

Chapter 17

Enhancing Energy Consumption Using BIM: A Case Study of Egyptian Palace



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Introduction

The significance of a whole building analysis in assessing existing and potential performance levels has been demonstrated in multiple studies in which the analysis succeeded in providing building performance information related to the effect of different building variables. Thus, conservation strategies of existing structures could have never been sustainable without the reliance on valid building simulation tools that have been recently developed to interplay with point cloud data and BIM tools. Numerous research papers [1, 2] used such tools and evaluated performance levels guided with multiple guidelines and rating systems that evaluate the greenness of the building as well. Building thermal and daylight analysis are considered main influential factors in assessing the whole building performance levels. Daylighting simulation tools make it possible to evaluate the quantity and distribution of daylight in a room while taking into account the key influential parameters such as window placement, building geometry, external obstruction, interior divisions, and material properties. Several research efforts assessed the effect of building elements using both thermal and daylighting analysis. Nebia and Aoul [3] studied thermal gain and daylight in residential units and proved their strong connection with the window glazing, apartment unit orientation, and floor level position. Al Qadi et al. [4] developed an approach to create a successful building performance assessment method and investigated the different factors that affect the building energy performance. They utilized a method that aims to reduce the gap between the actual building measurements and the simulated ones.

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Existing buildings should be retrofitted and conserved to become an added value rather than being neglected and later found in a deteriorated state, as in case of the palace under study. Ahmad et al. [5] studied the setting of a sensitive historic museum retrofit, with attention to preserving artifacts, and provided visual comfort at recommended illuminance levels for artifacts. They compared the daylight performance of a flat ceiling and a pitched roof ceiling model of a historical museum. Onuwe et al. [6], on the other hand, reviewed different museum designs to discuss the significance of daylight in providing most desirable and comfortable light for users and mentioned that most museum designers rely on artificial light to avoid the negative effect of glare and high daylight levels on effective artifact preservation. De Luca et al. [7] performed a simulation study on a single floor commercial space to assess building performance, proved that energy savings is possible, ranging from 1.9 to 58.6%, emphasizing that the use of a daylight control element would enhance energy savings higher than 50%. Banfi [8] presented several case studies to study a new tool that is able to model complex historical building forms efficiently and replace the usual simplification of historical models that is not even close to the reality. López et al. [9] extensively reviewed recent BIM-related tools and software involved in historical conservation and documentation procedures. They bridged the historical data retrieval using photogrammetry and scanning, subsequently, the appropriate modeling and analyzing software were used. Recent related publications were categorized according to the software utilized, process, and output data type.

Research Methodology

Simulation was performed using two software in parallel, DesignBuilder for daylighting factor calculations and Diva for Rhino for glare probability analysis. The location and orientation were adjusted in the simulation software to allow current state simulation of the sun angle. Building GBXML file was imported into DesignBuilder Software (see Fig. 17.1a). Modifications were done in the model to ensure smooth building analysis by adjusting the North orientation, removing unneeded elements, merging zones to reduce the zone number for simulation (maximum 50 zones for the evaluation license), and adjusting building construction fabric/occupancy schedule/ventilation type. Sun Path diagram was analyzed in DesignBuilder to provide shading and sun analysis of the building by which solar gain could be further reduced when needed (see Fig. 17.1b). According to the palace parameters listed in Table 17.1, simulation is performed in both software. Initially, the palace was modelled using Autodesk's Revit, then exported as a GBXML file which was finally imported into DesignBuilder. The current skylight was reopened in the model. The current rooms are illustrated by the software into thermal zones. However, the trial version does not include more than 50 zones in the single simulation, and thus zones reduction is done by merging common ones.

