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DESIRED POINTS AT MINIMUM COST IN THE "OPTIMIZE ENERGY PERFORMANCE" CREDIT OF LEED CERTIFICATION

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Abstract. This paper presents a method that guides designers in obtaining the desired number of earned points in the "Optimize Energy Performance" credit of the "Energy and Atmosphere" category of LEED version 4 (v4) certification at minimum cost. The model creates different scenarios, identifies the LEED points and costs for each scenario. The energy analysis calculations are performed by Sefaira, the quantities of materials are received from Autodesk Revit, and the cost information comes from the RSMeans Database. A macro in Excel automates the process. An office building was used as a case study to illustrate the applicability of the proposed method. The minimum cost necessary to achieve any number of points in the "Optimize Energy Performance" credit were calculated, such as a minimum cost of $842,500 to obtain 16 points, and $476,684 for 5 points. The primary contributions of this research include (1) the development of a tool that allows designers to pick the most economical alternative for the desired points in the "Optimize Energy Performance" credit, and (2) the first time integrated use of an energy simulation software (Sefaira), a cost database (RSMeans), and a BIM software (Autodesk Revit).

Keywords: sustainability, LEED, energy, green building.

Introduction

The world's energy demand has increased with the rapid increase in industrialization and population, whereas energy sources are being depleted. The construction industry's impact on global energy issues is quite pronounced. In the U.S., buildings are responsible for 73% of electricity consumption, 38% of CO_2 emissions, and 13.6% of potable water consumption (USGBC 2016). As a result of this situation, the sustainable building movement has gained popularity in recent years. Green buildings play an important role in establishing and administering sustainable strategies in the construction industry. Green Buildings can reduce CO_2 emissions, water use, solid waste, and energy use.

To measure the level of sustainability, in other words, the greenness of buildings, more than 34 green building rating systems have been developed (Fowler, Rauch 2006). The British Research Establishment Environmental Assessment Method (BREEAM), Canada's Building Environmental Performance Assessment Criteria (BEPAC), and the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) are the main rating systems that are extensively used in the construction industry. As LEED uses simple checklists (Ding 2008) and involves a well-organized rating system (Dakwale *et al.* 2011), it is the most extensively used green building certification system all over the world. The LEED rating system was used to assess more than 72,000 buildings in more than 150 countries (USGBC 2016). In addition, 88 of the Fortune 100 companies are also using LEED as a green building rating system (USGBC 2016). LEED rates new and existing commercial, industrial and high-rise residential buildings according to their environmental attributes and sustainable features. The LEED rating system is regularly improved to satisfy the market's demand. LEED v4 is the latest version of the rating system and was launched in 2013.

LEED v4 has twelve prerequisites and 45 credits that can earn 110 elective points. These prerequisites and credits are organized in six categories and two bonus categories. The Energy and Atmosphere category accounts for the largest number of points (33 out of the possible 110) and constitutes 30% of achievable points. On the other hand, as Da Silva and Ruwanpura (2009) mentioned, although the largest number of points can be achieved in the Energy and Atmosphere category, designers are often able to achieve only few of these points. So this category should be given extra attention by project owners and designers.

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The Energy and Atmosphere category consists of four prerequisites and seven credits. Among these credits, a maximum of 18 points can be achieved in the "Optimize Energy Performance" credit, by far the largest number of points in the Energy and Atmosphere category, constituting 55% of the achievable points in this category. The energy performance of a building can be improved by designing efficient heating, ventilation and air conditioning (HVAC) systems or by specifying appropriate building envelopes. This can be achieved by performing building energy modeling using simulations. This process allows the analyst to obtain the energy consumption in a specific time period. Energy simulation is performed according to thermodynamic equations, principles, and assumptions (Maile *et al.* 2007). The accuracy of the energy simulation tool depends on input data that includes the building geometry (building floorplan, building orientation, building components), HVAC systems, location, and internal loads (equipment and lighting loads). The output is the energy use intensity (EUI) of the building. So in order to improve the energy performance of a building, in other words, to decrease the EUI of a building, building geometry, HVAC systems, and internal loads should be designed accordingly. It should be noted that the "Optimize Energy Performance" credit is the most complex credit in this category.

In order to earn points in the "Optimize Energy Performance" credit, designers have to prepare two simulation models for the project. In the first simulation, they calculate the yearly energy use intensity (EUI) for the baseline project which is determined according to American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2010; in the second simulation, they obtain an improved yearly energy use intensity (EUI). As seen in Table 1, the number of points earned in this credit depends on the percentage of the improvement compared to the baseline.

The highest level of certification requires considerable effort and extra initial cost. Therefore, the main question for project owners is how they can get the desired points in each category at minimum cost. The objective of this research is to develop a method that allows designers to obtain the desired points in the "Optimize Energy Performance" credit by picking glazing, wall, floor, and roof components that have acceptable insulation characteristics at minimum cost.

