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The Influence Of The Plants LAI On The Energy Performance Of Green Facade In Hot-Dry Climate With Special Reference To Residential Buildings

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ABSTRACT

The green façade installation considered as one of the effective energy saving tool especially during the hottest seasons. Although, the plants leaf area index (LAI) have been known as one of the main parameters that effect on the potential of the green façade systems as an energy saving's passive tool, a lack of knowledge remains on the value of LAI index's and its effect on the required cooling and heating loads for the building. As most of researches ignored the effect of the chosen plants characteristics especially LAI and its effect on the energy consumption, this paper aimed to define the influence of annual different LAI of Hedra Helix – IVY vegetation layer on the energy consumption under hot dry climate, by using Design-builder simulation program during the different seasons to measure the effect of different LAI on the energy consumption. The simulation results shows that the higher LAI value caused a heighr efficiency as the LAI 4.82 caused 9% in energy saving while the LAI 3.66 caused 4.6%. Finally the paper shows that how the WWR% effect on the energy saving beside using the green facades as it shows that in the intial case the energy consumption reduced by 10% in case of WWR 20% instead of 30% and by 16.6% in case of adding the green façade layer.

KEYWORDS: Green Facades, Leaf Area Index, and Energy Consumption Efficiency

تأثير مؤشر المساحة الورقية للنباتات على أداء الطاقة للواجهة الخضراء في المناخ الحار الجاف مع إشارة خاصة للمباني السكنية

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الملخص

تعتبر انظمة الواجهة الخضراء أحد الانظمة الفعالة لتوفير الطاقة خاصة خلال الفترات الحارة. على الرغم من ان مؤشر مساحة أوراق النباتات (LAI) يعتبر من اهم المعايير الرئيسية التي تؤثر على إمكانات الواجهة الخضراء كأداة سلبية لتوفير الطاقة، إلا أنه لا يزال هناك نقص في المعرفة حول قيمة المؤشر وتأثيره على احمال التبريد والتدفئة التى يحتاجها المبنى. ونظرا لان معظم الابحاث والتجارب السابقة تتجاهل تأثير خصائص النباتات المستخدمة فى انظمة الواجهات الخضراء وخاصة مؤشر سطح الورقة LAI وتأثيرها على استهلاك الطاقة، لذلك يهدف البحث إلى قياس تأثير تحديد مؤشر المساحة الورقية لاوراق نبات Hedra Helix – IVY على استهلاك الطاقة في ظل المناخ الحار الجاف، وذلك باستخدام برنامج محاكاة Design-builder خلال المواسم المختلفة لقياس تأثير LAI المختلفة على استهلاك الطاقة. تظهر نتائج المحاكاة أن قيمة LAI الأعلى تسببت في زيادة نسبة توفير الطاقة حيث كانت اعلى نسبة خفض فى استهلاك الطاقة بنحو 9%} فى حالة LAI 4.82 بينما كانت نسبة الخفض

فى استهلاك الطاقة 4.6% فى حالة LAI 3.66. واخيرا يقوم البحث بعرض تأثير نسبة الفتحات على معدل استهلاك الطاقة حيث فى الحالة الاساسية للمبنى بدون تعديلات قل استهلاك الطاقة بنحو 10% عند تقليل نسبة WWR من 30% الى 20% بينما قلت بحوالى 16.6% عند اضافة طبقة الواجهات الخضراء مع تقليل نسبة WWR.

الكلمات المفتاحية : الواجهات الخضراء، مؤشر المساحة الورقية، كفاءة استهلاك الطاقة

1. INTRODUCTION

The residential building sectors consumes about 50% of the total energy consumption and 35% of it is for cooling and heating systems [1]. Using vegetation on the building's facade is an eco-friendly method that not only reduce the energy consumption of the buildings but also, provides a multiple benefits such as; reducing the urban heat island effect (UHI), improving the air quality (indoor and outdoor), reducing the amount of CO_2 emissions, working as a sound insulation layer, improving the building aesthetic value… etc [2].

1.1. Research problem

The problem of this research is that most of researches ignored the effect of LAI and its effect on the required cooling and heating loads for the building which directly effect on the energy consumption of the building.

