2018 Building Performance Analysis Conference and
SimBuild co-organized by ASHRAE and IBPSA-USA
Chicago, IL
September 26-28, 2018

EXTERNAL SHADINGS EFFECT ON OPERATING ENERGY BASED ON LCEA, CASE STUDY: A RESIDENTIAL BUILDING IN TEHRAN

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ABSTRACT

Increasing awareness of energy waste and destructive environmental effects of buildings has led to particular tendencies toward improving buildings details and performance in order to save energy resources and protect the environment. The daylightophil envelope protects the building from sunlight by preventing the solar radiation entrancement, then causes decreasing building loads in the operational phase. At the essence, this paper focuses on building Operational Energy (OE) and Embodied Energy (EE), when external shading systems are applied as an energy efficient element in the building. To evaluate external shading system role in building thermal needs and environmental impact, Life Cycle Energy Assessment (LCEA) method is employed. LCEA is influenced by OE and EE. EE is total energy consumed in the life cycle stages of building, whereas operational energy is the energy required to operate the building in the process such as space conditioning, lighting and operating other building appliances. LCEA notion not only illustrates the usefulness of the building's life cycle but also facilitates decision-making on the energy efficiency of the system to benefit the optimization. The comparison baseline for simulation is the shading sytems effect on the consumued energy by building in Tehran. The results prove that building in the target climate with an external shading meets the lower OE over the building life cycle about 4%, and accordingly lower-polluting because of the lower consumed energy – especially cooling loads – comparison with the absence of shading system, but the shading material causes some environmental impact too.

INTRODUCTION

Eco-efficiency concept refers to the environmental and economic performances. An eco-efficient building is a sustainable construction that is beneficial or non-harmful to the environment and it is equipped with cost-effective strategies over the building life cycle. Building envelope plays a significant role in controlling the thermal needs. They use a significant amount of energy during their life cycle, from construction to recycling; therefore, consumed energy by buildings envelope reflects their environmental impacts and cost too. Then equipping buildings with more efficient systems – such as shading systems- to improve their thermal performance is one of the optimization solutions of saving energy.

which multi-objective optimization technics adopted to enhance interaction of building envelope and level of energy efficiency. Performance-based design is to control heat transfer from inside to outside, solar heat load from outside to inside, better efficiently in solar energy (Mahdavinejad et al, 2017).

In 2016, about 40% of total U.S. energy consumption was consumed by the residential and commercial sectors. (Energy Department of USA) and around half is used for heating and cooling. (Colt group, 2015) General, the energy lost through windows accounts for 20-25% of the total energy demand for buildings. So, windows are one the most crucial building elements to improve. To achieve this aim, building elements (Mahdavinejad and Tabrizi, 2017).

Solar shading systems have a great potential to impact on energy use and thereby to reduce the use of fossil fuels. The largest thermal loads on the facades are present on the south east and south west facades. (Rungta,2011) Shading denotes the partial or complete obstruction of the sunbeam directed toward a surface by an intervening object or surface. Shading devices are essentially a second link between daylighting and the thermal performance of perimeter spaces. (Geetha, 2003) Direct radiation falling on and through the transparent surfaces on a building contributes disproportionate amounts of energy to the building's heat balance (Givoni, 1981).

A well-conceived shading device must be able to maximize heat gains in winter conditions and to control the radiant heat in summer conditions, as well as to improve visual and acoustic comfort of the interior. (Cellai, et al, 2014) The main function of a shading system is the protection of the building transparent envelope from solar radiation in summer conditions, thus preventing overheating by blocking the access of unwanted energy flow into the building (Mahdavinejad and Tabrizi, 2017).