1. Background research

Sustainability and green buildings have recently been getting the attention of researchers. Several research studies were performed to analyze the different types of green building rating systems (e.g., Xia *et al.* 2013; Kibert 2008; Aktas, Ozorhon 2015; Castro-Lacouture *et al.* 2009; Bond 2010; Da Silva, Ruwanpura 2009; Reed *et al.* 2009) and the importance of LEED certification in reducing energy consumption (e.g., Scofield 2013; Fuerst 2009). Several research studies were conducted to analyze the design, operation, and optimization of HVAC systems in buildings (e.g., Congradac, Kulic 2009; Chow *et al.* 2002; Fong *et al.* 2006; Huang, Lam 1997; Kumar *et al.* 2010; Bichiou, Krarti 2011; Lu *et al.* 2005), building envelope optimization to increase building performance (e.g., Ouarghi, Krarti 2006; Yi, Malkawi 2009; Wright *et al.* 2002; Wang *et al.* 2006; Adamski 2007; Wang *et al.* 2005; Caldas, Norford 2003; Marks 1997), the importance of lighting for sustainable movements (e.g., Khan, Abas 2011; Aman *et al.* 2013; Houri, Khoury 2010; Ryckaert *et al.* 2012; Moeck, Yoon 2004), and the economic benefits of green buildings (e.g., Ries *et al.* 2006; Kats 2003; Sherwin 2006; Joshua 2010).

Table 1. LEED points corresponding to percentage improvement in energy use intensity (EUI)

Percentage Improvement in EUI (P_i)	Points (L_i)
$6\% \le P_i < 8\%$	1
$8\% \le P_i < 10\%$	2
$10\% \le P_i < 12\%$	3
$12\% \le P_i < 14\%$	4
$14\% \le P_i < 16\%$	5
$16\% \le P_i < 18\%$	6
$18\% \le P_i < 20\%$	7
$20\% \le P_i < 22\%$	8
$22\% \le P_i < 24\%$	9
$24\% \le P_i < 26\%$	10
$26\% \le P_i < 28\%$	11
$29\% \le P_i < 32\%$	12
$32\% \le P_i < 35\%$	13
$35\% \le P_i < 38\%$	14
$38\% \le P_i < 42\%$	15
$42\% \le P_i < 46\%$	16
$46\% \le P_i < 50\%$	17
$50\% \le P_i$	18

In addition to quite a few research studies related to sustainability and green buildings, there has been a limited number of research studies that guide project owners about how to earn points when pursuing LEED certification. For example, Castro-Lacouture *et al.* (2009) proposed an optimization model that helps stakeholders in material selection. The model satisfies design and budget constraints while maximizing LEED points. This model is helpful for project owners but does not guide project owners about material, equipment, and method selection in order to obtain the desired points in the Energy and Atmosphere category.

The most comprehensive optimization model that helps project owners in achieving the desired LEED points while minimizing cost was proposed by Abdallah *et al.* (2016) and Abdallah and El-Rayes (2016). This optimization model was developed for existing buildings, not new buildings.

The studies that were performed to improve the energy performance of buildings can be grouped into two main categories, namely: (1) building envelope optimization, and (2) HVAC systems optimization. Concerning building envelope optimization, Shan (2014) proposed building facade optimization method to obtain minimum energy cost for the building. He calculated the energy load by using building performance simulation program called TRNSYS. Yi and Malkawi (2009) developed a method to optimize the building form by defining hierarchical relations between geometry points. Ouarghi and Krarti (2006) used neural networks and genetic algorithms to optimize the shape of an office building in order to minimize energy use intensity. Wang *et al.* (2006) presented a multi objective optimization model that helps designers to optimize the window type and the orientation of a building. Adamski (2007) presented a method to optimize the orientation of a building by considering heat losses through floors, walls, and roof, hence attempting to achieve minimum heat energy demand at minimum construction cost. Caldas and Norford (2003) presented an optimization model to determine the size and placement of windows, and the composition of building walls.

Concerning the optimization of HVAC systems, Congradac and Kulic (2009) used genetic algorithms and energy simulation software to optimize the performance of HVAC sytems and save energy. Fong *et al.* (2006) proposed a metaheuristic simulation-optimization approach to deal with the effective energy management of HVAC systems, resulting in maximum thermal comfort and minimum energy consumption. Bichiou and Krarti (2011) developed an energy simulation model to optimally select not only building envelope features but also HVAC system designs by using three different optimization algorithms, namely genetic algorithms, particle swarm optimization, and a sequential search algorithm. Wright *et al.* (2002) proposed multi objective optimization to achieve maximum thermal comfort and minimum energy cost in HVAC systems.

The literature tends to indicate that there is a vast amount of research that investigates various aspects of green building design and construction, but very few of the studies look into achieving LEED points in the most economical way.

2. Proposed method

The objective of this research is to develop a method that provides the desired number of LEED points in the "Optimize Energy Performance" credit of the Energy and Atmosphere category at minimum cost. The method optimizes the trade-off between the number of earned points and material costs. To develop such a method, energy simulation software is needed. There are several simulation programs that are used by energy analysts such as Energy Plus, DOE-2, Design Builder, eQuest, TRANSYS, IDA ICE, MIT Design Advisor, and Energy-10. In this research, a new and popular simulation program called "Sefaira" is used. In contrast to currently available energy simulation programs, Sefaira provides designers with energy analysis in early design. With the help of energy information early in the design process, the designer can explore alternatives that can generate different numbers of points (Sefaira 2016). One of the most important advantages of Sefaira is that it can work as an add-in to Autodesk Revit. In addition, the user interface is simple to use compared to other simulation software.