1.2. Research aim

The paper aimed to illustrate the influence of the annual LAI of the green facade's vegetation layer on the amount of energy saving with considering the effect of the building's WWR%

1.3. Research Methodology

The research is depended on addressing the influence of annual LAI on the building energy saving and how the LAI could enhance the thermal performance of the green facades and provides higher energy saving through;

1- Reviewing the literature related to the green facades and it's LAI effect
2- Defining the methods and data collection for the chosen case study
3- Using Design-Builder simulation program to define the effect of different annually LAI on the building's energy consumption

2. Litrature Review

Previous researches showed that the green facades can reduce the energy consumption passively from 34% to 59% during the hot periods in the hot-dry climates [3], as it reduced the energy consumption by 11 to 31 KW.hr for every m^2 of the green façade [4]. When it comes to the green façades impact on the thermal performance of buildings, it's important to consider that the different layers of green facades construction could lead to different thermal behavior. The below figure (Fig. 1) shows the general classification of vertical greening systems/green walls. The research is focused on the effect of indirect green facades with 60 cm air gap which installed using the light stainless-steel mesh to support an evergreen climber that widely used around the world known as Hedra Helix – IVY. According to Perez et al, 2014 research has been classified the effect of VGSs into four different effects: shade, cooling, insulation effect and, wind barrier effect. The research focused on the effect of green facades on the energy consumption, the below table (Table 1) shows the related effects and its potential variables.

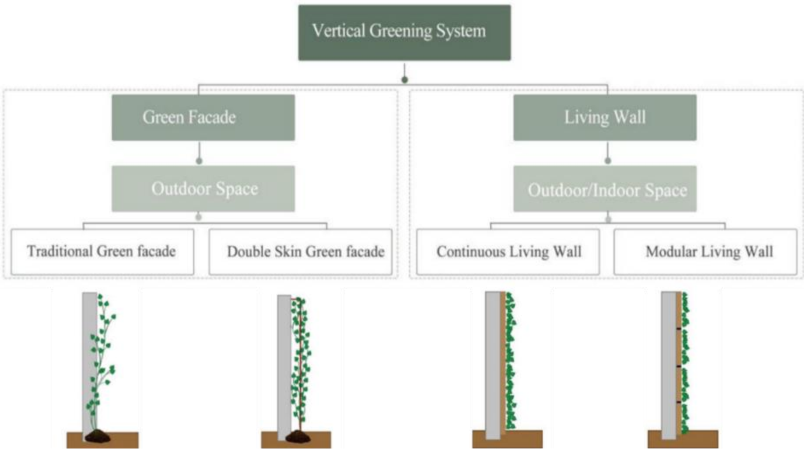


Figure 1: The classification of vertical greening systems(VGS) [5].

Table 1: The main three effect of the VGS related to its thermal behavior [6].

Effect	Potential variables	Method
Shade Effect	▪ LAI ▪ Substrate Thickness ▪ Orientation of Installation	Blocked the direct solar radiation by plants
Insulation Effect	▪ LAI ▪ Substrate Thickness ▪ Air Gap Thickness	The insulation capacity which provided by system layers; plants, air gap, substrates, panels… etc.
Cooling Effect	▪ LAI ▪ Climate Condition ▪ Substrate Thickness ▪ Type of Plants ▪ Wind Speed	Evapotranspiration from the plants

As the research focused on the effect of VGS on the energy consumption, the research focused on the main 3 effects related to the energy consumption (Shading, insulation and cooling effect) and its potential key parameters so that, The table 1 shows that the plants LAI considered as the most influenced common variable that effects on the thermal behavior of building envelope which directly effects on the amount of energy consumption. The LAI is defined as "the cross-sectional area of the leaf per unit covered area" [7] so that, the LAI is used to compared between the thermal effects of several types of plants that could be used in green facades as in Wong study the linear correlation between both LAI and shading coefficient values for different types of green walls which means that the higher LAI's values results into the higher thermal performance for the building envelope has been identified [7]. By reviewing the litrature, it's noted that only few studies done experimentally studies on how VGS can influence the thermal behavior of the building as seen in (Table 3) which summerized some of these studies. And the main weakness of these studies could be summerized as the following;

- Values' Dispersion.
- Lack of easy to apply methodology for LAI measurements for green facades.
- Most of these studies focused on seasonal period not the whole year.
- Some of these studies estimated the LAI from agriculture references without considering the green facades's context for both urban and building scale.