The shadow varies in position and size depending upon the geometric relationship between the sun and the surface concerned. According to Brennan in 2012, passive louver shading systems are defined as a series of fixed, horizontal or vertical extensions of a building's

façade, used to reflect direct insolation away from a building's interior (Brennan, 2012).
In the other study, shadings are categorized to: fixed, and mobile shadings, roller blinds, and curtains (G. Cellai, et al, 2014).
The effectiveness of sun protection depends on different factors:

1- Fixed or mobile

Fixed shading devices are generally used on the external face of glazing since they lower direct radiation from reaching the internal ambient, dissipating the heat to outside (Datta,2001). They do not allow variation in energy responses; on the contrary, mobile shading devices permit, manually or by automated systems, to adapt to the sun path daily and yearly, due to a punctual control of the shading elements to ensure natural light maximum efficiency (Cellai, et al, 2014) .

2- Screen positioning with respect to the frame

Exterior sun shading is better in function than interior sunshade (Khorraminejad, 2010). They intercepting the incident solar radiation before the glass panes and preventing, therefore, the greenhouse effect. The outer shields are most effective, Furthermore, the placement of the shielding outside also allows to interact with the outer sound waves. Thus, if properly designed, external shielding can help to significantly reduce the sound pressure incident on the façade. Outdoor sunscreen solutions bring higher added value both in terms of architecture and in terms of economic performance; external shielings, much more effective than internal ones, are usually more expensive and subject to maintenance since they are permanently exposed to atmospheric agents. The type of material of screen components plays a fundamental role (Cellai, et al, 2014). They block the sun and prevents of penetrating heat inside the room. In contrast, interior sunshade blocks the sun but still allows heat to enter interior space (Khorraminejad, 2010) and keep out unwanted solar heat (Rungta,2011).

3- Screen disposition, according to the façade exposition

Often, the shield with vertical fixed elements is conceived for the areas facing east and west on which solar radiation affects the morning and late afternoon, with a lower height on the horizon profile (Cellai, et al, 2014). Generally shading system disposition depends on the geographical location and thermal loads.
Sunlight penetrates in two ways: direct radiation, and reflected radiation. Sun shading system just prevents the direct radiation entrance. Exterior shading system is more effective than interior sunshade. It blocks the sun and prevents of penetrating heat inside space than the cooling load decrease. Each orientation of the building requires a different approach to the design of shading according to the sun penetration and sun rays angle.
The north elevation (in the northern hemisphere) essentially does not require shading because except in the summer months in the early morning and late evening, no sun penetration occurs. At this time of day, the sun angle is so low that horizontal projections would be useless as shading devices. It is best to limit opening as much as possible in the north elevation as there will be very little solar heat gain and much direct heat loss from this side. If opening is required for day lighting, then it is important to select highly efficient glazing assembly to reduce energy transfer. The south elevation (in the northern hemisphere) allows for the easiest control of solar energy (Khorraminejad, 2010).
The focus of this study is conduct a comparing the feasibility of the window shading involving or not. The results of the environmental inventories and consumed energy amount – LCEA - during building lifespan when windows are equipped with the external shading system are compared with the building without shading. When the building lifespan is supposed, the result of thermal analysis of building is OE and EE. However, OE in buildings is the consumed energy during the usage phase, while EE is needed energy during manufacturing to demolishing. Both concepts are different from building to building depending on the variety of scenarios in buildings materials, construction, details, site characters, climate condition, orientation and many other factors. For making uniform comparison conditions, all features of models are equal except that a wood external shading (Table 1).

Table. 1 Building and the shading system features

Activity	Residential building		
Geometry	Rectangular		
Area	About 70 m^2		
Glazing properties	Window to wall (%)	South	70
		North	30
	Windows width and height	3 m, 1.5 m	
	Glazing type	DBI blue 6/13mm	
Shading details	Material	Wood	
	Type	Overhang	
	Projection	0.5 m	
	Thickness	0.002 m	
	Length	5 m	
HVAC type	Fan coil unit (4-Pipe), Air cooled chiller		
Environmental control	Heating set point (°C)	Heating	18
		Set back	12
	Cooling set point (°C)	Cooling	25
		Set back	28

In this paper, shading device is designed as horizontal projections in the southern elevation above the window. The shading type is overhang as Figure 1 illustrates. The length of the projection is determined as the height of the window and the angle is supposed 0° (horizontally in parallel to the window).
The Design Builder software was used to perform energy simulations and calculate monthly building energy consumption (for lighting, cooling, and heating loads) for each model to evaluate model's OE. EE and environmental impact were referenced from e TOOLLCD open access resources. By applying LCEA definition, OE (over building lifespan, that is supposed 30 years in Tehran) and EE numerical results confirm whether or not an external shading optimize the building LCEA in Tehran.