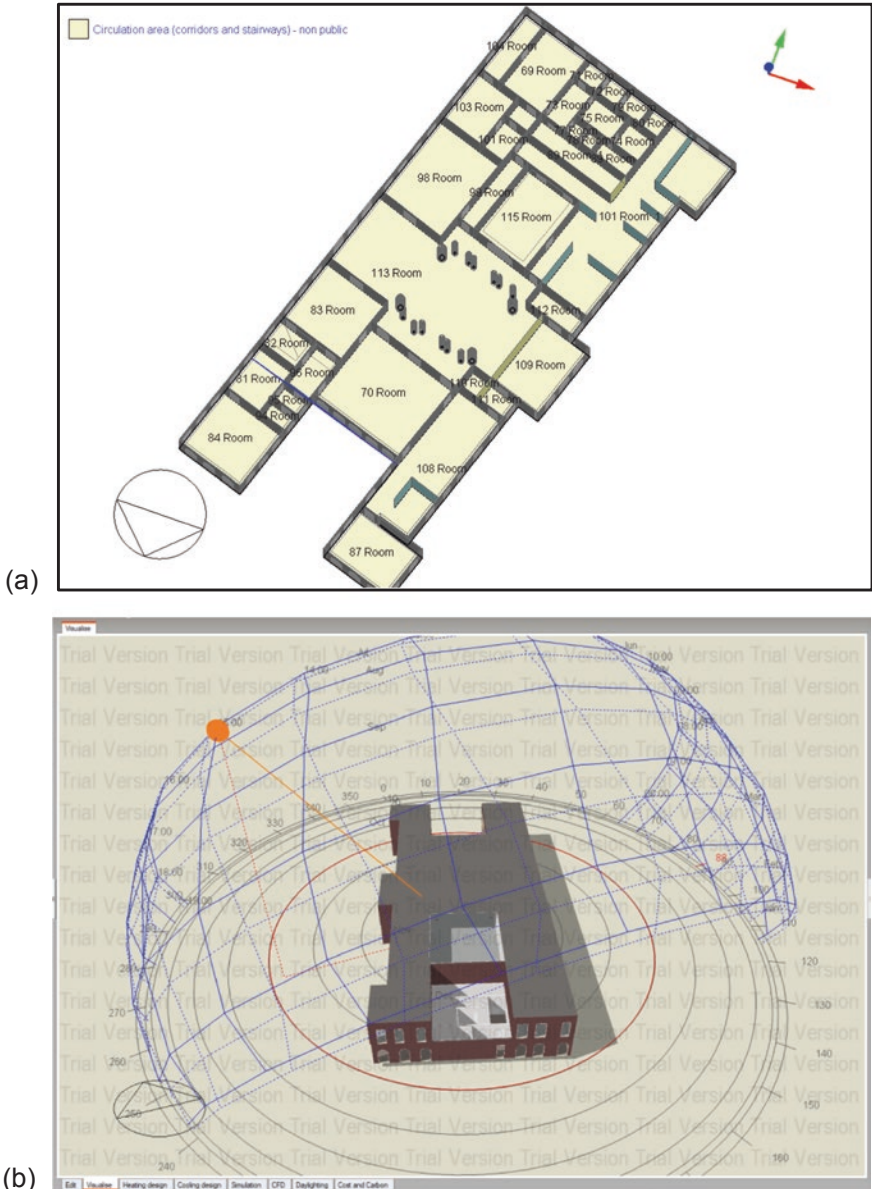


Fig. 17.1 (a) GBXML file input in Design-Builder and (b) Sun Path diagram of the palace model

The parallel analysis is performed using DIVA which is a tool that integrates daylighting and energy simulations. It uses Rhinoceros as its CAD modeling platform and has a component for its visual scripting environment, Grasshopper. The BIM model was imported to Rhino where additional information are added for Diva analysis.