The proposed model is presented in Figure 1. The first step for the analyst is to enter the Building Information Model (BIM) of the project as an input to Sefaira, including the address of the site and the type of the building. Sefaira allows the analyst to pick the appropriate version of the ASHRAE Standard from the many listed for use in the current project. It then performs energy optimization.

ASHRAE Standard 90.1-2010 is mandated by LEED v4 as the baseline condition. After the simulation is performed, the software generates information about a *U*-factor and three *R*-values. The *U*-factor represents the insulating properties of windows, whereas the *R*-values represent the insulating properties of walls, floors, and roofs. The *U*-factor for glazing is a parameter that shows the rate of heat loss of the windows. If the *U*-factor increases, the insulation of a window is weaker. In contrast to the *U*-factor, the *R*-values show the effectiveness of the insulation related to walls, floors, and roofs. If the *R*-value increases, the insulation is more effective.

In the proposed model, once the insulation coefficients which satisfy ASHRAE Standard 90.1-2010 are obtained, the analyst needs to identify the *low*, *middle* and *high* values for the *U*-factor and each *R*-value in order to create different scenarios.

U-Factor for Glazing

The value of the *U*-factor for glazing varies between 0.40 to 6.02 W/m^2.K. The high, middle, and low values of the *U*-factor are set as follows.

The low value:

$$U_L = 0.40 \text{ W/m}^2\text{.K.} \quad (1)$$

The high value:

$$U_H = U_{ASHRAE\ Standard\ 90.1\text{-}2010}, \quad (2)$$

where $U_{ASHRAE\ Standard\ 90.1\text{-}2010}$ is the output generated by Sefaira which satisfies ASHRAE Standard 90.1-2010 for the specific characteristics of the building considered (location and type of building).

The middle value:

