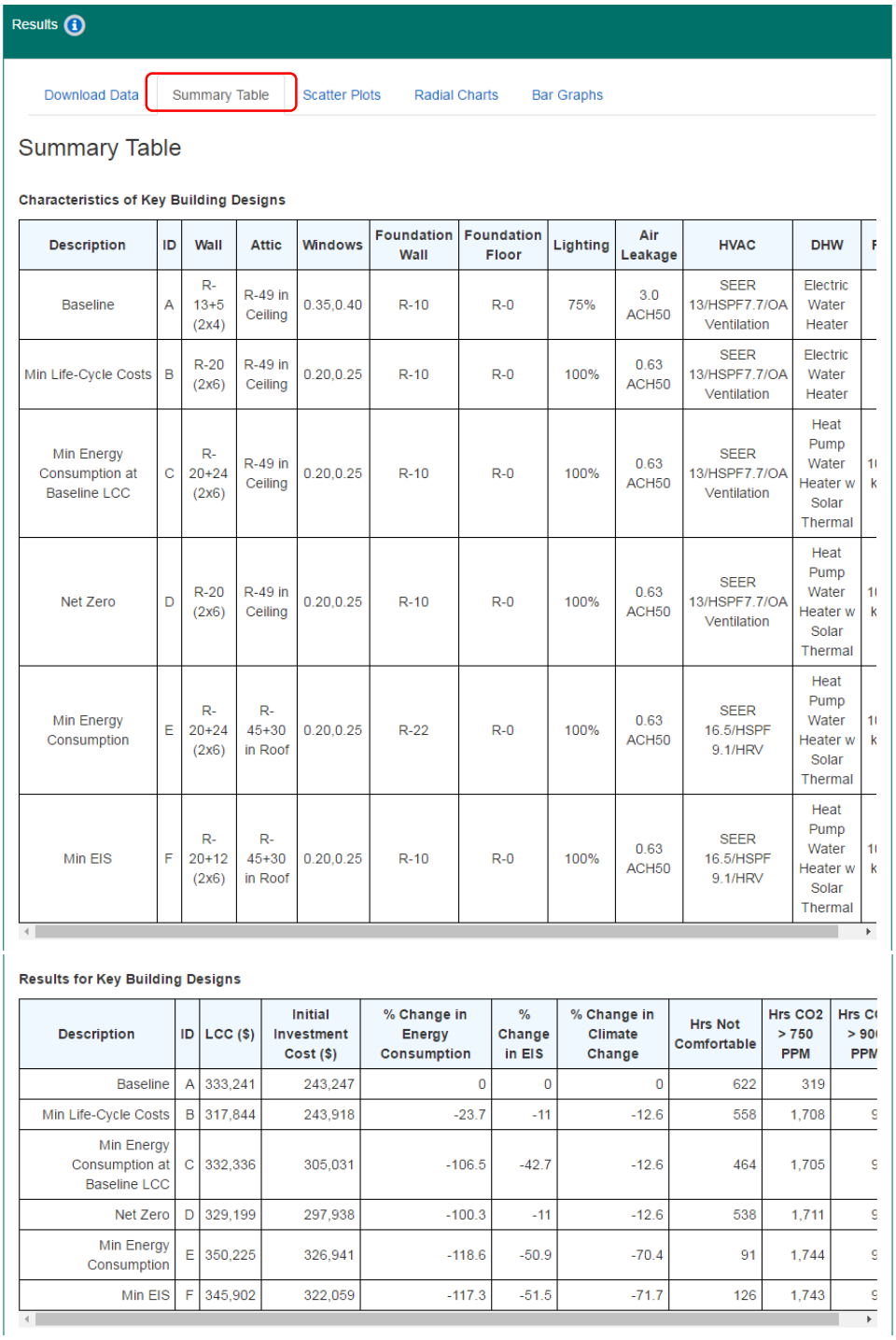

Figure 2-17 Summary Tables

2.4.3 Scatter Plots

Clicking on the **Scatter Plots** tab will display scatter plots as shown in Figure 2-18 that compare the life-cycle cost and initial investment costs (down payment at the time of home purchase) to energy savings relative to the baseline for two series of data: the key building designs shown in

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the **Summary Table** tab (**Key Points**) and the complete set of building designs selected in Step 1and Step 2 (**All Selected Points**). The Key Points are shown in yellow and can be identified by hovering the pointer over them. These comparisons allow a user to visualize how the LCC changes as energy savings are increased for the subset of building designs selected by the user. Additionally, the user can see how much additional investment cost the user will have to pay upfront to obtain that energy savings. A user can hide either series shown on the scatter plots by clicking on the series name (see red square in Figure 2-18). The scatter plots are most useful when the user selects a large number of alternatives across multiple building components.

For the results shown in Figure 2-18, the lowest LCC design also leads to energy savings of 23.7 % at almost no additional investment costs. The lowest cost net-zero energy design has lower LCC than the baseline design, and the greatest energy savings that can be obtained for the same LCC as the baseline design is 106.5 %. However, reaching net-zero energy performance has significant additional investment costs.

