INTEGRATING SOLAR THERMAL AND PHOTOVOLTAIC SYSTEMS IN WHOLE BUILDING ENERGY SIMULATION

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ABSTRACT

This paper introduces methodologies on how the renewable energy generated by the solar thermal and solar photovoltaic (PV) systems installed on site can be integrated in the whole building simulation analyses, which then can be available to analyze the energy impact of solar systems installed in commercial buildings. A large prototypical office building (124,000 ft^2) was used in simulation modeling. The DOE-2.1e program was used for whole building simulation, F-Chart (Beckman et al., 1977) for solar thermal systems analysis, and PV F-Chart (Klein and Beckman, 1983) for solar PV systems analysis.

INTRODUCTION

This study is an extension of previous research. The preceding studies were (1) development of a detailed calibrated simulation model for a large office building, presented at the SimBuild 2008 Conference in 2008 (Cho and Haberl, 2008a), (2) development of a simplified geometry model to compare the results between as-is geometry simulation and simplified geometry simulation, presented at the Sixteenth Symposium on Improving Building Systems in Hot and Humid Climates in 2008 (Cho and Haberl, 2008b), and (3) development of a high-performance simulation model (ASHRAE 90.1-1999 code-compliant model as a baseline) for a large commercial office building, presented at the BuildingSimulation 2009 Conference in 2009 (Cho and Haberl, 2009).

In the previous study (Cho and Haberl, 2009), a total of 14 high-performance measures were selected and simulated. The maximum cumulative savings from the 14 measures were 48.1% compared to the ASHRAE Standard 90.1-1999 code-compliant building, which was achieved by selecting more efficient equipment or improving operations. In this paper, renewable energy sources were analyzed to achieve further energy consumption reductions. To accomplish this, the F-Chart program was used for the solar thermal system analysis and the PV F-Chart program for the solar photovoltaic (PV) system analysis.

Authors show how DOE-2.1e simulation outputs can be used for the inputs of F-Chart and PV F-Chart analyses and evaluate how the outputs of whole building simulation match those from solar analysis programs. Finally, additional energy conservation benefits (or energy generations), which were available from implementing the solar systems, on top of energy savings achieved by energy efficiency measures are presented.

APPLICATION OF SOLAR THERMAL SYSTEMS

Thermal energy generated by the solar thermal systems in commercial buildings can provide heat in two different ways; one as service hot water for hand washing and shower, and the other as converted heat (hot air) from hot water through heat exchanger for space heating. To determine these thermal loads, there are two outputs available from DOE-2.1e simulation such as “Service Hot Water Energy Use” and “ Space Heating Energy Use”.

There are three main simulations in the DOE-2.1e program such as LOADS, SYSTEMS, and PLANT. In SYSTEMS simulation, outputs (DOE-2.1e Report SS-A & SS-P) yield the space heating loads and service water heating loads provided by boilers and water heaters in plant, respectively, while PLANT outputs (DOE-2.1e Report PS-E) include the fuel energy combined with fuel efficiencies for boilers and water heaters. Therefore, the PLANT outputs typically show more energy consumtion than the SYSTEMS reports due to the equipment fuel utilization efficiencies.

Table 1 and Figure 1 compare the monthly thermal loads reports between SYSTEMS and PLANT from the DOE-2.1e simulation run. In this table, the monthly average dry bulb temperature (Tdb) is from the College Station 2006 TRY (Test Reference Year) weather data measured and packed for this study. Monthly space heating loads and service water heating loads are shown in both cases from the SYSTEMS simulation and from the PLANT simulation. The SYSTEMS monthly loads were retrieved from the SYSTEMS reports, SS-A for space heating loads and SS-P for service water heating loads. The PLANT simulation's monthly loads were retrieved from the PLANT reports, PS-E. As shown, the PLANT reports show higher energy uses than the SYSTEMS reports do.

Table 1 Comparison of loads and energy uses for space heating and service hot water for the base-case (ASHRAE Standard 90.1-1999 code-compliant) building.