$$U_M = \frac{U_H + U_L}{2}. \quad (3)$$

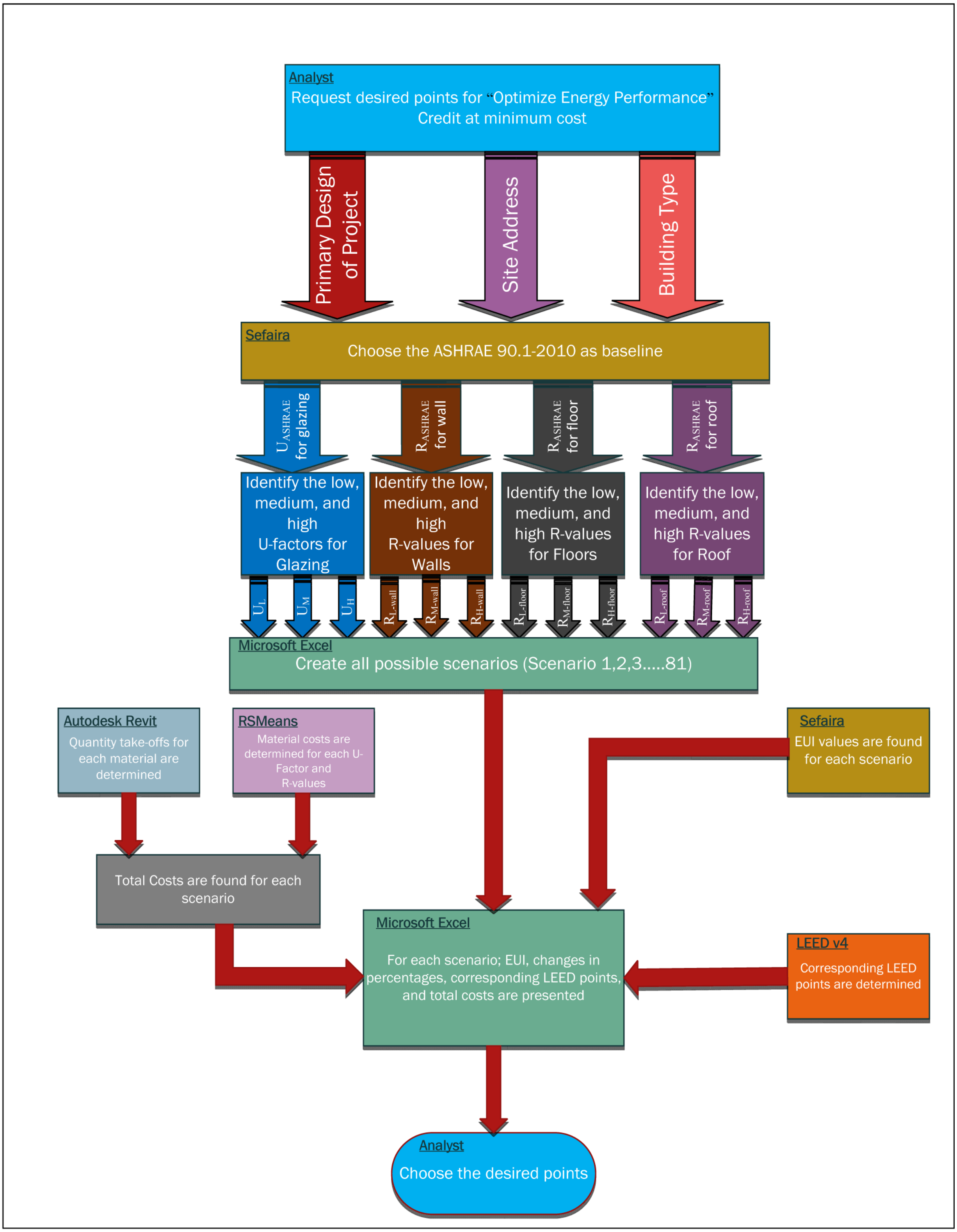

Fig. 1. Proposed model

R-value for walls

The R-value for walls varies between 0.20 to 9.80 m^2.K/W. The high, middle, and low *R*-values for walls are set as follows.

The low value:

$$R_{L-wall} = R_{ASHRAE\ Standard\ 90.1\text{-}2010}, \quad (4)$$

where $R_{ASHRAE\ Standard\ 90.1\text{-}2010}$ is the output generated by Sefaira which satisfies ASHRAE Standard 90.1-2010 for the specific characteristics of the building considered (location and type of building).

The high value:

$$R_{H\text{-}wall} = 9.80 \text{ m}^2\text{.K/W}. \quad (5)$$

The middle value:

$$R_{M\text{-}wall} = \frac{R_{H\text{-}wall} + R_{L\text{-}wall}}{2}. \quad (6)$$

R-value for floors

The *R*-value for floors varies between 0.20 to 9.80 m^2.K/W. The high, middle, and low *R*-values for floors are set as follows.

The low value:

$$R_{L\text{-}floor} = R_{ASHRAE\ Standard\ 90.1\text{-}2010}, \quad (7)$$

where $R_{ASHRAE\ Standard\ 90.1\text{-}2010}$ is the output generated by Sefaira which satisfies ASHRAE Standard 90.1-2010 for the specific characteristics of the building considered (location and type of building).

The high value:

$$R_{H\text{-}floor} = 9.80 \text{ m}^2\text{.K/W}. \quad (8)$$

The middle value:

$$R_{M\text{-}floor} = \frac{R_{H\text{-}floor} + R_{L\text{-}floor}}{2}. \quad (9)$$

R-value for roofs

The *R*-value for roofs varies between 0.20 to 9.80 m^2.K/W. The high, middle, and low *R*-values for walls are set as follows.

The low value:

$$R_{L\text{-}roof} = R_{ASHRAE\ Standard\ 90.1\text{-}2010}, \quad (10)$$

where: $R_{ASHRAE\ Standard\ 90.1\text{-}2010}$ is the output generated by Sefaira which satisfies ASHRAE Standard 90.1-2010 for the specific characteristics of the building considered (location and type of building).

The high value:

$$R_{H\text{-}roof} = 9.80 \text{ m}^2\text{.K/W}. \quad (11)$$

The middle value:

$$R_{M\text{-}roof} = \frac{R_{H\text{-}roof} + R_{L\text{-}roof}}{2}. \quad (12)$$

After the low, middle and high values are found for each insulation coefficient, the possible scenarios are created. As there are four parameters and since each parameter has three different values, the total number of scenarios can be calculated as follows:

$$\text{Total Number of Scenarios} = \binom{3}{1} \times \binom{3}{1} \times \binom{3}{1} \times \binom{3}{1} = 81. \quad (13)$$

In theory, the range between the highest and lowest values can be split into an infinite number of alternatives, but the number of combinations can be very large and impractical. Splitting the range into three alternatives and creating 81 combinations was found to be adequate for this study. The first scenario is the baseline scenario, in which the values for thermal coefficients are the values that satisfy the ASHRAE Standard 90.1-2010. The remaining 80 scenarios are combinations of the high, middle, and low values of the four factors U and R_W, R_F, and R_R. The EUIs are found by Sefaira for each scenario using Eqn (14):

$$EUI_i = f(U_i, R_{W\text{-}i}, R_{F\text{-}i}, R_{R\text{-}i}), \quad i = 1......81, \quad (14)$$

where: EUI_i is the energy use intensity for Scenario i; $f(U_i, R_{W\text{-}i}, R_{F\text{-}i}, R_{R\text{-}i})$ is the energy use intensity calculated by Sefaira by taking into account the U-factor, the R-values, and the total area of glazing, floors, walls, and roof; U_i is the U-factor for glazing in the i^{th} scenario; $R_{W\text{-}i}$, $R_{F\text{-}i}$, and $R_{R\text{-}i}$ are the R-values for walls, floors, roof in the i^{th} scenario, respectively. The lower the EUI, the lower is the energy consumption. Lower EUIs deserve higher LEED points (see Table 1).

