CHP EVALUATION - DATA AND TECHNOLOGY DRIVEN METHODOLOGY

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1- Introduction

New Jersey Board of Public Utilities has approved a Combined Heat and Power (CHP) Incentive Program intended to provide financial incentives for CHP & FCs, which are installed at behind-the-meter (BTM) customers' premises. This program supports New Jersey's goals to enhance energy efficiency through onsite power generation, and the recovery and productive use of the waste heat, reducing demands to the electric power grid. In the past, the CHP program has allowed electric-only fuel cells (FC) to participate in this program, even though these systems aren't able to capture the waste heat and offset an onsite thermal load, so the system efficiencies are lower than that of CHP systems. Considering that efficiencies and benefits across all types of CHP systems may vary depending on the actual use and application, RU LESS was asked to develop an operational model to evaluate how different use scenarios impacted efficiency and cost effectiveness.

To quantify and confirm the benefits of BTM CHP systems, Rutgers Laboratory for Energy Smart Systems (RU LESS) has been working on the development of operational models of CHP projects. The findings from these models are intended to assist BPU staff to identify how various factors affect the cost-effectiveness and value of CHP projects. Estimated value, determined by these operational models feed into a rigorous cost and benefit analysis. It should be noted that the same methodology can be adopted by applicants to evaluate the operational and economic outcomes of a project on both short- and long-term basis. The proposed methodology have been demonstrated and verified through use cases along with sensitivity analysis. Figure 1 illustrates the overall methodology framework.

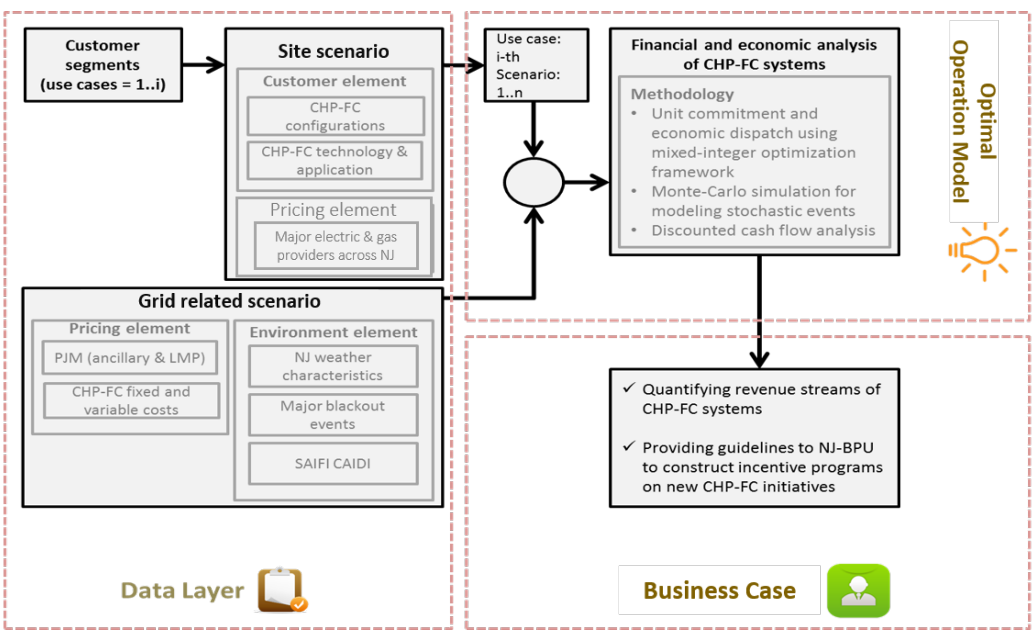


Figure 1- Proposed methodology framework

The study was divided into two phases: In Phase I a preliminary analysis was performed entailing the benefits and the value generated by fuel cell with no heat recovery and on the basis of limited use cases. Phase II involved the evaluation of additional CHP technologies and fuel cell with heat recovery, entailing extensive sensitivity analysis and the interaction between CHP/FC and other distributed energy resources (e.g. storage, etc.).