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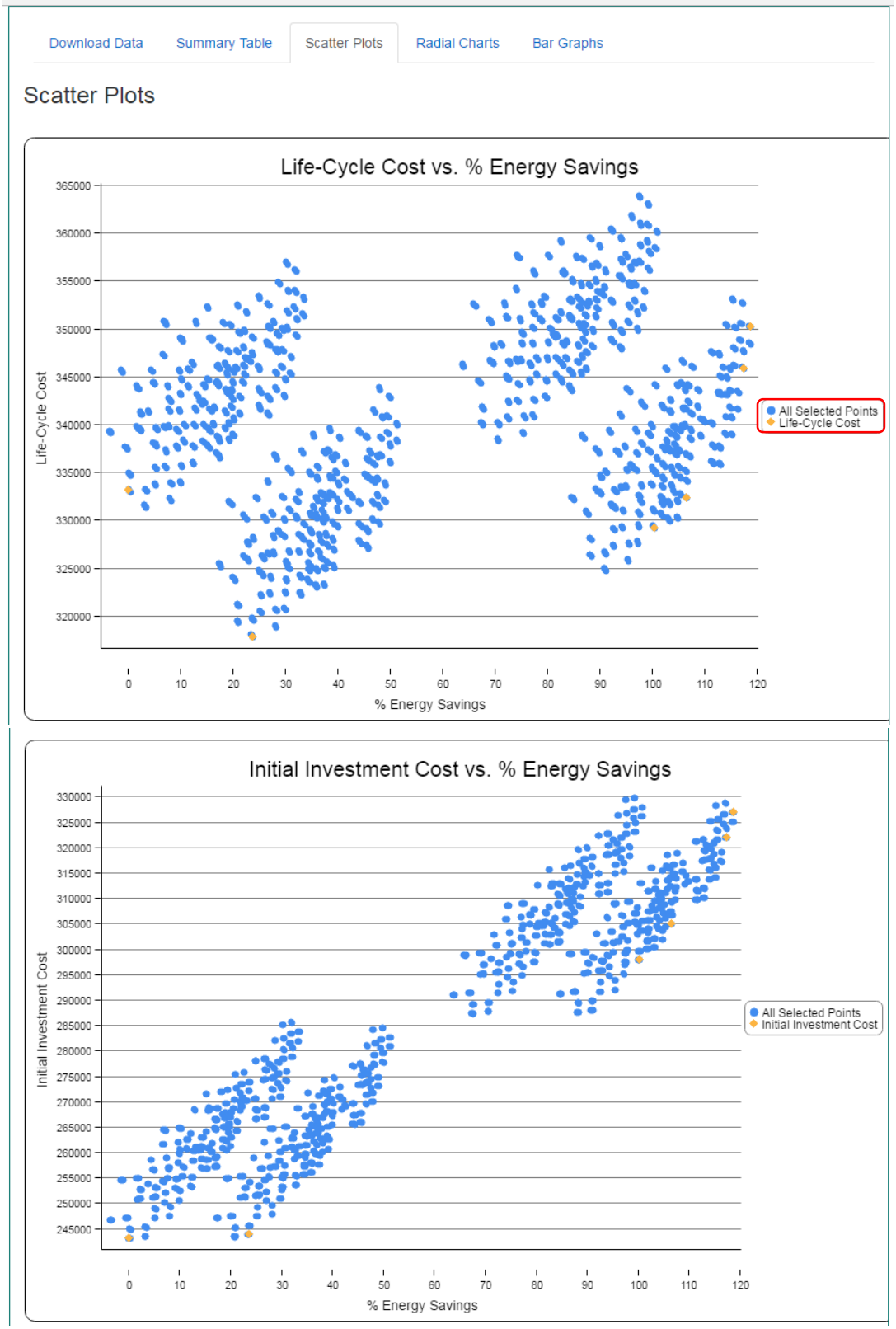

Figure 2-18 Scatter Plots

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2.4.4 Radial Charts

Clicking on the **Radial Charts** tab will display radial charts for two series of data as shown in Figure 2-19: the metrics displayed in the **Summary Table** tab and the 12 environmental impact categories. These results are displayed as the percent change relative to the baseline and percentage of the baseline building design value, respectively. A user can hide any series shown on the radial charts by clicking on the series letter in the legend.

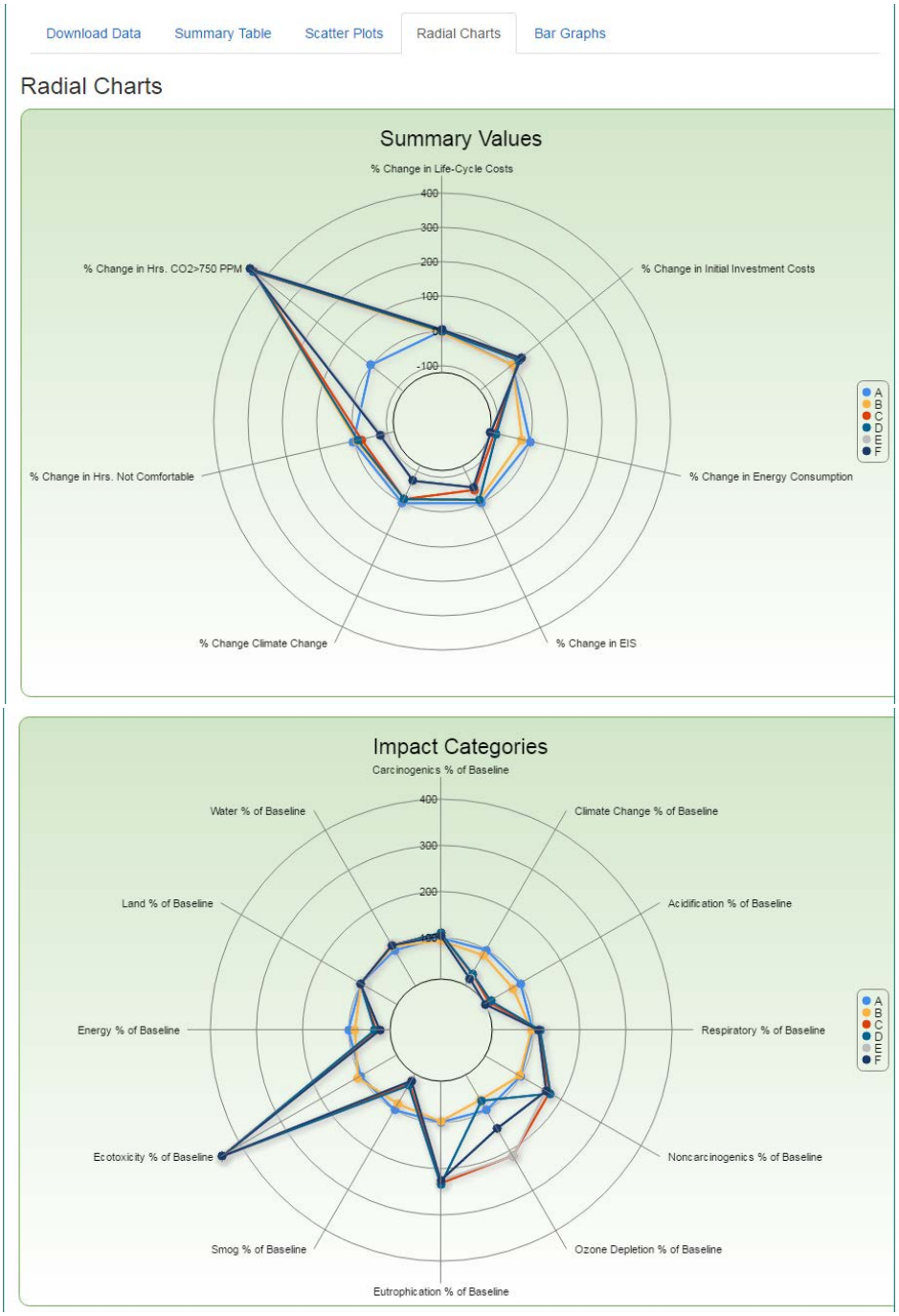

Figure 2-19 Radial Charts

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The radial charts provide a visual comparison for each of the metrics considered in the **Summary Table** tab. The most energy efficient building designs generally lead to lower hours for which the occupants are uncomfortable (**Hrs. Not Comfortable**). However, the number of hours during which the average CO_2 levels in the house are higher than 750 ppm (**Hrs. CO2>750 PPM**) is higher for all key points relative to the baseline, showing the importance of considering a range of metrics in determining the relative comparison of the performance of building designs. As the energy consumption decreases, so does the overall **EIS**, **Climate Change**, **Smog**, and **Acidification** impact category results due to the reduction in energy-related emissions. However, some of the individual environmental impact category results are worse for the more efficient building designs. The greatest percentage change is in **Ecotoxicity**. Significant increases are also realized in **Eutrophication**, **Ozone**, and **Non-carcinogenics** human health effects.