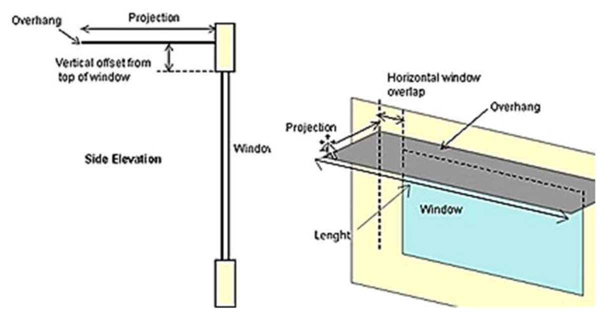

Figure 1. Overhang shading location and features.

LITERATURE REVIEW

Some scientists believe external solar shadings are one of the most effective ways to control the internal conditions of a building. Colt group in 2015, mentioned that radiation from the sun is transmitted, absorbed and reflected by the louvers (Colt group, 2015). As a result, solar heat gaining is prevented from passing into the building, minimizing ventilation requirements and reducing cooling loads. This study focuses on office buildings because shadings are the most effective elements in office buildings comfort. An appropriate selection of solar shading devices can control indoor illumination from daylight, solar heat gains, and glare while maintaining view out through windows, thus saving lighting and thermal energy while maintaining visual comfort (Abu Sadin et al, 2013).
In 1977, Adalberth presented a new method describing the calculation of the energy use during the life cycle of a building (Adalberth, 1977). Minimizing LCEI in buildings by the optimal solution and using structured genetic algorithms done by Weimin and et al (Weimin, 2003).
Kozáková et al studied about LCEA of buildings resulting from 73 cases across 13 countries. Results show that OE (80–90%) and EE (10–20%) phases of energy use are significant contributors to building's life cycle energy demand (Kozáková, 2014). Babaizadeh studied the external shading system to evaluate LCA the life cycle assessment of the shadings through all life cycle stages. The Building for Environmental and Economic Sustainability (BEES) model and SimaPro software are applied to indicate shading EE and environmental impact, and by Energy Plus software energy analysis of buildings were done. Models were simulated in case of shadings that are made of wood, aluminum, and polyvinyl chloride (PVC) in the different climate condition in the USA. The results of the study illustrate that the use of external shadings on residential window panes, in most cases, carries a positive effect on fossil fuel depletion impact, while it increases environmental loads in other environmental impact categories. Among the three aforementioned materials, wood and PVC shadings are the most and the least environmentally-friendly materials, respectively (Babaizadeh et al in, 2014).
Karimpour et al, in 2014 studied EE and OE in building sector by comparing 24 buildings in 10 cities with the different climate. They extracted the reliance between OE and LCEA as a linear. The results revealed that buildings EE is related to the climate, while it is higher in temperate temperature rather than mild climate (Karimpour et al in, 2015).

In 2017, Ramasamy et al focused on assessing the LCE of an infrastructure building by identifying the phases that consume more energy and to develop strategies for its reduction and improvements. Results of the study show that embodied and operational energy are the main contributors to the building's life cycle energy demand. They supposed that the type of material has a significant effect on the total EE in a building over its lifetime (Ramasamy et al, 2017).

