INVESTIGATING ENERGY EFFICIENCY OF PV PANELS MOUNTED ON BUILDINGS' EXTERNAL WALLS

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ABSTRACT

One of the solutions for reducing the amount of depletable energy use in buildings' operation period is the use of solar energy. This energy can be converted into electrical energy by photovoltaic (PV) systems. PV systems can be mounted on roof or wall surfaces or designed as a part of building envelope directly.

In this paper, the efficiency of PV panels mounted on the external wall surfaces of an office building as a shading component is comparatively discussed and assessed for different cities of Turkey considering their locations, orientations and tilt angles.

INTRODUCTION

Buildings are substantially responsible for global warming caused by fossil fuel use to provide their operation energy for heating, cooling or lighting in their usage period, among others. One of the solutions for reducing this environmental impact occurring through building life cycle is the use of renewable energy resources instead of depleting fossil fuels. Among renewable resources, solar energy is the most widely used one in order to reduce buildings' depletable energy use. It can be used for water heating by solar thermal systems or converted into electrical energy by photovoltaic (PV) systems, both of which is known as active solar systems. Solar thermal systems are usually installed on roof surfaces. PV systems, on the other hand, can be mounted on roof or wall surface subsequently, or designed as a part of building envelope directly (Strong, 2011)

Solar thermal systems are widely used in the south regions of Turkey although the other regions also have high solar energy potential due to Turkey's geographical location when compared to many other countries. According to the General Directorate of Electrical Power Resources Survey and Development Administration and the General Directorate of State Meteorology Affairs of Turkey, our country's annual average total sunshine duration is 2640 hours (7.2 hours/day), the average total radiation intensity is 1311 kWh/m²-year, i.e. 3.6 kWh/m² per day (EIE, n.d.). The figures show the good potential of solar energy use. On the other hand, PV systems, besides solar thermal systems, are hardly used in Turkey because of high investment costs and lack of knowledge. Besides, it is reported that the main barrier in developing solar PV technologies in Turkey is linked to the 600 MW limitation introduced in Renewable Energy Law (No. 5346; ETKB, 2005 and 2010) for each producer (ETKB, 2014). However, in the Strategic Plan of ETKB (2014), solar energy utilization was targeted to be 5000 MW by 2023. Thus, the investments for PV systems can be assumed to increase in the next decades.

The efficiency of a PV system depends on the location, orientation, surface tilt angle, material type, maintenance / cleaning conditions and back surface temperature of the panel. Its efficiency can be predicted by the use of simulation softwares, and in such cases, determining the alternative that generates maximum energy becomes significant. Designers should know how to increase panel efficiency depending on the aforementioned criteria.

In addition, in providing electricity by using renewable resources, it is also important to promote the use of PV system on building façades as well as roof surfaces. These issues are especially important for our country, because awareness of the public on PV sytems and their efficiencies is limited, and there is not enough research about the efficiencies of these systems for our climatic conditions.

In this paper, the energy efficiency of PV panels mounted on the external walls of an office building, which also serves as a shading component, and their contribution to building energy load are comparatively discussed considering the building locations, and the orientations and tilt angles of the panels.

METHOD

The energy loads of the building model were calculated by Autodesk Ecotect Analysis 2011 software, and PV-SOL software was utilised for determining the amount of electrical energy which will be produced by PV panels. Ecotect calculates heating and cooling loads, and uses a simplified steady-state method that is based on a 24-hour cycle. It is usually used as an early-stage design tool for comparative analysis (Autodesk, 2011). It was preferred since it has a user-friendly interface. PV-SOL is a tool to design and optimize grid-connected PV systems (Valentin Software, 2015). Climatic data files used by both software were taken from Meteonorm software, which contains worldwide weather data (Meteonorm, n.d.).