Table 2. Previous studies which highlighting LAI as a key variable when studying the green facade as a passive tool for energy savings in buildings.

Plants	Plants' Typology	LAI Value	Method	Author, Date
Boston IVY	Deciduous	Summer: between 4.13 and 4.80 Fall: between 1.5 and 2 Winter: between 0.91 to 2.35 Spring: the plant was shifted from a LAI value between 0 and 1 to a LAI value of almost 5	Experimantal study has been done by using the SRS-NDVI sensors (spectral reflectance sensors) which placed at the appropriate height and distance away from the facade to be able to generate a reading cone on the facade to be as a representative of the entire surface	Gabriel Pérez et al., 2022 [8]
Phaseolus vulgaris L	Plants are not compatiable with green façade systems	Between 6.1 and 7.2	Using Li-Cor LAI-2200 for ten isolated measurements	Suklje T. et al., 2019 [9]
Lonicera japonica	Deciduous	0.24	Isolated destructive leaf harvesting	Lee L.S.H and Jim C.Y., 2019 [10]
Rhyncospermum Jasminoides	Evergreen	Between 2 and 4	AccuPAR PAR/LAI Ceptometer (model LP-80, Decagon Devices Inc., Pullman, WA, USA)	Vox G et al., 2018 [11]
Hedra Helix - IVY	Evergreen	Spring: 3.72 Summer: 4.29 Fall: 2.78 Winter: 3.66	Adapted from Pitman and Broadmeadow, 2001's previous study	Poddar S et al., 2017 [12]
Partenocissus tricuspidata	Deciduous	Between 2.1 and 3.9	540 measurements in three different orientations and three different levels using PAR Sunfleck Ceptometer	Pérez et al., 2017 [13]

3. Material and Methods

This section of the research is designed to include two significant steps. First, we review the literature of the researches related to studying the effect of LAI of green facades vegetation layer on the building's thermal behavior to be able to define the missing parameters that helped in measuring the effect of LAI on the building's energy consumption. Second, the research used Design-builder simulation program which is the most established and advanced user interface to EnergyPlus [14] to measure the effect of the different evergreen plants LAI on both heating and cooling loads which reflected on the total energy consumption of the residential building with considering the climate and building contexts.

4. Data Collection For Case Study

The chosen case study is a residential building in Janna New Cairo project, which is considered as on of the main governmental modern residential projects that located in the new cities such as; new cairo, al-sheikh zayed, 6th of october, badr, al-shrouk... etc.) its started since 2014 as a middle income housing but in its third phase it changed to be a high income housing, the appartments areas are varying from 100 to 150m^2.

The chosing building as a case study is consists of 6 floors and each floor consists of 4 appartments with two different areas 115 m2 and 130 m2 with WWR 30%. (Fig. 2).

A- B-

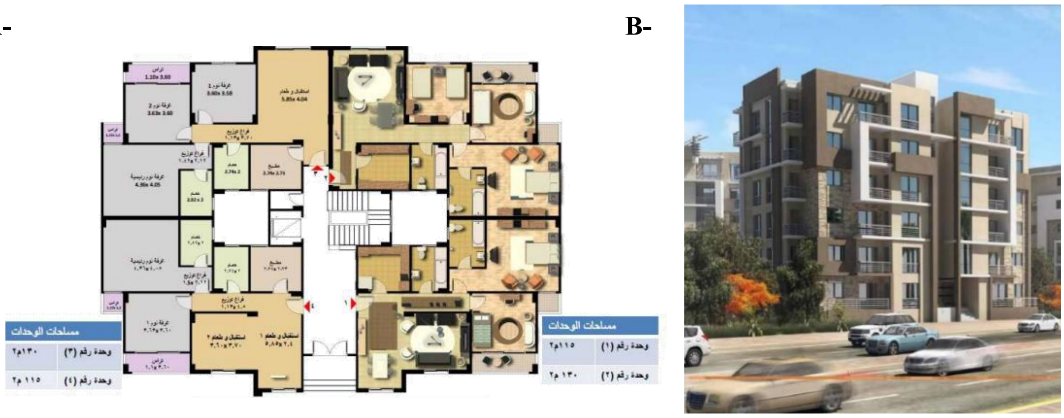


Figure 2. The Resdintial Building Case Study Plan (A) – The Resedintail Building 3D model (B).