Table 17.1 Palace model simulation parameters

<i>Palace parameters</i>	
Building type	Heritage residential palace
Building size	13H × 38W × 88L (m)
Operating schedule	9:00–15:00 (5 days/week)
Floor numbers	Two floors
Front entrance orientation	SW
Occupancy	1 person per 10 m ²
<i>Construction materials</i>	
Walls	Single stone block (1 m width in ground/0.7 m width in first)
Roof ceiling	Concrete and wooden board
Main hall floor	Concrete slab with marble
Rooms	Concrete slab with parquet
Internal partition:	800 mm wall-bearing stones
Slab thermal mass	130 mm concrete slab
<i>Internal surfaces materials and reflectance</i>	
Walls: Medium colored	50%
Ceiling: White colored ceiling	80%
Floor: Generic floor	20%
<i>Window and shading parameters</i>	
Window-to-wall ratio (WWR)	85%
Glazing	Single glazing
Window frame	Wooden
Local shading type	Overhang shading
<i>Equipment</i>	
Lighting type:	Candescent light fixtures
Office equipment	No office equipment included
Cooling type	Mixed mode: natural ventilation and HVAC

Simulation Results

Climatic data of the site are installed automatically on selecting the nearest weather station (Cairo International Airport). Local temperature, wind speed, air pressure, and solar heat gain influence the building performance and simulation results. The annual heat gain and energy consumption of the palace according to the current state are shown in Figs. 17.2 and 17.3. It has been specified that the palace is naturally ventilated, has no computers, and minimum building equipment are present, and thus most of the energy consumption is utilized by the electric lighting of the palace as shown in Fig. 17.2. The palace current state performance was evaluated through the monthly and annual energy consumption. In the annual consumption, 3000 MWh of total energy are consumed by the palace in one year that includes almost 1000 MWh for cooling if electric cooling is used to achieve occupants thermal comfort in hot days and includes 900 MWh of solar gain of existing windows. Such results mean that glazing areas act as an large source of heat gain and affect energy consumption greatly.