After the EUIs are found for each scenario, the corresponding percentage improvements compared to the baseline scenario (P_i) are calculated for each scenario using Eqn (15):

$$P_i = \frac{EUI_i - EUI_1}{EUI_1}, \quad i = 1.....81. \quad (15)$$

Once the percentage improvements are calculated for each scenario, the LEED points (L_i) are found for each scenario by using Table 1.

In order to identify the cost of each scenario, a material database was required for windows, walls, floors, and roofs. For this purpose, the RSMeans Database was chosen. Having more than 75,000 unit prices, the RSMeans Database is one of the biggest databases for use in the

U.S. and Canada (RSMeans 2016). The cost information in this database is updated annually, and it is available online, in book form, or via CD (RSMeans 2016). By using RSMeans data, one can easily access the type of material, the insulation coefficients, and the unit costs. With the help of this database, one can easily identify the material combinations for each scenario. Once the material and costs are known, the total cost is calculated for each scenario by multiplying the quantities and unit costs using Eqn (16):

$$C_i = Q_G \text{ x } C_{G\text{-}i} + Q_W \text{ x } C_{W\text{-}i} + Q_F \text{ x } C_{F\text{-}i} + Q_R \text{ x } C_{R\text{-}I}, \quad (16)$$

where: C_i is the total cost for scenario i; Q_G, Q_W, Q_F, Q_R are the respective quantities for glazing, walls, floors, and roof received from Autodesk Revit; C_G, C_W, C_F, C_R are the respective unit costs for windows, walls, floors, and roof received from RSMeans database that satisfy U and R values in the i^{th} scenario.

As per Eqn (15), totally, there are 81 different scenarios which means 81 different material combinations, 81 LEED points, and 81 different costs. As it is a time-consuming process to examine all these scenarios one by one, a macro was created in Microsoft Excel. By entering the desired LEED points in this macro, one can easily see the material combination at minimum cost, and also the unit cost for each material. In addition, the macro provides a total cost versus LEED points graph, and shows the costs and points for all possible scenarios.

3. Case study

A ten-storey office building (Sefaira 2016) was analyzed as a case study in order to show the use of the proposed method (Fig. 2). The office building had a total floor area of 3,995 m^2 and was located in Chicago Midway, Illinois.

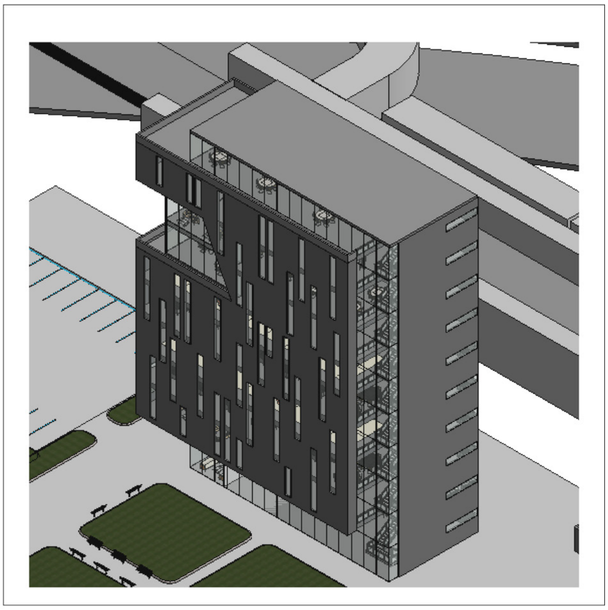

Fig. 2. Ten-storey office building for case study

As a first step, the primary design of the project was entered as an input to Sefaira. After the address of the site (Chicago) and the type of the building (office building) were entered, ASHRAE 90.1-2010 was specified as the standard for baseline conditions (as mandated by LEED v4). Based on this information, Sefaira generated the baseline *U*-factor and *R*-values as follows:

$$U_{glazing} = 2.00 \text{ W/m}^2\text{.K};$$

$$R_{wall} = 2.78 \text{ m}^2\text{.K/W};$$

$$R_{floor} = 2.80 \text{ m}^2\text{.K/W};$$

$$R_{roof} = 3.70 \text{ m}^2\text{.K/W}.$$

The high, middle, and low *U*-factors and *R*-values were set by using Eqns (1) to (12).

Glazing: $U_L = 0.40$ W/m^2.K; $U_M = 1.20$ W/m^2.K; $U_H = 2.00$ W/m^2.K;

Walls: $R_{L\text{-}wall} = 2.78$ m^2.K/W; $R_{M\text{-}wall} = 6.29$ m^2.K/W; $R_{H\text{-}wall} = 9.80$ m^2.K/W;

Floors: $R_{L\text{-}floor} = 2.80$ m^2.K/W; $R_{M\text{-}floor} = 6.30$ m^2.K/W; $R_{H\text{-}floor} = 9.80$ m^2.K/W;

Roof: $R_{L\text{-}roof} = 3.70$ m^2.K/W; $R_{M\text{-}roof} = 6.75$ m^2.K/W; $R_{H\text{-}roof} = 9.80$ m^2.K/W.

All 81 combinations of the *U* and *R* values are presented in Table 2, which also shows the energy use intensities (EUI_i), changes in EUIs compared to the baseline value percentages (P_i), LEED points (L_i), and costs (C_i) for each scenario.

