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Solar PV Feasibility Study on Higher Education Institutions in Connecticut

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SOLAR PV FEASIBILITY STUDY ON HIGHER EDUCATION INSTITUTIONS IN CONNECTICUT

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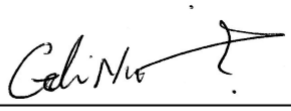

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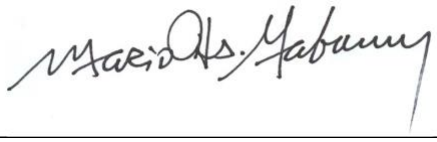

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ABSTRACT

One of the most common issue in Connecticut (CT) is the high electricity rates. CT stands among the top five states for its high electric rates due to limitation in transmission facilities and storage of natural gas. Education institutions serve as good places to install photovoltaic systems as they have a large number of buildings available. Photovoltaic systems are a growing alternative energy source that reduces the electricity demand and hence higher education institutions should start implementing these technologies to reduce the burden of paying more for electricity bills.

The primary objective of the study was to analyze the economic feasibility of solar photovoltaic systems (PV) in higher education institutions in Connecticut (CT). To perform the objective, several economic parameters were calculated and the annual electricity revenue for the University of New Haven was determined and applied to the entire state of Connecticut. The study was expanded to other states in the U.S. by normalizing the available roof area, electricity rate and solar index by each state.

The total electricity generation was estimated for various regions by normalization. This estimation can be used by university administration for calculation of total power generation and total revenue per year in that particular state. With the normalization ratio obtained, one can identify the total power generation in other regions of the U.S. beforehand while considering installation of PV systems. Results from the study regarding the total revenue reveal that the Southwestern and Western regions of the U.S have more solar power generation capacity due to high solar radiation.

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CHAPTER 1. INTRODUCTION

1.1 PROBLEM STATEMENT

The increasing consumption of conventional fossil fuel sources led many organizations and individuals to become concerned with the future energy needs of our society. The electricity rate in Connecticut (CT) is 21.62 cents/kWh, which is almost 62% higher than the national average which is 13.31 cents/kWh (Electric Choice, 2020). In addition, with continually increasing energy demands due to high standards of living and growth, there is a need for alternative energy that fulfils the needs of society at present and in future in a sustainable manner.

Photovoltaic systems (PV) have been developed as one of the renewable energy sources for a sustainable future in higher education institutions. The adoption of such systems would also have a positive impact on our environment. PV will also provide a great opportunity for higher education institutions to show their commitment toward sustainability since college and university campuses use an enormous amount of energy on a daily basis to operate buildings and facilities for students, faculty, staff and visitors. Although solar PVs seem to be an attractive option for overcoming the huge electricity prices, the feasibility of implementing PV for higher education institutions is still in question.

Therefore, a feasibility study of solar PV systems at higher education institution buildings will be useful to predict the reduced energy costs and pay back periods. This study will provide a viable plan about installing solar PVs in higher education institutions in Connecticut and expands toward other regions in the U.S.

Figure 1-1 shows that the state of Connecticut is increasingly growing in solar installations. CT has ranked in the top 10 nationally for energy efficiency programs and policies since the early 2000s (Abdelhamid, 2016).

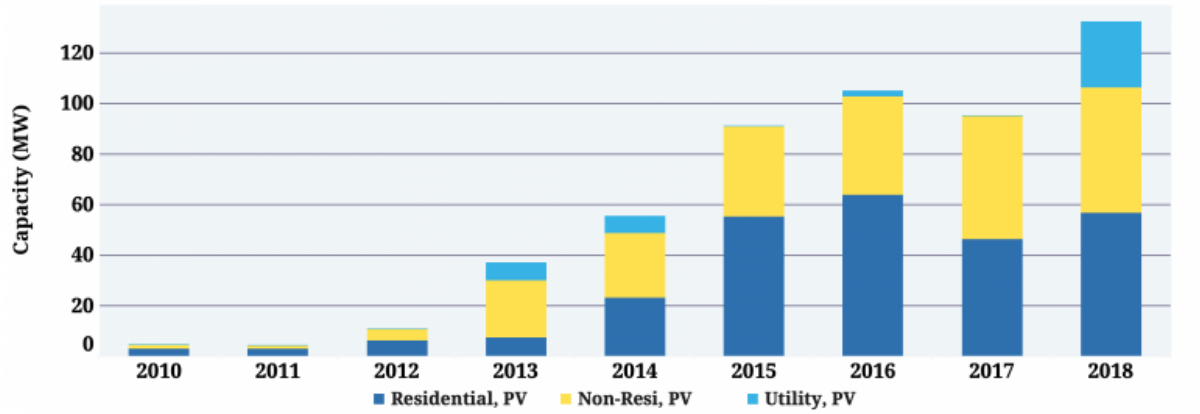


Figure 1-1. Connecticut annual solar installations (Jones, 2019)

According to statistics issued by IRENA (Bellini, 2019), the world's total PV capacity is about 480 GW as of December 2018. North America has attained a cumulative PV capacity of 55.3 GW in which 49.6 GW is in the U.S. The growth of renewables has been intense and the upheaval to low-carbon energy production will need more countries to swap to increasing renewable capacity and also transform their existing fossil fuel power plants.

There are a large number of commercial buildings available for PV installation but there are many associated stakeholders involved which makes it difficult to control and maintain the solar panels. A typical higher education institution has large number of buildings which makes it favorable for installing solar panels. Another good reason is that all the buildings are managed by a single entity. Hence the installation paves the way for smooth operation and maintenance of the solar panels. Many university campuses have already installed solar PV on rooftops and parking lots. Solar installation costs have been subsidized

by more than two-thirds over the last eight years (Environment America Research Centre and Policy, 2017). The implementation of energy storage systems can aid campuses to meet resilience and emergency preparedness goals, while encouraging adoption of solar energy.

1.2 OBJECTIVES

The primary objective of the study is to analyze the economic feasibility of solar systems in higher education institutions in Connecticut. In order to perform this, the net benefit, net present value, internal rate of return and pay-back period are determined. The final conclusion of the study is likely to provide a realistic perspective of the successful performance of PV systems at university campuses in Connecticut that share similar climatic and economic factors. The study also expands the study to other regions in the U.S.

1.3 CHAPTER OVERVIEW

This thesis contains a total of six chapters. Chapter 1 discusses the problem statement and the primary objective of the study. A general description about the feasibility analysis is provided as well. In order to fulfill the purpose of the study, various source of literature review regarding solar PV were conducted and addressed in Chapter 2. The main source of information for finding the recent updates of solar PV systems and other significant information used for this study are from technical reports, journal articles and engineering websites. Chapter 3 describes solar energy in Connecticut. Information about the weather, solar insolation, average temperature, sunshine availability in Connecticut are introduced. Methodology in Chapter 4 details the economic analysis for PV system installed in Celentano Hall at the University of New Haven. The net present value, internal rate of return, simple pay-

back period, simple cash flow, discounted cash flow, profitability index, savings and annual cash flow are the parameters considered for the economic analysis. Chapter 5 provides results and discussions which contains the analysis procedure, while Chapter 6 concludes the study for feasibility of solar PV systems.

CHAPTER 2. LITERATURE REVIEW

The literature review is focused on the feasibility analysis of the photo-voltaic system (PV), which includes the amount of energy production and consumption of energy and the economics in the market. In addition, literatures regarding various practices and experiences in this area were reviewed.

Solar photovoltaics have become popular. In some regions or states, there are subsidies granted by the state government or agencies for solar installers. The rooftop installation in higher education institutions will fetch more successive results as there will be more space available than commercial buildings.

A comparative economic analysis was performed in various countries around the world for promoting PV systems and the main goal was to find which country presents the most viable results for investing in a PV system (Rodrigues, et al., 2016). In two case studies with 1 kW and 5kW PV systems, Internal Rate of Return (IRR), Net Present Value (NPV) and Discounted Pay Back Period (DPBP) were performed through several countries and the study indicated that Germany and India were more favorable locations to invest for 1kW PV system while Italy and USA were more suitable locations to invest for 5kW PV system as highest profits are expected. The viability of the PV system project depends on the combination of the investment cost, electricity tariff, government incentives, and solar radiation.

Another case study (Meyer, Zaman, & Norton, 2014) performed at Boston College shows that the PV system produces only 5% of the building's annual energy, which lowered the energy bill. The roof area the study was manually calculated using google Earth and for energy generation, solar energy calculator on PV Watts's website and Energy sage website were used.

A 19-year old fourteen rack mounted polycrystalline modules (Quansah, Adaramola, Takyi , & Edwin, 2017) was assessed. The modules were installed on the Kwame Nkrumah University of Science and Technology in Ghana. They were physically checked as well as assessed by current voltage characterization and thermal ranging. The data were collected from the panels and the degradation rates was considered. In conclusion, the physical condition of the modules was good and there were only minor problems like discoloration, corrosion at the edge of the cells and bubbles on front side. The modules have a warranty of 10 years with a tolerance of +/ – 10%. The annual degradation rate was determined to be 1.3% which exceeded the warranty expectations.

Nejad (Nejad, 2015) worked on solar radiation basics, estimation of technology progression, cost investigation, and photovoltaic generation. The total solar radiation on the horizontal and the tilt surface were discussed in the study. An approach for assessing the output power of PV module systems were developed and.the results shows meaningful power gain to the system. The cost analysis shows that for a PV cell, the cost reduction did not alter very much if the size of the flat plate PV module was more significant than 140 Wp (Watt-peak). For smaller flat-plate PV cell sizes (<100 Wp), the cost reduction for a PV cell with single-axis tracking and fixed panel became insignificant.

Morgan Anne Wampler (Wampler, 2011) determined the feasibility of solar panels on the almond ranch to power the water pumps in California. Cost benefit analysis was conducted over a 30-year period and the results proved that the solar PV provides more financial benefits than the financial costs. State and federal rebates and incentives were also considered in the annual cash flows which had significant impact on cost saving. The payback period was determined to be about 11 years. The net present value (NPV) was $360,000 with an internal

rate of return of 11.9%. The results of the study will serve as a reference for other farms in California which has an idea of integrating the solar PV systems.

Arizona State University (ASU) is the largest energy consumer in the state of Arizona, where in 2016 has the capability to produce enough solar energy to meet nearly half of its peak daytime energy demand. The usage of solar energy avoided carbon dioxide emissions which is equivalent to annual emissions of nearly 5000 cars (Environment America Research Centre and Policy, 2017). An extensive solar program was responsible for over 50 MW in Arizona State University campuses in onsite and offsite components. The onsite components include four campus locations and the ASU research Park while offsite components consist of collaboration between ASU and Arizona Public service at APS Red Rock, Arizona site. Third parties and ASU own the facilities. The total number of the solar panels installed are 174,664 which capacity is around 53 MW in 2019 and the total solar energy generated is 104 MWh (ASU Business and Finance, 2019).

A study performed by Lee (Lee et al, 2016) focused on economic feasibility of campus wide photovoltaic systems in New England. The power generation data from implemented arrays were collected from Celentano Hall at University of New Haven (UNH). The solar radiation data, PV module details, and electricity rate for the building were gathered and an economic analysis model was created based on the information. The annual estimated solar energy was 82,800 kWh and the total cash flow was determined to be $360,000. The payback period was found to be 11 years. The study suggested that PV system at UNH was profitable based on parameters like Net Present Value (NPV), Internal Rate of Return (IRR) and cash flow. The result also suggests that application of the economic model to other buildings will fetch positive cash flow over the lifetime of the system. The total savings from the campus was

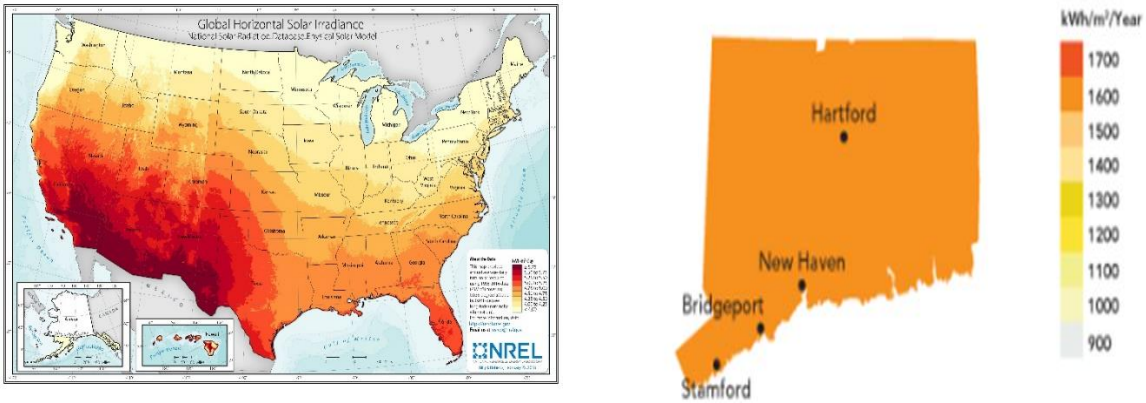
expected to be $6.3 million over 25-year design period. The implementation of the solar panels not only generate renewable energy but also saves building expenses.

CHAPTER 3. SOLAR RADIATION IN CONNECTICUT

3.1 CONNECTICUT

Connecticut (CT) is one among the six New England states located in the northeastern corner of the U.S. Figure 3-1 shows the solar insolation map for the U.S including CT. As shown in the figure, Connecticut falls under 1600 kWh/m^3/year (NREL, 2020). Figure 3-2 shows the daily annual average temperature which varies between 4.3 ℃ (39.74 ºF) and 15.7 ℃ (60.26 ºF).

There are annually 194 days (2460 hours) of sunshine in CT. July in CT is the hottest month with strong solar insolation. The average high temperature in Jul is 28 ℃ in CT. As shown in Figure 3-2, there are four comfortable months (June, July, August and September) with high temperatures in the range of 21.1℃(69.98 ºF) - 29.4℃(84.92 ºF) in CT (Climate, 2020). As a reference, CT is located geographically in the northern hemisphere with a latitude of 41.60 ºN and a longitude of 73.08 º W.



