MATEC Web of Conferences 13, 06003 (2014)
DOI: 10.1051/matecconf/20141306003

Skylight Application for Natural Lighting in a Building; the University of Tehran Branch of Melli Bank Case Study

Yahya Nasersharifi [1a], Morteza Khalaji Assadi [2]

[1] M.Sc. Student Islamic Azad University of Iran, Science and Research Branch, Faculty of Environment & Energy, Energy Engineering Department, Tehran, Iran
[2] Associate Professor, Mechanical Engineering Department,Universiti Teknologi PETRONAS, Malaysia

Abstract This study investigated the quality and potential lighting energy savings in a bank building retrofitting project in Tehran by using solar passive lighting. The retrofitting scenarios are based on OFFICE project findings. Despite the increase in occupancy and service quality of the bank after retrofitting, the peak electricity consumption significantly decreased (approximately 20%). The results showed that even the proper solar passive lighting in most of day hours had been enough to satisfy the existing building luminance before retrofitting due to the initial passive design of the building, however, by retrofitting and improving the lighting system using skylight and artificial lighting the quality of lighting increased meaningfully to cover the standards of lighting for precision activities required for banking.

1. Introduction

There is an increasing global demand for higher quality office buildings that satisfy the needs of the occupants and also provide opportunities to decrease global energy consumption and the emission of greenhouse gases. Many governmental and non-governmental organizations have made significant efforts to improve the energy efficiency of existing buildings, especially commercial and office buildings, where decision making is primarily depends on strategic management decisions.

In Australia, the Commercial Building Disclosure program requires large commercial office buildings to provide energy efficiency information to potential buyers. In the 2009–2010 state budget, the Queensland government invested $8.0 million to retrofit existing government buildings to increase their energy efficiency. The IEA has initiated a set of projects to promote energy efficiency of existing buildings [1]. Many researches focused on developing and investigating energy efficiency solutions to improve the energy performance of existing buildings. The results showed that energy consumption in existing buildings can decrease with adequate retrofitting [2-4].

A number of methods have been investigated to provide reliable retrofitting of buildings in different areas while considering risk assessment in the projects. Guo et al. [5] developed software to integrate knowledge-based and database approaches to provide solutions for commercial building

[a] Corresponding author: ynsharifi@gmail.com

Article available at http://www.matec-conferences.org or http://dx.doi.org/10.1051/matecconf/20141306003

lighting retrofitting; tests have shown that this software performs consistently and can be modified to reflect other practices. Rey developed a methodology with multiple criteria for evaluating office building retrofit strategies. This methodology considers socio-cultural, environmental, and economic criteria simultaneously [6].

Fluhrer et al. [7] investigated whole building retrofitting of existing commercial buildings. They used a commercial building as a case study to compare the difference between whole building retrofit and typical retrofit approaches. The results indicated that more energy can be saved using a whole building retrofit. Energy in office buildings is generally consumed for heating, cooling, and lighting. Of studies on the effect of retrofitting to increase energy efficiency, Cooperman et al. [8] found that the selection of a retrofit strategy should be based on the specific characteristics of the energy in the building and not on a general plan.

The main challenge to retrofit a building is uncertainties such as changes in the climate, services, human behavior, and government policy, all of which directly affect the selection of retrofit technologies and the success of the project. It is difficult to consider all parameters for all building and climate types and strategies for a specific case. The lack of a simple and comprehensive method suggests the need for general solutions and guides for retrofitting an existing building considering the specific characteristics of the building at the same time. The results of the OFFICE project were used in the current study; it was comprehensive and was able to approximate the project environment and the specific main characteristics of the building to be retrofitted. Providing specific guide-lines for retrofitting special buildings (such as our case) by this project results, and its adaptability to the project specifications were identified as the main reasons to use it. The objective of the OFFICE project is to promote passive solar and energy efficient retrofitting measures in office buildings. This was accomplished by studying low energy retrofitting measures for energy, the indoor environment, and economy as a basis for developing general retrofitting strategies and design guidelines. Within the OFFICE project the energy conservation potential of combined retrofitting actions was investigated for five building types in four different climatic regions. The studied actions involve interventions on the building envelope, HVAC and artificial lighting systems as well as integration of passive components for heating and cooling. The objective of such retrofitting actions is to optimize the energy performance of the building, while maintaining thermal and visual comfort for the occupants [9, 10].