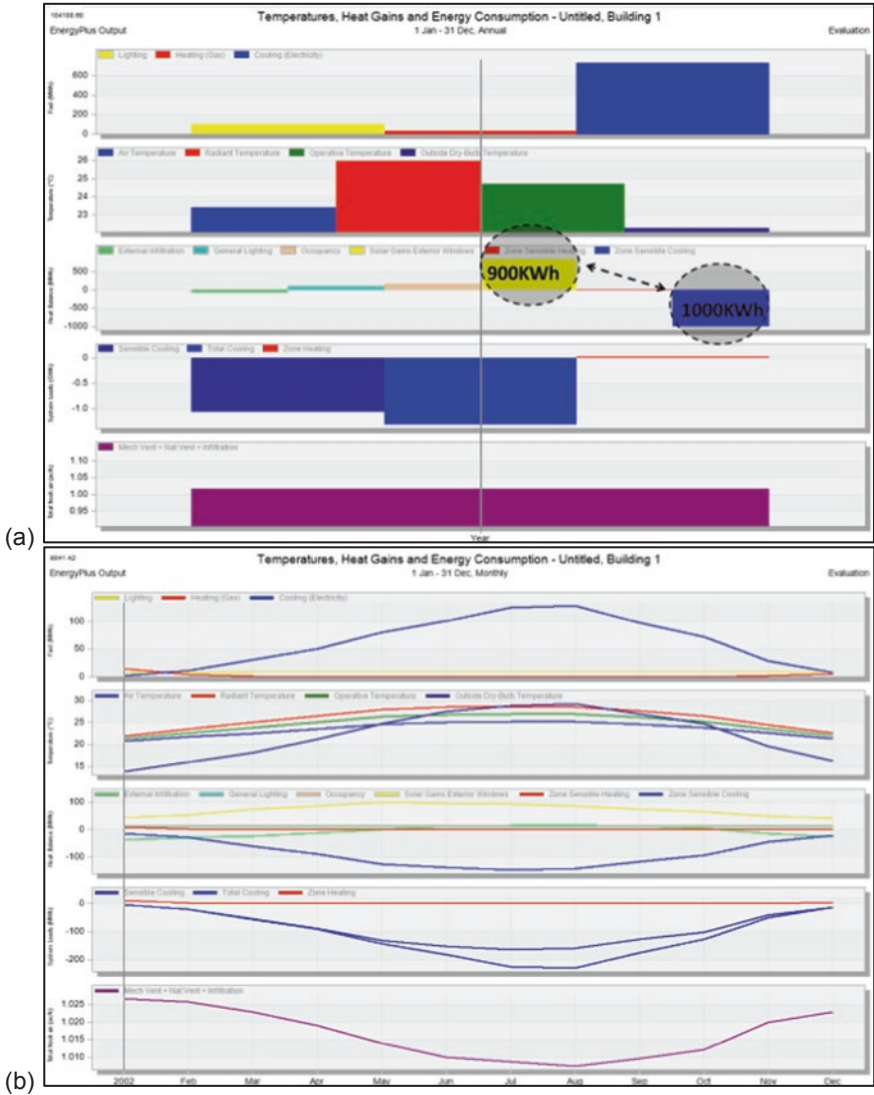


Fig. 17.2 Annual (a) and monthly (b) heat gain and energy consumption of palace. However, to fully understand the behavior of the palace during the hottest day in the year, a simulation is performed on 15 July to demonstrate the main sources of heat gain and temperature rise as shown in Fig. 17.3. The solar gain through exterior windows reaches 400 kW in peak hours of the day in a cooling design strategy performed by the software to propose possible solutions to overcome heat gain during the hottest day in the year

Considering the palace daylight analysis, whole building illuminance analysis was carried out using two metrics; the daylight factor (DF) and annual glare analysis. DF is the ratio of the light level inside a structure to the light level outside and is shown in Fig. 17.4.

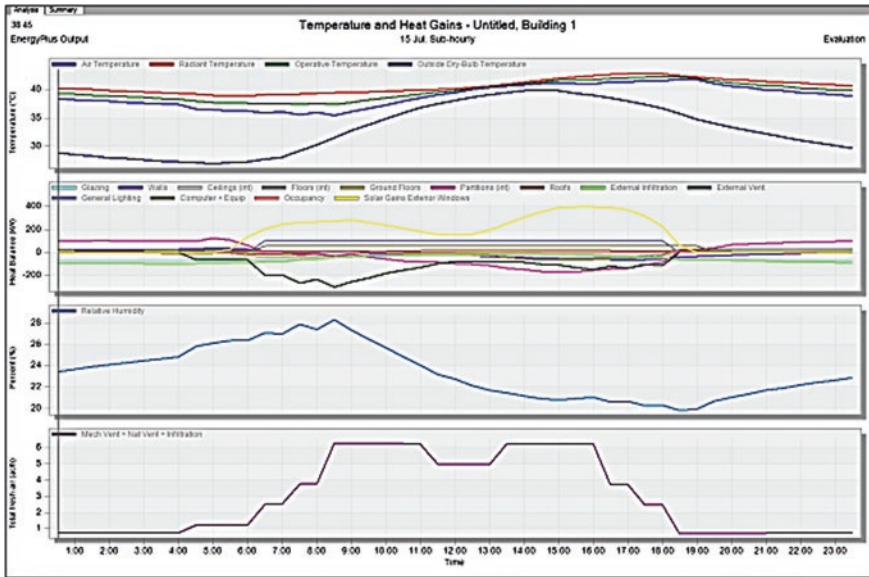


Fig. 17.3 Palace cooling design in 15 July

It is clear from Fig. 17.4 that DF is inadequate in most inner spaces (highlighted in gray color) that reaches 2.0 in the darkest regions while very high daylight factor reaches 10 beneath the skylight and close to the windows. As for building performance assessment systems, Green star and LEED rating systems are used for sustainable performance evaluation of buildings [1, 10–12]. Both systems are embedded in the software for compliance check, as shown in Fig. 17.5.