Month	Tdb (F)	SYSTEMS Report (kBtu/mo)		PLANT Report (kBtu/mo)	
		Heating (SS-A)	SHW (SS-P)	Heating (PS-E)	SHW (PS-E)
JAN	57.4	64,127	3,988	102,147	5,398
FEB	53.0	113,311	3,816	169,833	5,166
MAR	64.6	26,253	4,361	47,188	5,903
APR	72.5	473	3,820	8,717	5,171
MAY	76.4	0	3,884	8,160	5,258
JUN	81.5	0	3,363	7,897	4,552
JUL	82.6	0	2,978	8,160	4,031
AUG	84.8	0	2,966	8,160	4,016
SEP	78.7	0	2,756	7,897	3,731
OCT	70.2	3,196	3,004	13,290	4,067
NOV	60.5	40,248	3,300	67,362	4,468
DEC	53.9	114,972	3,566	173,514	4,828
Total		362,580	41,800	622,325	56,589

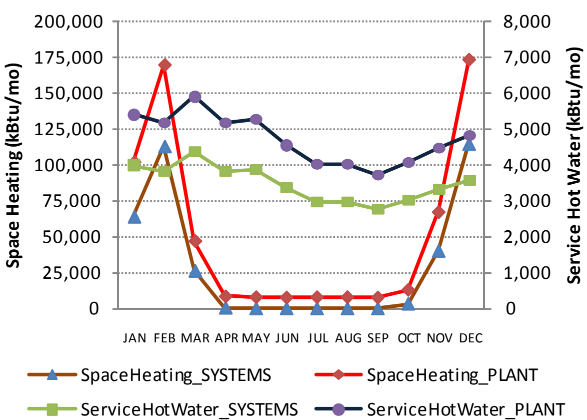


Figure 1 Time series plots of space heating and service hot water loads from SYSTEMS and PLANT simulation runs

Due to the fact that the solar thermal systems analysis program, F-Chart, takes into account the system efficiencies in its loads calculation of the building, it is therefore necessary to use the SYSTEMS output of DOE-2.1e simulation when integrating an F-Chart solar thermal system with results from the DOE-2.1e simulation.

INTEGRATING THE DOE-2.1E SPACE HEATING AND SERVICE WATER HEATING LOADS WITH THE F-CHART PROGRAM

The F-Chart program uses Heating Degree Days (HDDs) to calculate the building's heating loads. Also needed for the loads calculation are the building's UA (Btu/hr-^{o}F) value and a balance point temperature (Tbal or Tb) for the calculation of the HDDs.

The HDD calculation equation is:

$$HDD = Tb - Ta$$

Where,

Ta is an average between maximum and minimum temperatures of a day, (Tmax+Tmin)/2.

Tb is a balance point temperature for the HDDs,

$$Tb = T_{Design} - Qi/(UA)_{Total}$$

Where,

Tdesign is the room design temperature

Qi is internal heat gain, and $(UA)_{Total}$ is total UA value of the building.

Figure 2 is a scatter plot of the monthly average hourly space heating energy use (DOE-2.1e Report SS-A) from the base-case building model versus the monthly average ambient temperature. The twelve points in the figure indicate each month's hourly average energy use.

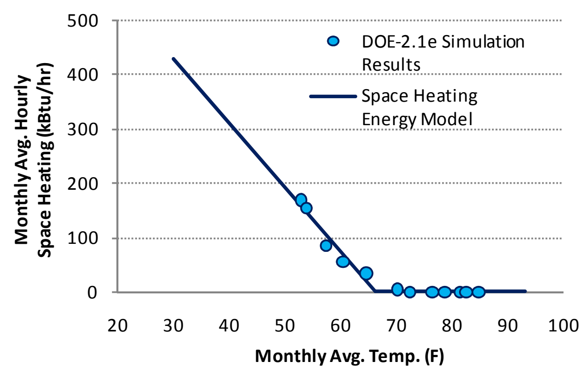


Figure 2 Scatter plot and regression model of the monthly average hourly space heating energy consumption of the base-case (ASHRAE Standard 90.1-1999 Compliant) building model.

