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Overall energy evaluation for different integration methods of photovoltaic modules in facade building

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Abstract

The study presents a numerical dynamic model carried out using TRNSYS and discusses the thermal performance of façade building integrated with PV modules on its west and east vertical sides. The needed thermal peak power and energy of the building were estimated added to the produced electrical energy of the installed PV system. The comparative study includes different climatic conditions within two European cities i.e. Venice and Helsinki, two locations of PV modules and two facade inner layer compositions.

Keywords - PVIB;Glazed facades; TRNSYS

1. Introduction

According to the European directive [2010/31/EU], the building sector accounts for about 40% of the total energy consumption, while Heating-Ventilating-and-Air-Conditioning (HVAC) systems contribute for about 32% of it. The energy required for the heating and cooling of buildings is affected by outdoor air temperature and humidity, solar radiation, and wind speed (Jylhä et al, 2015). The realization of a smart interaction between the serving systems in the building, i.e. HVAC systems, and renewable energy systems, e.g. PV modules, would be considered a nucleus of having an urban scale application of efficient Nearly Zero Energy Buildings (NZEB). Integration of PV modules in buildings have been discussed thoroughly. Park et al. (2010) have investigated the electrical and thermal performance of a semi-transparent PV module that was designed as a glazing component. The results showed that the power decreased about 0.48% (in Standard Test Conditions STC) and 0.52% (in outdoor conditions, under 500 W/m2) per 1°C increase of the PV module temperature. Li Mei et al. (2003) presented a thermal building numerical model that includes sub models of the ventilated PV façade. The work established that accurate modelling of buildings incorporating ventilated PV facades can be achieved within the TRNSYS environment. Conversion efficiency of the PV cell is depending mainly on its surface temperature and solar illumination (Skoplaki et al., 2008). Roeleveld et al (2015) have developed a numerical CFD model to predict the temperature profiles inside a Building Integrated PhotoVoltaics/Thermal system BIPV/T system. This model consisted of a PV panel, air channel, insulation and plywood. The numerical results were compared with experiments. Multiple orientations of 0°, 45° and 90° were tested at two different mass flow rates of approximately 174 kg/h and 232 kg/h. The experimental/numerical results showed good agreement Also, the present paper highlights the innovative integration of PV modules inside the façade cavity versus the conventional one concerning the reduction on ventilation energy, especially in cold climates after utilizing DSF as an energy recovery unit. Finally, the paper investigates two compositions of the inner glazed layer while drawing attention on the radiation heat exchange consequences on both thermal and PV electrical performance.

2. Methods

The numerical study has clarified based on test reference year (TRY) and a dynamic simulation carried out by TRNSYS16.1and TRNflow (S.Klein et al., 2004) the thermal energy performance of an office building consists of 4 typical floors and ground floor.Fig.1. TRNSYS is a software which simulates dynamically thermal behavior of buildings, it relies on modular approach to solve equations described by FORTRAN subroutines. While TRNflow is a ventilation network calculation software and add on program in TRNSYS; it can iteratively solve for the airflow and heat transfer simultaneously. Air links between thermal zones of the cavity are assumed to be large openings or windows because they are capable of processing a two way air flow within one time step. TRNflow was applied to identify the cavity air parameters in both the natural and forced ventilation phases; Fig. 2a depicts the TRNSYS simulation model and Fig. 2b the air nodes scheme used in natural ventilation evaluation.

This numerical model was previously validated by comparing calculated and measured data of exhaust air temperature from façade cavity of a test room. More detailed illustration concerning TRNSYS and TRNflow implementation were discussed in (Elarga et al., 2016). On the other hand in the present study three main comparative items were considered within the evaluation, two European cities (Venice and Helsinki), two composition of the inner façade glazing layer (single layer and double layer), and as mentioned earlier two locations of PV modules PV on external layer and PV inside the façade cavity.