2.4.5 Bar Graphs

The bar graphs allow a user to make two types of comparisons in building performance:
(1) comparisons of different editions of IECC for which one is comparing the combination of building component changes from one edition to another
(2) comparisons of incremental changes of a single building component holding all other building components constant using the selected baseline building design

This tutorial will cover an example of both types of comparisons, first for changing the wall assembly of the baseline building design and then for comparing three IECC editions. Note that if a user does not select any alternative incremental building component options in Step 2, then the bar graphs will only display the value for the baseline building design.

2.4.5.1 Wall Assembly Comparisons

Clicking on the **Bar Graphs** tab will display the "Select Chart Options" menu to create bar graphs of select comparisons. Five different analysis options are available in the application: **Life-Cycle Cost**, **Operating Energy**, **Environmental Impact**, **Thermal Comfort**, and **Indoor Air Quality**. As shown in Figure 2-20, the user must first "Select Analysis" from the dropdown menu, then the "Building Component for Comparison" for the comparison to be made, and the "Units" in which the user prefers the results. Note that the units include a per unit of floor area impact, which is only reported in square feet (ft^2) within BIRDS and not square meters because the tool is designed for use in the United States. For additional information, a user can click on the information icons. Once the user has made these selections, the user presses the "View" button to see the results, at which point the results graph with its corresponding data table will be displayed. Assume that the user is interested in comparing the incremental impacts from increasing the thermal performance of the wall assembly.

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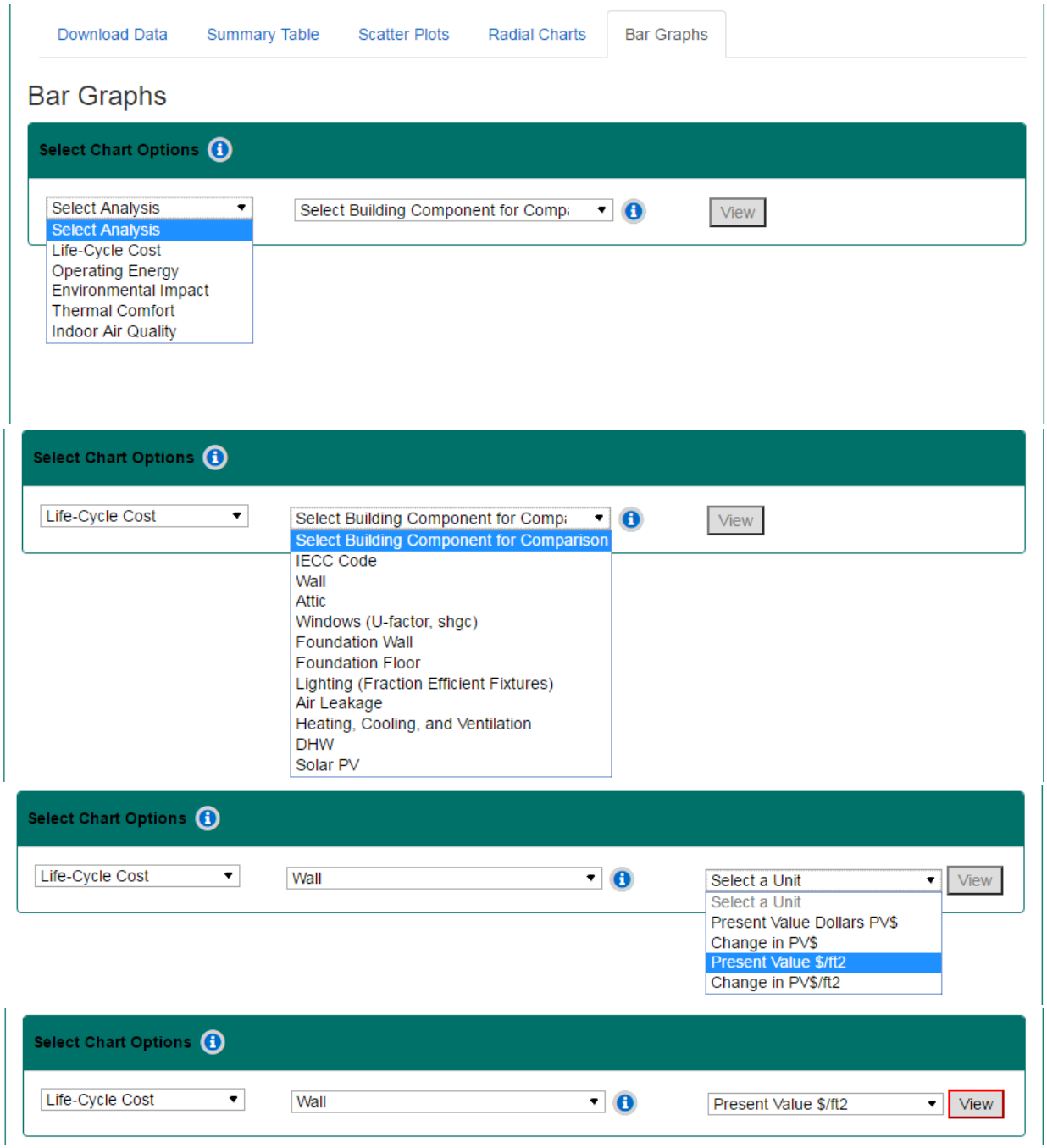

Figure 2-20 Selecting Bar Graph Options

Assume that the first comparison the user would like to view is the life-cycle costs of the baseline building design as the wall assembly is changed. Figure 2-21 shows the Life-Cycle Cost results with a graph of the total life-cycle costs per ft^2 in present value dollars (PV$) for the baseline and the three design alternatives given a 30-year study period. As can be seen in the graph, total present value life-cycle costs per unit of floor area vary from \$1330/m^2 (\$123.40/ft^2) to \$1340/m^2 (\$124.30/ft^2). Switching from **R-13+5 (2x4)** to an **R-20 (2x6)** wall assembly has