The solid line is a linear regression model representing the monthly average hourly energy consumption pattern developed using the ASHRAE's Inverse Model Toolkit (IMT). The linear line's slope is -11.786 and the changing point or Tb is 66.4 ^{o}F.

So, the equation of the regression model is,

$$Q_{Heat} = -11.786x + 782.59 \text{ (with Tb = 66.4 }^oF)$$

For the solar thermal analysis, the absolute value of the slope or 11.786 from the regression model can then be used as the building's UA value in the F-Chart calculation. The monthly space heating load calculation equation in the F-Chart program is:

$$Q_{Month} = (UA)_{Total} * (HDD_{Tb})_{Month} * 24 \text{ (Hours)}$$

Where UA (Btu/hr-°F) is the measure of whole-building heat loss relative to the ambient temperature difference below 66.4 °F.

Next, to run the F-Chart program, a new weather file was created using the same measured weather data used for the DOE-2.1e simulation. Table 2 shows the F-Chart monthly weather data inputs for College Station, TX in 2006. The monthly average daily solar radiation and monthly average temperature and humidity ratio data were retrieved from the TRY measured weather file developed for the DOE-2.1e simulation of this study.

For the mains water temperature, the monthly average ground temperatures from the DOE-2.1e simulation output were used. The ground reflectance of 0.2 is the same value used for the DOE-2.1e simulation.

Table 2 Weather data input of the F-Chart program run for College Station, TX.

College Station TX		Latitude: 30.4 °N		Degree-day base: 66.4 F		
Month	Solar Rad. (Btu/sqft-day)	Temp. (F)	Humidity (lbw/lba)	Mains (F)	Reflect	HDDs
Jan	964	57.4	0.0058	64.1	0.2	286
Feb	966	53.0	0.0060	61.7	0.2	375
Mar	1,186	64.6	0.0089	61.5	0.2	102
Apr	1,669	72.5	0.0118	62.6	0.2	10
May	1,833	76.4	0.0130	67.3	0.2	0
Jun	2,088	81.5	0.0138	71.9	0.2	0
Jul	1,897	82.6	0.0169	75.9	0.2	0
Aug	1,941	84.8	0.0164	78.4	0.2	0
Sep	1,468	78.7	0.0129	78.6	0.2	0
Oct	1,223	70.2	0.0112	76.6	0.2	24
Nov	976	60.5	0.0081	72.7	0.2	192
Dec	713	53.9	0.0066	68.2	0.2	389

The HDDs of each month are automatically calculated by the F-Chart program based on the balance-point temperature of 66.4 °F (Degree Day base in the program screen), which is the balance point temperature where the heating is required.

F-Chart consists of two input screens, one for the collector parameters and the other for the systems parameters as shown in Table 3 and Table 4, respectively. The type of the collector used was an evacuated tubular collector as shown in Table 3. In this analysis a total of 22 collectors were used with a collector area of 32 ft^2 each, totaling 704 ft^2 of collector area.

Table 3 Collector input for the F-Chart program run.

Evacuated Tubular Collector		
Number of collector panels	22	
Collector panel area	32	sqft
FR*UL (Test Slope)	0.05	Btu/hr-sqft-F
Collector slope	35	degree
Collector azimuth (South=0)	0	degree
Receive orientation	NS	
Incidence angle modifier (Perpendicular)	AngDep	
Incidence angle modifier (Parallel)	AngDep	
Collector flow rate/area	11	lb/hr-sqft
Collector fluid specific heat	1	Btu/lb-F
Modify test values	NO	

The FR*UL (Test Slope) of 0.05 and the FR*TAU*ALPHA (Test Intercept) of 0.42 were obtained from test results for the evacuated tube type (Newton and Gilman, 1981). The collector was designed to face south and was tilted at 35 degrees from the roof surface. The water flow rate in the collector loop was eleven pounds per hour per unit square foot of collector area. The specific heat of water is one Btu/lb- °F.