The input data of the simulation is divided into four main parts as the following;

First, Climate Data: The climate classisification is hot climate (Köppen climate classification BWh) with the latitude of 30.1°, longitude 31.18° and elevation above sea level is 232 m2. The Daily direct normal irradiation is 6 kWh/m2, the maximum average outside dry bulb temperature is 29 °C in August and the minimum is 13 °C in January, the maximum outside dew point temperature is 20 °C in August and the minimum is 6 °C in February, and finally the maximum wind speed is 4.5 m/s in April and 4.1m/s in May and the minimum is 2.7 m/s in January.

Second, Installation Orientation; the installation will be on the three locations (East, South and West) with 100% coverage of obaque parts.

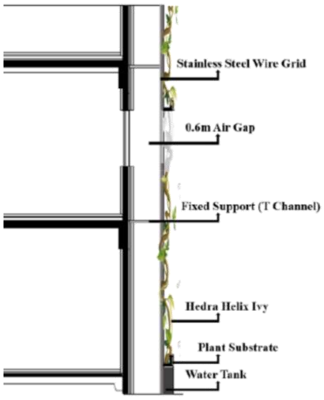
Third, The Simulation Program: the researchers used Design-builder simulation program which is a 3D environmental model that designed for architect, engineers andenergy assisstors to evaluate the environmental effect such as; energy consumption, cooling and heating loads, CO2 emissions, temperature reduction… etc. The study used Design-Builder to measure the energy saving of different plant LAI in different season by calculating the monthly energy consumption for both cooling and heating loads [15].

Fourth, Building input data: the simulation will be done in two cases, intial case and after green façade installation. The layers will be as shown in (Fig. 3) and the input data will be as the following;

- The installation will be a free-standing stainless-steel structure with air gap 60 cm
- The vegetation layer plants is Hedra Helix –IVY with leaf area index (LAI) in Spring 3.72, Summer: 4.29, Fall: 2.78 and Winter: 3.66 with max. growth height: 20–30 m, the thermal properties will be as shown in (Table 3)
- WWR = 30% and the glass type is clear single glazing 6mm
- Coverage ratio is 100% of the opaque surfaces
- Substrate is a sturdy-steel planter box (100 x 500 x 15 cm)
- Irrigation method will be simple self-irrigation system

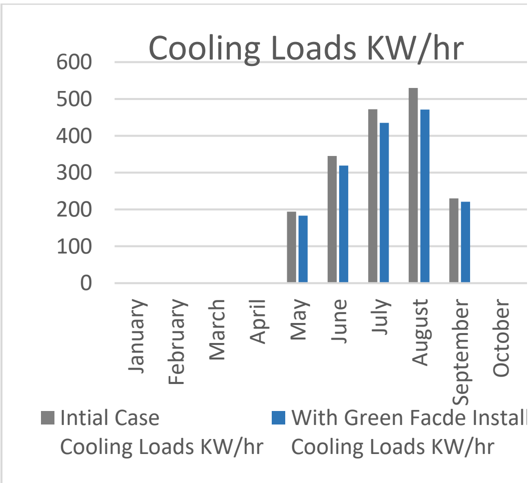
Table 3. The thermal properties of Initial Case and green facade installation with 60 cm air gap.

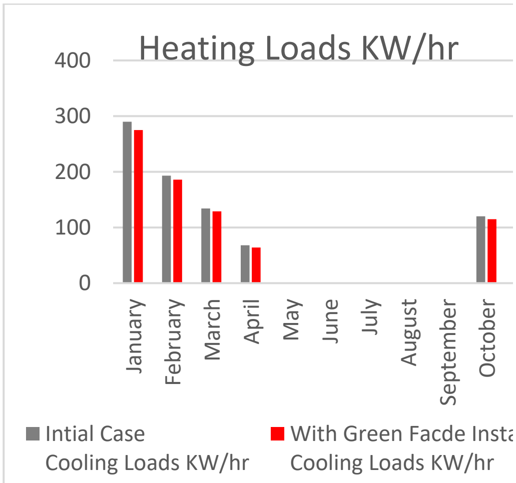
Wall layers [16]	**Initial Case**				**Indirect Trans-functional GW with air gap 60 cm**			
	Sp.H J/kg.K	**Den. g/m^3**	**Cond. W/m.K**	**Thick-ness m**	**Sp.H J/kg.K**	**Den. g/m^3**	**Cond. W/m.K**	**Thick-ness m**
Water vapor	---	---	---	---	1966	0.60	5.56	0.002
Vegetation	---	---	---	---	2.8	533,28	0.36	0.20
Air gap	---	---	---	---	1004	1.3	5.56	0.60
Stainless-steel (structure system)	---	---	---	---	460	7900	17	0.05
Softwood	---	---	---	---	1880	110	0.14	0.015
Plaster	1000	600	0.16	0.005	1000	600	0.16	0.005
Mortar	896	1570	1.00	0.02	896	1570	1.00	0.02
Concrete Blocks	840	1950	0.97	0.25	840	1950	0.97	0.25
Mortar	896	1570	1.00	0.02	896	1570	1.00	0.02
Plaster	1000	600	0.16	0.005	1000	600	0.16	0.005