METHODOLOGY

According to the paper target, LCEA of two models are compared to illustrate the impact of external shading in decreasing consumed energy and environmental energy. The research method is applying energy, emissions, and cost evaluation tools, methods and software. Three steps of research start with collecting information of LCEA, consists of OE and EE, and impact on the environment of building in case of involving wood external shading (overhang shading) and without shading system in step 1. Both of models are thermal simulated (in Tehran climate condition) by Design Builder software, that applies Energy Plus motor for simulating and analyzing to evaluate lighting, heating, and cooling loads of buildings. External shading materials are evaluated to find each material embodied energy and environmentally impacts in e TOOL LCD[1] free access web-based database. All results are analyzed in Excel. Comparing part 1 results is the process of step 2. In this phase, data of the previous step are applied to compare the total LECA of each model. Results of step 2 are analyzed and compared in step 3 to illustrate an energy efficient and environmental friendly model.

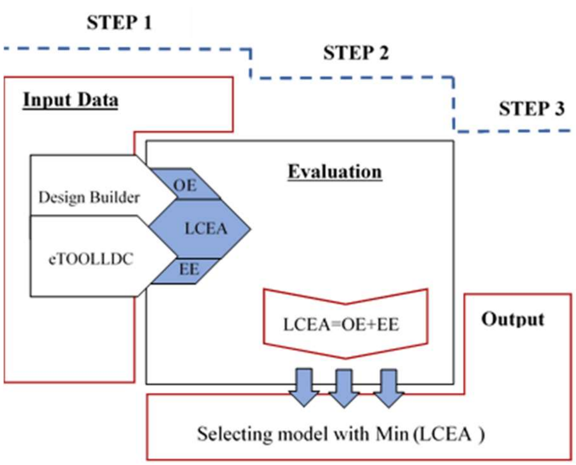

Figure 2. The methodology of research.

Step 1: Input Data

EE, Embodied Energy

Buildings are constructed with wide select icons of building materials, and each of these materials consumes energy throughout its different stages of use. Likewise, each building consumes energy during its life cycle in different stages, such as in raw material extraction, transport, manufacture, assembly, installation, disassembly, demolition, and disposal. The energy that is consumed in these different stages of a building is termed as Embodied Energy (Ramasamy et al, 2017).
EE for external shading as a wood base element -that is added to the building- are evaluated as the paper objects. EE of wood according to the eTOOLlCD shows in Table 2. As wood is an environmental friendly material, producing it causes lees consumed energy, about 6352 MJNCV.
1NCV= 42.50 MJ/kg for gas-oil; 41.51 for fuel-oil; 45.55 for refinery gas (Ndiaye et al, 2005).

[1] e Tool LCD produces comprehensive reports complete with comparable sustainable building data with outputs compliant with international standards ISO 14044 and EN 15978.

Table. 2 Embodied Energy, EE of wood.

Embodied Energy (MJ NCV[2])	Products	1744
	Transport	1623
	Construction	12
	Recurring	2961
	Energy	0
	Water	0
	End of Life	47
	Energy Export	0
	Product Reuse	-35
	Total	**6352**

SIMULATION

Energy analysis, and OE calculation

Building performance is mostly shown by energy simulation. This is a method to illustrate thermal behavior and energy consumption of building during a special period of time. All energy simulations are done by Design Builder software that uses Energy Plus motor for simulation according to the site weather data (Tehran, Mehrabad weather station), that is available in Design Builder software from ASHRAE handbook weather data.

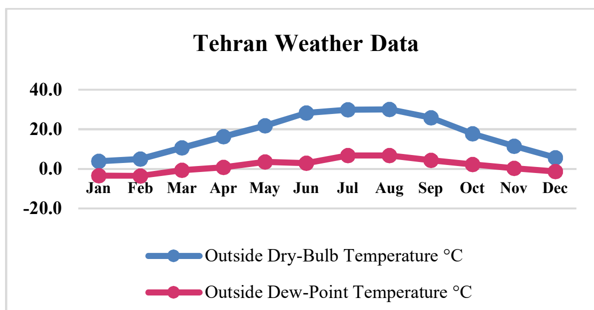

Figure 3. Tehran weather data.

According to Figure 3, in Tehran, the dry bulb temperature is between 0 °C and 35°C, then during the warm days building need cooling to create thermal comfort for occupants. Then the dominated thermal load in Tehran is cooling. Thermal simulation of both models (with and without shading system) are done in Tehran summer design weeks, 1 April to 30 September. It is obvious that cooling loads are dominated in this season that the external shading system targets to decrease it.