SIMULATION

The study aims to determine the amount of electrical energy produced by PV panels, and to assess the energy efficiencies of PV panels used as shading component on building's external walls and their contributions to building energy load for different cities of Turkey. The panels, during the simulations done by PV-SOL, were assumed that they are in the space, not on the external wall, in order to determine the amount of electrical energy produced by PV panels. The aim was to ignore the effects of thermal gains and losses of the exterior wall on the produced energy amount and to ease in geometrical modelling. PV panels, however, during the simulations done by Ecotect, were considered as mounted on the exterior wall in order to determine their effects on energy loads.

In the study, the simulation data are first determined, and the alternatives were then generated for the simulations. These processes are explained in the following sub-sections seperately.

Determining Simulation Data

The simulation data are composed of three groups:

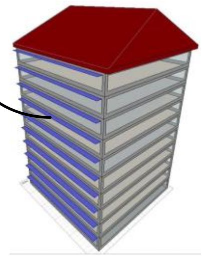
- data on climatic conditions
- data on building model
- data on building functional elements (BFEs)

The climatic data such as altitude, latitude, air temperatures, precipitation, wind velocity, etc. were taken from data files formed by the Meteonorm software program.

The data related to building model given in Table 1 are building properties, building location, internal conditions, building occupants, and PV properties. In the study, an office building type with square plan was used for the simulations. This building was assumed to be located in different climatic regions of Turkey. These locations were determined according to the degree-day zones given in the Turkish Standard on Thermal insulation requirements for buildings "TS 825" (TSI, 2009), and Solar Energy Potentials of the geographical zones of Turkey (YEGM, n.d.). Thus, Izmir, Istanbul, Ankara, Van and Erzurum were selected for this study. Every selected city is at different degree-day zone, and has different solar energy potential. The properties related to the internal conditions and building occupants were assumed to be the same. In each case, PV panels were accepted to be mounted only on one façade facing different orientations, and with changing tilt angles.

Table 1
Simulation data for the building model

BUILDING PROPERTIES



Plan type: Square
Size: 24x24m
Number of storeys: 10
Storey height: 3m
No shading on its surrounding
Roof type: Hipped roof with inclined of 30%
Windows size: 1.5x 23m at every storey and on every facade of the building

BUILDING LOCATION*
Izmir: 1^{st} DDZ, SEP: 1550-1600 kWh/m^2/year, AAT: 9.7^0C
Istanbul: 2^{nd} DDZ, SEP: 1400-1450 kWh/m^2/year, AAT: 6.5^0C
Ankara: 3^{rd} DDZ, SEP: 1500-1550 kWh/m^2/year, AAT: 1.6^0C
Van: 4^{th} DDZ, SEP: 1750-1800 kWh/m^2, AAT: -2.4^0C
Erzurum: 4^{th} DDZ, SEP: 1600-1650 kWh/m^2/year, AAT: -7.8^0C

INTERNAL CONDITIONS
Air conditioning system for heating and cooling
Natural ventilation system for ventilating
Lighting level: 400 lux
Relative humidity: 60%
Air temperatures: 22^0C, 26^0C for winter and summer conditions respectively, and 12^0C at holiday days and non-working hours
Working Hours: Monday to Friday between 08.00-17.00

BUILDING OCCUPANTS
Number of occupants: 29 people per floor
Area for every occupant: 20 m^2
Wearing factor: 1.00 clo
Activity Level: 70 W

PV SYSTEM
Panel properties: 1640x990x40mm, 19,1kg
Number of panels on one façade: 130
Panel type: Polycrystal silisium cells
Panel Efficiency and Power: 16.01%, 260Wp
Inverter properties: 645x431x204mm, 19.9kg.
Number of inverters: 10
No battery (there is no need to store electricity)

*Degree-Day Zones (DDZs), Solar Energy Potentials (SEPs), and Average Air Temperatures (AATs) are taken from (TSI, 2009; YEGM, n.d; MGM, 2015). AATs are three months average of the coldest months, which are December, January, and February.

The data related to BFEs given in Table 2 are the material properties of the components and thermal insulation thicknesses calculated for BFEs exposed to climatic agents, considering the boundary values suggested in TS 825 for the selected cities. In these calculations, thermal convection coefficients for internal and external surfaces were accepted 0,13 and 0.04 m^2K/W respectively (TSI, 2009).