5. Results

The vegitation layer in the green facades works as a thermal insulation layer and protect the building facades from direct solar radiation and heat gain and that is depending on the LAI of the plants, as the Hedra Helix – IVY is an evergreen plants which its LAI is changing seasonly, and as shown in the (Fig. 3) The needed cooling loads and heating loads is reduced after green façade installed. The cooling loads decreased from 194 to 183 kw/hr in May, from 345 to 319 kw/hr in June, from 472 to 435 kw/hr in July, from 530 to 471 kw/hr in August, and from 230 to 221 kw/hr in September. While the heating loads secreased from 120 to 115 kw/hr in October, from 158 to 149 kw/hr in November, from 245 to 235 kw/hr in December, from 290 to 275 kw/hr in January, from 193 to 186 kw/hr in February, from 134 to 129 kw/hr in March, and from 68 to 64 kw/hr in April. Which means that the largest LAI caused the largest energy saving as the energy saving ratios were 4.3% when the LAI is 2.78 in winter, 4.6% when LAI is 3.66 in fall, 9% when LAI is 4.29 in summer and 5.4% when LAI is 3.72 in spring.





*leaf area index (LAI) in Spring 3.72, Summer: 4.29, Fall: 2.78 and Winter: 3.66

Figure 3: The cooliong and heating load after applying green façade with different LAI value according to the seasons

As the egyptian energy code for the resedential building mentioned that the WWR% is should be between 15 to 20% [17] and the initial case WWR% is exceeded this percentage by 10% the research mesured the effect of these extra 10% on the initial case. The below table (Table 4) shows that by following the local codes the building annualy energy consumption will be reduced by 5.5%.

Table 4. The energy saving results of reducing the WWR% from 30% to 20%.

	Cooling Loads (annually) KW/hr	**Heating Loads (annually) KW/hr**	**Total energy consumption (annually) KW/hr**	**Energy saving ratio %**
Initial Case (WWR 30%)	1771	1208	2979	
With (WWR 20%)	1667	1148	2815	5.5%

Also, as the openning is one of the façade elements that affect on the heat gain of building facades the researcher measured the effect of replacing the 6mm single clear glazing with double clear glazing and found that the energy consumption for initial case without green façade after applying double clear glazing reduced by 10% and in case of replacing the glazing type with installing the green facades with 60cm air gap the energy consumption is reduced by 16.6% as shown in (Table 5) and (Fig. 4).

Table 5: The energy saving results after replacing the 6mm single clear glazing with double clear glazing

	Cooling Loads (annually) KW/hr	***Heating Loads (annually) KW/hr***	***Total energy consumption (annually) KW/hr***	***Energy saving ratio %***
Initial Case	1771	1208	2979	
Initial Case with double glazing window	1589	1112	2701	10%
Indirect green façade with 60 cm air gap & double-glazing window	1398	1087	2485	16.6%

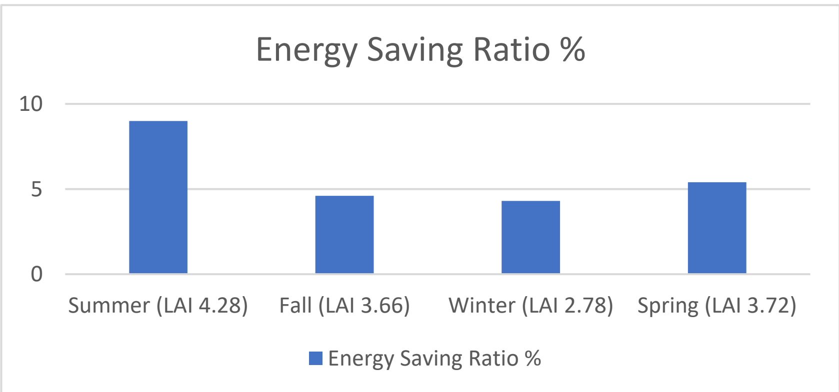


Figure 4. The energy saving ratio in different seasons related to the LAI for each season.