Cost is a key issue when retrofitting a building. The advantage of the current project is that the building has been slated for other types of renovation; allowing for simultaneous addition of passive and low-energy techniques decreases the overall cost for these changes. Investment in this case is more economically feasible than for a building only retrofitted to decrease energy use. The aim of the current retrofitting project was the development of a bank building to increase quality of service and provide a logical and comfortable environment for customers and clerks. Changes must consider energy consumption with a focus on passive solar lighting while considering the building’s architectural characteristics. The main focus of the present study was quality hybrid lighting after retrofitting.

2. Building Specifications

The selected building was the University of Tehran branch of Melli Bank; it was designed and completed in 1962 by Danish architect Jørn Utzon, the designer of the Sydney Opera House. The building contains a large banking hall with a number of offices (Fig.1). The building faces north. The focus was to retrofit the building to provide solar lighting during the main hours of operation, which coincide with the sunniest times of day. The roof is V-shaped and was originally equipped with reflectors to increase the use of the southern exposure to illuminate the main hall (Fig. 2) [11]. These reflectors have become opaque over time and the lack of information about the architectural nature of the building prompted bank management to install 14 high-energy consumption 2000W projectors. The comprehensive program for retrofitting the building was to add an ATM, increase the number of bank counters from 12 to 28, add a safety deposit section, and increase energy efficiency. After studying the architectural maps in preparation for retrofitting, the planners decided to revive the passive solar lighting of the building and institute other changes to increase energy efficiency.

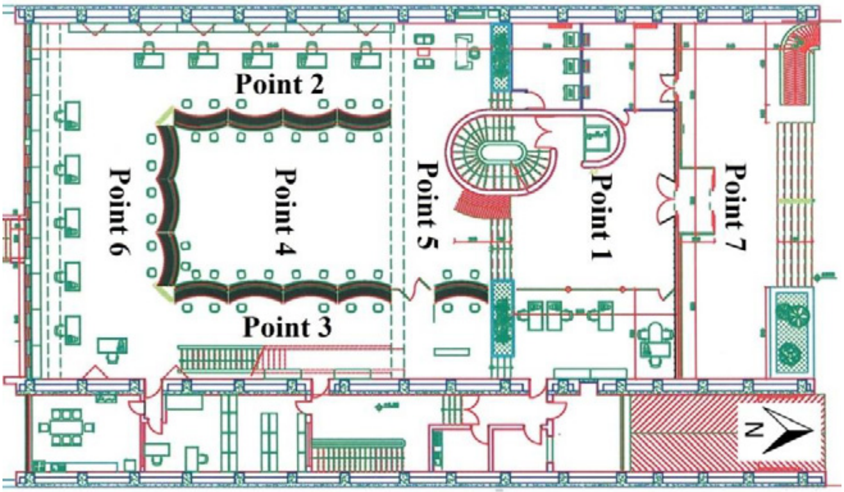

Fig. 1.Bank building plan.

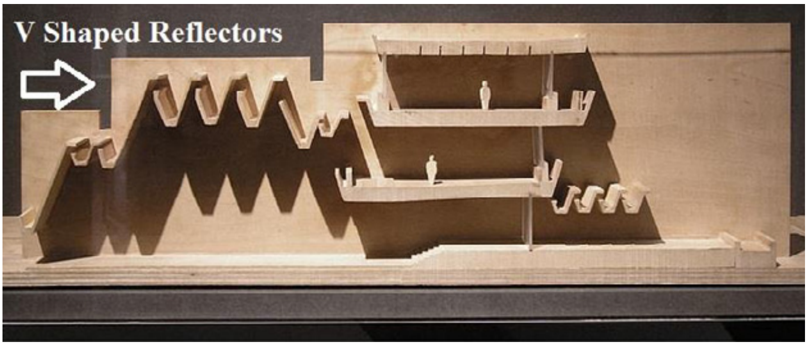

Fig.2.Bank building model.