(a) U.S. (b) Connecticut

Figure 3-1. Annual solar insolation (NREL, 2020)

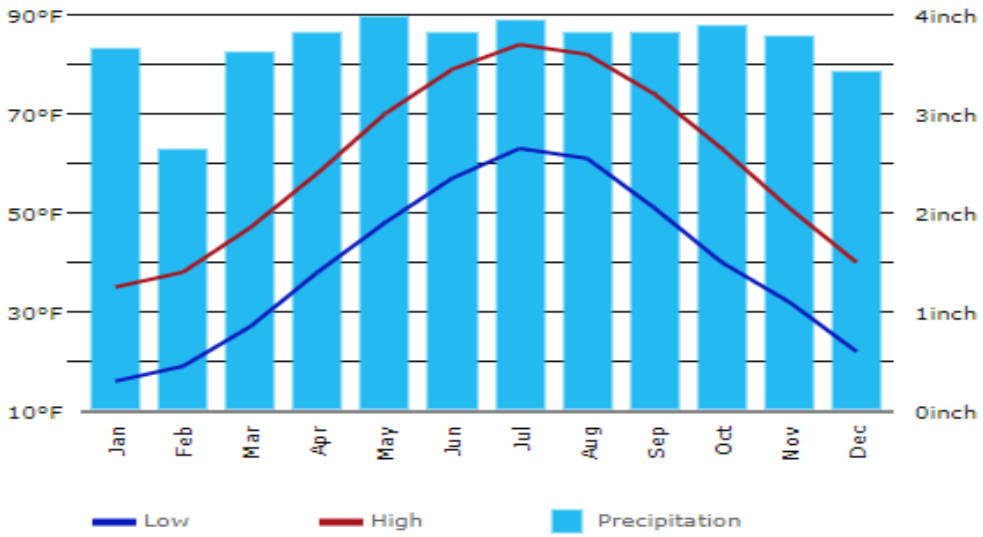


Figure 3-2. Connecticut annual climate data (US-Climate, 2020)

3.2 HIGHER EDUCATION INSTITUTIONS CONSIDERED FOR THE STUDY

In Connecticut, there are fourteen 4-year higher education institutions (see Figure 3-3). They are University of New Haven, Yale University, University of Connecticut, University of Hartford, Wesleyan University, Central Connecticut State University, Quinnipiac University, Fairfield University, Southern Connecticut State University, University of Bridgeport, Sacred Heart University, Western Connecticut State University, Eastern Connecticut State University and Trinity College.

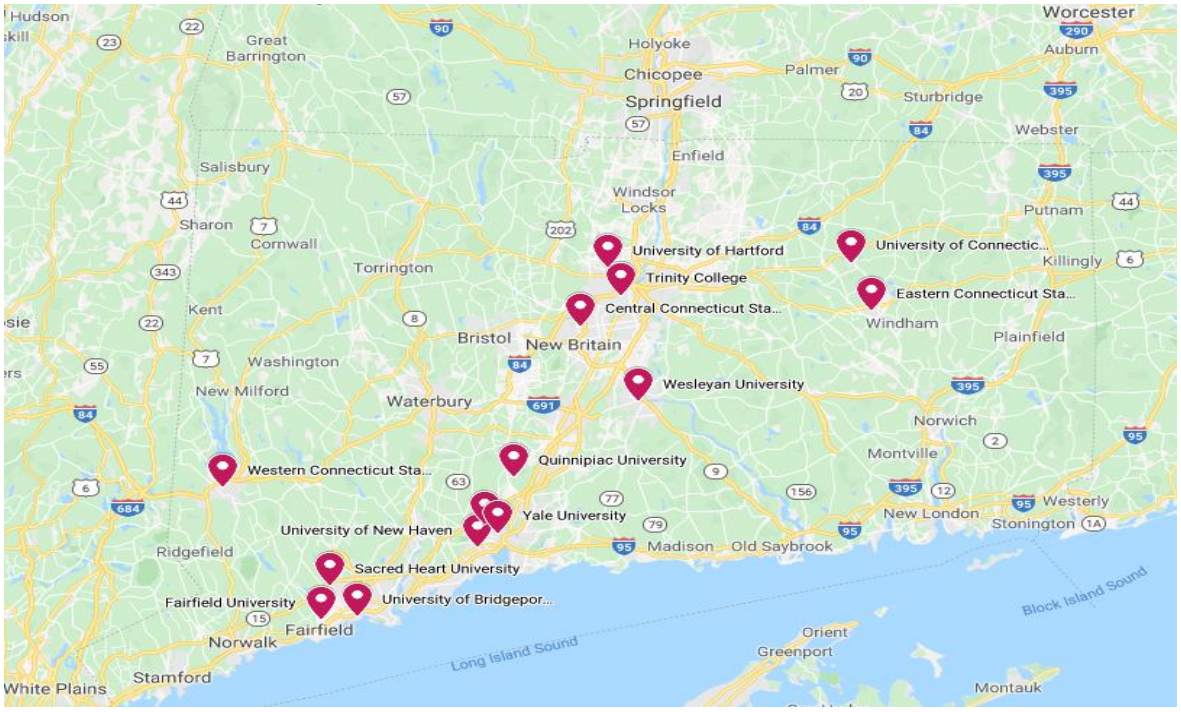


Figure 3-3. Higher education institutions in Connecticut

3.3 SOLAR PV INSTALLATION IN THE UNIVERSITY OF NEW HAVEN

Celentano Hall is the first Gold LEED gold certified building at the UNH. The building has begun to serve from May 2014. The total construction cost was $43 million. The hall consists of 4-person single and double rooms and 6-person single rooms. There is a total of 402 beds for the students in the building.

A solar PV array was installed on the roof of the Celentano Hall at the end of 2014. A total of 226 photovoltaic modules were installed to conserve energy and reduce the carbon footprint. The PV system installed on the building is Hanwha HSL 72 model mounted on Panel Claw Polar Bear racking with three Solectria inverters (Fitzpatrick, 2014). The panel array system was fixed with south facing at an inclination of 12º. The installed PV system capacity is 67.27 kW. Table 3-1 presents the specifications of PV system installed on Celentano Hall.

The setback from the roof edges was taken as four feet for convenience. The design period for the panels are considered as 25 years.

Table 3-1. Celentano Hall PV specifications and design criteria used for the analysis

Roof height	55 ft	Module brand and model	Hanwha HSL 72P6-PB-4-300Q
Module inclination	12º	Module surface area	20.77 ft^2 (1.93 m^2)
Azimuth	152/134	Module efficiency	15.50%
Setback from roof edge	4 ft	Racking	Panel claw polar bear III
Roof parapets	2 ft	Inverter	Solectria PVI20TL
Temperature range	6-91º F	Connection	Grid inter-tie
Design wind speed	110 mph	System capacity	67.27 kW
Estimated annual module degradation	0.5%	Module design lifetime	25 years

The total building size of Celentano Hall in construction plan is 2057 m^2. The area obtained by Google Earth application is 2186 m^2 and so the difference in both measurements is about 6%. The entire gross roof area cannot be used in solar PV array size calculation because of many obstructions that includes skylights, water tanks and AC units on the roof. Figure 3-4 shows an example of rooftop PV panels along with some obstructions. The solar PV panels placement should be designed to neglect shading caused by edges of the parapet wall and include margins for maintenance and shading caused by the other panels. The modules are placed 4 to 6 feet from the edges of parapet wall for ease of access for maintenance. Figure 3-5 shows the top view of the PV system on the Celentano Hall. In this study, the type of solar module (Hanwha HSL 72 model) installed on the building was used as a reference for the further calculation of feasibility study for other universities.

Figure 3-4. Celentano Hall PV installation with obstructions

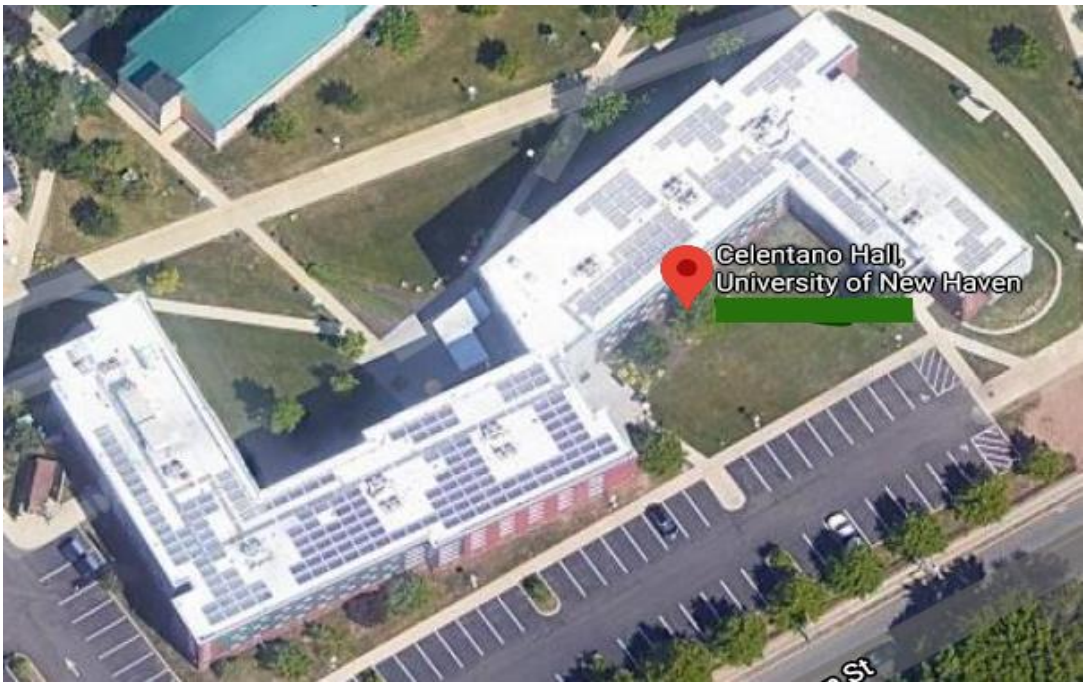


Figure 3-5. Top view of Celentano Hall PV installation

3.4 SOLAR PV INSTALLATION IN OTHER INSTITUITIONS

As discussed in Section 3.3, the available rooftop space for solar PV installation depends on the margins for maintenance and shaded area by the other panels. Also, the followings would affect the roof surface area: weather condition in the region, shape of the roof, purpose of the roof, demand of power and other important factors. Estimation of the available rooftop space for installing solar PV provides an idea about the number of panels that can be installed on the rooftops in a typical higher education building. The estimation of solar PV availability (called the solar ratio) can be obtained from the ratio of the solar PV space over the rooftop area.

$$Solar\ ratio = \ solar\ covered\ area/total\ roof\ area$$

The solar ratio data were measured from 15 different universities in various regions of U.S. and the average ratio was applied to other university. There are few solar installations in New England and hence universities around U.S were considered. The solar ratio is based on full installation condition. Since the PVs were not fully installed over the roof of the University of New Haven building (Celentano Hall), the data were not considered in the solar ratio calculation. The solar installation in Santa Clara University is shown in the Figure 3-6 as an example. The total roof area was found to be about 6888 m^2 and the area covered by the solar panels was measured as 5461 m^2. Thus, the solar ratio was determined to be 0.79 as an example. Google Earth was used for measuring those areas approximately. The average solar ratio for the measured universities was found to be 0.662 as shown in Table 3-2. The standard deviation of the data is 0.117 and the standard error is determined to be 0.037.

Figure 3-6. Solar PV installation at Santa Clara University

Table 3-2 Solar PV ratio in other higher education institutions in U.S. (US News, 2019)

Higher Education Institution	Location	Solar PV ratio on the roof
U. of Arizona	Phoenix, AZ	0.71
Santa Clara U.	Santa Clara, CA	0.79
Colorado State U.	Fort Collins, CO	0.66
U. of MASS. at Lowell	Lowell, MA	0.51
Furman U.	Greenville, SC	0.59
Northwestern U.	Evanston, IL	0.50
SUNY-Buffalo	Buffalo, NY	0.64
Princeton U.	Princeton, NJ	0.83
Harvard U.	Cambridge, MA	0.60
Georgia Tech. U.	Atlanta, GA	0.79
		Average: 0.662

Note: The standard deviation of the data is 0.117. The standard error is 0.037.

3.5 ECONOMIC IMPACTS OF PV SYSTEMS

The data collected by the Census Bureau (The Solar Foundation, 2018) for measuring the state of the nation's workforce has revealed that solar workforce has grown 159% since the first census was performed in 2010. This growth provided approximately additional 150,000 jobs and about 242,000 employees benefit from the solar energy (see Figure3-7). According to the department of Energy (2017), the number of people employed in solar industry is more than other fossil fuel industries such as oil, gas and coal combined.

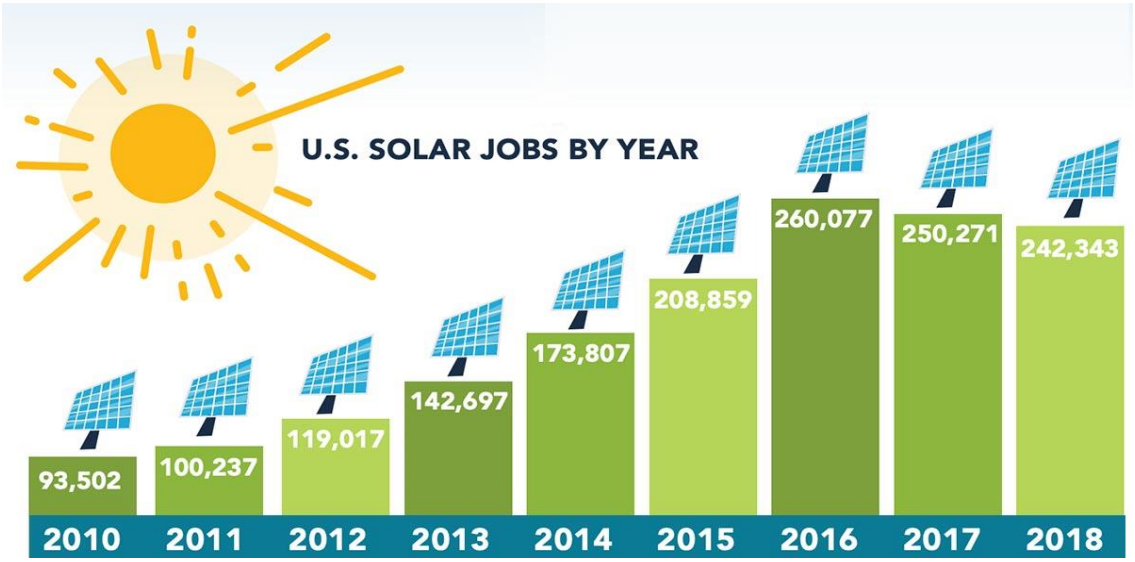


Figure 3-7. U.S. Solar Job (The Solar Foundation, 2018)

3.6 INCENTIVES

Connecticut has been more open minded in adopting the clean energy policies, programs and incentives. Especially, incentives promoted toward homeowners and businesses to choose solar energy over traditional power utilities.

Another incentive is Federal Tax Credit (FTC) also known as Investment Tax Credit which is available in many states. The FTC was launched by the federal government in 2005

through the Energy Policy Act and the tax credit was valid until the end of 2007. However, due to increasing popularity, congress extended it to the end of 2021 (Smith, 2019). The tax credit deduction is up to 30% of the cost of installation. There is no tax liability for non-profits which is a drawback, where the non-profits cannot take advantage of tax credits available for solar (Energy sage, 2017). The University of New Haven (UNH) is a non-profit organization and hence does not take the advantage of credit but was able to benefit from the Zero Emission Renewable Energy Credits (ZREC) (Lee et al, 2016). Celentano Hall in the UNH was awarded $0.148/kWh electricity generation and this value was considered later in this study for the feasibility analysis.