Finally, as the type of window glass has a great impact on the amount of space heat gain the simulation study the case of replacing the single clear glass 6mm to a double glazing window only and with green façade installation with 60 cm air gap and it shows that the energy consumption reduced by 10% im the case of double glazing only and by 16% in case of green façade installation with 60 cm air gap (Fig. 5)

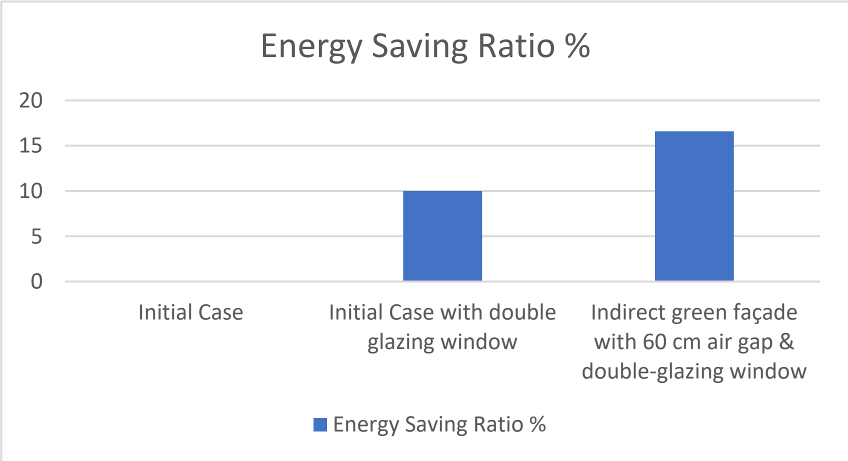


Figure 5. The annual energy saving after changing the type of glazing before and after installing the green facades with 60cm air gap.

CONCLUSIONS

The residential building only consumes about 50% of total energy consumption and most of these consumption is for H-VAC and heating systems to achieve the thermal comfort inside the spaces. According to that most of designer are going to use eco-friendly treatment tools such as green walls to protect the building envelope from the outdoor circumistances with decreasing the harmful of built environment on natural enviroment. Numerous studies have attempted to elucidate the impact og green walls at both urban and building scales, with approximatly 75% of these inquiries concenterating on their thermal performance and its influence on the building's energy consumption. However, only a limited numbers of researches have examined the effect of LAI on the energy conservation, despite LAI being curcial determinante of green facades' potentials as a passive energy saving tool.

According to that the research aimed to study the effect of seasonal LAI of Hedra Helix – IVY vigitation layer which used in the indirect green façade system with 60cm air gap to measure the LAI effect on the energy consumption of the building with considering the green façade microclimate, installation orientation and the seasonal characteristics of the chosen plants and its thermal behavior. A residential building in New Cairo, Cairo, Egypt has been choosen as a case study to measure this effect and the simulation shows that the cooling load reduction was between 3.9% and 11% and heating load reduction was between 3.6% and 5.9% and also shows that the highest LAI (4.28) in summer caused a highest energy saving ratio with 9% and the lowest LAI (2.78) caused the lowest energy saving ratio 4.3%.

Also, by following the egyptian energy code for resedntial building the energy consumption of the building without using any environmental treatment has been reduced by 5.5%. By considering the type of glazing in window by replacing the 6mm single clear glazing to double clear glazing the energy consumption in the initial case decreased by 10% and in case of green façade installation with 60cm air gap decreased by 16.6%.

Finally designers should consider the other elements of building facades such as opening glazing type, WWR% beside the Vegetation layer LAI and thermal characteristics, orientation and the type of installation to ensure achieving the maximum energy saving with maximizing the thermal comfort for buildings' users.

CONFLICT OF INTEREST

The author has no financial interest to declare in relation to the content of this article.

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