Our studies in Phase I and II covered natural gas (NG) fueled CHP technology with the following use cases:

A) **Four different technologies and prime movers were considered**:
   1. Fuel cell (SOFC) without heat recovery
   2. Fuel cell with heat recovery
   3. Micro turbine
   4. Reciprocating engine

B) **The operational value of CHP for eleven (11) different facilities were studied and reported.** Different facilities have different energy profiles with different characteristics, and our hypothesis was that characteristics of these profile have significant impacts in the value a CHP project can generate. Following facilities were studied in this work:

   1. Hospital
   2. Hotel
   3. Full-service restaurant
   4. Outpatient
   5. Mid-rise apartment
   6. Large office
   7. Secondary school
   8. Stand-alone retail
   9. Strip-mall
   10. Supermarket
   11. Warehouse

C) Two levels of CHP sizing (rated capacity – kW) were included in our experiments:

   a) Sizing based on thermal demand
   b) Sizing based on electricity demand.

D) Three different electric distribution companies (EDCs) and two different gas distribution companies (GDCs) with corresponding tariffs and rate structure were investigated. Different elements of cost structure for electricity (e.g. energy charges, demand charges, etc.) and gas (e.g. per therm charges, per demand therm charges, per balancing therm charges, etc.) were included in the analysis. Incentives provided by these entities were also included in our studies.

E) Operational value of CHP was investigated in two applications:

1. Energy Bill Management (EBM)
2. Backup system during the outage events (Resiliency)

The following assumptions were made:

- Annual energy cost saving per installed capacity ($/ kW) is our main measure for the financial evaluation of CHP system.

- Dividing the installation cost per capacity by the annual energy cost saving per installed capacity results in approximation of simple pay-back-period in years. Also, pay-back-period considering Investment Tax Credit (ITC) is calculated as a financial measure.

- Percentage of served critical load during outage events is a good measure for resiliency application evaluation. Since power outage is a random and stochastic event, multiple scenarios of outage are simulated and mean value and standard deviation of percentage of served critical load are reported.

The rest of the report is organized as follows:

- Section 2 summarizes the synopsis of findings;
- Section 3 describes use cases analyzed in the study;
- Section 4 describes modeling methodology (mathematical programming);
- Section 5 presents the detailed results for different customer segments analyzed in the use cases.

2- Summary of Findings

The following emerging themes were observed across our simulations:

a) Phase 1- Electric-only FC

- **Finding 1**: Electric-only FC generates more value in facilities with less variation in the daily energy profile. Our analysis shows that facilities such as Mid-rise apartment, hotels, hospital and outpatient have higher $/kW because of the low variation in their daily energy demand (similar load profiles for weekdays and weekend).

- **Finding 2**: We assumed two Electric-only FC sizes and we found out that increasing rated capacity of the system does not necessarily lead to higher $/kW annual value.

- **Finding 3:** Electric-only FC systems with higher rated capacity enhances the resiliency capability and environmental benefit of a project. Higher rated capacity results in more onsite generated electricity and lower purchased energy from the main electricity grid, which reduces the amount of emission (i.e. SO2, CO2 and NOX).

- **Finding 4:** Incentives offered by GDC companies to DG installer improves the value of CHP projects. Most of the cost-effective CHP projects in our experiments are located in the territory of a GDC 2, which incentivizes DG installed customer by assigning a lower NG rate.

- **Finding 5:** Our experiments for the eleven (11) facilities examined in this study indicate that FC without heat recovery system is not cost effective in most of the use cases, since the approximate pay-back period (PBP) (without tax credit and incentive) is more than 10 years. However, in facilities with low demand profile variation and in the presence of an incentive from utilities (i.e. lower natural gas rate) and the Federal ITC, FC without heat recovery begins to be cost effective. The following figure shows the annual value per installed capacity ($/kW) for FC without heat-recovery within the eleven (11) facilities in our study.