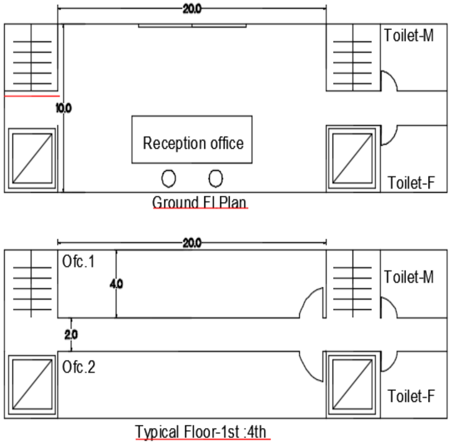


Fig.1 Office Building plans

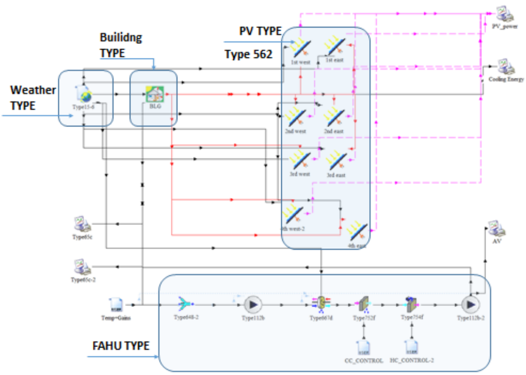


Fig.2a TRNSYS simulation model

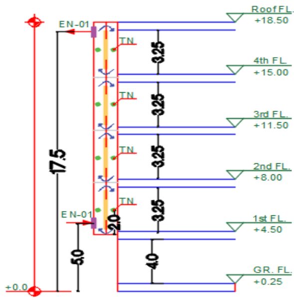


Fig.2b Thermal /external nodes schematic

2.1 Comparative Items

- **Integration of The PV Module within The Building**

The efficient integration of PV modules in buildings is a vital future step. It means not only to increase the electrical free output electrical production but also to evaluate and improve the initial and running HVAC system costs included in peak power and thermal energy respectively. Two locations of PV modules have been investigated, as prescribed in Fig.3a and 3b.

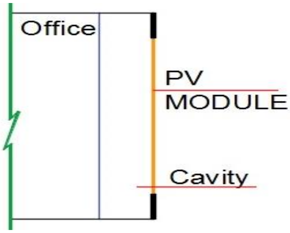


Fig.3a PV module on external layer -PVEXT

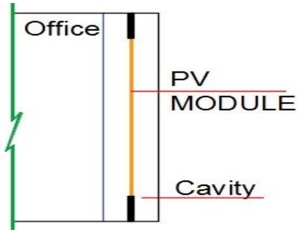


Fig.3b PV module inside the cavity –PVIN

- **Inner Layer Design Optimization**

Design optimization of the inner glazed layer, and whether it is better to use single or double inner glazed layer is one of the targets to be clarified by the study. Fig4a illustrates the first schematic of the single inner layer, while Fig.4b is the double inner layer schematic. It is well known that having a higher resistance glazed system included in the double inner layer shall improve the thermal performance of the building. On the other hand, concerning the installation of PV modules inside the façade cavity, it is important to highlight the influence of the radiation heat exchange which happens between the module surfaces, inner and outer glazed layer of the façade and in case of the PV is installed as the outer layer and the radiation exchange happens with the sky surface. Table. 1 illustrates the technical specifications of the two inner glass compositions.

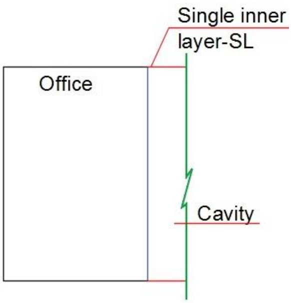


Fig.4a Single inner layer -SL

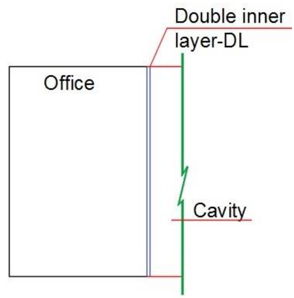


Fig.4b Double inner layer -DL

Table 1. Technical glazed layers specifications

	Composition	**U W/m^2K**	**Transmissivity τ**	**Absorptivity α**
SL	3mm clear glass	5.9	0.9	0.01
DL	3 mm clear glass 10mm Air 3 mm clear glass	2.8	0.7	0.1

- **Cities**

In order to clarify the effect of latitude and climatic conditions on the thermal and electrical performance of the PVIB system, two cities have been chosen to apply the numerical study on. Venice city -Italy is considered because of its warm temperate, fully humid climate. On the other hand, Helsinki city- Finland has a snow fully humid cool summer (Kottek et al., 2006). These two test cases have been selected to have a more clear point of view about the advantages and disadvantages of installing PV modules inside the cavity over diverse climatic conditions.

2.2 Ventilation Mood

Since it is important to ventilate the glazed façade cavity to avoid the green house phenomena; accordingly, natural ventilation has been implemented in heating season while in the cooling season the ventilation was forced as clarified in Fig.5 which shows the ventilation mood along the year months.