Table 4 System inputs for the F-Chart program.

Water Storage Heating System		
Location	College Station, TX	
Water volume / collector area	2	gallon/sqft
Building UA (0 if only DHW)	11,786	Btu/hr-F
Fuel	Gas	
Efficiency of fuel usage	85	%
Domestic (Service) hot water?	Yes	
Daily hot water usage	343	gallons
Water set temperature	120	F
Environmental temperature	69.7	F
UA of auxiliary storage tank	7.6	Btu/hr-F
Pipe heat loss	NO	

In Table 4, the building UA value in the third row was input in case where the user wants to evaluate the space heating availability from the solar thermal system. The UA value of 11,786 Btu/hr-°F was input, which was the slope of the regression model in Figure 2.

In this analysis, natural gas was used as the heating source and the efficiency of the auxiliary heater was 85 percent. Both space heating and service water heating were provided by the solar thermal system.

For the service hot water usage evaluation, the daily hot water usage was calculated based on the information available in the ASHRAE Applications Handbook, which recommends a maximum daily value of 0.4 gallon per person for office buildings. The service hot water schedule used the schedule published in the ASHRAE Standard 90.1-1989, which is shown in Figure 3. Using these values, the average daily hot water usage was calculated as 343 gallons per day (Table 4). The hot water temperature was set to 120 ^{o}F. An environmental temperature of 69.7 ^{o}F was used as the annual average temperature of College Station, TX in 2006.

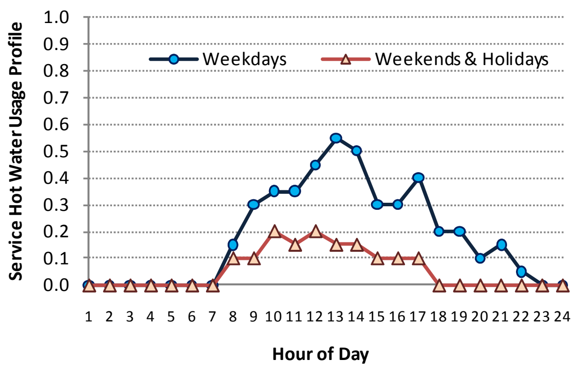


Figure 3 Service hot water usage profiles for office buildings.

The results of the F-chart run are shown in Table 5. In this table, the first column of results shows the monthly available solar energy incident on the solar collector. As the user increases or decreases the type, number, and size of the collector, the available solar energy changes. The second column shows the monthly heating loads.

This calculation was based on the HDDs at the balance-point temperature of 66.4 ^{o}F and UA value (11,786 Btu/ ft^{2}-^{o}F) of the building. The third column shows the service hot water loads of the building. The forth column is the thermal energy requirement from another source to meet the building space heating and service hot water loads. The last column shows the fraction of the building thermal loads that was provided by the solar thermal system.

The results show there are six months when the solar thermal system supplies all the needed thermal energy and another six months when the system supplies less energy than required. The total annual fraction of the loads that meets thermal loads was 19.1%, which reflects the large space heating loads in the winter.

Table 6 compares the load calculations results for the space heating and service hot water. The annual space heating loads were 362,580 kBtu/yr from the DOE-2.1e base-case model simulation (DOE-2.1e SYSTEMS Report SS-A) and 378,500 kBtu/yr from the F-Chart program, which is 4.2% higher than the DOE-2.1e results. The service hot water use was 41,800 kBtu/yr from the DOE-2.1e base-case simulation (DOE-2.1e SYSTEMS Report SS-P) and 42,199 kBtu/yr from the F-Chart program, which is 0.9% higher.

Table 5 F-Chart results using the UA value as the slope of the linear regression model representing the space heating energy consumption of the base-case building.