An example of how these values are found is shown for Scenario 29. In the first step, Sefaira calculates the Energy Use Intensity by using Eqn (14):

$$E_{29} = f(U_{29}, R_{W\text{-}29}, R_{F\text{-}29}, R_{R\text{-}29}) = 262 \text{ kWh/m}^2\text{/yr.}$$

The percentage improvements compared to the baseline scenario are determined by using Eqn (15):

$$P_{29} = \frac{E_{29} - E_1}{E_1} = \frac{262 - 331}{331} = -21\% \text{ (where (–) means decrease in EUI).}$$

Then, the corresponding LEED points are determined by using Table 1.

As $P_{29} = 21\%$ ➔ $20\% \leq P_{29}\ 22$ ➔ $L_{29} = 8$ points.

And finally, by using Eqn (16), the total cost for each scenario is determined:

$$C_{29} = Q_G \text{ x } C_{G\text{-}29} + Q_W \text{ x } C_{W\text{-}29} + Q_F \text{ x } C_{F\text{-}29} + Q_R \text{ x } C_{R\text{-}29},$$

Table 2. A table for all possible scenarios and values for the case study

	Glazing U-Factor	Wall R-Value	Floor R-Value	Roof R-Value	EUI (kWh/m2/yr)	Change in percentages (%)	LEED Points	Cost (Dollars)
Scenario-1	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(1) = E (Baseline) = 331	P(1) = 0	L(1) = 0	C(1) = 431,685
Scenario-2	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(2) = 322	P(2) = 2.9	L(2)= 0	C(2) = 437,776
Scenario-3	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(3) = 315	P(3) = 4.8	L(3)= 0	C(3) = 441,820
Scenario-4	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(4) = 325	P(4) = 1.9	L(4)= 0	C(4) = 472,005
Scenario-5	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(5) = 318	P(5) = 3.8	L(5)= 0	C(5) = 512,325
Scenario-6	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(6) = 315	P(6) = 4.8	L(6)= 0	C(6) = 478,086
Scenario-7	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(7) = 309	P(7) = 6.7	L(7)= 1	C(7) = 482,140
Scenario-8	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(8) = 312	P(8) = 5.7	L(8)= 0	C(8) = 518,406
Scenario-9	$U_H = 2.00$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(9) = 306	P(9) = 7.6	L(9)= 1	C(9) = 522,460
Scenario-10	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(10) = 306	P(10) = 7.6	L(10)= 1	C(10) = 446,685
Scenario-11	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(11) = 299	P(11) = 9.5	L(11)= 2	C(11) = 452,766
Scenario-12	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(12) = 296	P(12) = 10.5	L(12)= 3	C(12) = 456,820
Scenario-13	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(13) = 303	P(13) = 8.6	L(13)= 2	C(13) = 487,005
Scenario-14	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(14) = 299	P(14) = 9.5	L(14)= 2	C(14) = 527,325
Scenario-15	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(15) = 293	P(15) = 11.4	L(15)= 3	C(15) = 493,086
Scenario-16	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(16) = 287	P(16) = 13.3	L(16)= 4	C(16) = 497,140
Scenario-17	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(17) = 290	P(17) = 12.4	L(17)= 4	C(17) = 533,406
Scenario-18	$U_H = 2.00$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(18) = 284	P(18) = 14.3	L(18)= 5	C(18) = 537,460
Scenario-19	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(19) = 281	P(19) = 15.2	L(19)= 5	C(19) = 476,684
Scenario-20	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(20) = 277	P(20) = 16.2	L(20)= 6	C(20) = 482,766
Scenario-21	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(21) = 271	P(21) = 18.1	L(21)= 7	C(21) = 486,820
Scenario-22	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(22) = 277	P(22) = 16.2	L(22)= 6	C(22) = 517,004
Scenario-23	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(23) = 274	P(23) = 17.1	L(23)= 6	C(23) = 557,324
Scenario-24	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(24) = 274	P(24) = 17.1	L(24)= 6	C(24) = 523,086
Scenario-25	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(25) = 268	P(25) = 19.0	L(25)= 7	C(25) = 527,140
Scenario-26	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(26) = 271	P(26) = 18.1	L(26)= 7	C(26) = 563,406
Scenario-27	$U_H = 2.00$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(27) = 265	P(27) = 20.0	L(27)= 8	C(27) = 567,460
Scenario-28	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(28) = 268	P(28) = 19.0	L(28)= 7	C(28) = 490,965
Scenario-29	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(29) = 262	P(29) = 21.0	L(29)= 8	C(29) = 497,046
Scenario-30	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(30) = 259	P(30) = 21.9	L(30)= 8	C(30) = 501,100
Scenario-31	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(31) = 265	P(31) = 20.0	L(31)= 8	C(31) = 531,285
Scenario-32	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(32) = 262	P(32) = 21.0	L(32)= 8	C(32) = 571,605
Scenario-33	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(33) = 259	P(33) = 21.9	L(33)= 8	C(33) = 537,366
Scenario-34	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(34) = 252	P(34) = 23.8	L(34)= 9	C(34) = 541,420
Scenario-35	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(35) = 255	P(35) = 22.9	L(35)= 9	C(35) = 577,686
Scenario-36	$U_M = 1.20$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(36) = 249	P(36) = 24.8	L(36)= 10	C(36) = 581,740
Scenario-37	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(37) = 246	P(37) = 25.7	L(37)= 10	C(37) = 505,965
Scenario-38	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(38) = 243	P(38) = 26.7	L(38)= 11	C(38) = 512,046
Scenario-39	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(39) = 240	P(39) = 27.6	L(39)= 11	C(39) = 516,100
Scenario-40	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(40) = 236	P(40) = 28.6	L(40)= 11	C(40) = 546,285
Scenario-41	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(41) = 233	P(41) = 29.5	L(41)= 12	C(41) = 586,605
Scenario-42	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(42) = 230	P(42) = 30.5	L(42)= 12	C(42) = 552,366
Scenario-43	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(43) = 227	P(43) = 31.4	L(43)= 12	C(43) = 556,420
Scenario-44	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(44) = 230	P(44) = 30.5	L(44)= 12	C(44) = 592,686
Scenario-45	$U_M = 1.20$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(45) = 224	P(45) = 32.4	L(45)= 13	C(45) = 596,740
Scenario-46	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(46) = 224	P(46) = 32.4	L(46)= 13	C(46) = 535,964
Scenario-47	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(47) = 221	P(47) = 33.3	L(47)= 13	C(47) = 542,046
Scenario-48	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(48) = 218	P(48) = 34.3	L(48)= 13	C(48) = 546,100
Scenario-49	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(49) = 224	P(49) = 32.4	L(49)= 13	C(49) = 576,284
Scenario-50	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(50) = 224	P(50) = 32.4	L(50)= 13	C(50) = 616,604
Scenario-51	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(51) = 221	P(51) = 33.3	L(51)= 13	C(51) = 582,366
Scenario-52	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(52) = 218	P(52) = 34.3	L(52)= 13	C(52) = 586,420
Scenario-53	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(53) = 221	P(53) = 33.3	L(53)= 13	C(53) = 622,686
Scenario-54	$U_M = 1.20$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(54) = 218	P(54) = 34.3	L(54)= 13	C(54) = 626,740
Scenario-55	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(55) = 214	P(55) = 35.2	L(55)= 14	C(55) = 787,365
Scenario-56	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(56) = 211	P(56) = 36.2	L(56)= 14	C(56) = 793,446
Scenario-57	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(57) = 211	P(57) = 36.2	L(57)= 14	C(57) = 797,500
Scenario-58	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(58) = 214	P(58) = 35.2	L(58)= 14	C(58) = 827,685
Scenario-59	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(59) = 211	P(59) = 36.2	L(59)= 14	C(59) = 868,005
Scenario-60	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(60) = 211	P(60) = 36.2	L(60)= 14	C(60) = 833,766