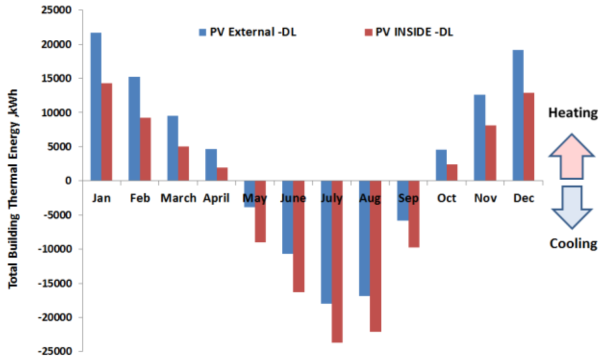
Fig.5 Façade cavity ventilation mood

3. Results

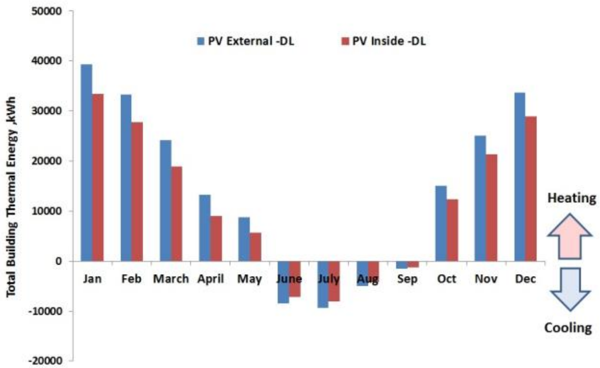
The power and energy use of buildings is influenced by different factors, such as the weather, the physical characteristics of the building, HVAC systems and their settings (Zhao and Magoulès, 2012). Heating systems in Venice usually start from January till the end of April and starts again from October till the end of December. On the other hand, in Helsinki the heating season is extended to include May due to lower average external temperatures in that month. The results of the dynamic energy building simulation are shown in the following sections.

3.1 Overall Thermal Loads of The Building

The overall thermal balance include internal loads, solar gains, convection losses and ventilation loads. However, the double skin façade has been used in winter season as an energy recovery unit to reduce the ventilation loads. Hence, The achievements in thermal loads improvements were due to the decreasing in ventilation loads added to the dynamic insulation effect of having an active 'ventilated' facades.. In Venice, the overall thermal energy loads in the case of installing PV as an external layer (PVEXT case) resulted higher within the heating months of January until April and, then, within the cooling season thermal energy loads decreased comparing to installing PV as an internal layer (PVIN case). On the other hand, the same trend was not precisely followed in Helsinki city: all along the year the required thermal loads were higher in PVEXT over PVIN, as illustrated in Fig.6a and 6b.



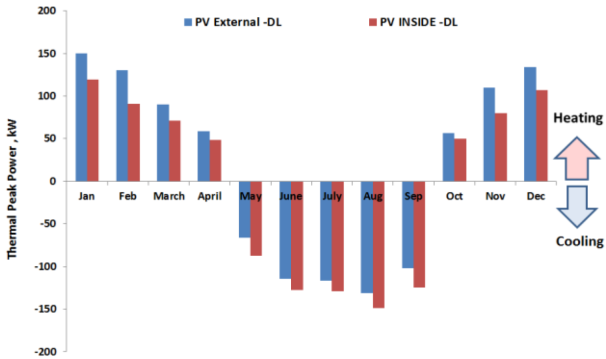
(a)



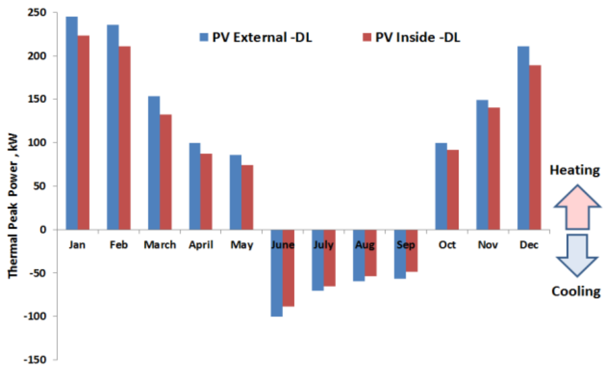
(b)

Fig.6 Total building thermal energy, kWh: (a) Venice, (b) Helsinki

Usually peak power is complying the initial cost of the HVAC system, since all heating and cooling equipment are determined based on the maximum coincident loads. In Venice, the peak power was higher in all heating months in the case of PVEXT over PVIN with a range from 12% to 33%, while in summer the increment ranges between 11% and 22%. In Helsinki, the PVEXT values along the whole year were higher than PVIN, in winter ranges between 6% and 14% while in summer it ranges between 7% and 13%. The building thermal peak power over a year reported in Fig.7a and Fig.7b.