3. Methodology and Retrofitting Scenarios

Although there is a wide range of possible retrofit technologies, methods of identifying the most cost-effective retrofit for a particular project remains the major technical challenge. The most effective method for the current project was OFFICE. It allowed examination of the energy conservation potential of combined retrofitting actions for five building types in four different climatic regions. According to the adopted classification, office buildings can be free standing or enclosed based on their location in the urban texture, heavy or light, depending on the kind of structure and materials of construction, skin or core dependent, according to the relative importance of the outer envelope and the installed systems in their energy performance ,open plan, consisting of large spaces and minimum interior partitioning or cellular, consisting of small spaces communicating through corridors. Based-on a study of the typology of office buildings, the investigated buildings were classified into five categories:

- Free standing-heavy-core dependent-open plan (Type A),
- Enclosed-heavy-skin dependent-cellular (Type B),
- Free standing-heavy-skin dependent-cellular (Type C),

• Free standing-light-skin dependent-open plan (Type D)
• Enclosed-light-skin dependent-cellular (Type E).

In the current project, the pre-retrofitting bank building was a combination of all of these types but most similar to Type A in energy consumption behavior and lighting condition except free standing specifications. This type of building consumes more energy than buildings belonging to other types under all climatic conditions. In Type A buildings, daylight penetration is insufficient for the deep plan structure of the working areas, making the use of an artificial lighting system necessary throughout the daylight working hours. This results in increased energy consumption for lighting purposes and, combined with the internal gains, adds to the cooling load of the building. Retrofitting scenarios described by OFFICE for Type A buildings in four important sections were considered including building envelope, passive systems and techniques, lighting, and HVAC. [12]

Energy auditing identifies areas with energy-saving potential and provides a building performance assessment using all data from before and after retrofitting. This data recorded using an energy audit standard guide, the Australian/New Zealand Standard [13, 14]. To meet the Office criteria for this project, a Dialux simulation was used for the lighting and electrical section. All 770 traditional 40 W fluorescent bulbs were replaced with 36 W bulbs with electronic ballasts and all 2000 W projectors used for illuminations of the main hall were replaced with 18000 low consumption LEDs with life cycles of >100000 hr. These LEDs were located in aluminum tiles and were installed at top of the hall to complete a hybrid system with daylight and to neutralize the intermittent nature of solar passive illumination. (Fig.3)

In the solar reflectors section, the opaque steel reflectors were replaced with a white coating on the walls of the V-shaped portion of the building (reflectors) that were enriched with nano-particles (Ecoat). This increased the reflection effect more than 88%. To take advantage of the positive effect of cooled roof technology and decrease the cooling energy consumption in summer [15, 16], the coating was used to cover the entire roof. Since in OFFICE projects for these types of buildings in all climates the potential decrease in lighting energy use is limited [12], the angle of the reflectors was modified to produce the best possible effect. In addition, all wiring systems were replaced and a capacitor bank was added to decrease the reactive power effect.

Fig.3. Lighting comparison between before (left) and after (right) retrofitting conditions

For the building envelope and HVAC sections, all windows and their frames were replaced with double-glazed windows in aluminum frames. The BMS system had 16 pre-programmed modes and controls for illumination and temperature, and used HVAC thermostats to control all instruments. The central powerhouse was modified by insulating the pipes and installing a new high-efficiency boiler connected to the BMS. All the high-energy consuming split-system air conditioners were replaced with a new central chilling system that was under BMS control.