Connecticut's Public Act 98-28 has established separate funds for renewable energy and energy efficiency. The other funds include Connecticut Green bank which is officially known as the Clean Energy Finance and Investment Authority whose total funding was $151 Million from 2000-2010. Another advantage for Connecticut residents is that they are exempted 100% from additional property taxes if they install solar panels in their houses. There is also an exemption of 100% sales tax (Rhodes, 2018).

CHAPTER 4. ECONOMIC ANALYSIS OF SOLAR ENERGY IN THE UNIVERSITY OF NEW HAVEN

The goal of the study was to conduct the economic analysis of solar Photovoltaic (PV) systems at the University of New Haven (UNH) and apply the methodology to other universities in Connecticut (CT) since they have similar climatic characteristics and academic environments. The UNH's annual electricity generation by solar PV systems has been collected since 2015. The payback period for Celentano Hall was calculated so that efficiency of the PV systems could be determined. An overall derate factor (a scaling factor which accounts for reduced output in real world operating conditions when compared with conditions under which PV panels were rated) of 0.75 (Lee et al, 2016) was considered for the Celentano Hall PV system and used for electricity generation calculations.

4.1. ECONOMIC ANALYSIS OF CELENTANO HALL

Table 4-1 shows the financial factors that are used for the economic analysis calculation. The total number of solar panels on the Celentano hall are 226 with an array size of 67.27 DC kW. The annual electricity usage by Celentano Hall was 1.5 Million kWh during January 2017-December 2019. The cost of installation was around $288,500. The annual electric cost increase is 3.5 % which is similar to the average of residential electricity price increase in the U.S. between 2018 and 2019 (Wang, 2019). The insurance cost is about 0.17% of the total installation cost and annual inflation rate of 3% is considered for the analysis. The costs for annual operation and maintenance costs are estimated to be $10/kW per year. A solar array

covering 2186 m^2 would produce approximately 1.31 GWh AC annually (1.74 GWh DC at a 0.75 DC to AC derate efficiency factor).

Table 4-1. Financial factors for Celentano Hall PV system

Number of solar panels	226 panels	ZREC reward	$0.15 /kWh
PV array size	67.27 DC kW	ZREC term	15 years
Module efficiency	15.5 %	ZREC escalator	0.50% /year
Module degradation	0.5 %/year	Interest rate	6%
Electric cost escalation	3.5 %/year	Inflation rate	3% /yr
Installation costs	$288,500	Insurance	0.17%
Maintenance	$10.00 /kW/year	Annual solar production	73273 kWh (2019)

4.2 PERFORMANCE OF UNIVERSITY OF NEW HAVEN

The actual electricity generation of Celentano Hall has been collected from the facility office. Consecutive five-year power generation from the solar PV system has been monitored and Figure 4-1 presents monthly electricity generation (kWh) for Celentano Hall from 2015. The highest electricity generation was during summer from May to August when compared to the rest of the year and 50% of total generation is generated during these four months. The year 2016 had highest generation when compared to other years.

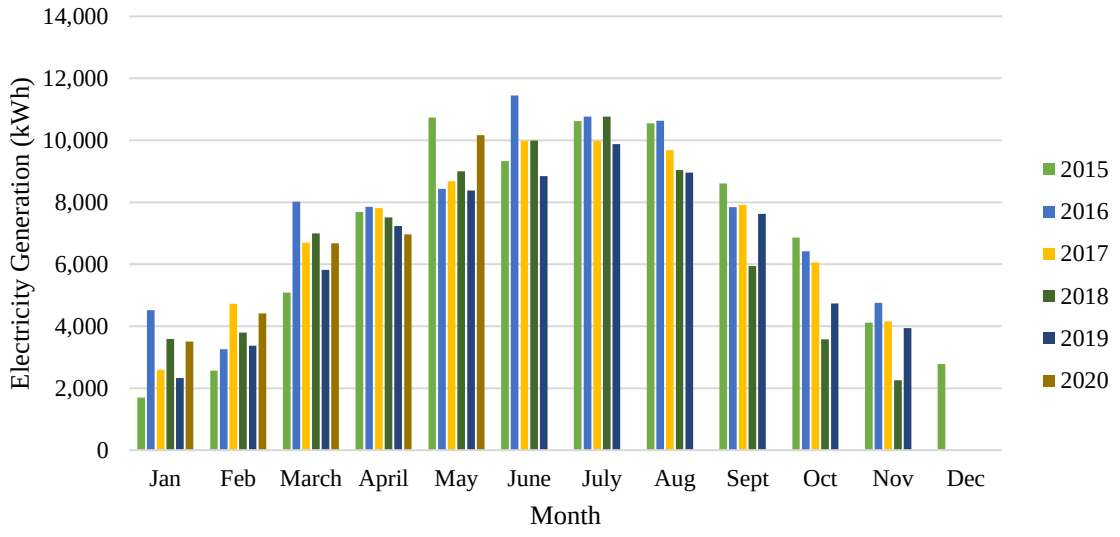


Figure 4-1. Electricity generation from Celentano building during 2015-2020

4.3 ECONOMIC ANALYSIS

An important factor in determining the feasibility of PV systems is the Zero Emissions Renewable Energy Credit (ZREC) credit which offer a long term aid to reduce the unit cost of electricity generated through the system. A ZREC is a credit obtained based on additional energy produced by a solar energy system. The solar PV system installed in Celentano Hall was awarded 0.148$/kWh ZRECs for electricity generated by the system (Lee et al, 2016).

The return on investment (ROI) represents the costs effectiveness of a solar PV system. The feasibility of the solar PV system was assessed by evaluating the economic indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Simple Payback Period (SPBP), Discounted cash flow and Profitability Index (PI). The lifetime of the system was considered as 25 years, which is the standard for many solar companies. The discount rate of 6% was used for the analysis (Rodrigues, et al., 2016).

4.3.1 Net present value

Net Present Value (NPV) is a technique to find the value of expense to the future value of money based on inflation and returns. It is used to find which project gives the greatest profit. The calculation of net present value can be done using the following Equation (1).

$$\text{NPV} = \sum_{y=1}^{Y} \frac{(\text{Cash Flow})_y}{(1+\text{r})^y} - \text{Initial Investment} \quad (1)$$

Where, r =Discount Rate and y = Time Period.

4.3.2 Internal Rate of Return

Internal Rate of Return (IRR) is a term which is used to analyze the profitability of a potential investments. IRR can be found by equating the NPV value to zero.

$$0 = \text{NPV} = \sum_{y=1}^{Y} \frac{(\text{Cash Flow})_y}{(1+\text{IRR})^y} - \text{Initial Investment} \quad (2)$$

4.3.3 Simple Payback Period

The payback period means the time taken to recover the initial investment through cash inflows generated by the investment. The attractive investments depend on shorter payback periods. This can be used in determining the savings that can be made by an investment. It is

found by dividing the cost of investment by the annual cash flow. The pay-back can be used by businesses to know the return on energy efficient technologies (Kagan, 2019).

$$\text{Simple Payback Period} = \frac{\text{Initial Investment}}{\text{Annual savings per year}} \tag{3}$$

4.3.4 Simple Cash Flow

Simple cash flow means the net amount of cash that is being moved into and out of a business. The skill to build value for shareholders is established by its ability to generate positive cash flows.

4.3.5 Discounted Cash Flow

The value of an investment can be evaluated using an evaluation method called Discounted Cash Flow (DCF). This analysis finds the present value of expected future cash flows using a discount rate (Chen, 2019). An investment can be considered profitable if the value calculated through DCF is higher than the current cost of investment.

$$\text{DCF} = \sum_{y=1}^{Y} \frac{\text{Cash Flow}}{(1 + r)^{y}} \tag{4}$$

4.3.6 Profitability Index

Profitability Index (PI)is determined by the ratio between the present value of future cash flows and the initial investment. PI is a useful tool for ranking the investment projects because it shows the value created per unit of investment. Profitability Index is found by

dividing the Net Present value & Initial Investment by the Initial investment. If the Profitability index is greater than 1 for a project, then the company can continue with the project as it generates value.

$$\text{Profitability Index} = \frac{\text{NPV}}{\text{Initial Investment}} + 1 \quad (5)$$

4.4 PAYBACK PERIOD AND SAVINGS

From 2015 to 2020, the energy generated by the Celentano hall solar panels are expected to decline over the lifetime of the solar panels due to degradation. As presented in Table 4-2, the PV system is expected to generate a positive cash flow in 11^{th} year (Payback Period) from 2016. In addition, the system is estimated to accumulate around $460,000 by its end of life of 25 years. The operation and maintenance for solar PV system was considered to be $10/kW/year.

The installation cost is considered same for all the buildings as the panels are maintained by the same entity. The electricity costs are calculated using an escalation rate of 3.5% and generation is calculated with degradation rate of 0.5%. The costs savings are found by multiplying the electricity generation by electricity costs. The ZREC credit was determined by multiplying the electricity costs savings by 14.8 cents (ZREC reward). An insurance of 0.17% was used in the analysis. The effective cash flow is summation of installation costs and O&M, Electricity costs savings, ZREC credit and insurance. Then cumulative cash flow is shown in Table 4-2.

Table 4-2. Economic analysis of Celentano Hall PV system

Year	Installation costs and O&M ($)	Electricity costs ($/kWh)	Electricity generation (kWh)	Cost savings ($)	ZREC Credit ($)	Insurance ($)	Effective cash flow ($)	Cumulative cash flow ($)
2016	(288,500)	0.172	87,302	15,016	12,921	(490)	(261,054)	(261,054)
2018	(693)	0.216	74,544	16,102	11,033	(520)	25,921	(207,916)
2020	(735)	0.225	78,580	17,649	11,630	(552)	27,992	(154,429)
2025	(852)	0.267	76,635	20,442	11,342	(640)	30,292	(7,724)
2026	(878)	0.276	76,252	21,052	11,285	(659)	30,801	23,077
2030	(988)	0.317	74,739	23,678	-	(742)	21,948	140,650
2040	(1,328)	0.447	71,085	31,767	-	(997)	29,443	399,540

Note: The values within parenthesis mark denotes negative values

Table 4-3 summarizes the economic indicators of Celentano Hall which show that the installation of solar panels on UNH campus is economically feasible as the Profitability Index is greater than 1. The NPV for the Celentano Hall solar PV system was calculated as $121,134 and IRR as 9.19%. The project is about to generate positive cash flow within 11 years.

Table 4-3. Economic parameters of Celentano Hall.

NPV	$121,134
IRR	9.19%
Simple Cash Flow	$399,540
DCF (25 years)	$117,985
Profitability Index	1.42
Simple Pay Back Period	10.5 years

In Figure 4-2, it is evident that the cash flow from solar PV panels increase with the time. The average life span of a solar panel is about 25-30 years (Energysage, 2019). The average payback period of a solar PV installation in U.S is about 8 years (Centrica, 2020). By the year 2026 which will be ten and a half year from installing solar, there is positive cash flow and increment in the following years. This proves that by installing solar PV panels on the Celentano Hall at the university, there is pay-back from the 11th year and there are significant savings from the particular year.

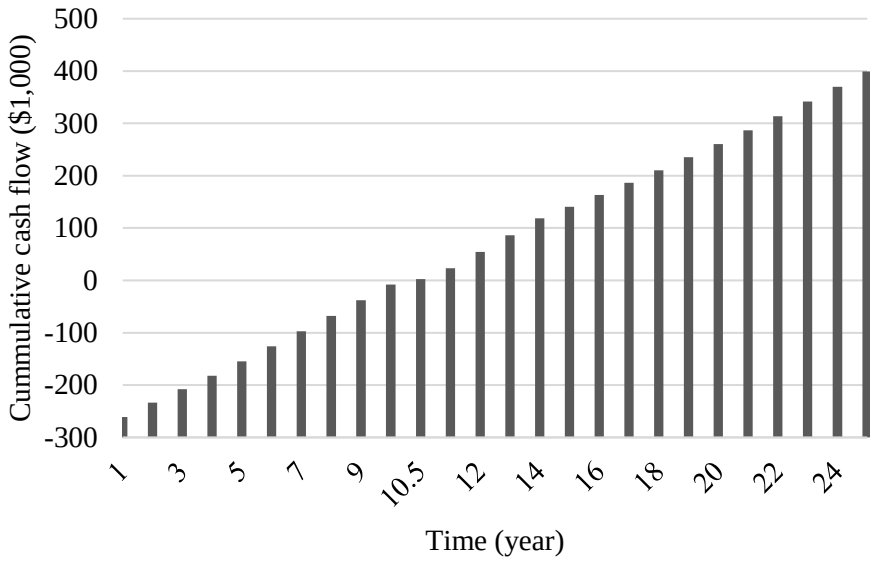


Figure 4-2 25-year cash flow

CHAPTER 5. ECONOMIC ANALYSIS OF SOLAR ENERGY IN HIGHER EDUCATION INSTITUTIONS IN CONNECTICUT

This chapter focuses on the economic analysis of PV system for the higher education institutions in Connecticut (CT). This is achieved by developing a model that can be applied to any campus-wide PV system located within the state. The results from the research on University of New Haven's PV system were considered as a reference.

5.1 FLOWCHART OF ANALYSIS PROCEDURE

A rooftop gross area is one of the critical factors to determine the feasibility study of solar energy. However, as mentioned earlier, the entire gross roof area cannot be used in the economic analysis of solar PV because of obstructions, margins for maintenance and shaded area by the other panels and so on. Thus, the solar ratio on the rooftop is one of factors in the analysis of solar PV feasibility. Roof type, campus location, number of students and campus size were considered in addition to the solar ratio.

An overview of approach to assess the total revenue obtained by PV is illustrated in Figure 5-1. A university is classified as urban or suburban based on the surroundings. Rural or city was not considered since there is not many school in CT belonging to the surrounding. The total roof area in the campus is measured using Google Earth.