Table 2
Material properties of BFEs

	Material	d (m)	D (kg/m^3)	λ_h (W/mK)
EXTERINAL WALL	Plaster	0.02	900	0.35
	Expanded Polistren	0.03 (1)*	19	0.035
		0.04 (2)*		
		0.05 (3)*		
		0.07 (4)*		
		0.08 (5)*		
	Cement Mortar	0.01	2000	1.60
	Brick	0.19	1000	0.45
	Gypsum Plaster	0.01	1800	1.0
FLOOR ON GROUND	PVC	0.005	1500	0.23
	Concrete Screed	0.02	2000	1.40
	Plywood	0.02	800	0.13
	Expanded Polistren	0.03 (1)*	19	0.035
		0.03 (2)*		
		0.05 (3)*		
		0.06 (4)*		
		0.07 (5)*		
	Reinforced Concrete	0.80	2400	2.20
	Water insulation	0.006	2000	0.19
	Concrete Screed	0.02	2000	1.40
	Blinding Concrete	0.10	1800	1.10
	Gravel	0.15	1800	0.70
ROOF	Concrete	0.15	2200	1.65
	Expanded Polistren	0.06 (1)*	19	0.035
		0.07 (2)*		
		0.10 (3)*		
		0.13 (4)*		
		0.14 (5)*		
	Plaster	0.01	1800	1.0
WINDOW	Float Glass	0.006	2300	1.046
	Air Gap	0.030	1.3	5.560
	Float Glass	0.006	2300	1.046

Abbreviations: d: Thickness, D: Density, λ_h : Thermal conductivity, 1: Izmir, 2: Istanbul, 3: Ankara, 4: Van, 5: Erzurum.

* Thermal insulation thicknesses calculated considering upper limits defined in TS 825 (TSI, 2009) for the selected cities.

The heat transmission coefficients (U values) calculated for BFEs exposed to weather conditions, considering the boundary values suggested in TS 825 (TSI, 2009) for every city, are given in Table 3.

Table 3
The calculated U values for BFEs

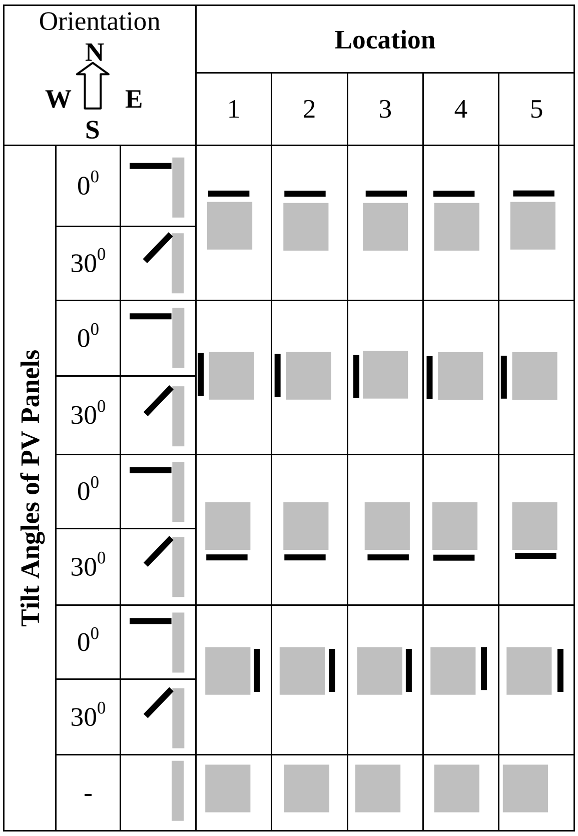
City	1	2	3	4	5
U_W (W/m^2K)	0,66	0,55	0,48	0,37	0,36
U_R (W/m^2K)	0,41	0,36	0,28	0,22	0,21
U_F (W/m^2K)	0,57	0,57	0,43	0,38	0,34
U_{Wd} (W/m^2K)	1,80	1,80	1,80	1,80	1,80

Abbreviations: $_{W:}$ Wall, $_{R:}$ Roof, $_{F:}$ Floor on ground, $_{Wd:}$ Window.