Month	Thermal Output				
	Solar (10^6 Btu)	Heat (10^6 Btu)	SHW (10^6 Btu)	Aux. (10^6 Btu)	f
Jan	30.3	78.5	4.08	70.8	0.143
Feb	22.4	103.9	3.87	99.1	0.081
Mar	26.3	27.3	4.30	22.1	0.299
Apr	31.4	2.6	4.07	0.0	1.0
May	31.3	0.0	3.81	0.0	1.0
Jun	32.3	0.0	3.32	0.0	1.0
Jul	31.5	0.0	3.09	0.0	1.0
Aug	35.6	0.0	2.88	0.0	1.0
Sep	30.4	0.0	2.77	0.0	1.0
Oct	31.4	6.3	3.03	0.4	0.958
Nov	28.1	52.3	3.25	44.8	0.193
Dec	21.3	107.6	3.74	103.0	0.075
Year	352.2	378.5	42.20	340.2	0.191

Table 6 Comparison of results between DOE-2.1e and F-Chart for the space heating and service hot water load calculations.

Month	Tdb	DOE-2 (kBtu/mo)		F-Chart (kBtu/mo)	
		Heating	SHW	Heating	SHW
JAN	57.4	64,127	3,988	78,500	4,080
FEB	53	113,311	3,816	103,900	3,867
MAR	64.6	26,253	4,361	27,300	4,298
APR	72.5	473	3,820	2,600	4,070
MAY	76.4	0	3,884	0	3,811
JUN	81.5	0	3,363	0	3,315
JUL	82.6	0	2,978	0	3,090
AUG	84.8	0	2,966	0	2,880
SEP	78.7	0	2,756	0	2,771
OCT	70.2	3,196	3,004	6,300	3,031
NOV	60.5	40,248	3,300	52,300	3,250
DEC	53.9	114,972	3,566	107,600	3,736
Annual Total		362,580	41,800	378,500	42,199

These comparisons show acceptable differences, which indicate that the DOE-2.1e SYSTEMS simulation results can be used to develop the UA value of buildings, which can then be used to calculate the buildings' space heating loads in the F-Chart program.

Figure 4 shows the monthly average hourly heating loads from both DOE-2.1e and F-Chart along with the regression model for the development of the building UA value. The results indicate that the values from the DOE-2.1e simulation could be used for the load calculations in the F-Chart program.

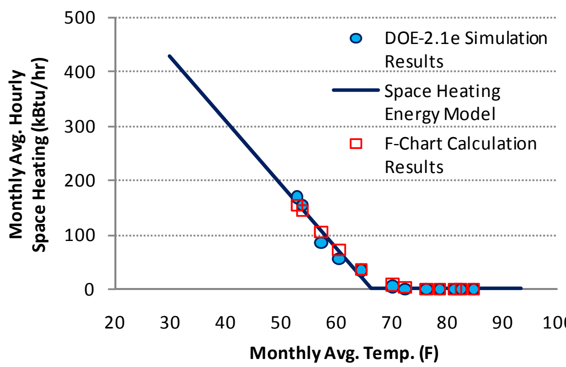


Figure 4 Comparison of DOE-2.1e space heating load and the F-Chart space heating load that used the UA value from the regression model.

Aplicability of Solar Thermal Systems for Space Heating and Service Hot Water

Although the space heating and the service water heating energy can be provided by the solar thermal systems, only the service water heating was considered to be supplied by the solar thermal systems in this case-study analysis.

As shown in Table 5, the service water heating loads could be met by the solar thermal systems year round. However, the space heating loads could not be met by the solar thermal systems for the winter period. To meet all the winter space heating loads, the required solar collector would have been 220 collectors, which are ten times the collectors used in this analysis.

Unfortunately, such a large system would not be well utilized during the summer period with the current electric cooling system. To absorb all this thermal energy, an absorption system or liquid desiccant system would have to be used, which are beyond the scope of this study.

In contrast, the service water heating loads were 56,589 kBtu/yr, which are easily met by a properly-sized solar thermal system.