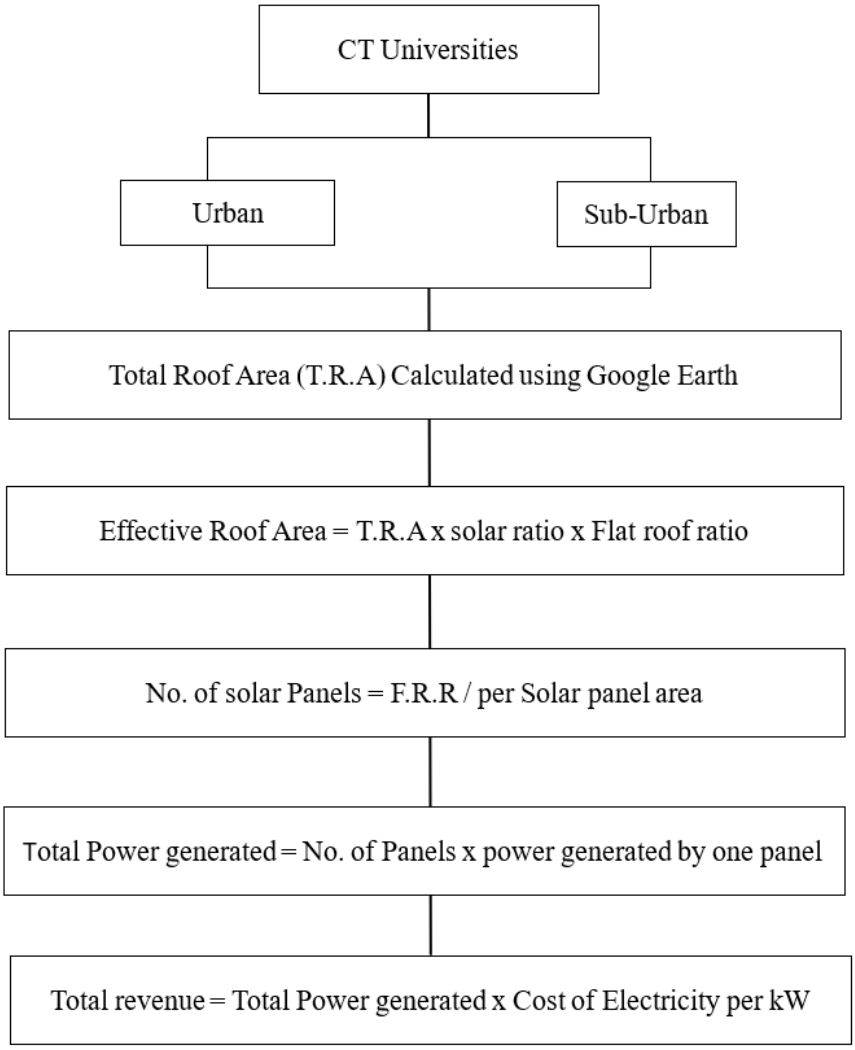


Figure 5-1 Flowchart of analysis procedure

5.2 TOTAL ROOF AREA

The important information necessary for economic analysis is the rooftop area of the university buildings. A university website provides the campus size and the number of students enrolled in the university, but the information for a rooftop area of a specific building is not typically available. The total rooftop area of each building in a university was measured using Google.

As an example, Figure 5-2 represents the Celentano Hall of University of New Haven. The total roof area for the building comes out to be 2,186 m^2 from Google Earth. While the total building size of Celentano Hall in construction plan is 2,057 m^2. So, the difference in both measurements is about 6%.

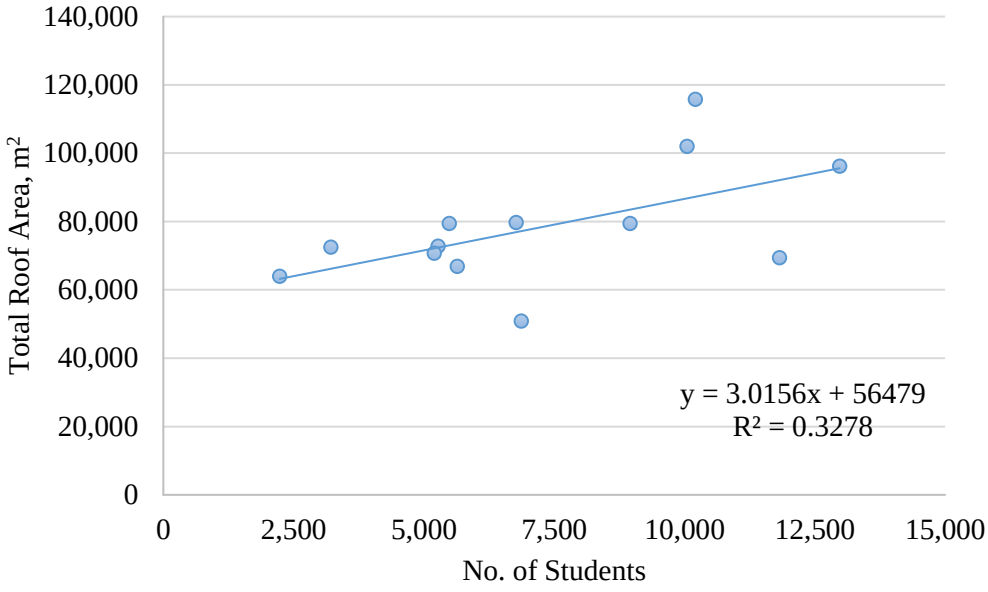
Similarly, the total roof areas for other buildings in the universities were measured and the measurements are listed in Appendix A. Table 5-1 shows the roof measurement for the higher education institutions in Connecticut including other information (i.e., number of buildings, number of enrollments, campus size, and surrounding).

Figure 5-2. Celentano Hall of University of New Haven

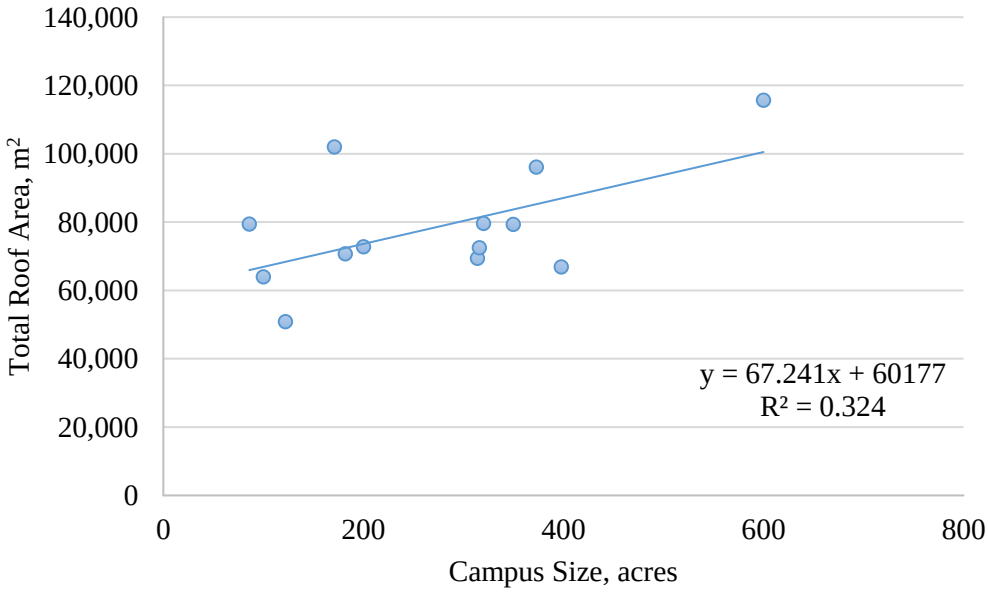
Table 5-1. Higher education institutions in Connecticut (as of 2019)

Higher Education Institution	Location in CT	Surrounding	Campus Size (acres)	No. of Enrollment	No. of Building	Total roof area (m^2)
University of Connecticut	Storrs	Rural	4109	27,412	159	1,222,207
Yale University	New haven	Urban	373	12,974	161	96,187
Western CT State university	Danbury	Urban	398	5,642	26	52,679
Wesleyan University	Middletown	Urban	316	3,217	68	78,836
Central CT State University	New Britain	Suburban	314	11,822	35	69,441
Fairfield University	Fairfield	Suburban	200	5,273	36	72,790
Eastern CT State University	Windham	Suburban	182	5,198	48	70,767
Southern CT State University	New haven	Urban	171	10,050	37	102,009
University of Bridge port	Bridgeport	Urban	86	5,485	35	79,466
Sacred heart University	Fairfield	Suburban	350	8,958	31	76,302
Trinity College	Hartford	Urban	100	2,235	72	68,103
University of New haven	New haven	Suburban	122	6,867	54	50,911
University of Hartford	Hartford	Suburban	320	6,770	37	79,682
Quinnipiac University	Hamden	Suburban	600	10,207	40	117,837

Based on the data from Table 5-1, two plots were developed to find a major factor to estimate a total roof area. One is the total roof area versus the number of students enrolled while the other is the total roof area versus the campus size in acres. Note: University of Connecticut data are out of the range since the number of students and the campus size are too large compared to other universities in Connecticut. As shown in Figure 5-3, no meaningful relationship was found. R^2 for both fitted plots (0.33 and 0.32, respectively) are too low.



(a)



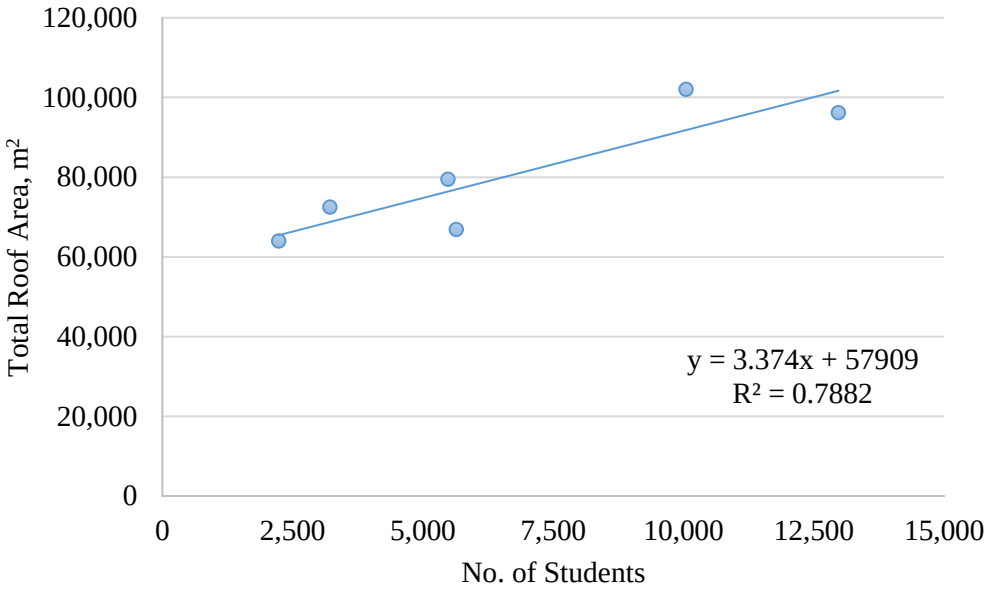
(b)

Figure 5-3. Total roof area versus (a) No. of students and (b) Campus size

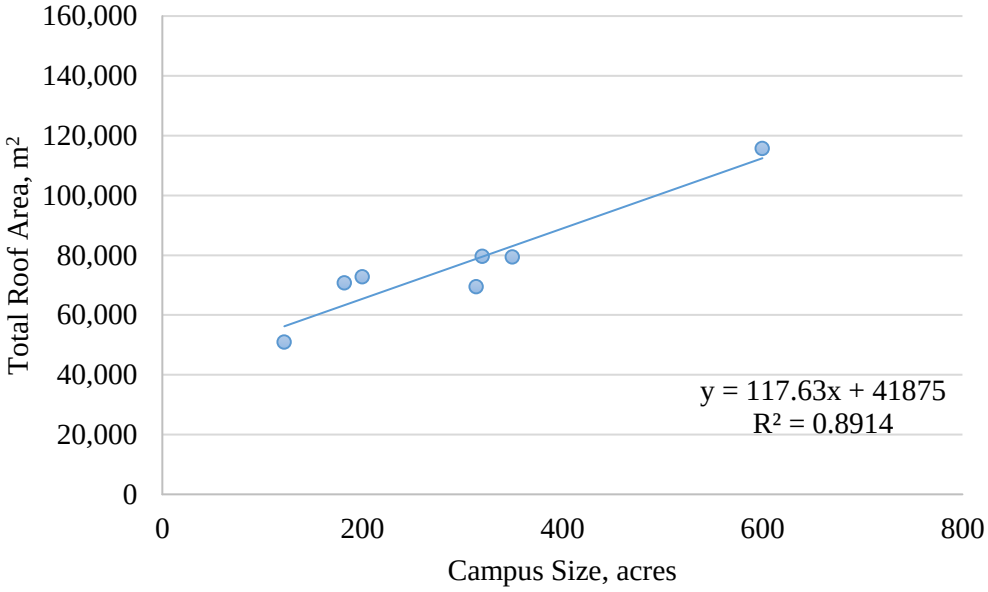
Note: University of Connecticut is out of the range since the number of students and the campus size are too large compared to other universities in Connecticut.

Since the density of building and number of students are different between campus surrounding (i.e., suburban and urban), different plots (see Figure 5-4) were developed again

and Figure 5-4 splits the total roof area by two surroundings, Urban and Suburban. Rural was not considered in the data since only single datum is available.



(a)



(b)

Figure 5-4. Total roof area: (a) Urban and (b) Suburban

As shown in Figure 5-4, R^2 has increased and the fitted line shows meaningful trend line. In addition to universities in Connecticut, some universities in other regions were also considered for the total roof area estimation to expand the data rage (x-axis). The universities are University of New Hampshire, Michigan State University, University of Cincinnati, Kent State University, Rochester University, Auburn University, University of Maryland, Boston College, Grand Valley State University, Drexel University, Rowan University, Cleveland State University, DePaul University.

While the range of a-axis in Figure 5-4 (top) is about 13,000 as a number of students, Figure 5-5 extends it up to about 38,000 and R^2 has increased a little bit. The six red dots indicate new data from other regions in addition to Connecticut universities. The standard deviation of the total data is determined to be 11,085 m^2 and the ± standard deviation are added in the plot.

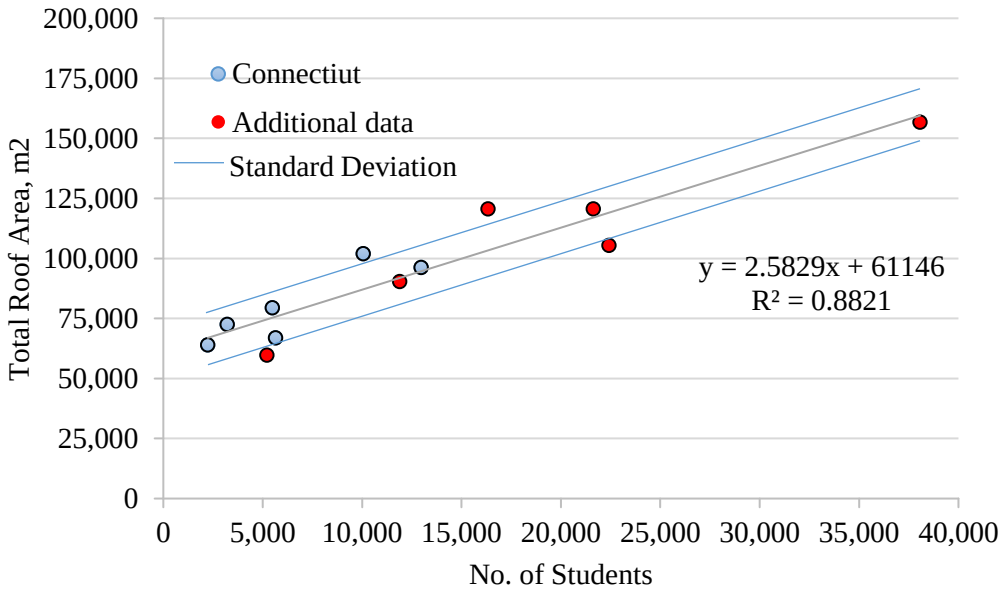


Figure 5-5. Estimation of the total roof area for urban universities

Similarly, the Suburban university plot were developed by adding a few more data from other regions as well. Figure 5-6 extends the data in a-axis (campus size) upto about 1,400 acres but R^2 has decreased a little bit. The five red dots indicate new data from other regions in addition to Connecticut universities. The standard deviation of the total data is determined to be 9,843 m^2 and the ± standard deviation are added in the plot.