Generating Alternatives

In the study, only the building locations, and the tilt angles and orientations of the panels were considered as variables. The decreases in PV system efficiency due to shading, back surface temperatures and surface pollution of the panels are not considered. The alternatives generated for the simulations are given in Table 4.

Table 4
The generated alternatives



A code system was developed to easily analyse and assess the alternatives. The numbers and letters used in this system are as follows:

- The first letter indicates the location of the building (1: Izmir, 2: Istanbul, 3: Ankara, 4: Van, and 5: Erzurum).
- The second letter indicates the orientation of the exterior wall on which PV panel is mounted (N: North, S: South, E: East, and W: West).
- The last two numbers indicate the tilt angle of the panel (i.e. $0^0$and 30^0).

According to this code system, for instance, an alternative coded as 3S30 defines the PV panel with a tilt of 30^0 positioned on the south façade of an office building located in Ankara. If the code of an alternative is only 1, 2, 3, 4, or 5, it means that it does not have any PV panel on the external wall.

ASSESSMENT OF THE RESULTS

In this section, the changes in heating / cooling loads and PV system efficiency, and the contribution of PV system to energy load are assessed in terms of location, orientation, PV panel use and tilt angle of PV panel.

Heating/cooling loads

The amount of energy loads calculated for all alternatives, which include heating and cooling loads, is given in Figure 1.

- **Location:** The highest energy consumptions are obtained for the alternatives in Erzurum at the 5th degree-day zone of Turkey, which is 53.86 kWh/m^2 per year in the case without PV and 54.21 kWh/m^2 per year in the case with PV.

  The energy consumption in Izmir and Van are similar to each other both with and without PV. Similarly, the results in Ankara and Istanbul are very close to each other.
- **Orientation:** The energy consumptions of buildings with PV in Izmir and Istanbul increases at the orientations of west, east and south in the given order, while in Ankara, Van and Erzurum these results increase at the orientations of south, east and west respectively.
- **PV panel use:** The total energy loads composed of heating and cooling loads decrease for all alternatives by using PV panels. In addition, the use of PV increases heating loads while it decreases cooling loads in the simulated cities because, in winter, it prevents solar radiation to enter into the building and increases energy use. Table 5, as an example, shows the heating and cooling loads for the façade facing south with and without PV panel. In this example, PV panel is mounted on the wall with an angle of 30^0.
- **Tilt angle of PV panel:** The total energy loads for all alternatives with a tilt angle of 30^0 are higher than that of the alternatives with an angle of 0^0, because the inclined panel increases heating energy load by obstructing solar radiation in winter.

Table 5
Heating and cooling loads

Code	Annual Heating Energy Load (kWh/m^2)	Annual Cooling Energy Load (kWh/m^2)
1S30	8,52	23,82
1	8,39	24,36
2S30	14,85	13,04
2	14,71	13,45
3S30	19,48	9,84
3	19,22	10,02
4S30	25,24	7,12
4	24,94	7,33
5S30	53,64	0,57
5	53,26	0,59

PV system efficiency

The amount of energy generated by PV panels for all alternatives is given in Figure 2.

- **Location:** The highest performance for PV panels is achieved for the alternatives in Izmir at the 1st degree-day zone of Turkey, with a generation of 9.69 kWh/m^2 per year. Van, Erzurum, Istanbul and Ankara follow it respectively with a generation of 8.93, 8.82, 7.63 and 7.13 kWh/m^2 per year. While Van has the highest value in terms of solar energy potential according to the atlas of solar energy potential of Turkey (YEGM, n.d.), the highest energy generation is obtained for the city of Izmir where the other climatic agents such as air temperature, air humidity, wind velocity and rainfall are effective on this performance.
- **Orientation:** The highest amount of energy generated by PV panels is obtained for the alternatives at the orientation of south, and the orientations of east, west and north follow it respectively.
- **Tilt angle of PV panel:** The energy generation of the alternatives with a tilt angle of 30^0 are higher than that of the alternatives with an angle of 0^0 at the orientation of south because 30^0 is the optimum tilt angle for a PV panel in the latitude of Turkey, since the sunlight and the panel are perpendicular to each other. The reason of obtaining equal energy amounts for all alternatives with a tilt angle of 0^0 mounted on different orientations is that the

panel is simulated by considering that it is in the space, not on the wall. Thus the results are the same for all orientations.