The analysis of the palace current state failed to meet both rating system requirements. Thus, further investigation by other daylight analysis tools that use validated engines such as Daysim and radiance engines was needed. Hence, based on the preliminary reports from DesignBuilder, Diva for rhino was used to perform an annual glare analysis so as to visualize the main problem with daylight in the palace. In Fig. 17.6, it is clear that the main daylight problem in the palace is the high glare probability and visual discomfort risk for occupants. Thus, enhancements to reduce glare and redistribute direct sunlight will be essential to achieve proper daylight distribution in the palace. Also, the results revealed that the main source of direct sunlight is the enormous skylight opening in the middle hall.

Discussion and Conclusion

Finally, a parametric and optimization study is performed in DesignBuilder in terms of both minimizing energy consumption and increasing occupants thermal comfort (see Fig. 17.7). The parametric configuration performed by DesignBuilder shown in

Fig. 17.4 Daylight analysis for palace in terms of daylight factor (DF)

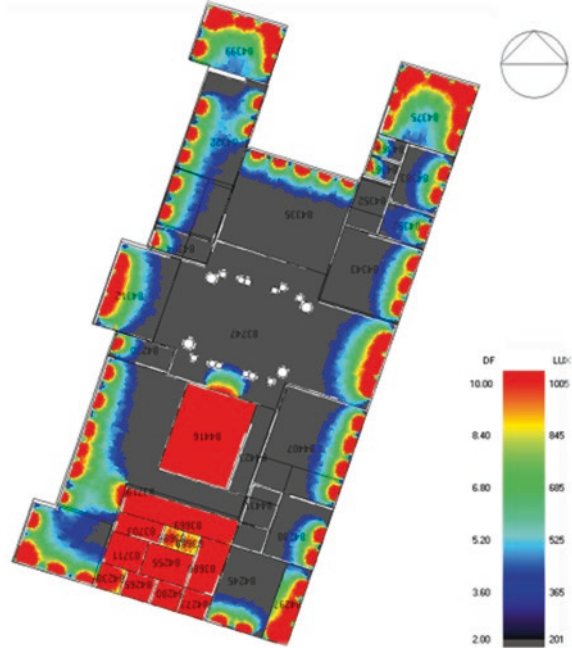
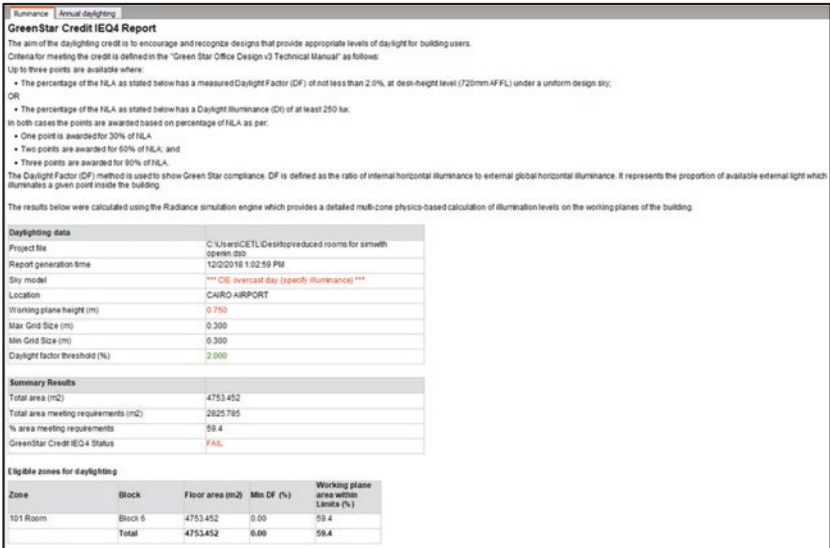
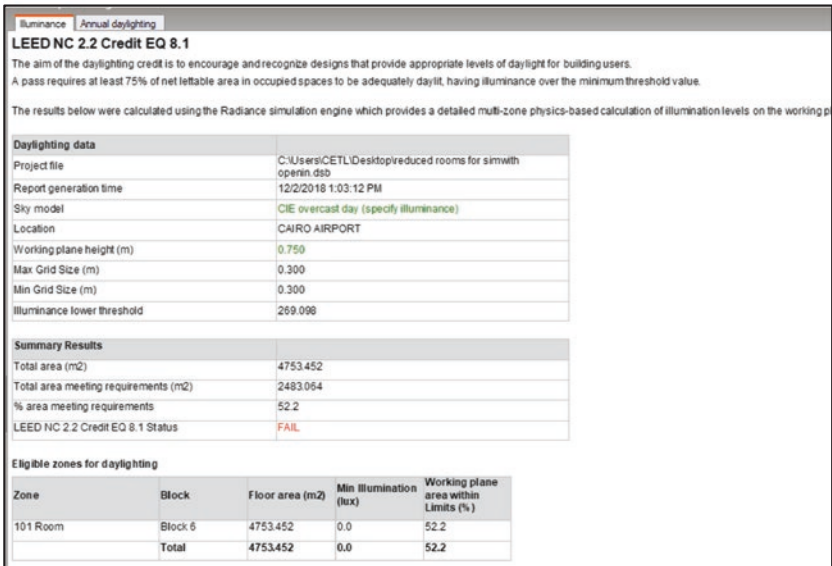