Some universities in suburban area are extremely large even though there are not many. University of New Hampshire and Michigan State University are those universities. The campus size of Michigan State University is 5192 acres (US News, 2019). When additional two data are added into Figure 5-6, the fitted line is linear but follow the second-degree polynomial with a higher R^2 (0.98). Both linear (thin grey) and polynomial (thick black) fitted lines are shown together in Figure 5-7.

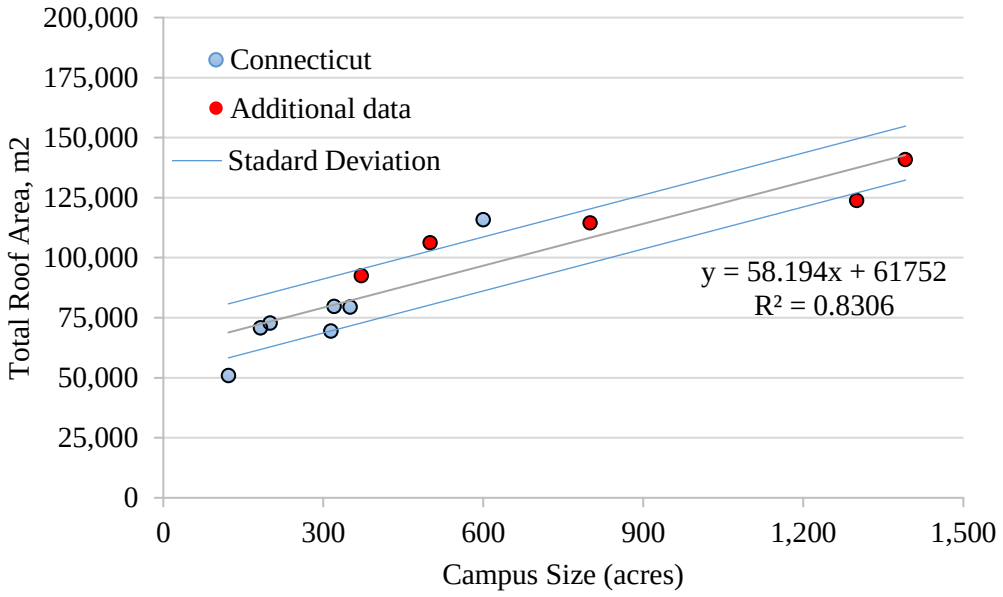


Figure 5-6. Estimation of the total roof area for urban universities

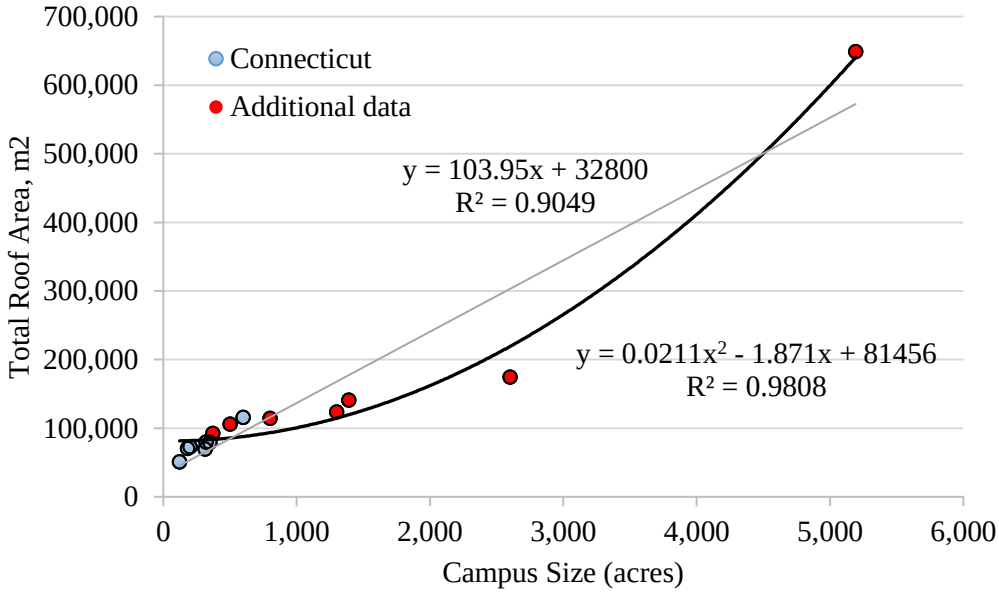


Figure 5-7. Estimation of the total roof area for Urban universities with large campus size

5.3 FLAT ROOF RATIO

It is assumed more economical if solar panels are installed on flat roofs than slope roofs. More panels can be installed on flat roofs and maintenance and installation costs can be less expensive than slanted roofs. Thus, the ratio of the number of flat roofs in Connecticut universities was investigated and the ratio was determined manually by counting the flat buildings from the university campus map and Google Earth. The flat roof ratio is defined as a ratio of total number of flat roofs over the total number of buildings. The average flat roof ratio in CT was found to be 0.551 (see Figure 5-8). The standard deviation of the data is 0.131 and the standard error is 0.041.

5.4 EFFECTIVE ROOF AREA

The effective roof area is the area that can be used for installing solar panels excluding some necessary margin such as spaces for operation and maintenance, space from parapet wall, solar module inter row spacing and other obstructions (skylights, cooling tower, connecting pipelines etc.,).

The available solar area to the total roof area ratio (solar ratio) was determined to be 0.662 which was addressed in Section 3.4. The effective roof area can be calculated by Equation 6.

$$\text{Effective Roof area} = \text{Total Roof area x Solar ratio} \times \text{Flat Roof Ratio} \qquad (6)$$

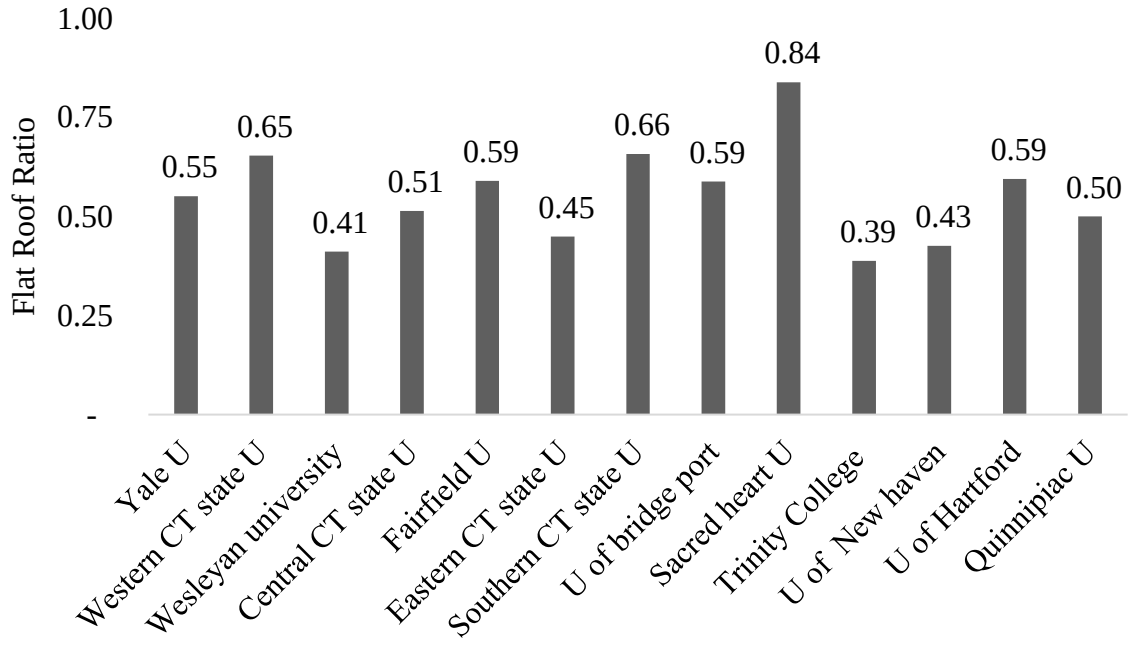


Figure 5-8. Flat roof ratio of universities in Connecticut

Note: The standard deviation of the data is 0.131 and the standard error is 0.041

5.5 SOLAR PANEL

Solar panel calculation describes the number of solar panels that can be installed in flat roof area. The number of solar panels can be determined by following Equation (7).

$$\text{Number of solar panels} = \frac{\text{Effective Roof Area}}{\text{Single solar panel area}} \quad (7)$$

The solar panels used for the study is Hanwha HSL 72 model which is the same model that was installed in Celentano Hall of the University of New Haven has. The panel area for the model is 20.77 ft^2 (1.93 m^2) (Lee et al, 2016).

5.6 TOTAL REVENUE CALCULATION

The energy generation for the latest year (2019) from Celentano hall was 73,273 kWh and one panel among 226 panels generates approximately 324 kWh per year. Then, the power generated by the total solar panels can be multiplied by cost of electricity per kilowatt to get the total revenue from the solar generation. The cost of buying electric per kilowatt in Connecticut was found to be 16.48 cents for December 2019 (U.S Energy, 2020). The total annual revenue from the universities in CT was found to be about $10.5 M. The information regarding university location, surrounding, campus size, student's enrolled, total roof area, and effective roof area is shown in the Table 5-2 (a) while the total revenue per each university is calculated in Table 5-3 (b).

Table 5-2. Estimation of Solar PV annual revenue from universities in Connecticut

(a) Total roof area

Universities	Location	Surrounding	Campus (acres)	No. of students	No. of buildings	Total roof area (m²)
Yale U	New Haven	Urban	373	12,974	161	96,187
Western CT State U	Danbury	Urban	398	5,642	26	66,898
Wesleyan U	Middletown	Urban	316	3,217	68	72,518
Central CT State U	New Britain	Suburban	314	11,822	35	69,441
Fairfield U	Fairfield	Suburban	200	5,273	36	72,790
Eastern CT State U	Windham	Suburban	182	5,198	48	70,767
Southern CT State U	New Haven	Urban	171	10,050	37	102,009
U of Bridge Port	Bridgeport	Urban	86	5,485	35	79,467
Sacred Heart U	Fairfield	Suburban	350	8,958	31	79,402
Trinity College	Hartford	Urban	100	2,235	72	63,994
U of New Haven	West Haven	Suburban	122	6,867	54	50,911
U of Hartford	Hartford	Suburban	320	6,770	37	79,682
Quinnipiac U	Hamden	Suburban	600	10,207	40	115,737
						Total = 1,019,803

(b) Total annual revenue

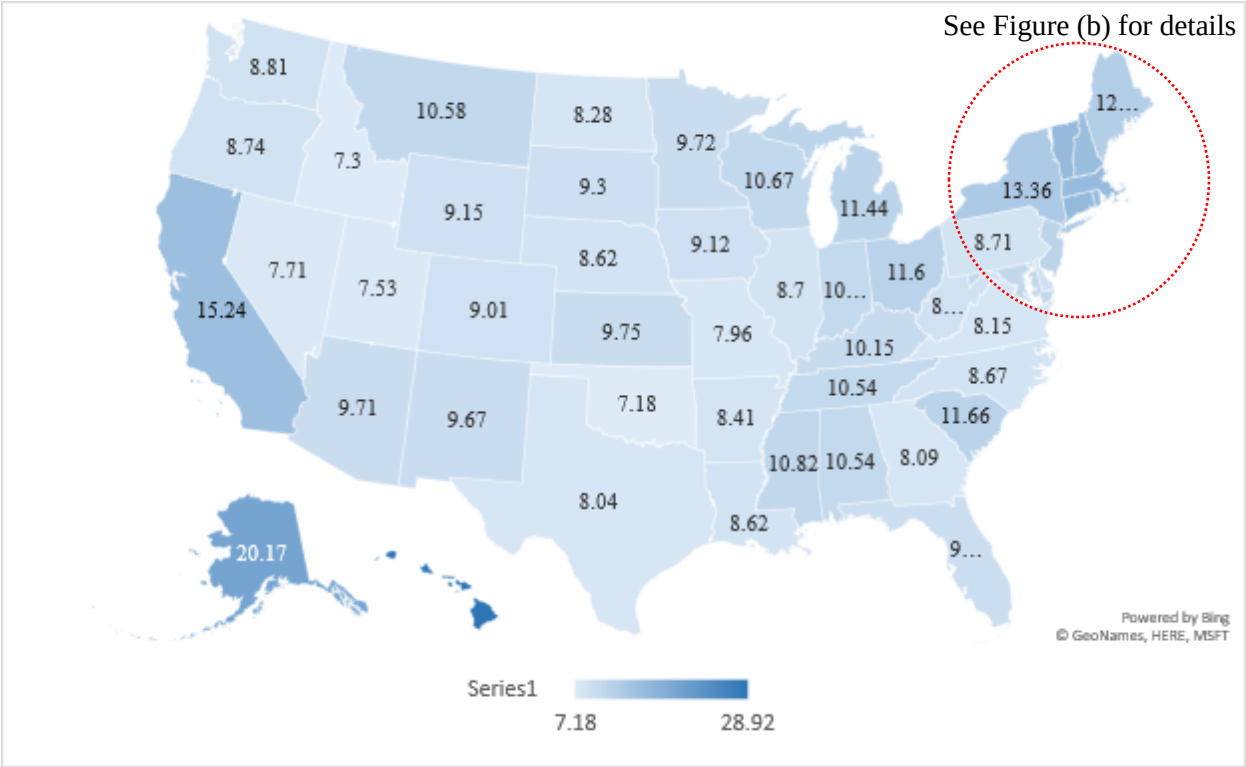
Universities	Flat roof ratio	Effective Roof Area (m²)	Possible No. of solar panel	Total energy (kWh)	Total annual revenue ($)
Yale U	0.551	35,509	18,399	5,965,020	983,035
Western CT state U	0.654	29,313	15,188	4,924,190	811,506
Wesleyan U	0.412	20,018	10,372	3,362,691	554,171
Central CT state U	0.514	23,914	12,391	4,017,196	662,034
Fairfield U	0.59	28,774	14,909	4,833,566	796,572
Eastern CT state U	0.449	21,289	11,030	3,576,194	589,357
Southern CT State U	0.658	44,972	23,301	7,554,544	1,244,989
U of Bridge port	0.588	31,307	16,221	5,259,059	866,693
Sacred Heart U	0.839	44,634	23,127	7,497,860	1,235,647
Trinity College	0.388	16,636	8,620	2,794,569	460,545
U of New Haven	0.426	14,531	7,529	2,440,985	402,274
U of Hartford	0.595	31,765	16,459	5,336,065	879,383
Quinnipiac U	0.5	38,772	20,089	6,513,076	1,073,355
			Sum =	64,075,013	10,559,562

The standard errors for the solar ratio and flat roof ratio were determined to be 0.037 (Mean = 0.662 and STD = 0.117) and 0.041 (Mean = 0.551 and STD = 0.129), respectively. If both the standard errors of mean are considered together in the estimation, Estimation of Solar PV annual revenue from universities in Connecticut varies between 113.5% and 87.4%, which are calculated to be $11,979,404 and $9,227,552 from Table 5-2.