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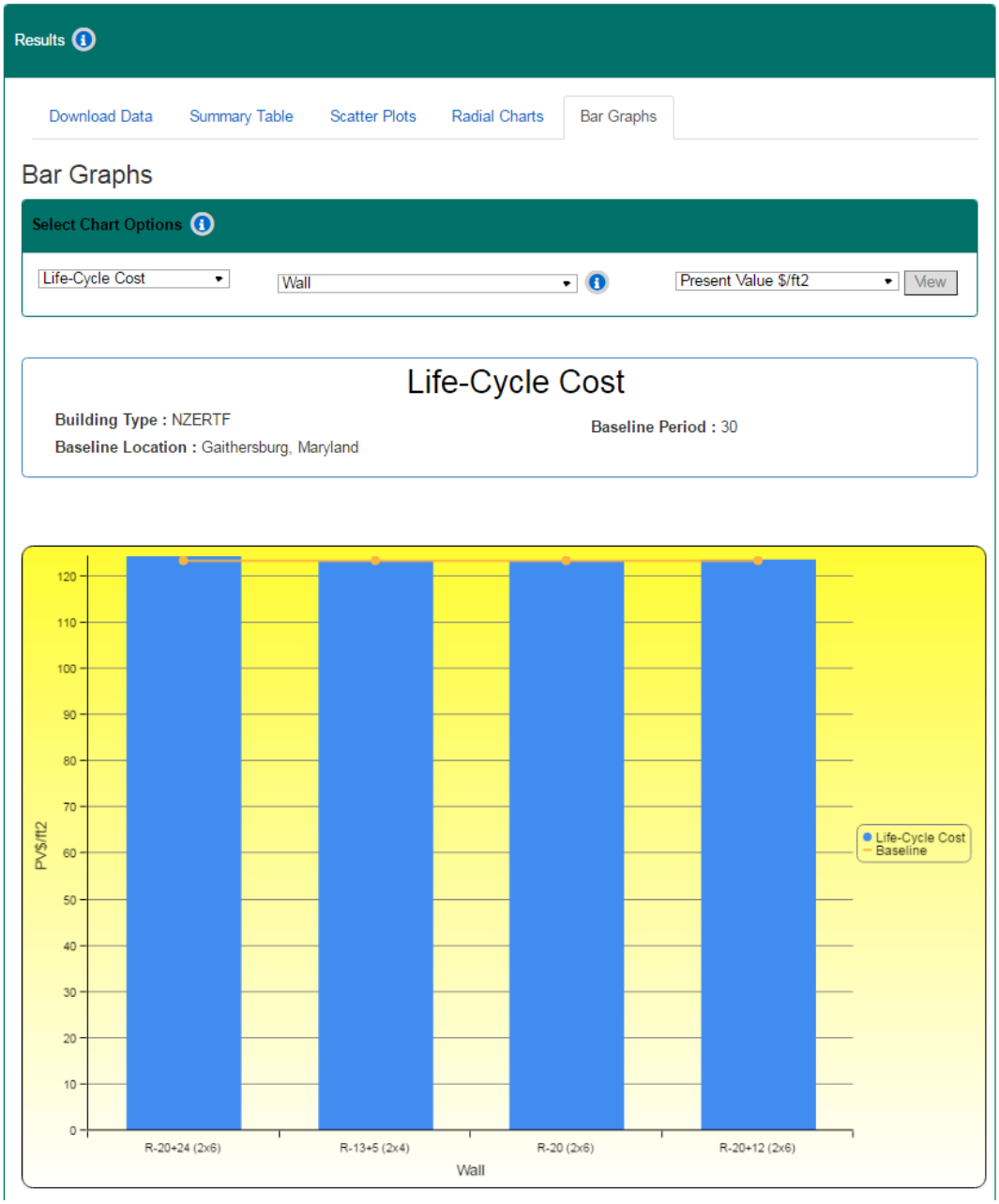
relatively no impact on costs per ft^2. Only in the cases where the additional rigid insulation is added are there noticeable changes (small increases) in the life-cycle costs per unit of floor area.



Life-Cycle Cost	Unit	R-20+24 (2x6)	R-13+5 (2x4)	R-20 (2x6)	R-20+12 (2x6)
Total	Present Value Dollars PV$	335,722	333,241	333,337	333,940
Change from Baseline	Change in PV$	2,481	0	97	699
Total	Present Value $/ft2	124.3	123.4	123.5	123.7
Change from Baseline	Change in PV$/ft2	0.9	0	0	0.3
Change from Baseline	%	0.7	0	0.0	0.2

Figure 2-21 Life-Cycle Cost Graph by Wall Assembly for Baseline Assumptions

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A user can interact with the graph by scrolling over and viewing the value of each data point.

The data table displayed below the graph is more comprehensive, and includes all the possible metrics available for comparisons across wall assemblies given the baseline assumptions. The table includes total life-cycle costs, change in life-cycle costs relative to the baseline, total life-cycle costs per ft^2, change in life-cycle cost per ft^2 relative to the baseline, and percentage change in life-cycle costs relative to the baseline.

The next series of steps are used to evaluate the impacts of wall assembly structure changes on energy use. By changing the chart type from **Life-Cycle Cost** to **Operating Energy**, keeping **Wall** as the building component for comparison, selecting **Change in kWh** as the unit of measure and clicking "View", the user can now observe the total changes in annual energy use (in kWh) across the four selected wall component alternatives (Figure 2-22) relative to the baseline (**R-13+5 (2x4)**). Because all building designs are being compared to the baseline, the change in energy consumption is 0 (zero) for the baseline design. Switching from the baseline to an **R-20 (2x6)** wall assembly leads to only a minimal increase in total energy use of 765 kWh over 30 years. Although the wall assembly structures have changed between the baseline and the alternative, the overall thermal integrity of the wall has slightly declined, resulting in a slight increase in consumption. On the other hand, use of either R-12 or R-24 rigid insulation in addition to the R-20 batt insulation significantly improves the overall thermal resistance of the walls, reducing total energy use by roughly 4.9 % (34 650 kWh) and 6.8 % (48 276 kWh), respectively. Again, a more comprehensive data table can be found below the graph.