(a)

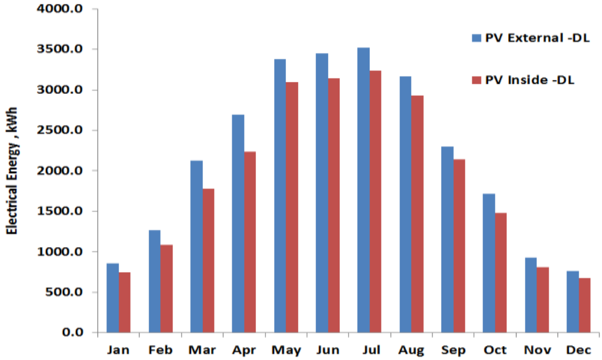


(b)

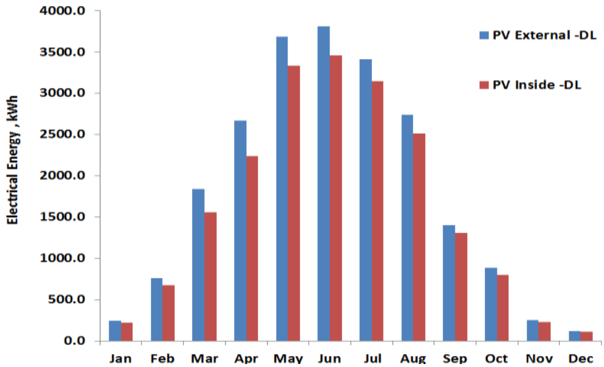
Fig.7 Building peak power, kW: (a) Venice, (b) Helsinki

3.2 The Yearly Electrical Performance of PV Modules System.

Several items affect the electrical performance of PV integrated in buildings. The module Surface temperature, radiation heat exchange between module surface, as well as sky and opposite surfaces and of course the intensity of vertical solar radiation. Based on two different locations of PV modules inside the cavity and as external layer of the cavity, the yearly production of PV modules is clarified in Fig.8a and Fig.8b.



(a)



(b)

Fig.8 PV system electrical production, kWh: (a) Venice, (b) Helsinki

3.3 Inner Layer Design Optimization

Table(2) summarizes the results. Increment/decrement percentage of thermal peak power and energy have been noticed along heating and cooling season in case of PV modules are installed on the external layer comparing to the location inside the cavity. Mostly the same patterns have been repeated in the other integration of PV modules inside the cavity, except for 3% to 4 % decrement with in the mid-season, hence the higher conductive resistance might not be favourable.

Table 2 Thermal Energy and peak power Increment /decrement percentages %

Venice City												
PV external Layer												
Months	J	F	M	A	M	J	J	A	S	O	N	D
Energy	19	18	11	4	24	15	13	12	14	3	17	19
Peak Power	9	10	11	14	13	11	10	11	12	14	11	10
PV inside the cavity												
Energy	3	2	-3	-3	9	9	8	8	8	-4	4	4
Peak Power	4	4	7	9	18	13	11	10	13	3	3	4
Helsinki City												
PV external Layer												
Months	J	F	M	A	M	J	J	A	S	O	N	D
Energy	35	38	45	39	37	-60	-58	-67	-79	42	36	36
Peak Power	12	13	19	29	23	-21	-22	-27	-59	26	20	14
PV inside the cavity												
Energy	8	8	7	6	11	18	15	18	21	6	8	8
Peak Power	3	4	2	1	4	14	8	11	15	3	4	4

4. Conclusions

The integration of PV modules inside a façade cavity increases the thermal performance efficiency within the heating months in warm temperature climates and it increases the cooling loads with percentage ranges between 20 and 50% in Venice, while in the case of Helsinki it is preferable to install PV inside the cavity as it supports heating and cooling thermal needs. Taking into consideration that installing PV inside the cavity is lowering the PV system electrical production due to that radiation heat exchange between PV module and the sky surface is better than radiation heat exchange with glazed surface inside the cavity. However the reduction in electrical production is not considerable comparing to savings in building thermal energy. Along the year, this reduction in the overall yearly production reached 12% in Venice, while in Helsinki it reached 10%.

The innovative integration of PV modules inside the cavity would be considered a good ecological solution in cold climates, not only acting as an active insulative layer but also producing free energy. On the other hand, in hot and humid climates, it is a little more complicated in summer season and some precautions have to be applied such as using a higher conductive resistance inner-glazed layers, higher ventilation mass flow rate or applying PCM.

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