[2] MJNCV Net Calorific Value (42.50 MJ/kg for gas-oil; 41.51 for fuel-oil; 45.55 for refinery gas)

Results of models' simulation and energy analyzing are in Table 3.

Table. 3 .The comparison of models' OE.

	LIGHTING	HEATING	COOLING	EOA	OE
	kwh	kwh	kwh	kwh	kwh
Without shading	361.7	88.8	5818.3	6,269	1,647,428,186
With shading	361.7	95.7	5559.4	6,017	1,581,207,332

As Table 3 demonstrates, lighting and cooling loads are according to the consumed electricity (kwh), but heating loads are according to the consumed natural gas (kwh). Two models have not considerable differences in lighting loads, but as external shading creates an obstruction of the directed sunrays the cooling loads in inner spaces decrease.

Ramesh and et al prepared (1) for OE evaluation in building lifespan (Ramesh, 2010)

$$\textbf{OE} = \text{EOA}^* \text{ Lb} \quad (1)$$

EOA= operating energy annual

Lb= Lifespan[3] of the building

As function (1) mentions, OEA as annually operation loads that confirms OE over the lifespan[4]. Furthermore, EOA is calculated by applying the function (2).

Annually thermal loads = Lighting loads + cooling loads + heating loads (2)

Environmental impact evaluation

As previously discussed, simulated external shading in the model, are supposed a wood-based device. Then the environmental impact of wood has evaluated that Table 4 shows.

Table. 4 .Environmental impact of wood.

Global Warming Potential (kg CO2 eq)	Products	-34	**Abiotic Resource Depletion Minerals and Energy (kgSbe)**	0
	Transport	109		1
	Construction	6		0
	Recurring	197		1
	Energy	0		0
	Water	0		0
	End of Life	40		0
	Energy Export	0		0
	Product Reuse	0		0
	Total	**318**		**2**
Land Use (m2. year arable)	Products	1090	**Ionizing Radiation (DALY) (IR)**	12
	Transport	6		0
	Construction	0		0
	Recurring	3		27
	Energy	0		0
	Water	0		0
	End of Life	0		0
	Energy Export	0		0
	Product Reuse	0		0
	Total	**1099**		**39**
Ozone Depletion Potential (kg CFC-11 eq)	Products	2	**Marine Aquatic Ecotoxicity (uDay)**	9
	Transport	0		1
	Construction	0		0
	Recurring	1		10
	Energy	0		0
	Water	0		0
	End of Life	0		0
	Energy Export	0		0
	Product Reuse	0		0
	Total	**3**		**21**
Acidification Potential for Soil and Water (kg SO2 eq.)	Products	0	**Ecotoxicity (uCTUe)**	2
	Transport	1		2
	Construction	0		0
	Recurring	1		4
	Energy	0		0
	Water	0		0
	End of Life	0		0
	Energy Export	0		0
	Product Reuse	0		0
	Total	**2**		**7**
Human Toxicity Potential (uDALY)	Products	2	**Net Use of Fresh Water (m3)**	0
	Transport	0		0
	Construction	0		0
	Recurring	2		0
	Energy	0		0
	Water	0		0
	End of Life	0		0
	Energy Export	0		0
	Product Reuse	0		0
	Total	**4**		**1**

[3] 1 year = 8760 hours

[4] lifespan in Tehran is supposed 30 years, and each year is 8760 hours

According to the Table 4, wood creates less pollution and negative impact, when it manufactures and uses. Except than land use and global warming potential items in Table 4, others are not considerable. It confirms the definition of wood as an environmental-friendly material. All data are available in eTOOLLCD open source.

DISCUSSION AND RESULT ANALYSIS

Step 2: Evaluation

Life Cycle Energy Assessment (LCEA)

Ramesh et al. (2017) and Cabeza et al. (2014) define LCEA as an approach that accounts for all energy inputs to a building in its life cycle.