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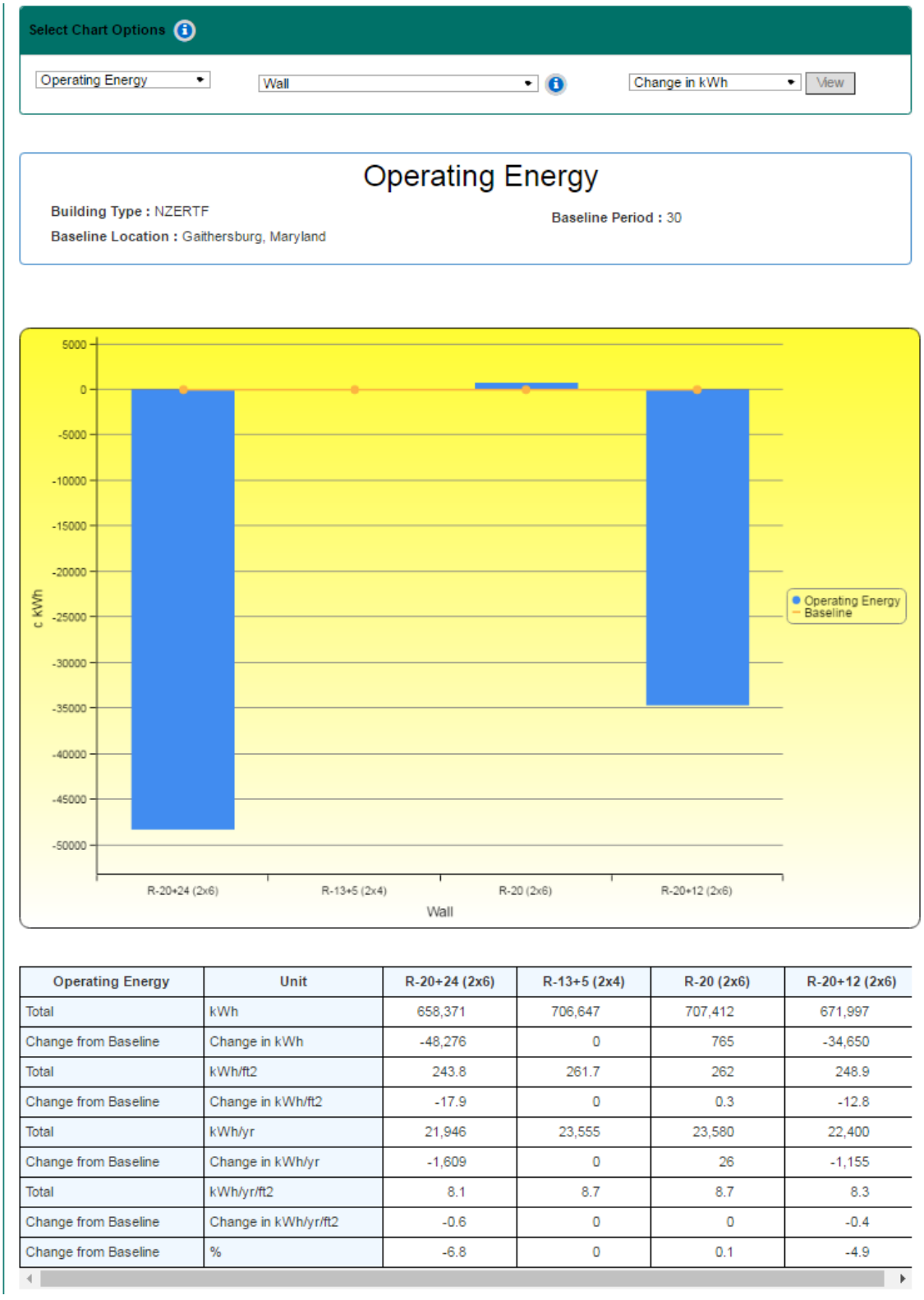

Operating Energy	Unit	R-20+24 (2x6)	R-13+5 (2x4)	R-20 (2x6)	R-20+12 (2x6)
Total	kWh	658,371	706,647	707,412	671,997
Change from Baseline	Change in kWh	-48,276	0	765	-34,650
Total	kWh/ft2	243.8	261.7	262	248.9
Change from Baseline	Change in kWh/ft2	-17.9	0	0.3	-12.8
Total	kWh/yr	21,946	23,555	23,580	22,400
Change from Baseline	Change in kWh/yr	-1,609	0	26	-1,155
Total	kWh/yr/ft2	8.1	8.7	8.7	8.3
Change from Baseline	Change in kWh/yr/ft2	-0.6	0	0	-0.4
Change from Baseline	%	-6.8	0	0.1	-4.9

Figure 2-22 Operating Energy Graph by Wall Assembly for Baseline Assumptions

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If the user is interested in seeing how the different building designs impact the life-cycle environmental performance of the house, he/she must select the environmental impact category, which can be either a single impact category or the weighted average impact (Environmental Impact Score – EIS) based on the weighting approach selected in Step 3 (**My Weights**). In this case, assume that the user wishes to view the Environmental Impact Score. By selecting **Environmental Impact – All (weighted) – Environmental Impact Score**, the user sees the results in Figure 2-23, which shows that the **R-20+24** wall assembly leads to the lowest EIS (12.957).[6]