APPLICATION OF SOLAR PV SYSTEMS

Solar PV systems were considered as the renewable electric power generating systems for this case-study. The PV F-Chart program was used for the evaluation of the PV systems. Like the F-Chart program, a new weather file was created for the measured College Station weather conditions. As shown in Table 7, the monthly solar, temperature, and ground reflectance data were input into the PV F-Chart program.

Table 7 PV F-Chart weather file created for the College Station weather conditions.

City: College Station, TX (Latitude: 30.4 °N)			
Month	Solar (Btu/sqft)	Temp (F)	Ground Albedo
Jan	964	57.4	0.2
Feb	966	53.0	0.2
Mar	1,186	64.6	0.2
Apr	1,669	72.5	0.2
May	1,833	76.4	0.2
Jun	2,088	81.5	0.2
Jul	1,897	82.6	0.2
Aug	1,941	84.8	0.2
Sep	1,468	78.7	0.2
Oct	1,223	70.2	0.2
Nov	976	60.5	0.2
Dec	713	53.9	0.2

To evaluate the performance of the PV systems, a directly connected system was considered, which sends electricity directly into the building's electrical systems without the use of batteries. Table 8 shows the inputs for the PV system.

Table 8 PV F-Chart inputs for the utility feedback system with flat-plate PV panels using 2,000 ft² PV array area.

Utility Feedback PV System			
1	City number for College Station, TX	247	
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1	
3	Cell temperature at NOCT conditions	113	F
4	Array reference efficiency	0.133	
5	Array reference temperature	77	F
6	Max. power eff. temperature coeff. (times 1000)	2.5	1/F
7	Eff. Of maximum power point tracking electronics	0.9	
8	Efficiency of power conditioning electronics	0.88	
9	Percent standard deviation of the load	0	%
10	Array area	2,000	sqft
11	Array slope	35	deg
12	Array azimuth (south=0)	0	deg

A city number was selected for College Station. The PV cell temperature was set to 113 °F, which was obtained from a manufacturer for a specific product, Suntech STP170 (Suntech, 2008). Other parameters such as array reference efficiency, array reference temperature, and other related efficiencies were also referenced by the manufacturer's data. The array slope was set to 35 degree and faces south. An array area of 2,000 ft^2 was used.

Table 9 shows the PV F-Chart analysis results. The building electric load was set to all "0" (third column) for 12 months to see how many kWh of electricity can be generated. As a result, the last column shows the available electricity from the PV systems. As a consequence, the fourth column (^{o}F) shows all "100%" for twelve months and there is no month to buy (fifth column) electricity from grid. The annual total electricity generation by the PV systems was 28,769.2 kWh/yr, which was 2.6% of the total electricity consumption of 1,095,509 kWh/yr from the high-performance building model (Cho and Haberl, 2009).

Table 9 PV F-Chart summary outputs showing the amount of electricity generated each month using 2,000 ft^2 PV array area.

PV F-Chart Output Summary					
Month	Solar	Load	F	Buy	Sell
	(kWh)	(kWh)	(%)	(kWh)	(kWh)
Jan	24,146	0	100	0	2,342
Feb	18,571	0	100	0	1,826
Mar	22,894	0	100	0	2,162
Apr	28,651	0	100	0	2,621
May	29,738	0	100	0	2,685
Jun	31,436	0	100	0	2,787
Jul	30,215	0	100	0	2,679
Aug	33,209	0	100	0	2,924
Sep	26,879	0	100	0	2,426
Oct	26,334	0	100	0	2,442
Nov	22,639	0	100	0	2,178
Dec	17,183	0	100	0	1,698
Year	311,894	0	100	0	28,769

Again, if a situation, in which the redundant electricity is available from the PV systems and exported to the grid, is considered, more PV panels can be installed. Multiple PV F-Chart runs showed that the electricity generation was linearly increased by adding more PV array areas.

As shown in Table 10, the PV array area of 8,000 square feet was considered, which was less than half of the case building's roof area of 17,670 square feet. In the case-study building, there are some equipment on the roof such as outside air handing units and exhaust fans, so that using half of the roof area was reasonably considered.