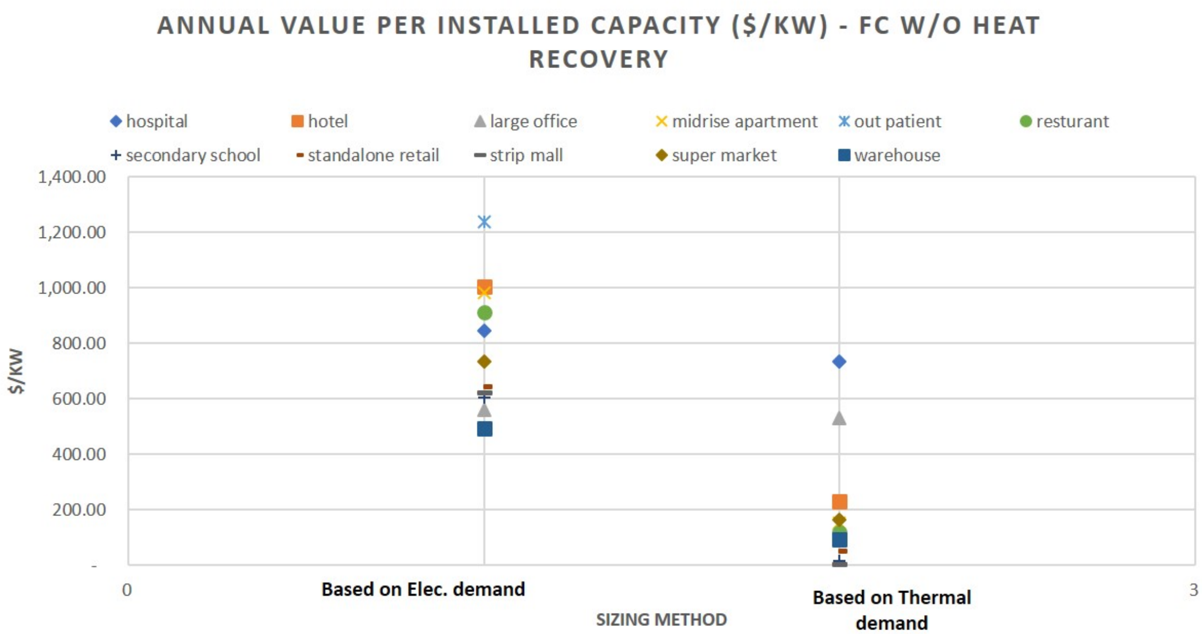


Figure 2- FC without HR annual value ($/kW) in different facilities

b) Phase 2– FC with heat recovery, Micro-Turbine and Reciprocating Engine

FC with heat recovery:

- **Finding 6**: Recovering and using wasted heat improves the financial and environmental impact of CHP projects. Using recovered heat results in lower energy cost and also lower emission generation.

- **Finding 7**: Heat recovery has significant impact on facilities with highly-correlated electricity and thermal demand. In facilities with positively correlated electricity and thermal demand profiles, increasing and decreasing in demand level occurs simultaneously in both electricity and thermal demands. This helps the CHP-FC facility to maximize the usage of recovered heat and increase the value of the project.

The following figure shows the annual value ($/kW) for FC with heat recovery projects.