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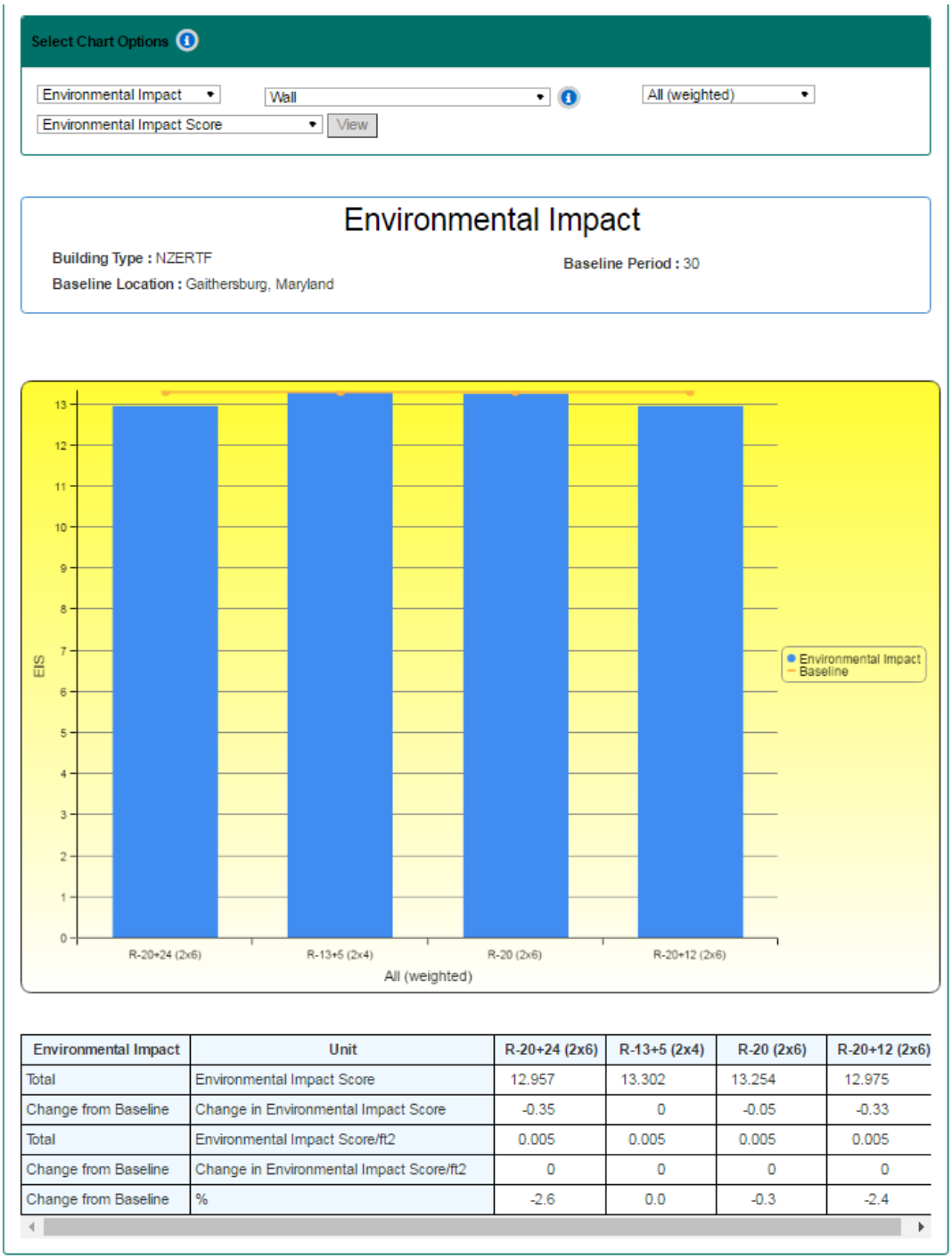
[6] Note that the EIS is an aggregate measure to allow for relative comparisons across building designs based on a user's environmental preferences, and is only useful when comparing designs using the same weighting approach. Therefore, the magnitude of a single EIS cannot be interpreted on its own.



Environmental Impact	Unit	R-20+24 (2x6)	R-13+5 (2x4)	R-20 (2x6)	R-20+12 (2x6)
Total	Environmental Impact Score	12.957	13.302	13.254	12.975
Change from Baseline	Change in Environmental Impact Score	-0.35	0	-0.05	-0.33
Total	Environmental Impact Score/ft2	0.005	0.005	0.005	0.005
Change from Baseline	Change in Environmental Impact Score/ft2	0	0	0	0
Change from Baseline	%	-2.6	0.0	-0.3	-2.4

Figure 2-23 Environmental Impact Score by Wall Assembly – for Baseline

The user can also view each individual environmental impact category result. For example, Figure 2-24 shows a graph of the total **Climate Change Potential** impacts in kilograms of carbon dioxide equivalent (CO_2e) emissions. Switching to an **R-20+12** wall assembly has the highest impact on climate change potential, with a decrease of 14 499 kg of CO_2e relative to the 2015 IECC design.

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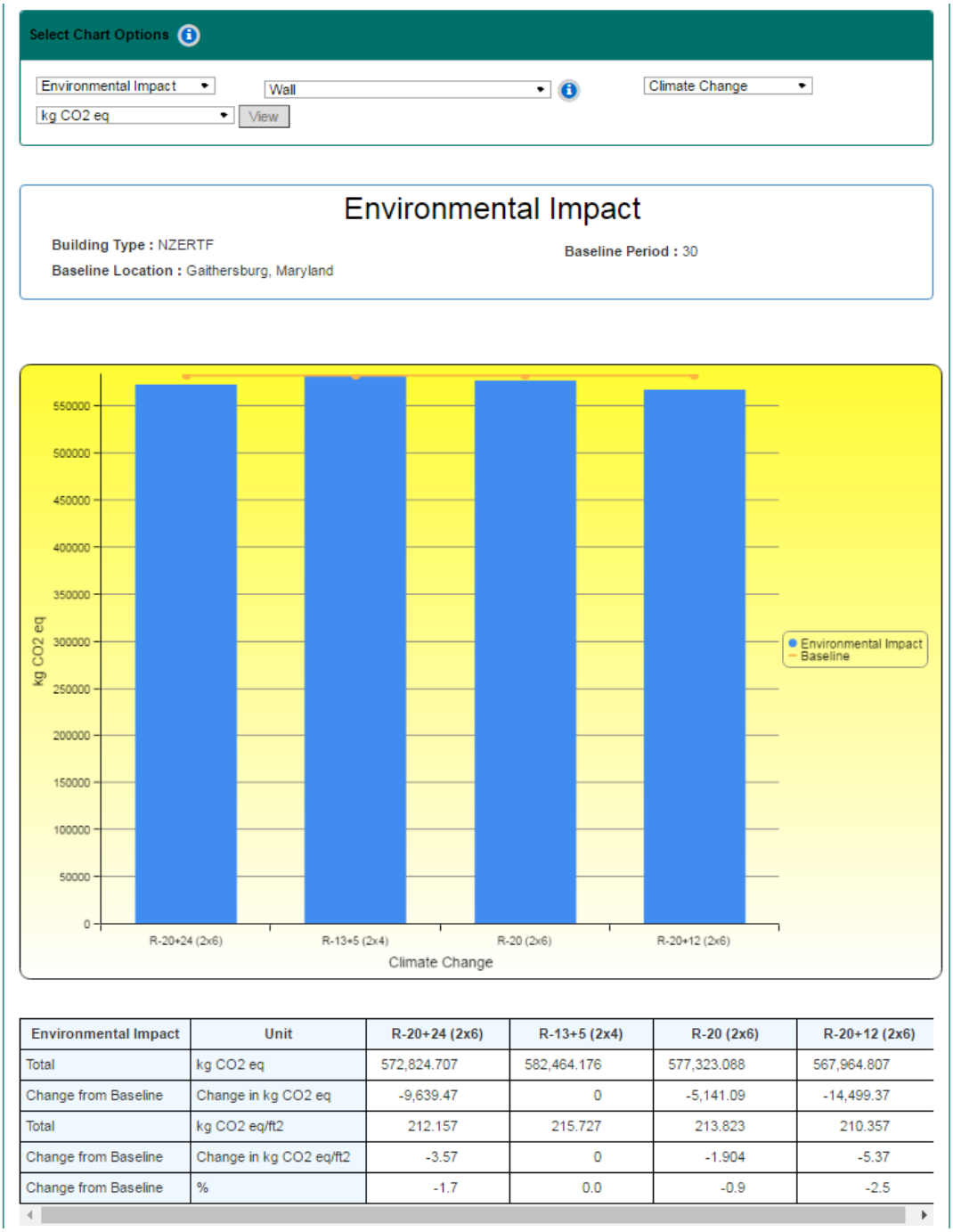