Fig. 17.7a gives a comprehensive overview of the possible energy performance related to the different proposed WWRs. In the total energy consumption (kWh) through the whole year, it is shown that the maximum of 900 kWh will be reached on the utilization of WWR of 20% or more. Only below 20% WWR was a recognized decrease in the total energy consumption obtained.

Optimization analysis of the palace, shown in Fig. 17.7b, reveals the optimum design in terms of thermal comfort and energy consumption. It shows that the optimum case lies around the WWR of 40%, cooling set point of 26.4 °C, and heating set point of 20.4 °C, producing 353,796.7 CO₂ (kg), and total discomfort hours of 2554 during the year. Highlighted with the red bar is the optimum point that reveals the intermediate successful points that lies on the Pareto-front curve which satisfies the optimization criteria. The optimum configuration is able to achieve minimum building CO₂ production and minimum occupant discomfort hours. Thus, it is concluded that appropriate reduction in the total external glazing area will provide higher comfort levels to the users, reduce cooling loads, and possibly participate in eliminating the visual discomfort from the high daylight levels. Further optimization and integration of different design parameters to increase users' comfort will increase the performance efficiency of the palace, and minimize the direct sunlight and heat gain through the reconfiguration of the skylight to enhance the users' comfort through passive design as shown in Fig. 17.8.



(a)



(b)

Fig. 17.5 Illuminance reports based on Green star (a) and LEED (b) daylight compliance rating systems