Table 10 PV F-Chart inputs for the utility feedback system with flat-plate PV panels using 8,000 ft^2 PV array area.

Utility Feedback PV System			
1	City number for College Station, TX	247	
2	Output: 1 for summary, 2 for detailed (Neg: graph)	1	
3	Cell temperature at NOCT conditions	113	F
4	Array reference efficiency	0.133	
5	Array reference temperature	77	F
6	Max. power eff. temperature coeff. (times 1000)	2.5	1/F
7	Eff. Of maximum power point tracking electronics	0.9	
8	Efficiency of power conditioning electronics	0.88	
9	Percent standard deviation of the load	0	%
10	Array area	8,000	sqft
11	Array slope	35	deg
12	Array azimuth (south=0)	0	deg

Table 11 shows the results of using the array area of 8,000 square feet. The annual total electricity generation was 115,077.1 kWh/yr, which was 10.5% of the total building's electric consumption of 1,095,509 kWh/yr.

Table 11 PV F-Chart Summary Output Showing the Amount of Electricity Generation Each Month Using 8000 PV Array Area.

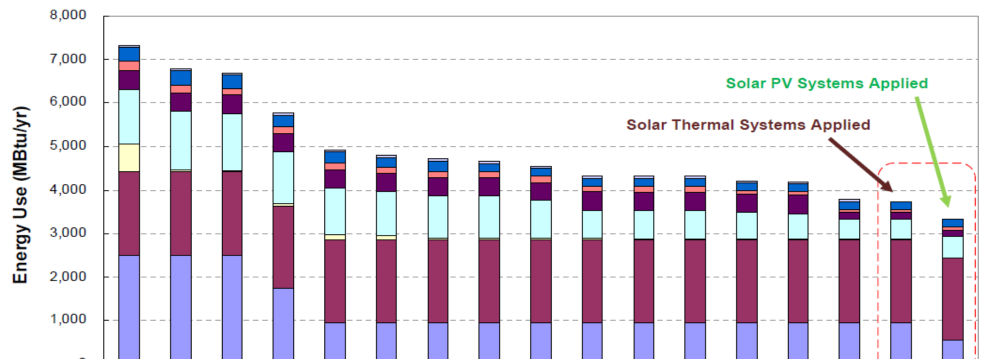
PV F-Chart Output Summary					
Month	Solar	Load	F	Buy	Sell
	(kWh)	(kWh)	(%)	(kWh)	(kWh)
Jan	96,582	0	100	0	9,368
Feb	74,283	0	100	0	7,302
Mar	91,576	0	100	0	8,647
Apr	114,602	0	100	0	10,484
May	118,950	0	100	0	10,741
Jun	125,744	0	100	0	11,148
Jul	120,860	0	100	0	10,716
Aug	132,837	0	100	0	11,697
Sep	107,515	0	100	0	9,702
Oct	105,334	0	100	0	9,766
Nov	90,557	0	100	0	8,714
Dec	68,733	0	100	0	6,793
Year	1,247,574	0	100	0	115,077

The high-performance building model's energy consumption was then finally reduced to 3,346 MMBtu/yr after the electricity generation of 115,077.1 kWh/yr was subtracted from the total electricity consumption. The final energy consumption of 3,346 MMBtu/yr was 54.3% lower than that of the base-case (ASHRAE Standard 90.1-1999 compliant) building, which was 7,318 MMBtu/yr.

SUMMARY

In this paper, a methodology was presented for the integration of the solar thermal and PV systems with the DOE-2.1e simulation program. In addition, energy savings were calculated by using properly sized solar thermal and solar PV systems for the case-study building.