Environmental Impact	Unit	R-20+24 (2x6)	R-13+5 (2x4)	R-20 (2x6)	R-20+12 (2x6)
Total	kg CO2 eq	572,824.707	582,464.176	577,323.088	567,964.807
Change from Baseline	Change in kg CO2 eq	-9,639.47	0	-5,141.09	-14,499.37
Total	kg CO2 eq/ft2	212.157	215.727	213.823	210.357
Change from Baseline	Change in kg CO2 eq/ft2	-3.57	0	-1.904	-5.37
Change from Baseline	%	-1.7	0.0	-0.9	-2.5

Figure 2-24 Climate Change Potential by Wall Assembly Structure – for Baseline Assumptions

If the user is interested in seeing how the different building designs impact occupants' thermal comfort, he/she can do so by selecting **Thermal Comfort** and **Change in Hours Uncomfortable**, the user sees the results in Figure 2-25, which shows that the **R-20+24** wall assembly leads to the greatest reduction in the number of hours for which the occupants are uncomfortable.

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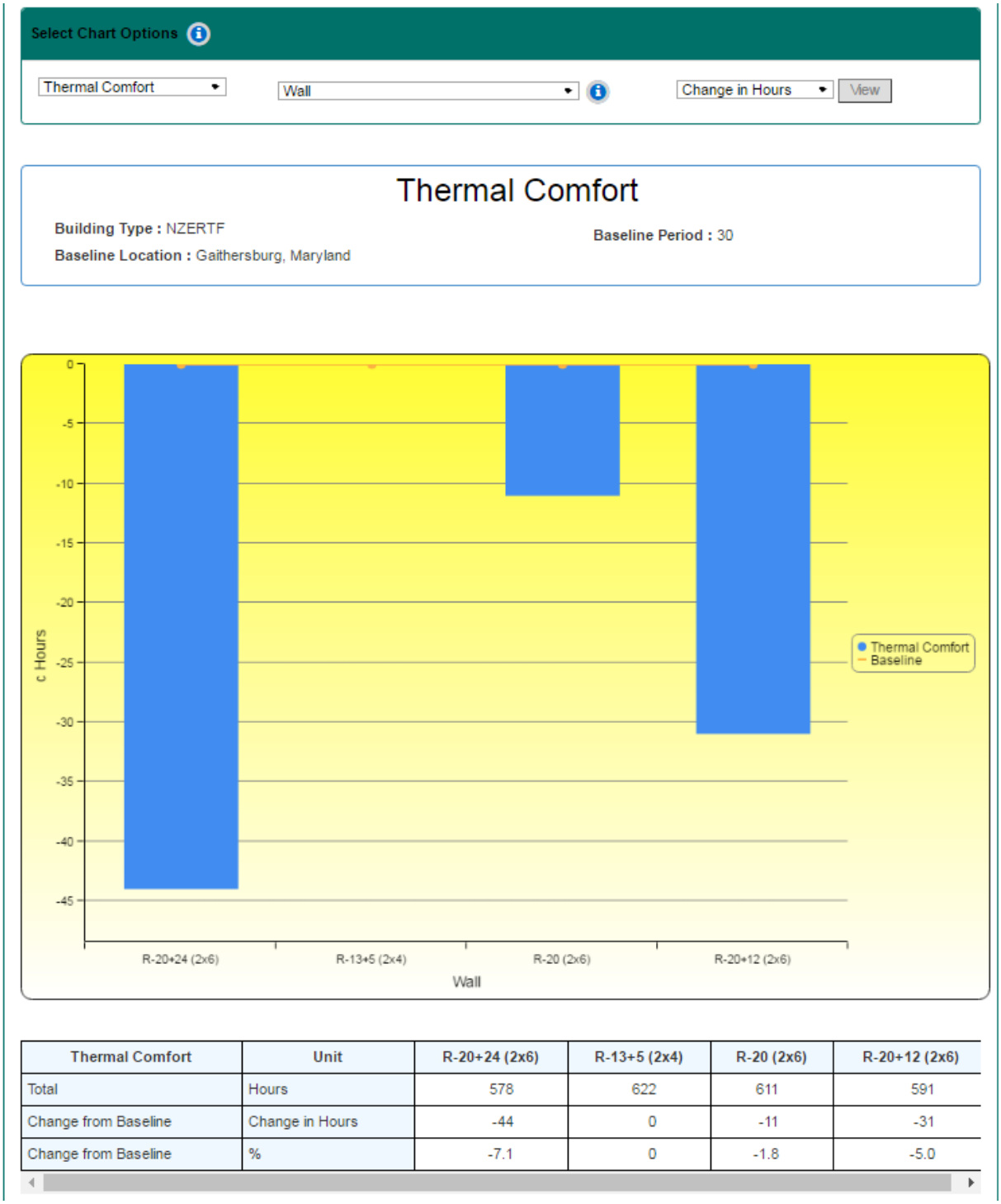

Thermal Comfort	Unit	R-20+24 (2x6)	R-13+5 (2x4)	R-20 (2x6)	R-20+12 (2x6)
Total	Hours	578	622	611	591
Change from Baseline	Change in Hours	-44	0	-11	-31
Change from Baseline	%	-7.1	0	-1.8	-5.0

Figure 2-25 Thermal Comfort

The other indoor environmental quality metric is a proxy for indoor air quality using the average level of CO_2. By selecting **Indoor Air Quality – Wall – Hours > 900 PPM**, the user sees the results in Figure 2-26, which show that the three alternatives do not have much impact on the indoor air proxy (approximately a one-hour difference).