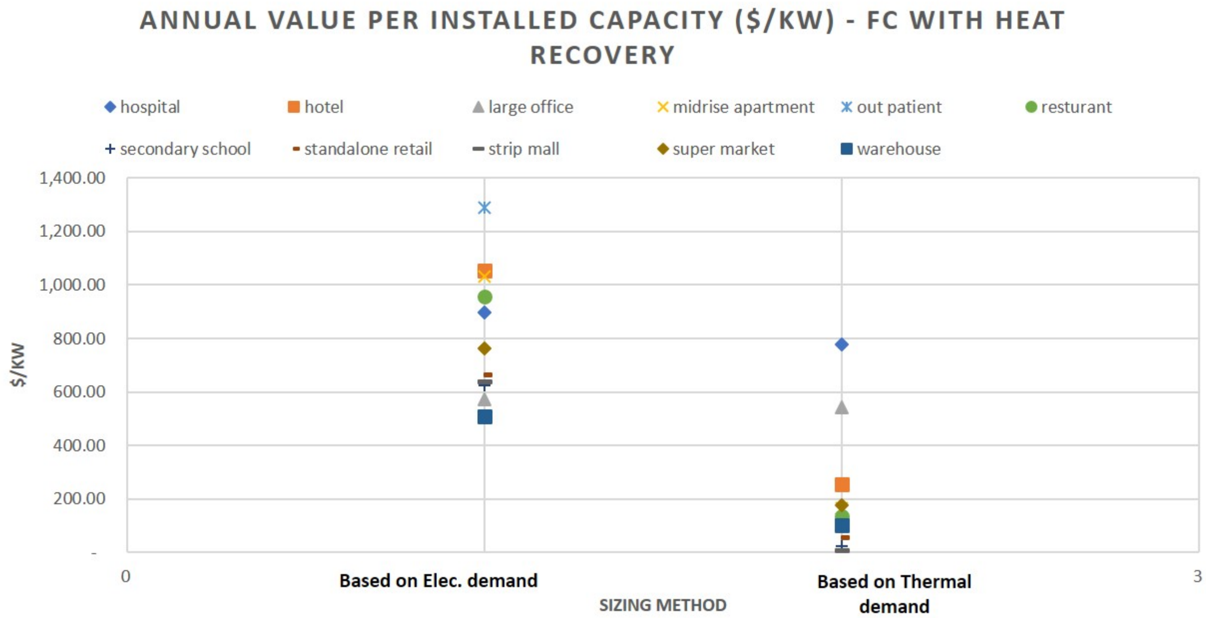


Figure 3- FC with HR annual value ($/kW) in different facilities

Micro-Turbine and Reciprocating Engine:

- **Finding 8**: Different prime movers have different operational characteristics such as efficiency. CHP systems with more efficient prime mover generate higher value. In our study, FC has the highest electric-efficiency, however Micro-turbine and Reciprocating Engine have higher heat to power ratio. The total efficiency of CHP systems is calculated as a function of electric-efficiency and heat to power ratio. Micro-Turbine (MT) has the highest total efficiency among the prime movers in our study. Therefor Micro-turbine generates more value ($/kW) in most of the facilities compared to other two prime-movers. Since the heat-to-power ratio is the dominant factor in micro-turbine total efficiency it is more cost effective in facilities with higher level of thermal demand.

- **Finding 9:** Micro-Turbine and Reciprocating-Engine have higher heat-to-power ratio compared to fuel-cell technology. Therefore, sizing based on the thermal demand results in smaller system for these two prime-movers and is more cost effective compared to fuel-cell technology.

- **Finding 10**: In PBP calculation, investment cost and ITC of prime mover are also important besides the generated $/kW value. Investment cost and ITC[1] for micro-turbine and reciprocating engine are lower than FC, however FC generates more $/kW. Considering all these three factors is crucial in PBP calculation.

Following figures show the annual value ($/kW) for micro-turbine and reciprocating engine projects.