Contribution of PV system to energy loads

The contribution of energy generated by PV system to building energy load is given as benefit ratio in Figure 3.

- **Location:** The contribution of the alternatives to building energy load in terms of location increases for Izmir, Istanbul, Van, Ankara, and Erzurum respectively. Although the electricity generation in the city of Van is higher than that of in Istanbul, the obtained benefit is lower in Van because of the higher building energy loads. The similar situation are considerably seen for Erzurum in Figure 3. This city has the lowest benefits compared to the other cities. The main reason is the increase of heating energy loads because of the climatic conditions of the city. The average air temperature of the city is "-7.8^{0}C" in winter period while this value increases upto "9.7^{0}C" in Izmir (see Table 1).
- **Orientation:** The highest benefit to the energy loads by PV panels is provided for all alternatives at the orientation of south. The orientations of east, west and north follow it respectively.
- **Tilt angle of PV panel:** The highest benefit to the energy loads is gained for all alternatives at a tilt angle of 30^0.

CONCLUSION

In this paper, the efficiency of PV panels mounted on the external wall surfaces of an office building as a shading component is comparatively discussed and assessed for different cities of Turkey considering their locations, orientations and tilt angles.

According to the results, it can be concluded that, the highest performance in terms of PV system efficiency was achieved in Izmir at the 1st degree-day zone of Turkey, with a generation of 9.69 kWh/m^2 per year. In terms of orientation and tilt angle, in all cities, the alternatives with a tilt angle of 30^0 mounted on south facades in all cities generated the highest amount of electricity when compared other alternatives. It can also be concluded that benefits provided by PV use decreases as the heating energy load increases, especially in the case observed in Erzurum.

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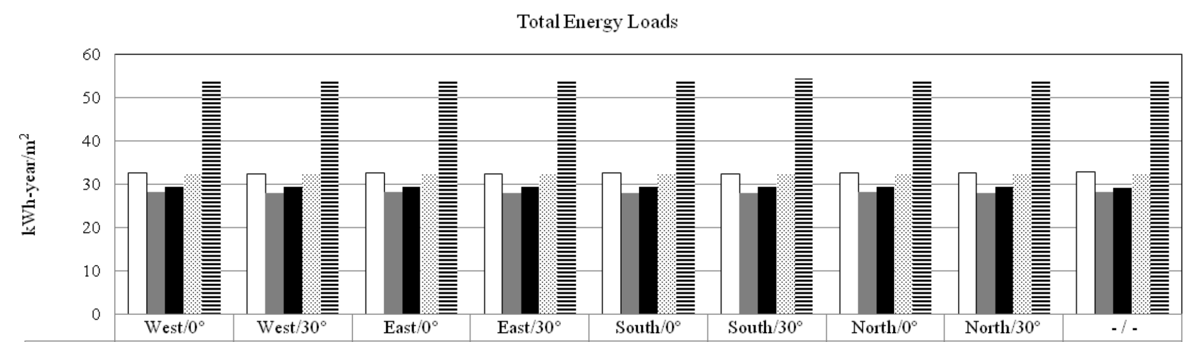
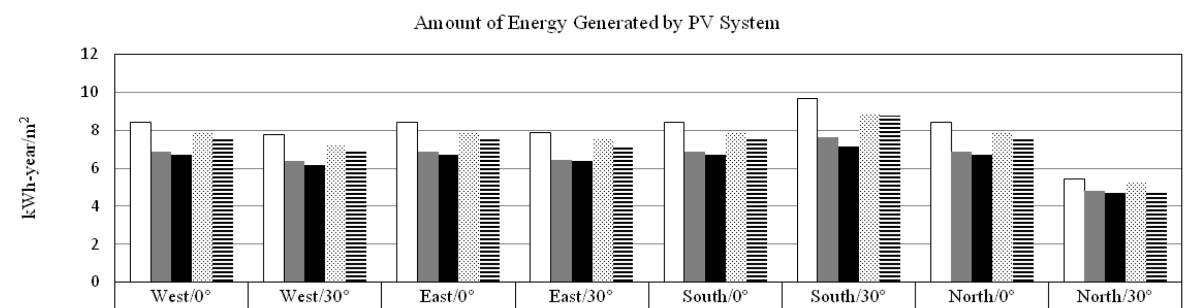