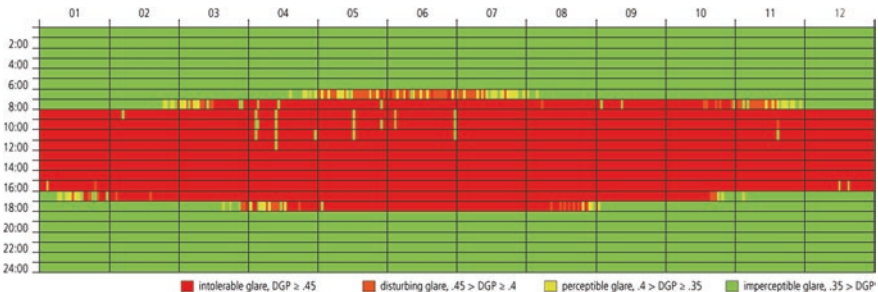
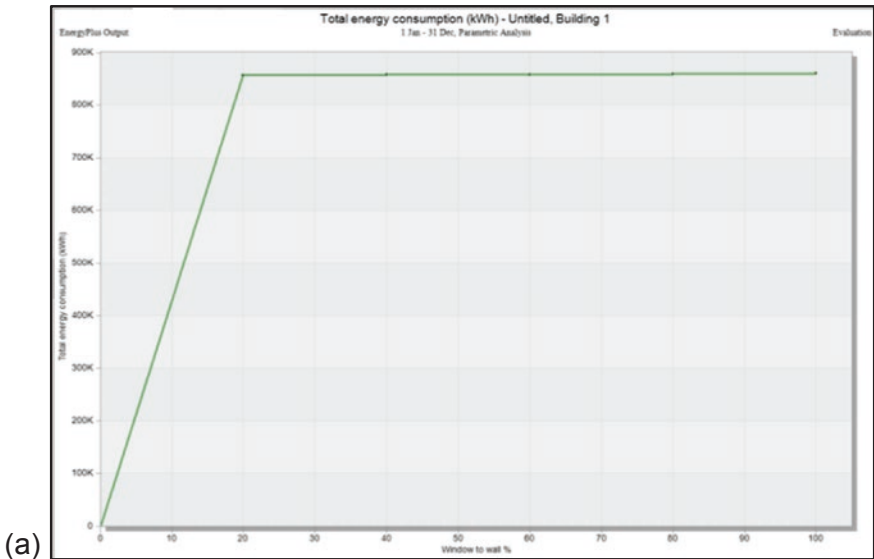
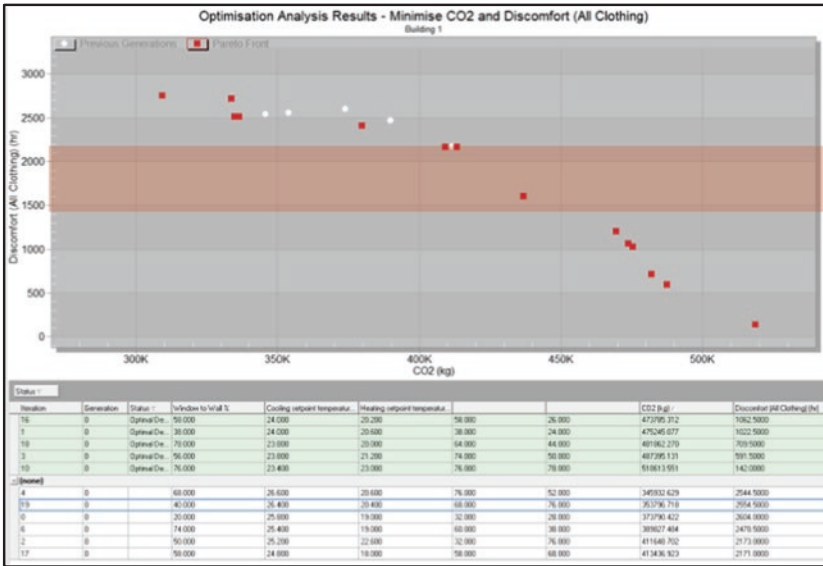


Fig. 17.6 Annual glare analysis in Diva for Toson Palace



(a)



(b)

Fig. 17.7 (a) Parametric configuration of the palace WWR and energy consumption. (b) Optimization of the palace thermal comfort and carbon emissions

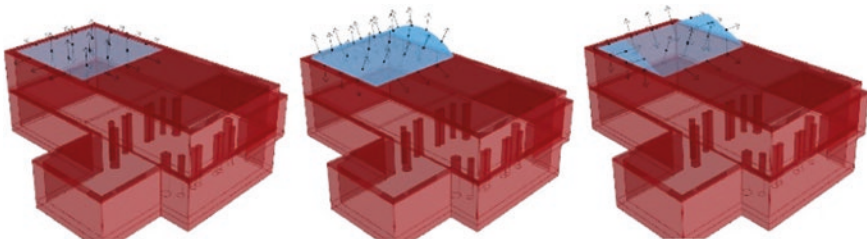


Fig. 17.8 Different shapes of the main hall skylight in Toson Palace

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