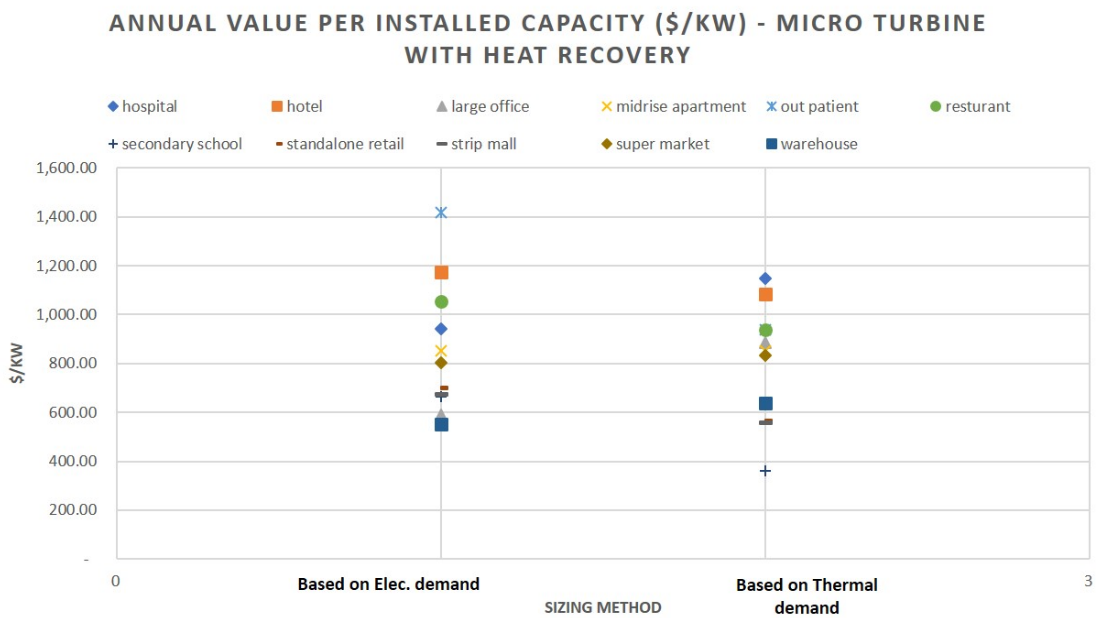


Figure 4-MT value ($/kW) in different facilities

[1] https://energy.gov/savings/business-energy-investment-tax-credit-itc

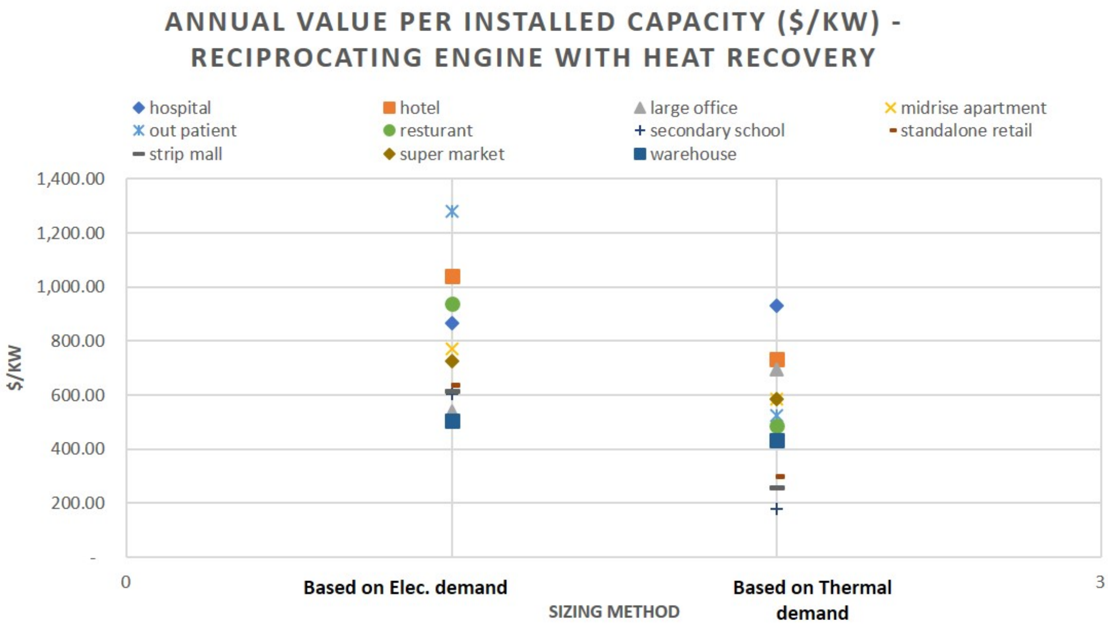
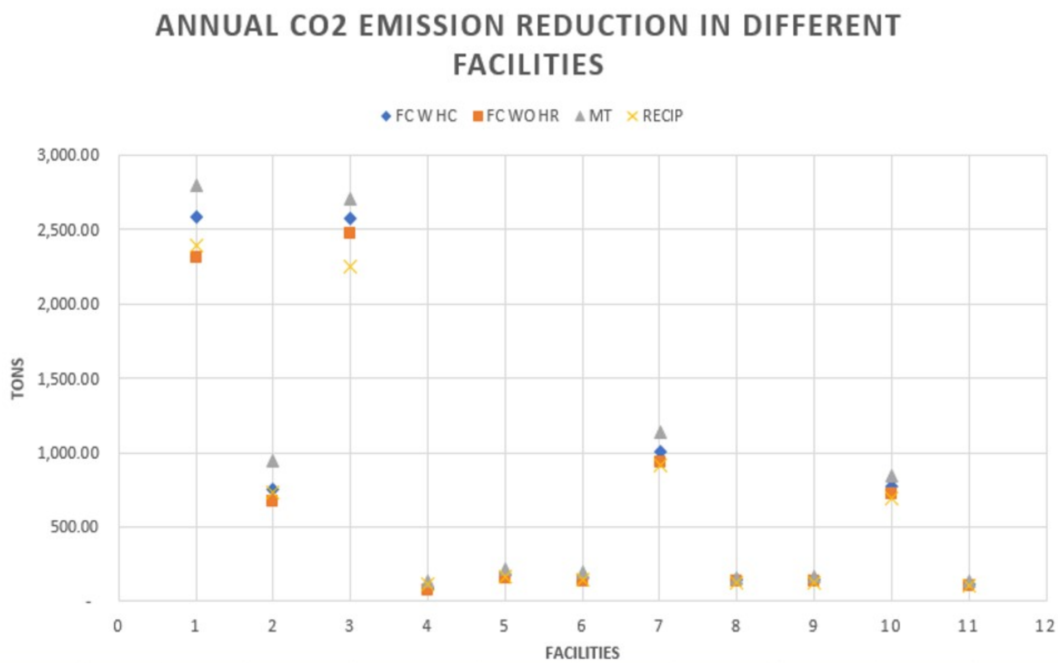