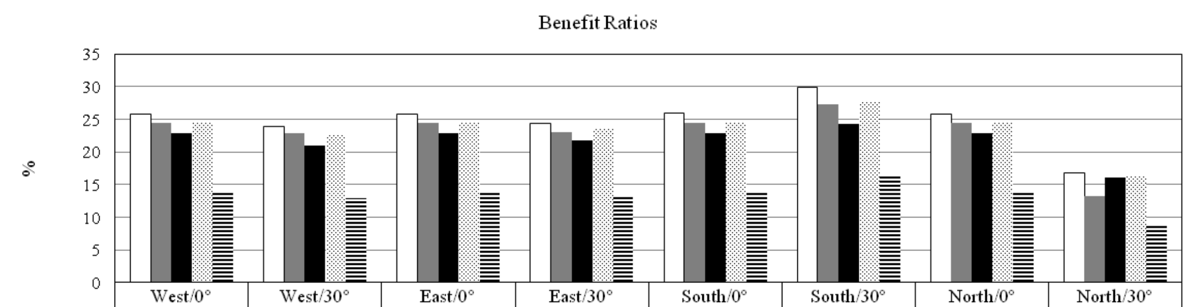
	West/0°	West/30°	East/0°	East/30°	South/0°	South/30°	North/0°	North/30°	- / -
□Izmir	32,64	32,4	32,61	32,39	32,51	32,34	32,67	32,47	32,75
■Istanbul	28,11	27,93	28,09	27,93	28,04	27,9	28,14	27,96	28,16
■Ankara	29,27	29,29	29,27	29,29	29,27	29,32	29,27	29,28	29,24
Van	32,3	32,31	32,31	32,33	32,34	32,36	32,29	32,29	32,27
≡Erzurum	54,03	54,07	54,03	54,11	54,11	54,21	53,99	54,01	53,86

Figure 1 Total energy loads (heating and cooling) optained for all alternatives



	West/0°	West/30°	East/0°	East/30°	South/0°	South/30°	North/0°	North/30°
□Izmir	8,42	7,74	8,42	7,88	8,42	9,69	8,42	5,44
■Istanbul	6,88	6,4	6,88	6,45	6,88	7,63	6,88	4,83
■Ankara	6,71	6,17	6,71	6,4	6,71	7,15	6,71	4,72
Van	7,9	7,27	7,9	7,6	7,9	8,93	7,9	5,3
≡Erzurum	7,53	6,95	7,53	7,2	7,53	8,82	7,53	4,82

Figure 2 The amount of energy generated by PV system for all alternatives



	West/0°	West/30°	East/0°	East/30°	South/0°	South/30°	North/0°	North/30°
□Izmir	25,79	23,88	25,82	24,32	25,89	29,96	25,77	16,75
■Istanbul	24,47	22,91	24,49	23,09	24,53	27,34	24,44	13,27
■Ankara	22,92	21,06	22,92	21,85	22,92	24,38	22,92	16,12
Van	24,45	22,5	24,45	23,5	24,42	27,59	24,46	16,41
≡Erzurum	13,93	12,85	13,93	13,3	13,91	16,27	13,94	8,92

Figure 3 Benefit ratios for all alternatives