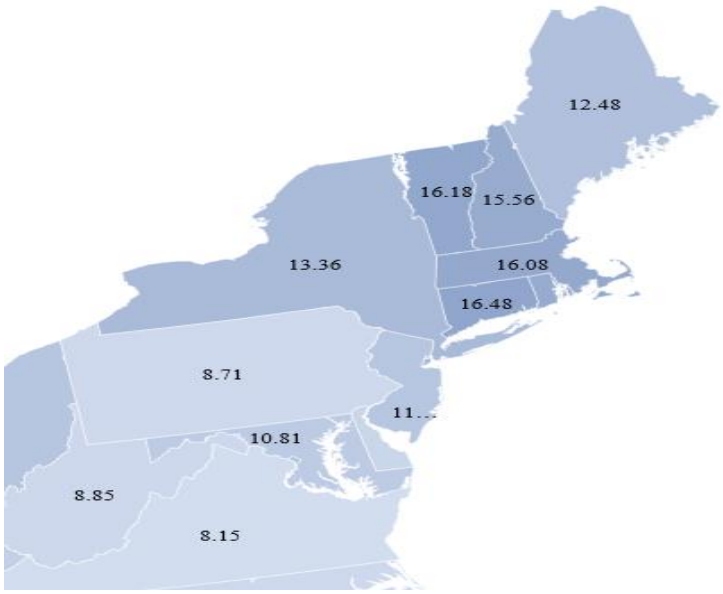
5.8 APPLICATION TO OTHER REGIONS IN THE U.S.

The total revenue from solar panels are determined for the universities in Connecticut. As a further step, the study is expanded to other regions of the U.S. There are commonly five regions in the U.S.: Northeast, Midwest, Southeast, Southwest and West. The electricity price varies in each state in the U.S. as shown in Figure 5-9. (U.S Energy, 2020). In order to apply the methodology used in Connecticut to other regions, the electricity price in each region must be considered since it varies by state. The averaged electricity price is provided in Figure 5-10.

In addition to the price difference in each state, other factors must be considered. Solar radiation, number of sunlight hours, and the total roof area of high education institution in each state. Gagnon (2016) provided detailed data driven analysis of the U.S. rooftop PV availability and technical electricity generation potential. For PV availability of rooftops, light detection and ranging data, geographic information system method and PV generation modelling were considered. The data were could benefit broad spectrum of solar energy researchers, planners, utility companies, investment offices and policy makers. The total estimated technical potential for rooftop PV for Connecticut is given as 95 Million m^2. Hence this area was taken as reference for further calculations for finding the revenue for the other regions in the U.S.



(a) Each state (cents/kW)



(b) Northeast (cents/kW)

Figure 5-9. Electricity prices in each state

Figure 5-10. Averaged electricity prices in each region

The solar index (NREL, 2006) was considered for various states since the solar radiation is not same for all the regions. Normalization was applied for the solar index and the potential rooftop area as shown in Table 5-3. The total roof area in universities in Connecticut was determined to be about 1.01 Million m^2 with the total electricity generation of 64 Million kWh (see Table 5-2). According to Gagnon's data (2016), the available rooftop area for PV installation Connecticut is about 95 Million m^2. The solar index from NREL (2006) indicates Connecticut is 0.79. Thus, if all the data for Connecticut are normalized as 1.0, the ratio for other states can be normalized to Connecticut, respectively. Table 5-3 provides the normalization by state for available roof area for solar PV and Solar Index. Thus, the estimated total revenue obtained per year from each state's higher education institution cab be determined by normalization (see Table 5-4). Hawaii and Alaska were not considered in the study since no data for potential roof area were available. Also, tariff, incentives, and their environmental factors were not considered because of lack of information.

Table 5-3. Normalization by state

(a) Available roof area

State	Available Roof Area (Million m^2)	Roof area of Universities (Million m^2)	Normalization
Connecticut	95	1.0100	1.000
Maine	45	0.4784	0.474
New Hampshire	38	0.4040	0.400
Vermont	21	0.2233	0.221
Massachusetts	165	1.7542	1.737
Rhode Island	28	0.2977	0.295
New York	340	3.6147	3.579
New Jersey	184	1.9562	1.937
Pennsylvania	316	3.3596	3.326
Maryland	142	1.5097	1.495
Delaware	20	0.2126	0.211
Washington D.C.	11	0.1169	0.116
Ohio	338	3.5935	3.558
Michigan	303	3.2214	3.189
Indiana	188	1.9987	1.979
Wisconsin	169	1.7967	1.779
Illinois	324	3.4446	3.411
Minnesota	168	1.7861	1.768
Iowa	99	1.0525	1.042
Missouri	204	2.1688	2.147
North Dakota	23	0.2445	0.242
South Dakota	26	0.2764	0.274
Nebraska	60	0.6379	0.632
Kansas	90	0.9568	0.947
Arkansas	88	0.9356	0.926
Louisiana	146	1.5522	1.537
Mississippi	84	0.8931	0.884
Alabama	147	1.5628	1.547
Georgia	251	2.6685	2.642
Florida	557	5.9218	5.863
Tennessee	175	1.8605	1.842
South Carolina	108	1.1482	1.137
North Carolina	252	2.6792	2.653
Kentucky	131	1.3927	1.379
West Virginia	45	0.4784	0.474
Virginia	205	2.1795	2.158
Texas	715	7.6016	7.526
Arizona	114	1.2120	1.200
New Mexico	45	0.4784	0.474
Oklahoma	140	1.4884	1.474
Washington	164	1.7436	1.726
Oregon	101	1.0738	1.063
California	961	10.2169	10.116
Montana	21	0.2233	0.221
Idaho	33	0.3508	0.347
Wyoming	12	0.1276	0.126
Utah	52	0.5528	0.547
Nevada	67	0.7123	0.705
Colorado	119	1.2652	1.253

(b) Solar Index

State	Solar index	Normalization
Connecticut	0.79	1.00
Maine	0.84	1.06
New Hampshire	0.83	1.05
Vermont	0.77	0.97
Massachusetts	0.83	1.05
Rhode Island	0.82	1.04
New York	0.83	1.05
New Jersey	0.81	1.03
Pennsylvania	0.83	1.05
Maryland	0.84	1.06
Delaware	0.84	1.06
Washington D.C	0.84	1.06
Ohio	0.74	0.94
Michigan	0.77	0.97
Indiana	0.83	1.05
Wisconsin	0.81	1.03
Illinois	0.79	1.00
Minnesota	0.84	1.06
Iowa	0.87	1.10
Missouri	0.87	1.10
North Dakota	0.84	1.06
South Dakota	0.87	1.10
Nebraska	0.89	1.13
Kansas	0.95	1.20
Arkansas	0.91	1.15
Louisiana	0.9	1.14
Mississippi	0.92	1.16
Alabama	0.89	1.13
Georgia	0.92	1.16
Florida	0.95	1.20
Tennessee	0.85	1.08
South Carolina	0.9	1.14
North Carolina	0.92	1.16
Kentucky	0.83	1.05
West Virginia	0.79	1.00
Virginia	0.87	1.10
Texas	0.98	1.24
Arizona	1.18	1.49
New Mexico	1.16	1.47
Oklahoma	0.98	1.24
Washington	0.67	0.85
Oregon	0.71	0.90
California	1	1.27
Montana	0.86	1.09
Idaho	0.93	1.18
Wyoming	0.96	1.22
Utah	0.95	1.20
Nevada	1.19	1.51
Colorado	0.99	1.25

Table 5-4 Estimated total revenue from universities in each state

State	Normalization of Roof Area	Annual Electricity (kWh)	Electricity Rate ($/kWh)	Normalization of Solar Index	Range of the total annual revenue ($ M) - Stanard Error	Mean	+ Stanard Error
Connecticut	1.000	64075013	16.48	1.00	9.23	10.56	11.98
Maine	0.474	30351322	12.48	1.06	3.52	4.03	4.57
New Hampshire	0.400	25630005	15.56	1.05	3.66	4.19	4.75
Vermont	0.221	14163950	16.18	0.97	1.95	2.23	2.53
Massachusetts	1.737	111288180	16.08	1.05	16.43	18.80	21.33
Rhode Island	0.295	18885267	15.65	1.04	2.68	3.07	3.48
New York	3.579	229321099	13.36	1.05	28.13	32.19	36.52
New Jersey	1.937	124103183	11.44	1.03	12.72	14.56	16.51
Pennsylvania	3.326	213133727	8.71	1.05	17.04	19.50	22.13
Maryland	1.495	95775283	10.81	1.06	9.62	11.01	12.49
Delaware	0.211	13489476	10.81	1.06	1.35	1.55	1.76
Washington D.C	0.116	7419212	10.81	1.06	0.75	0.85	0.97
Ohio	3.558	227972152	11.6	0.94	21.65	24.77	28.10
Michigan	3.189	204365568	11.44	0.97	19.91	22.79	25.85
Indiana	1.979	126801078	10.53	1.05	12.26	14.03	15.91
Wisconsin	1.779	113986076	10.67	1.03	10.90	12.47	14.15
Illinois	3.411	218529518	8.7	1.00	16.61	19.01	21.57
Minnesota	1.768	113311602	9.72	1.06	10.23	11.71	13.29
Iowa	1.042	66772908	9.12	1.10	5.86	6.71	7.61
Missouri	2.147	137592659	7.96	1.10	10.54	12.06	13.68
North Dakota	0.242	15512898	8.28	1.06	1.19	1.37	1.55
South Dakota	0.274	17536319	9.3	1.10	1.57	1.80	2.04
Nebraska	0.632	40468429	8.62	1.13	3.43	3.93	4.46
Kansas	0.947	60702644	9.75	1.20	6.22	7.12	8.07
Arkansas	0.926	59353696	8.41	1.15	5.02	5.75	6.52
Louisiana	1.537	98473178	8.62	1.14	8.45	9.67	10.97
Mississippi	0.884	56655801	10.82	1.16	6.24	7.14	8.10
Alabama	1.547	99147652	10.54	1.13	10.29	11.77	13.36
Georgia	2.642	169292929	8.09	1.16	13.94	15.95	18.09
Florida	5.863	375681918	9.58	1.20	37.82	43.28	49.10
Tennessee	1.842	118032919	10.54	1.08	11.70	13.39	15.19
South Carolina	1.137	72843173	11.66	1.14	8.46	9.68	10.98
North Carolina	2.653	169967403	8.67	1.16	15.00	17.16	19.47
Kentucky	1.379	88356071	10.15	1.05	8.23	9.42	10.69
West Virginia	0.474	30351322	8.85	1.00	2.35	2.69	3.05
Virginia	2.158	138267133	8.15	1.10	10.84	12.41	14.08
Texas	7.526	482248782	8.04	1.24	42.03	48.10	54.57
Arizona	1.200	76890016	9.71	1.49	9.75	11.15	12.65
New Mexico	0.474	30351322	9.67	1.47	3.77	4.31	4.89
Oklahoma	1.474	94426335	7.18	1.24	7.35	8.41	9.54
Washington	1.726	110613707	8.81	0.85	7.22	8.26	9.38
Oregon	1.063	68121856	8.74	0.90	4.68	5.35	6.07
California	10.116	648169342	15.24	1.27	109.27	125.04	141.85
Montana	0.221	14163950	10.58	1.09	1.43	1.63	1.85
Idaho	0.347	22257636	7.3	1.18	1.67	1.91	2.17
Wyoming	0.126	8093686	9.15	1.22	0.79	0.90	1.02
Utah	0.547	35072639	7.53	1.20	2.78	3.18	3.60
Nevada	0.705	45189746	7.71	1.51	4.59	5.25	5.95
Colorado	1.253	80262385	9.01	1.25	7.92	9.06	10.28
					- Range	Total	+ Range
					569.02	651.16	738.71

The lowest revenue was determined to be Wyoming. The total annual revenue is estimated to be $0.9 Million. Wyoming's normalized available roof ratio is only 0.126 compared to Connecticut and the electricity rate is 9.15 cents/kWh although the solar index is 1.22 which is 22% higher than Connecticut.

The highest revenue was determined to be California. The total annual revenue is estimated to be $125.04 Million. California's normalized available roof ratio is 10.12 compared to Connecticut and the electricity rate is 15.24 cents/kWh. The solar index is 27% higher than Connecticut.

The total estimated revenue by solar PV for the entire universities in the U.S. is determined to be about $651.2 Million annually. The range of the total estimated revenue with standard error is $569.0 Million and $738.7 Million annually. This reveals that the solar PV is one of significant energy source and cost saving factors.

CHAPTER 6. SUMMARY, CONCLUSION AND FUTURE WORK

6.1 SUMMARY

The primary objective of the study was to analyze the economic feasibility of solar photovoltaic systems (PV) in higher education institutions in Connecticut (CT). To perform the objective, several economic parameters were calculated and the annual electricity revenue for the University of New Haven was determined and applied to all of Connecticut. The study was expanded to other state in the U.S. by normalizing available roof area, electricity rate and solar index by each state.

The total electricity generation was estimated for various regions by normalization. This estimation can be used by university administration for calculation of total power generation and total revenue per year in that particular state. With the normalization ratio obtained, one can identify the total power generation in other regions of the U.S. beforehand while considering installation of PV systems. Results from the study regarding the total revenue reveal that the Southwestern and Western regions of the U.S have more solar power generation capacity due to high solar radiation.

6.2 CONCLUSIONS

- Photovoltaic solar energy economic analysis of rooftops of University of New Haven's Celentano building has been carried out. The study conducted on Celentano Hall shows that NPV is $ 121,134 and IRR value 9.19 % which is well over the discounted rate of 6%.

- The results of the study reveal that the payback period for Celentano Hall of the University of New Haven is 10.5 years and the profitability index is 1.42 which proves that the solar PV in the university is feasible.
- The estimated total annual revenue for solar PV systems at universities in Connecticut are $10.5 Million.
- The total roof area is correlated with the number of students enrolled in urban universities while it is correlated with the campus size of suburban universities.
- The lowest revenue was determined to be in Wyoming. The total annual revenue is estimated to be $0.9 Million. Wyoming's normalized available roof ratio is only 0.126 compared to Connecticut and the electricity rate is 9.15 cents/kWh although the solar index is 1.22 which is 22% higher than Connecticut.
- California provides the highest revenue. The total annual revenue is estimated to be about $125 Million. California's normalized available roof ratio is 10.1 compared to Connecticut and the electricity rate is 15.2 cents/kWh. The solar index is 27% higher than that for Connecticut.

6.3 FUTURE WORK

The measurement of roof area using Google earth is time consuming and provides only approximate values. Direct surveys about each about university's roof area would provide more accurate estimates.