Figure 5-Reciprocating-Engine value ($/kW) in different facilities

- **Finding 11:** Facilities with higher energy consumption need larger systems which results in more annual emission reduction.

Following figure shows the annual CO_2 emission reduction for different technologies in different facilities:



Facility code	1	2	3	4	5	6	7	8	9	10	11
Facility name	hospital	hotel	large office	midrise apartment	out patient	resturant	secondary school	standalone retail	strip mall	super market	warehouse

Figure 6- Annual CO2 emission reduction within different facilities

CHP-FC economics and energy provider billing structure:

- As mentioned in finding 4, incentives offered by GDC companies to DG installer improves the value of CHP projects. Our experiments show that customers located in GDC 2 territories have higher financial value because of the lower NG rate assigned to the DG installers. Following table illustrates the value of CHP-FC with and without heat recovery for hotel in different EDCs and GDCs territories.

Table 1- Impact of EDCs and GDCs on the project economics (Facility: Hotel)

Technology	Rated capacity (kW)	Annual value ($/kW) - Hotel					
		EDC 1 & GDC 1	EDC 1 & GDC 2	EDC 2 & GDC 1	EDC 2 & GDC 2	EDC 3 & GDC 1	EDC 3 & GDC 2
FC WO HR	150	522.20	818.59	433.90	731.50	785.15	1,083.47
	742	137.77	210.45	105.02	177.70	208.00	280.68
FC with HR	150	597.27	888.42	509.92	801.05	878.42	1,166.10
	742	166.72	234.40	133.97	201.65	236.95	304.64

<u>Impact of heat recovery on the economics of CHP-FC project:</u>

- As discussed in "finding 7", heat recovery has significant impact on facilities with highly-correlated electricity and thermal demand. The reason is that in such facilities increasing and decreasing in demand level occurs simultaneously in both electricity and thermal demands. This helps the CHP-FC facility to maximize the usage of recovered heat and increase the value of the project.

- The following illustrative example compares the improvement in the economics of FC project because of heat recovery system in two facilities, namely full-service restaurant and strip mall. As illustrated below, these two facilities have close energy consumption but different profile shapes.