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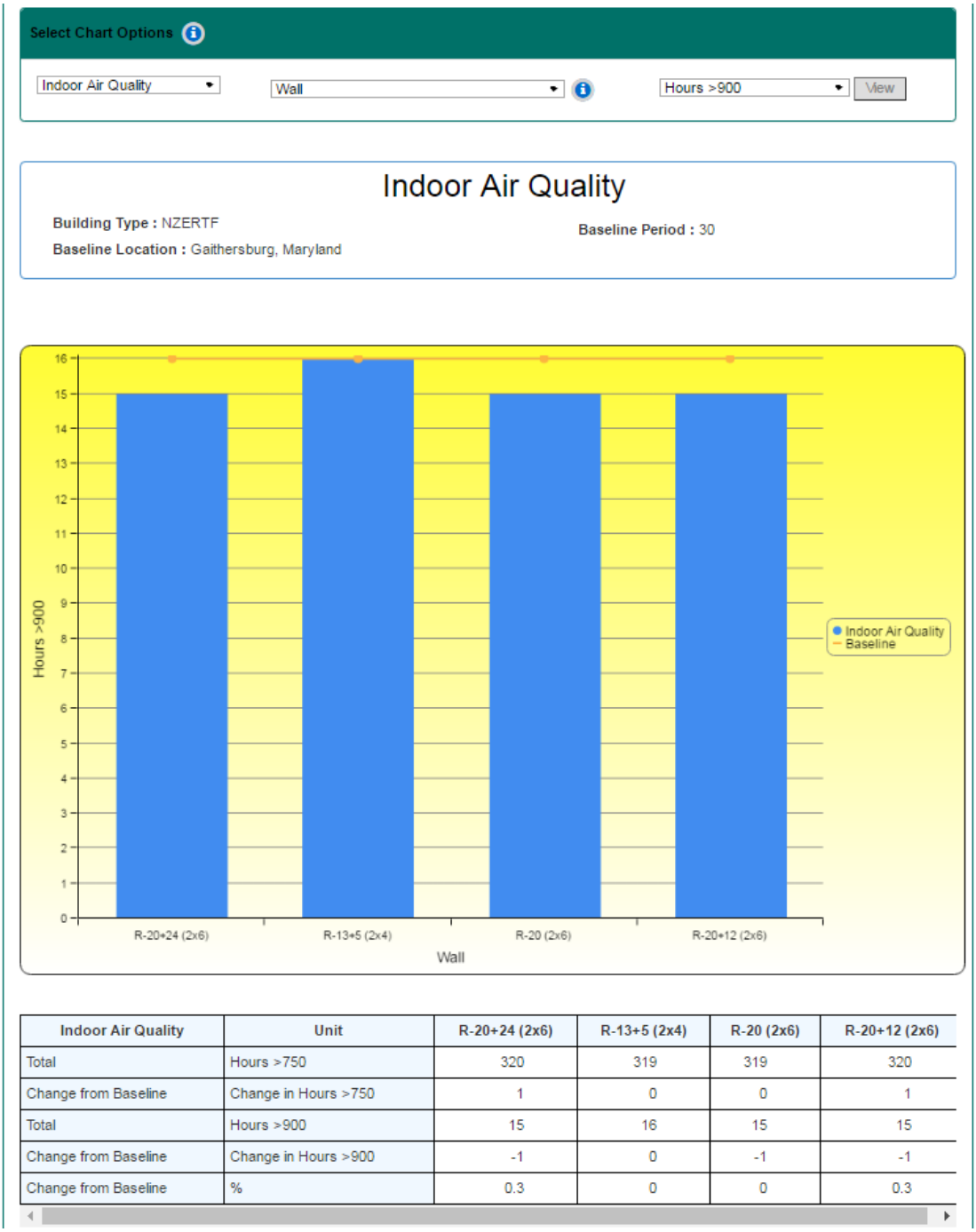

Indoor Air Quality	Unit	R-20+24 (2x6)	R-13+5 (2x4)	R-20 (2x6)	R-20+12 (2x6)
Total	Hours >750	320	319	319	320
Change from Baseline	Change in Hours >750	1	0	0	1
Total	Hours >900	15	16	15	15
Change from Baseline	Change in Hours >900	-1	0	-1	-1
Change from Baseline	%	0.3	0	0	0.3

Figure 2-26 Indoor Air Quality

2.4.5.2 IECC Edition Comparisons

The user can use the same approach to compare the performance of the different editions of IECC. As shown in Figure 2-27, the user selects **Operating Energy** from the "Select Analysis" dropdown menu, selects **IECC Code** from the "Building Component for Comparison" dropdown

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menu, and **Change in kWh** from the "Units" dropdown menu. The older the edition of IECC, the greater the increase in energy consumption.

Operating Energy	Unit	2012/2015	2006	2009
Total	kWh	706,647	986,037	973,218
Change from Baseline	Change in kWh	0	279,390	266,571
Total	kWh/ft2	261.7	365.2	360.5
Change from Baseline	Change in kWh/ft2	0	103.5	98.7
Total	kWh/yr	23,555	32,868	32,441
Change from Baseline	Change in kWh/yr	0	9,313	8,886
Total	kWh/yr/ft2	8.7	12.2	12
Change from Baseline	Change in kWh/yr/ft2	0	3.4	3.3
Change from Baseline	%	0	39.5	37.7

Figure 2-27 Selecting Bar Chart Options for IECC Edition Comparisons

As in the case of the wall assembly comparisons, IECC editions can be compared across the other four analysis types: LCC, environmental impacts, thermal comfort, and IAQ

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3 Summary

This tutorial walked a user step-by-step through using the BIRDS v3.1 Low-Energy Residential interface, including guidance and recommendations to assist a user in better understanding their selections and how to view and interpret results comparisons. The example in this tutorial compared the performance of a house based on the NZERTF, but built to minimally meet Maryland code requirements (2015 IECC), to alternative building designs using the following approaches:

(1) Constructing to meet requirements in different editions of the IECC relative to current Maryland code requirements
(2) Changing the thermal performance of the exterior wall assembly relative to current Maryland code requirements
(3) Considering different combinations of building components using current Maryland code requirements and the specifications of the NZERTF

The energy, environmental, economic, and indoor environmental quality performance were analyzed to show the capabilities of BIRDS, including the Download button that gives the user the option to analyze the data outside of BIRDS through a csv file download that includes all the results of the selected alternatives. Users can select as much (240 000 building design alternatives) or as little data as desired for comparisons. The associated documentation (Kneifel et al. 2017) for the BIRDS Low Energy Residential database will assist with any questions related to the underlying definitions, assumptions, data sources, and methodology.

Future versions of the BIRDS Low-Energy Residential database will expand on these general analysis assumptions to give the user even greater customization. A high priority has been placed on incorporation of additional locations and building prototypes as well as additional options for the parameters that already have two or more options available. In addition to new assumption options, additional building component options will be included in future versions of BIRDS, including gas space and water heating. Future versions of BIRDS will also update the other two databases (Commercial and Residential) and associated web interfaces with additional energy standard and code edition results and new features to improve the user experience. Please feel free to give your feedback on issues with BIRDS, information on how you use BIRDS, and/or what additional features you would like to have in future versions of BIRDS by sending an email to birds@nist.gov.

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