An environmental factor is recommended in future studies. The savings and reduction in pollution can be studied which will give a brief idea about the cost involved in environmental

concerns. Life Cycle Assessment (LCA) or Global Warming Potential (GWP) are examples of reference measures.

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APPENDIX: ROOF AREA MEASUREMENTS

A: University of New Haven

B: University of Bridgeport

C: Trinity College

D: University of Hartford

E: Southern Connecticut State University

F: Central Connecticut State University

G: Western Connecticut State University

H: Eastern Connecticut State University

I: Wesleyan University

J: Fairfield University

K: Sacred Heart University

L: Quinnipiac University

A: University of New Haven

Building Number	Building Name	Available roof area (m^2)	Total area(m^2)	Type of Roof
1	Maxy Hall	842.33	2954	Slope
2	Bayer Hall	168.91	326.57	Slope
3	Gate House	159.10	380.15	Slope
4	South Campus Hall	136.69	446.57	Slope
5	Harugari Hall	217.26	810.59	Flat
6	Marvin K.P Library	794.06	1579.13	Flat
7	UNH Campus Store	139.34	182.85	Slope
7A	Campus Police	394.66	595.54	Slope
8	Bartels Hall	305.15	1790.55	Flat
9	Buckman Hall	647.69	2031.9	Flat
10	Dodds Hall	705.34	2284.07	Flat
11	Kaplan Hall	376.62	722.95	Flat
12	Echlin Hall	442.10	1001.41	Flat
12A	North Hall	267.12	487.42	Flat
13	Bergami Hall	564.06	1518.76	Flat
14	Subway Building	106.06	362.09	Flat
15	UNH Dental center	471.69	907.36	Slope
16	Athletics offices	115.60	134.61	Slope
17	Charger gymnasium	1,980.98	2625.6	Flat

17A	Football offices	196.88	196.88	Slope
17B	Coaches Office	200.98	202.98	Slope
17C	Sports Medicine	107.49	139.74	Slope
18	Bartels Student Center	324.94	1669.37	Flat
19	Sheffield Hall	377.95	802.29	Flat
19A	N. Health Center	499.92	988.26	Flat
20	Bixler Hall	674.93	966.8	Slope
21	Bethel Hall	683.34	1060.45	Flat
22	Botwinik Hall	1,104.28	1322.82	Slope
23	Dunham Hall	683.74	736.01	Flat
24	Winchester Hall	1,538.12	1686.61	Flat
25A	RudenSt Apartments	232.27	240.9	Slope
25B	RudenSt Apartments	224.28	233.5	Slope
25C	RudenSt Apartments	178.35	180.44	Slope
26A	Forest Hills Apartment	795.92	795.92	Slope
26B	Forest Hills Apartment	785.01	785.01	Slope
26C	Forest Hills Apartment	818.62	818.62	Slope
26D	Forest Hills Apartment	790.78	790.78	Slope
27	D. Recreation Centre	2,483.72	2483.72	Flat
29	1124 Campbell Ave.	64.26	107.4	Slope
30	Celentano Hall	889.60	2186	Flat
31	Gehring Hall	425.66	621.31	Flat

32	1132 Campbell Ave.	91.15	143.95	Slope
33	1136 Campbell Avenue	73.34	117.22	Slope
35	Charger Plaza	637.83	1123.67	Flat
36	Charger Plaza	228.65	235.4	Slope
37	46 Ruden St.	64.28	134.95	Slope
40	Blake building	721.60	880.02	Flat
41	Westside Hall	2,257.62	2858.64	Flat
42	16 Rock view Street	124.65	126.15	Slope
43	1076 Campbell Avenue	75.01	106.05	Slope
44	196 Rockdale Road	85.54	119.53	Slope
45	Main building (Orange)	2,250.32	2250.32	Flat
46	North building	2,026.77	2026.77	Slope
47	South building	630.15	630.15	Slope
	Total area(m^2)	27275.47	50910.75	0.426

B. University of Bridgeport

Building Number	Building Name	Available Roof Area (m^2)	Total roof area(m^2)	Type of Roof
1	Wahlstrom Library	1,231.56	2799.19	Flat
2	Carlson Hall	1,368.26	1928.21	Flat
3	Mandeville Hall	1,334.80	1621.24	Flat
4	Bookstore	1,510.08	2253.26	Flat
5	John J. Cox Student Centre	674.43	1575.75	Flat
6	Engineering Technology Building	494.39	1536.5	Flat
7	Print and Mail Center	808.29	2460.46	Flat
8	Marina Dining hall	1,177.25	1574.35	Flat
9	Barnum Hall	1,170.09	1515.46	Flat
10	Seeley Hall	215.53	982.54	Slope
11	Waldemere hall	602.71	1425.52	Flat
12	Arnold Bernhard Arts and Humanities Center	1,160.79	1383.43	Slope
13	University Hall	1,164.96	4473.81	Slope
14	Wheeler Recreation center	693.47	12511.32	Flat
15	Cooper Hall	660.61	19862.22	Flat
16	Chaffee Hall	355.40	854.38	Slope

17	Courtright Hall	180.15	843.78	Slope
18	Bryant hall	127.97	968.35	Slope
19	Carstensen Hall	146.66	1786.32	Slope
20	Bodine Hall	1,429.95	1606.12	Flat
21	North South Hall	1,835.05	1887.33	Flat
22	Health Sciences Centre	722.56	1516.61	Flat
23	Eleanor N. Dana Hall	864.90	1175.34	Flat
24	School of Chiropractic	471.93	1036.86	Flat
25	Harvey Hubbell Gymnasium	2,497.24	2641.66	Flat
26	Security	330.71	500.68	Slope
27	Trustee Auditorium	187.97	685.56	Flat
28	Charles A. Dana Hall	2,073.11	2493.9	Flat
30	Bauer Hall	435.44	973.61	Slope
31	Bates Hall	178.20	303.05	Slope
32	Wisteria Hall	231.40	347.76	Slope
33	Buildings and Grounds	259.37	318.9	Slope
34	Courtright Annex	81.55	202.75	Slope
35	University Place apartments	1,103.42	1420.44	Slope
	Total Roof area m^2	27,780.202	79466.66	

C: Trinity College

Building number	Building name	Available Roof Area(m^2)	Total Roof Area(m^2)	Type of Roof
1	St Anthony Hall	139.77	250.28	Slope
2	Ogilby Hall	60.41	407.93	Slope
3	Alpha Delta Phi	334.84	419.55	Slope
4	Vernon Social	536.52	840.3	Slope
5	Vernon Place	300.05	874.59	Slope
6	High Rise Hall	shaded	773.23	Flat
7	North Campus hall	1,052.13	1010.09	Slope
8	The International House	90.50	171.36	Slope
9	Cleo Society of AX	155.86	266.47	Slope
10	Pi Kappa Alpha	shaded	233	Slope
11	Cultural Programs in Italy	127.95	358.93	Slope
12	Doonesbury Hall	242.18	292.19	Flat
13	The Charleston House of Interfaith Cooperation	shaded	328.2	Slope
14	Counselling and Wellness Centre	236.41	250.38	Slope
15	Hartford Youth Scholars	94.08	147.93	Slope
16	The Treehouse	20.80	160.3	Slope
17	Zach’s Hillel House	259.18	371.51	Flat
18	Campus Safety	140.92	172.71	Flat
19	Umoja House	110.86	213.13	Slope

20	Office of Study away	36.59	182.84	Slope
21	Studio Arts Senior studio	157.37	237.44	Flat
22	Drawing Studio	75.57	156.16	Flat
23	AASA House	12.84	168.76	Slope
24	La Eraca	20.36	133.42	Slope
25	Program on Public Values	102.75	219.58	Slope
26	The Mill	59.51	191.96	Slope
27	Psi Upsilon	18.70	376.99	Slope
28	Hansen Hall	801.60	1216.39	Slope
29	Koeppel Student Centre	400.00	414.65	Slope
30	Admissions and Career Development Centre	536.25	1041.95	Slope
31	English Department Building	79.88	512.87	Slope
32	Smith House	96.95	538.35	Slope
33	Presidents House	428.71	573.25	Slope
34	Trinfo Café	102.97	228.89	Slope
35	Chapel	600.08	834.96	Slope
36	Downes Memorial	334.05	850.97	Flat
37	Williams memorial	168.98	879.23	Slope
38	Jarvis Hall	100.53	651.77	Slope
39	Northam Towers	70.53	753.53	Slope
40	Seabury Hall	129.25	777.3	Slope

41	Cook Hall	193.60	475.89	Slope
42	Goodwin Woodward Hall	79.12	452.22	Slope
43	Clement Chemistry Building	214.07	1181.87	Slope
44	Raether Library and Information Technology Centre	1,633.92	3598.78	Flat
45	Ferris Atheletic Centre	6,568.46	9075.38	Flat
46	Gruss Music Centre	306.48	692.01	Flat
47	Austin Arts Centre	711.04	1147.96	Flat
48	Hamlin Hall	150.94	281.11	Slope
49	Mather Hall	1,637.49	3141.53	Flat
50	Elton Hall	423.70	632.92	Flat
51	Jones Hall	513.70	690.32	Flat
52	Mc Cook Academic Building	454.69	1710.36	Flat
53	Hall den Hall	696.14	1012.73	Flat
54	Wiggins Sculpture Studio	199.25	334.59	Slope
55	Crescent Street Townhouses-1	896.76	1987.54	Slope
56	Crescent Street Townhouses-2	1,364.76	1852.68	Slope
57	Albert C. Jacobs Life Sciences Centre	981.52	1528.37	Flat
58	Jackson Hall	576.23	970.13	Flat
59	Wheaton Hall	685.69	906.77	Flat
60	Smith Hall	177.00	354.83	Flat
61	Funston Hall	720.00	807.07	Flat

62	Roy Nutt Mathematics Engineering and Computer science centre	719.70	1131.03	Flat
63	Trinity College Community Child Centre	319.42	488.8	Flat
64	Queer Resource Centre	68.97	90.68	Slope
65	Stowe Hall	332.87	416.65	Flat
66	Clemens Hall	300.45	422.11	Flat
67	Facilities Services	1,026.68	1218.74	Flat
68	Summit Suites	1,845.49	2071.5	Slope
69	Trinity Commons	1,933.71	1629.09	Flat
70	Koeppel Community Sports Centre	4,427.03	4654.61	Slope
71	Cine studio	169.92	323.03	Flat
72	70 Vernon street	60.63	229.14	Slope
	Total area in m^2	38,625.36	63993.78	

D: University of Hartford

Building Number	Building Name	Total Roof Area(m^2)	Type of Roof
1	Bates House	329.32	Slope
2	Beatrice Fox Auerbach Computer and Administration Center	1217.82	Flat
3	United Technologies Hall	1354.48	Flat
4	Charles A. Dana Hall	2613.44	Flat
5	Biology-Chemistry Building	1647.32	Flat
6	Hartford Art School- A	2558.92	Flat
7	Hartford Art School-B	1268.49	Flat
8	University Commons	1949.86	Slope
9	Complex A: Andrews, Barlow, Crandall, Olmsted	1415.7	Flat
10	Complex B: Reeve, Beeches, Stevens, Warner	1471.78	Flat
11	Complex C: Poe, Willard, Malcolm X, Dubois	1471.78	Flat
12	Complex D: King, Smith, Occum, Roth	1471.78	Flat
13	Complex E: Bushnell, Garvey, Hillyer, Whitney	1471.78	Flat

14	Complex F: Gallaudet, Barnyard, Webster, Stow	1471.78	Flat
15	Hawk Hall (He)	1185.79	Slope
16	Quads 1	1753.88	Slope
17	Quads 2	1753.88	Slope
18	Quads 3	1753.88	Slope
19	Quads 4	1753.88	Slope
20	Quads 5	1753.88	Slope
21	Quads 6	1615.25	Slope
22	Quads 7	1615.25	Slope
23	Park River Apartments	2216.14	Slope
24	Regents Park	5916.52	Slope
25	Konover Campus Center	1483.34	Slope
26	Lincoln Theater	1858.98	Slope
27	Harry Jack Gray Center	6088.38	Flat
28	Abrahms Hall	599.88	Flat
29	Alfred C. Fuller Music Center	3819.94	Flat
30	Gingras Student Union	3600	Flat
31	East Hall	1128.62	Flat
32	Hillyer Hall	3890.47	Flat
33	Beatrice Fox Auerbach Hall	2684.42	Flat

34	University of Hartford Magnet School	4638.1	Flat
35	Public Safety and Facilities	2592.94	Flat
36	Financial and Administrative Services Building	602.76	Slope
37	University High School of Science And Engineering	3661.16	Flat
	Total Roof Area(m^2)	79681.59	0.594

E. Southern Connecticut State University

Building Number	Building Name	Roof Area(m^2)	Type of Roof
1	Facilities Operations	2218.72	Slope
2	Nursing Classroom Building	1553.04	Slope
3	Davis Hall	1954.13	Flat
4	Fitch Street Garage	4807.94	Flat
5	Peltz Gymnasium	3587.03	Flat
6	Academic Science & Lab Building	2399.16	Flat
7	Jennings Hall	3622.83	Flat
8	Morrill Hall	1418.57	Flat
9	Classroom Building	840.35	Flat
10	School of Business	2357.42	Flat
11	Engelman Hall	9977.84	Flat
12	Bluey Library	4608.87	Flat
13	Lyman Center	2811.07	Flat
14	Earl Hall	2811.7	Flat
15	Adanti Student Center	3416.97	Slope
16	C T Hall (CO) - Food Service	2219.78	Flat
17	Schwartz Hall (SZ) – Residence.	925.55	Flat
18	Ethnic Heritage Center	985.79	Flat
19	Alumni House	1548.22	Slope

20	Lang House-Dept. of Social Work	982.54	Slope
21	Orlando House (OR) - Department of Public Health	1254.68	Slope
22	Brownell Hall (BR) - Residence Hall	1691.49	Slope
23	Furnham Hall (FH) - Residence Hall	940.18	Flat
24	Wilkinson Hall (WI) - Residence Hall	911.31	Flat
25	Chase Hall (CH) - Residence Hall	916.69	Flat
26	West Campus Garage (WCG)	3480.99	Flat
27	Hickerson Hall (HI) - Residence Hall	992.32	Flat
28	Neff Hall (NE) - Residence Hall	911.94	Flat
29	West Campus Residence Complex	942.21	Flat
30	University Police and Granoff Student Health Center	892.85	Flat
31	Office Building 1	410.58	Slope
32	Temporary Building	1609.17	Slope
33	Energy Center	1365.85	Slope
34	Moore Field House	9856.92	Slope
35	Wintergreen Building	4972.58	Slope

36	North Campus Residence Complex	4789.28	Flat
37	Wintergreen Avenue Garage	8225.8	Slope
	Total Roof Area (m^2)	99212.36	0.658