Continued Table 2

Scenario-61	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(61) = 208	P(61) = 37.1	L(61)= 14	C(61) = 837,820
Scenario-62	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(62) = 208	P(62) = 37.1	L(62)= 14	C(62) = 874,086
Scenario-63	$U_L = 0.40$	$R_{L\text{-wall}} = 2.78$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(63) = 205	P(63) = 38.1	L(63)= 15	C(63) = 878,140
Scenario-64	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(64) = 205	P(64) = 38.1	L(64)= 15	C(64) = 802,365
Scenario-65	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(65) = 202	P(65) = 39.0	L(65)= 15	C(65) = 808,446
Scenario-66	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(66) = 202	P(66) = 39.0	L(66)= 15	C(66) = 812,500
Scenario-67	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(67) = 199	P(67) = 40.0	L(67)= 15	C(67) = 842,685
Scenario-68	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(68) = 199	P(68) = 40.0	L(68)= 15	C(68) = 883,005
Scenario-69	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(69) = 195	P(69) = 41.0	L(69)= 15	C(69) = 848,766
Scenario-70	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(70) = 192	P(70) = 41.9	L(70)= 15	C(70) = 852,820
Scenario-71	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(71) = 195	P(71) = 41.0	L(71)= 15	C(71) = 889,086
Scenario-72	$U_L = 0.40$	$R_{M\text{-wall}} = 6.29$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(72) = 192	P(72) = 41.9	L(72)= 15	C(72) = 893,140
Scenario-73	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{L\text{-roof}} = 3.70$	E(73) = 192	P(73) = 41.9	L(73)= 15	C(73) = 832,364
Scenario-74	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{M\text{-roof}} = 6.75$	E(74) = 192	P(74) = 41.9	L(74)= 15	C(74) = 838,446
Scenario-75	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{L\text{-floor}} = 2.80$	$R_{H\text{-roof}} = 9.80$	E(75) = 189	P(75) = 42.9	L(75)= 16	C(75) = 842,500
Scenario-76	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{L\text{-roof}} = 3.70$	E(76) = 192	P(76) = 41.9	L(76)= 15	C(76) = 872,684
Scenario-77	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{L\text{-roof}} = 3.70$	E(77) = 192	P(77) = 41.9	L(77)= 15	C(77) = 913,004
Scenario-78	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{M\text{-roof}} = 6.75$	E(78) = 192	P(78) = 41.9	L(78)= 15	C(78) = 878,766
Scenario-79	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{M\text{-floor}} = 6.30$	$R_{H\text{-roof}} = 9.80$	E(79) = 189	P(79) = 42.9	L(79)= 16	C(79) = 882,820
Scenario-80	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{M\text{-roof}} = 6.75$	E(80) = 192	P(80) = 41.9	L(80)= 15	C(80) = 919,086
Scenario-81	$U_L = 0.40$	$R_{H\text{-wall}} = 9.80$	$R_{H\text{-floor}} = 9.80$	$R_{H\text{-roof}} = 9.80$	E(81) = 189	P(81) = 42.9	L(81)= 16	C(81) = 923,140