4. Results and Conclusions

As the aim of the project was the development of the bank building to increase quality of service and provide a logical and comfortable environment for customers and clerks beside of energy consumption considerations, in addition to energy auditing actions, seven specific points were considered for photometry (Fig.1). The data from photometry in the seven points before retrofitting show that the average-luminance in the main hall was about 350 lux, which is not in accordance with the standards of lighting for precision activities required for banking. After retrofitting the passive system alone satisfied the pre-retrofitted average-luminance (Table 1) for most working hours, even in a low radiance month like December. When daylight conditions are not sufficient to cover the demand, the BMS system and artificial lighting responds to provide desirable conditions (Table 2).

Table 1. Solar passive illumination during bank hours (21 Dec.)

	Luminance [lux]						
Time	Point1	Point2	Point3	Point4	Point5	Point6	Outside
7.30	34	32	38	35	42	40	857
8.30	157	180	148	203	264	340	4270
9.30	293	356	348	236	524	637	4360
10.30	434	555	511	361	728	944	5330
11.30	589	714	714	458	946	1230	8200
12.30	524	637	657	451	900	1910	5410
13.30	457	565	593	433	827	1872	4480
14.30	313	403	350	256	584	1250	7500
15.30	116	157	151	107	212	435	2680

Table 2. Response of hybrid system during times of insufficient solar passive lighting (10 Dec.)

	Luminance [lux]							
time	Illumination type	Point1	Point2	Point3	Point4	Point5	Point6	Outside
11.30	Passive	5	190	188	347	50	470	5300
	Hybrid	1066	557	498	680	780	796	

It is predictable that buildings in Office-based projects have limited passive potential for decreasing lighting energy because these buildings have originally been designed to use artificial lighting, even in daylight hours, which is obvious during Jan and Feb results (Fig.4). However considering the significant increase in comfort conditions, the electricity demand growth was ignorable and the total results of the this study showed a meaningful decrease (approximately 20%) for the Melli Bank building at times of peak electrical demand in summer (Fig. 4). This decrease was achieved using a combination of retrofitting processes to decrease the cooling load that included changes to energy efficient lighting, the use of cool-roof technology and double glazed windows with aluminum frames, and the installation of a BMS system. Moreover, the results show that it is possible to significantly reduce the use of energy in existing buildings in different regions according to the OFFICE project guidelines, by using passive and low-energy technologies and considering the specifications of the given buildings. The results also indicate that energy efficient and renewable energy technologies can contribute to a reduction in the energy use in high-energy use office buildings.

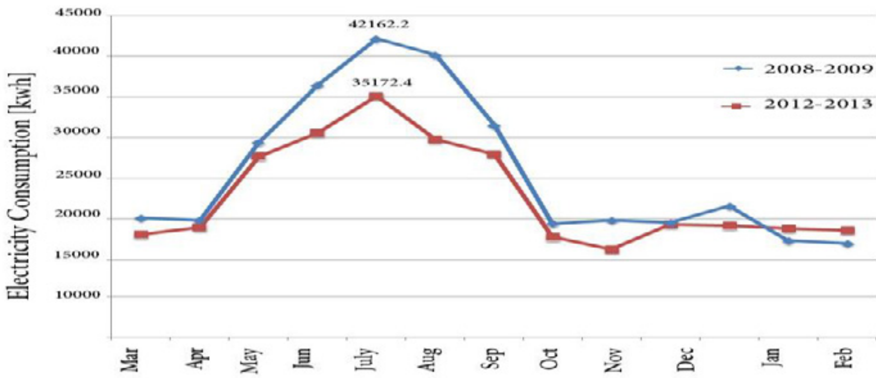

Fig 4. Comparison of electricity consumption before and after retrofitting.

Acknowledgments

This work presents the results of the Melli bank retrofitting project. The authors would like to thank Engrs. Mohamad Javad Jafari,Shahne, and Sabri, (Melli bank supervisors) for performing the tests and their helps in providing the project data during and after retrofitting, and to Engr. Mansouri who collected the primary data of this project (Arta Sakhtman Co, The project contractor).

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