F: Central Connecticut State University

Building Number	Building Name	Total Roof Area (m^2)	Type of Roof
1	Davidson Hall	4,075.38	Slope
2	Marcus White Hall	1,422.54	Slope
3	Marcus White Annex	1,588.41	Flat
4	Carroll Hall	1,142.11	Slope
5	Barnard Hall	1,848.68	Flat
6	Welte Hall	2,447.50	Slope
7	Kaiser Hall	5,885.97	Flat
8	Kaiser Hall Annex	3,723.29	Flat
9	Beecher Residence Hall	966.84	Slope
10	May Residence Hall	988.61	Slope
11	Seth North Residence Hall	962.33	Slope
12	Willard Hall	2,107.12	Flat
13	Sanford Hall	1,320.68	Flat
14	Student Center	6,035.60	Flat
15	Sheridan Residence Hall	807.12	Slope
16	Diloreto Hall	2,107.62	Flat
17	Gallaudet Residence Hall	858.85	Slope
18	Memorial Hall	2,731.67	Flat
19	Barrows Residence Hall	939.43	Flat

20	Vance Residence Hall	1,114.83	Flat
21	Elihu Burritt Library	2,708.70	Flat
22	Copernicus Hall	2,609.68	Flat
23	Bic Hum Engineering Laboratory	463.79	Slope
24	Maloney Hall	1,954.70	Flat
25	East Hall (Facilities Management)	2,044.52	Flat
26	Charter Oak State College	789.46	Slope
27	Public Safety Building (Police Department)	392.58	Slope
28	James Residence Hall	1,487.12	Slope
29	Vance Academic Center	1,823.78	Slope
30	Mid-Campus Residence Hall	2,786.44	Flat
31	Energy Center	1,908.72	Flat
32	Social Sciences Hall	1,949.01	Slope
33	Hilltop Café	1,284.94	Flat
34	Newman House	157.10	Slope
35	Lawrence J. Davidson Hall	4,006.32	Slope
	Total Roof Area(m^2)	69,441.44	0.51429

G: Western Connecticut State University

Building Number	Building Name	Total Roof Area (m^2)	Type of Roof
1	Berkshire Hall	3262.94	Flat
2	Ruth A Haas Library	1793.63	Flat
3	Warner Hall	1072.81	Flat
4	White Hall	3169.68	Flat
5	Fairfield Hall	986.65	Slope
6	Higgins Hall	1327.34	Flat
7	Higgins Annex	2400.78	Flat
8	Student Center	2450.6	Flat
9	Old Main	1540.08	Slope
10	Irfan Kathwari Honors House	364.73	Slope
11	Science Building	3530.57	Flat
12	Police	949.87	Flat
13	Newbury Hall	1301.06	Flat
14	Litchfield Hall	2880.3	Flat
15	University Hall	1504.45	Flat
16	190 White St	2920.04	Slope
17	O'neil Centre	5895.26	Flat
18	Ives Concert Park	2949.85	Slope
19	Visual & Performing Arts Center	5931.16	Slope

20	Campus Center	1746.44	Flat
21	Classroom Building	3774.34	Flat
22	Athletics Complex	949.51	Slope
23	Observatory	920.33	Slope
24	Penney Hall	3795	Flat
25	Grasso Hall	2704.37	Flat
26	Centennial Hall	6776.6	Slope
	Total Area(m^2)	66898.39	

H: Eastern Connecticut State University

Building Number	Building Name	Total Roof Area(M^2)	Type of Roof
1	Noble Hall	2316.21	Flat
2	Beckert Hall	113.08	Slope
3	Shafer Hall	2473.64	Flat
4	Heating Plant, South	159.64	Slope
5	Burr Hall	775.81	Slope
6	Center for Community Engagement	719.32	Slope
7	Grant Alumni House	425.31	Slope
8	160 Windham Street Extension	147.59	Slope
9	University Honors House	150.7	Slope

10	Counseling & Psychological Services	151.57	Slope
11	Counseling & Psychological Services	152.57	Slope
12	Knight House Multifaith Center	88.32	Slope
13	Winthrop Hall	887.58	Flat
14	Constitution Hall	1231.86	Slope
15	Laurel Hall	1590.72	Slope
16	Nutmeg Hall	1750.51	Slope
17	Health. S /Office of Access Ability	2342.6	Flat
18	Low Rise Apartments	272.7	Slope
19	High Rise Apartments	771.13	Flat
20	Science Building	3111.77	Slope
21	Webb Hall	2082.98	Slope
22	Eastern Hall	824.81	Slope
23	J. Eugene Smith Library	3133.31	Slope
24	Admissions Building	453.7	Slope
25	Wick Ware Planetarium	474.34	Flat
26	Goddard Hall	1898.37	Flat
27	Heating Plant, North	358.96	Flat
28	Communication Building	1854.59	Flat
29	Wood Support Center/Ability Office	1918.38	Flat
30	Gels'-Young Hall	1327.16	Flat
31	Fine Arts Instructional Center	4655.53	Flat

32	Barnes & Noble Bookstore	4594.06	Flat
33	Sports Center	4114.98	Flat
34	Shakespeare Parking Garage	5449.61	Flat
35	Burnup Hall	549.99	Flat
36	Niejadlik Hall	1436.81	Flat
37	Occum Hall	1483.99	Flat
38	Crandall Hall	531.37	Flat
39	Hurley Hall/Dining Services	1866.91	Slope
40	Cervantes Parking Garage	5038.37	Flat
41	Facilities Warehouse	690.68	Slope
42	Mead Hall	2267.6	Slope
43	Arboretum	80.83	Slope
44	Facilities Management, Planning & Maintenance	800.42	Flat
45	Center for Early Childhood Education	1481.32	Slope
46	Child and Family Development Resource Center	1030.3	Slope
47	Public Safety	409.68	Flat
48	Institute for Sustainable Energy	325.41	Slope
	Total Roof Area(m^2)	70767.09	0.448

I: Wesleyan University

Building Number	Building Name	Total Roof Area (m^2)	Type of Roof
1	Adzenyah Rehearsal Hall	337.63	Flat
2	Albritton Hall	672.59	Slope
3	Anthropology Department	248.89	Slope
4	Art Studios, North and South	943.34	Flat
5	Art Workshops	682.91	Flat
6	Bessie Schonberg Dance Studio	352.26	Slope
7	Boger Hall	797.83	Slope
8	Center for African American Studies	318.44	Slope
9	Center for The Americas	267.55	Slope
10	Center for Film Studies	1384.06	Flat
11	Center for The Humanities	444.3	Flat
12	College of The Environment	257.13	Slope
13	Continuing Studies	133.61	Slope
14	Cross Street Dance Studio	290.48	Slope
15	Downey House	743.24	Slope
16	English Department	247.13	Slope
17	Exley Science Center	3018.36	Flat
18	Fisk Hall	207.74	Slope
19	Hall-Atwater Laboratory	2632.53	Flat
20	Judd Hall	384.06	Slope

21	Mansfield Freeman Center for East Asian Studies	523.51	Slope
22	Music Studios	418.07	Flat
23	Olin Memorial Library	1122.67	Slope
24	Public Affairs Center	1127.76	Slope
25	Religion Department	280.6	Slope
26	Romance Languages and Literatures Department	340.8	Slope
27	Russell House	661.43	Slope
28	Science Library	1850.72	Flat
29	Shanklin Laboratory	713.81	Slope
30	Shapiro Center for Writing	243.35	Slope
31	Theater Department	506.69	Flat
32	Van Vleck Observatory	583.12	Flat
33	Wash Center for Retired Faculty	230.59	Slope
34	Freeman Athletic Center	17697.3	Flat
35	200 Church Street	1288.81	Flat
36	Bennet Hall	794.92	Flat
37	Butter Field Residence Halls	992	Slope
38	Clark Hall	772.06	Flat
39	Fauve Apartments	777.52	Slope
40	Hewitt	908.28	Flat

41	High Rise	595.37	Slope
42	Low Rise	432	Slope
43	45 Broad Street	243.71	Flat
44	Davison Health Center	450.32	Flat
45	Gordon Career Center	249.69	Flat
46	North College	414.5	Flat
47	Public Safety	295.13	Flat
48	Religious and Spiritual Life	1618.26	Slope
49	Student Resource Center	2482.3	Slope
50	Usman University Center	878.34	Slope
51	Wesleyan Rj Julia Bookstore	981.98	Flat
52	Center for The Arts Theater	2274.97	Slope
53	Crowell Concert Hall	974.24	Slope
54	Davison Art Center	1686.67	Flat
55	Ezra And Cecile Zilkha Gallery	1397.03	Flat
56	Fairweather	2878.74	Flat
57	Goldsmith Family Cinema	956.76	Flat
58	Memorial Chapel	661.51	Flat
59	Powell Family Cinema	566.41	Slope
60	Rick Nicita Gallery	184.45	Slope
61	Ring Family Performing Arts Hall	235.38	Slope
62	World Music Hall	665.39	Slope

63	Zenick Pavilion	2572.73	Slope
64	Admission Office Stewart M. Reid House	765.67	Slope
65	Human Resources	557.73	Slope
66	President’s House	440	Flat
67	South College	560.13	Slope
68	291 Main Street	300.46	Slope
	Total Area(m^2)	72517.96	0.411

J: Fairfield University

Building Number	Building Name	Total Roof Area(m^2)	Type of Roof
1	Kelley (Aloysius P.), S.J. Center	2338.65	Flat
2	Loyola Hall	1511.77	Flat
3	Canisius Hall	1222.79	Flat
4	Donnarumma Hall	1081.69	Flat
5	Egan Chapel of St. Ignatius Loyola	583.21	Slope
6	Bellarmine Hall	804.91	Slope
7	Jesuit Community Center (St. Ignatius Hall)	1367.84	Flat
8	Dolan School of Business	4883.92	Flat
9	Quick (Regina A.) Center for The Arts	3433.46	Flat
10	Dimenna-Nyselius Library	3698.88	Flat
11	Ban Now (Rudolph F.) Science Center	3764.01	Flat
12	Egan (Marion Peckham) School of Nursing And Health Studies	2523.59	Flat
13	Barone (John A.) Campus Center	4386.98	Flat
14	Alumni Hall – Sports Arena	2952.78	Slope
15	Complex	4250.53	Flat
16	Berchmans Hall – Fairfield Prep	1065.63	Slope
17	Xavier Hall – Fairfield Prep	1161.94	Slope
18	McAuliffe Hall	948.78	Slope

19	Alumni House	243.2	Slope
20	The Levee	266.75	Flat
21	Walsh Athletic Center	2066.04	Flat
22	Townhouse Complex	8601.6	Slope
23	Dolan Campus	3037.57	Slope
24	Campion Hall	75.11	Slope
25	70 McCormick Road	2041.03	Flat
26	Jogues Hall	1353.87	Flat
27	Regis Hall	1174.26	Flat
28	Gonzaga Hall	1009.84	Flat
29	Pepsico Theatre	460.52	Flat
30	Early Learning Center	383.59	Slope
31	South Well Hall	120.07	Slope
32	Maintenance Complex	1467.57	Slope
33	Faber Hall	1319.67	Flat
34	The Village	5598.08	Flat
35	Central Utility Facility	860.05	Flat
36	Center – Fairfield Prep	729.41	Flat
	Total Area(m^2)	72789.59	

K: Sacred Heart University

Building Number	Building Name	Total Roof Area(m^2)	Type of Roof
1	Art & Design Gallery	551.86	Flat
2	Bergoglio Hall	2927.19	Flat
3	Bobby Valentine Health and Recreation Centre	2272.56	Slope
4	Centre For Health Care Education	4073.42	Flat
5	Chapel of The Holy Spirit	1260.14	Flat
6	Christian Witness Commons	4112.63	Flat
7	Curtis Hall	1180.82	Flat
8	Edgerton Centre For the Performing Arts	2415.53	Flat
9	Future Upper Quad Residence Halls	3677.14	Flat
10	Health and Wellness Centre	485.02	Slope
11	Humanities Center	1436.23	Flat
12	Information Booth	26.2	Slope
13	Jp's Diner	558.03	Flat
14	Linda E. McMahon Commons & Bookstore	1494.03	Flat
15	Main Academic Centre	2863.43	Flat
16	Martyred Centre For the Liberal Arts	3246.33	Flat
17	Mellady Hall	1200.76	Flat

18	Merton Hall	1521.55	Flat
19	President's Residence	663.96	Flat
20	Roncalli Hall	2962.43	Flat
21	Ryan Matura Library	964.03	Flat
22	Public Safety/ Broadcast Center	743.39	Flat
23	Schine Auditorium	1986.27	Flat
24	Scholars Commons	2634.52	Flat
25	Science Center (Sc)	4873.92	Flat
26	Seton Hall	1695	Flat
27	Student Success Center	980.5	Slope
28	Toussaint Hall	4595.07	Flat
29	University Commons & Atrium	2529.68	Slope
30	West Campus	14585.8	Flat
31	William Pitt Athletic & Convocation Center	4884.62	Flat
	Total Roof Area (m^2)	79402.06	

L: Quinnipiac University

Building Number	Building Name	Total Roof Area(m^2)	Type of Roof
1	School of Law	4689.75	Flat
2	Echlin Center	1483.06	Flat
3	Clarice L. Buckman Center	3120.97	Flat
4	Tator Hall (Classrooms)	1533.54	Flat
5	Carl Hansen Student Center	2178.68	Slope
6	Dining Hall	2205.68	Flat
7	Arnold Bernhard Library Bursar	3975.89	Slope
8	Lender School of Business Center	1720	Slope
9	Ed McMahons Mass Communications Center	2067.18	Flat
10	Faculty Office Building Registrar	777.51	Flat
11	Athletic Center and Recreation Center	6905.73	Flat
12	Health and Wellness Center	389.98	Slope
13	The Commons Residence Hall	2844.08	Flat
14	The Hill Residence Hall	835.85	Slope
15	Irmagarde Tator Residence Hall Security Office	1149.22	Slope
16	Dana English Residence Hall	1129.59	Slope

17	Student Affairs Center, Residential Life, Bobcat Den	1561.99	Slope
18	The Village Residence Halls	9456.75	Slope
19	Perlroth Residence Hall	1350.26	Flat
20	Larson Residence Hall	1350.26	Flat
21	Troup Residence Hall	1352.06	Flat
22	The Complex Residence Halls	1275.44	Slope
23	The Ledges Residence Hall	2052.36	Slope
24	Mountainview Residence Hall	915.04	Flat
25	Pat Abbate Alumni House	419.42	Slope
26	Development and Public Affairs	817.38	Slope
27	Facilities/ Copy/ Mail Center	1774.96	Slope
28	Dean Robert W. Evans College of Arts and Sciences Center	2398.56	Slope
29	Hillel House	221.38	Slope
30	Albert Schweitzer Institute	273.77	Slope
31	Td Bank Sports Center	11303.82	Slope
32	“Rocky Top” Student Center	3059.66	Slope
33	The Crescent” Residence Hall	4374.4	Flat
34	“Westview” Residence Hall	2452.73	Flat
35	Townhouse Residence Hall	1188.31	Flat
36	Wind Garden	1150.8	Slope

37	Graduate Center:	4684.26	Flat
38	School of Medicine	3949.32	Flat
39	Future Quinnipiac Use	5813.25	Flat
40	Future Quinnipiac Use	15534.51	Flat
	Total Roof Area(m^2)	115737.4	