where:

- For windows:

Q_G = 550.73 m^2 (received from Autodesk Revit for glazing);

U_{29} = 1.20 ➔ "Double Glass 1.27 cm air space" is the material that satisfies the corresponding *U*-factor at minimum cost;

$C_{G\text{-}29}$ = \$430.57 per square meter of glazing (received from material database).

- For walls:

Q_W = 2,787.08 m^2 of wall (received from Autodesk Revit);

$R_{W\text{-}29}$ = 2.78 ➔ "25.4 cm Concrete Masonry with 6.35 cm closed-cell spray polyurethane foam" is the material that satisfies the corresponding R-value for wall at minimum cost;

$C_{W\text{-}29}$ = \$75.89 per square meter of wall (received from material database).

- For floors:

Q_F = 3,745.85 m^2 of floor (received from Autodesk Revit);

$R_{F\text{-}29}$ = 2.80 ➔ "20.96 cm of batt insulation" is the material that satisfies corresponding R-value for floor at minimum cost;

$C_{F\text{-}29}$ = \$10.76 per square meter of floor (received from material database).

- For roof:

Q_R = 376.65 m^2 of roof (received from Autodesk Revit);

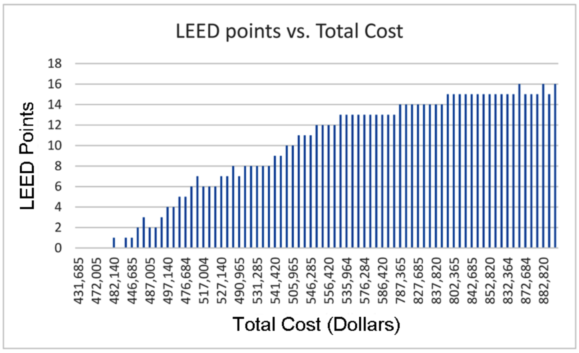

Fig. 3. LEED points vs. total cost for case study

$R_{R\text{-}29}$ = 6.75 ➔ "15.24 cm of spray foam insulation" is the material that satisfies corresponding R-value for roof at minimum cost;

$C_{R\text{-}29}$ = \$21.53 per square meter of roof (received from material database).

So:

$$C_{29} = (550.73\times430.57) + (2{,}787.08\times75.89) + (3{,}745.85\times10.76) + (376.65\times21.53) = \$497{,}046.$$

The same process is performed for each scenario. A graph is plotted that shows the total cost versus LEED points as shown in Figure 3. By using Table 2 or Figure 3, the analyst can choose the desired point at minimum cost.

Conclusions

This paper presents a method that can be used by designers who are pursuing LEED v4 certification. Using the proposed model, the designer should be able to obtain the desired number of earned points in the "Optimize Energy Performance" credit of the "Energy and Atmosphere" category at minimum cost. The model creates a multitude of scenarios in terms of *U* and *R*-values, identifies the LEED points and costs for each scenario. The energy analysis calculations are performed by Sefaira, the quantity of materials are received from Autodesk Revit, and the cost information comes from the RSMeans Database. A macro in Excel automates the process. An office building is used as a case study and illustrates the applicability of the proposed method. The results presented in Table 2 and Figure 3 indicate that in this office building, one can achieve the maximum 16 points in the "Optimize Energy Performance" credit of the "Energy and Atmosphere" category of LEED at a minimum cost of $842,500. Similarly, it was possible to determine the minimum cost for obtaining any number of points between 1 and 16, such as $552,366 for 12 points, and $476,684 for 5 points. The results show the capability of the proposed method.

The practical contribution of this research involves creating a tool that allows designers to establish their *U* and *R*-values to be used in their energy-related design by picking the most economical alternative for the desired points in the "Optimize Energy Performance" credit. The research contribution of this study is the first time integrated use of multiple software, i.e., an energy simulation software (Sefaira), a cost database (RSMeans), and a BIM software (Autodesk Revit).

It should be noted that in the presented model, it is assumed that the lighting and HVAC systems of the building were already determined by the analyst. Further research could take into account variations in the lighting and HVAC systems while creating a larger number of possible scenarios in order to obtain the desired LEED points. Also, the model presented in this paper could be expanded to cover the other credits in the "Energy and Atmosphere" category.

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