Figure 5 shows additional energy reductions by supplying renewable energy from the solar systems. This is actually not reducing energy consumption of the building but subtracting the energy amount generated by the solar energy systems from the building's total energy use. The solar thermal energy obtained from the solar thermal systems fully covered the service water heating energy that leaves the "SERHOT WATER" or service water heating energy use to be "0" MMBtu/yr from 53 MMBtu/yr in Figure 5. This saved additional 1% of total energy, making the total energy savings of 49% as shown in Figure 6. In addition, the total electricity use was subtracted by the electricity generation of 115,077.1 kWh/yr obtained from the PV systems that used 8,000 square feet of array area. The energy savings were further increased by 5%, resulting in the total energy savings of 54% as shown in Figure 5.



	Base-Case	Glazing U Factor (1.22 to	WindowToWall Ratio	Lighting Load (1.3 to 0.9	Light Control (None to	Shading (none to 2.5 ft	Cold Deck Reset	Supply Fan Total Pressure	Economizer (None to	Chiller COP (5.55 to	Boiler Efficiency (75%	DHW Heater Thermal	CHW Pump Control	HW Pump Control	Chiller Staging (One to	Solar Thermal Service	Solar PV Electric Generati
SERHOT WATER	57	57	57	57	57	57	57	57	57	57	57	53	53	53	53	-	-
VENT FANS	308	321	301	268	247	226	234	184	182	182	182	182	182	182	182	182	182
PUMPS & MISC	215	186	165	155	148	136	134	133	130	130	130	130	75	71	71	71	71
HEAT REJECT	427	427	427	426	425	425	425	425	425	425	425	425	425	425	154	154	154
SPACE COOL	1,258	1,353	1,318	1,189	1,063	1,006	964	956	859	636	636	636	600	600	470	470	470
SPACE HEAT	641	44	19	37	115	97	42	43	30	30	24	24	24	5	5	5	5
MISC EQUIPMT	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907	1,907
AREA LIGHTS	2,506	2,506	2,506	1,735	955	955	955	955	955	955	955	955	955	955	955	955	545

Figure 5 Energy use reductions by solar thermal and PV systems with the 14 high-performance measures.

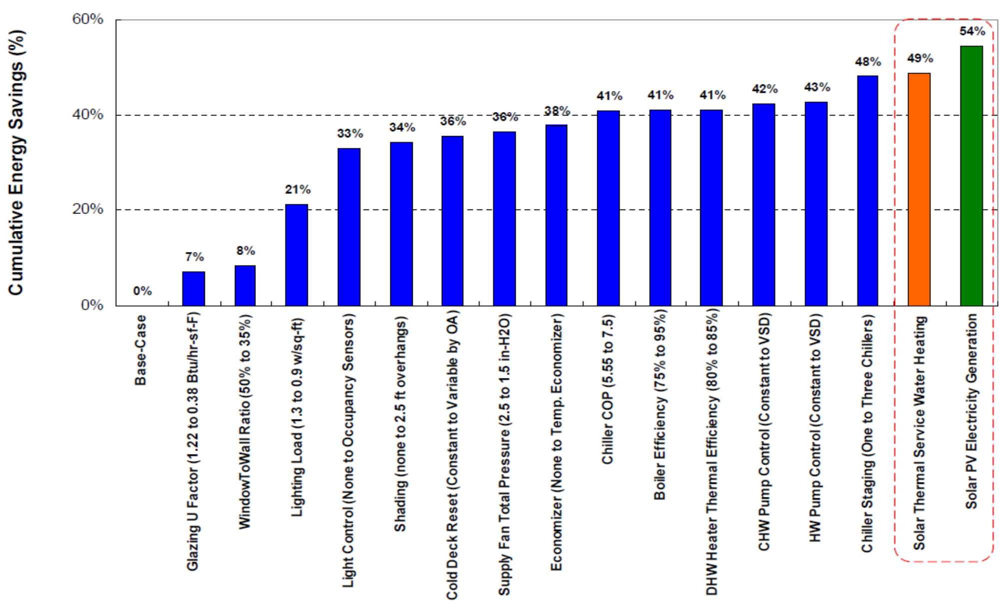


Figure 6 Energy savings by solar thermal and PV systems with the 14 high-performance measures.

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