LCEA illustrates the energy consumption during the life cycle and environmental impact.

Life Cycle Energy Analysis focuses on energy as the only measure of the environmental impact of buildings and products. The purpose of LCEA is to present a more detailed analysis of energy attributable to products, systems or buildings, to compare and evaluate the embodied energy and operational energy in materials and components (Ramasamy et al, 2017). (Figure 4)

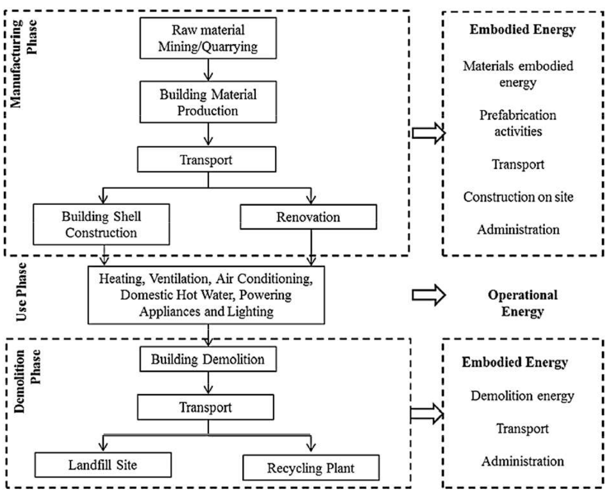

Figure 4. LCEA frame. (Ramesh et al, 2010), (Cabeza et al, 2014)

Then LCEA contains all energy that is consumed for EE and OE as (3) proves.

$$\textbf{LCEA}=\text{EE}+\text{OE} \tag{3}$$

Where, EE= embodied energy, the expanded cumulative energy consumption due to building construction (manufacturing phase).

OE= Operation energy, that is, the expanded cumulative energy consumption due to building operation (using phase).

LCEA definition is the numerical sum of OE and EE. (1kwh= 3.6 MJ)

Step 3: output, results analysis

Selecting model with Min (LCEA)

Figure 5 illustrates LCEA of building in case of containing external shading in the southern elevation or not. It confirms that although wood-based shading system in Tehran located building causes more EE, that it is not noticeable in comparison with OE over the building life cycle.

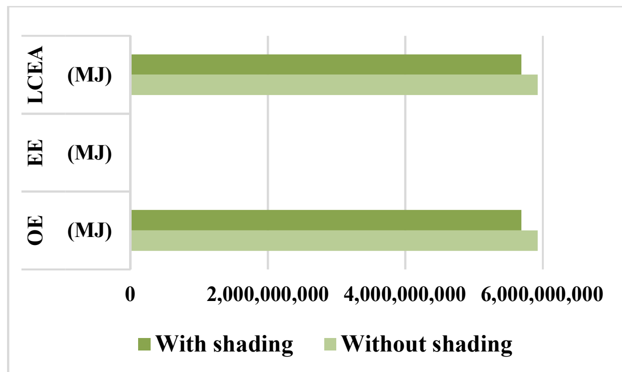

Figure 5. The comparison of models' LCEA.

CONCLUSION

The method of study and results provide a process that helps to make the decision in selecting an energy efficient system for enhancing building energy performance without causing the more negative environmental impact. Energy performances achievable by applying external solar shading for the residential building would reduce the total energy consumption for buildings over the life cycle. Saving energy will overcome the amount of fossil fuel depleted, pollution of energy consumption and emissions.

Not only equipping the building with details to slowdown consumed energy lead to the saving energy in building sector in the concept of OE, but also selecting materials that have less emission and polluted is a method for respecting to the environment, that means LCEA concept too.

At the essence, the wood made external shading causes about 4% less LCEA, the total of OE and EE energy consumption over the Tehran summer weeks over the building lifespan and simultaneous this type shading is an economic-environmental friendly alternative too.

ACKNOWLEDGMENT

This paper in result of a comprehensive study in TMU (Tarbiat Modares University) under supervision of Dr. Mohammadjavad Mahdavinejad.

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