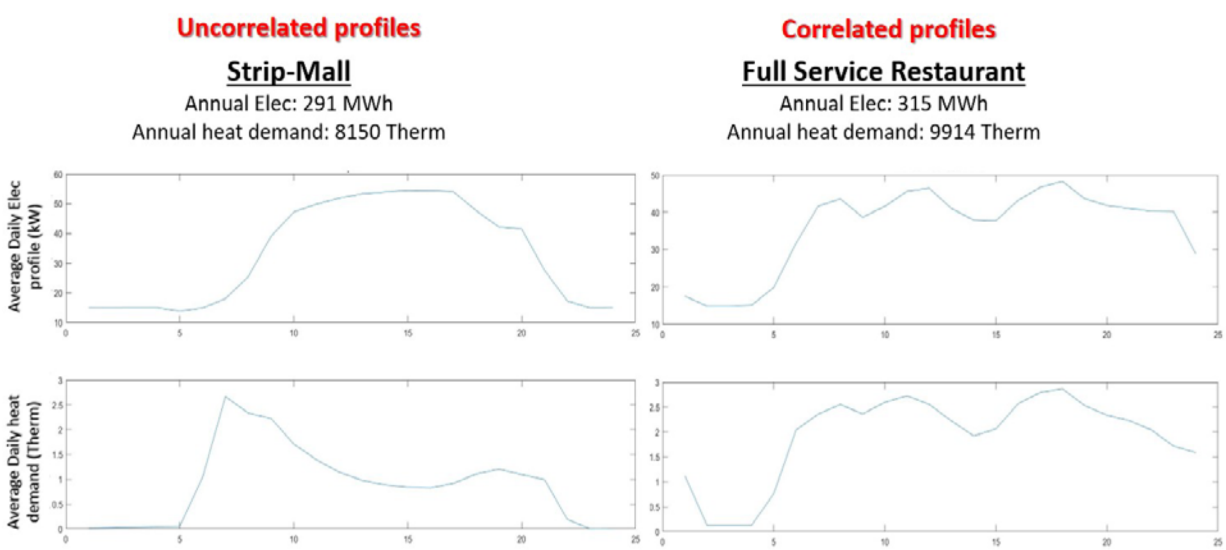


Figure 7- Two facilities; Strip-Mall with un-correlated profiles & Full-service restaurant with correlated profiles

Following table shows the economic improvement in these two facilities, because of heat-recovery system:

Table 2- Strip-mall (Un-correlated profiles) V.S. Full service restaurant (correlated profiles)

Facility	Rated capacity (kW)	Annual value ($/kW)		Improvement (%)
		FC W/O HR	FC with HR	
Strip-mall	49	622	638	2.5%
Full-service restaurant	34	880	976	11%

As illustrated in Table 2 adding heat recovery has significant impact in full-service restaurant facility compared to strip-mall. The reason is highly-correlated energy profiles in full-service restaurant facility.

More details about the factors in our design of experiment and methodology are provided in the following section:

3- Design of use cases and sensitivity scenarios

The intent of design of scenarios is to enable financial and resiliency evaluation of a set of comprehensive case studies. As such, we structure the scenarios to have use cases and with sensitivities around those use cases. Use cases will be defined based on two exclusive parameters, namely, customer segment (segments with the high adoption rate of CHP & FC such as: hospital, school, residential multi-family building, hotel, warehouse and etc.) and location (NJ Electricity and Gas providers). Within each use case we will design a set of extensive sensitivity scenarios. Factors included in sensitivity scenarios are: “CHP-FC application”, “system sizing configuration”, “technology” and “Electric & Gas tariff”. Different technologies with different prime movers (such as Micro turbine, Reciprocating Engine, Fuel Cell and etc.) and different fuel classes (such as Natural gas, biogas and etc.) will be included in sensitivity scenarios.

a) Customer segments

Different customer segments are considered in this study. These segments will include both critical and non-critical customers. Hourly (or sub-hourly) electricity and thermal demand profiles are required for financial analysis. Moreover, the critical demand profile for each customer segment is required for resiliency evaluation. In cases where real demand data are not available EnergyPlus building simulation will be used to generate the required data. Eleven customer segments are considered in this study. These are commercial building benchmark models developed by US DOE (containing 70% of the commercial building types in the U.S). For compliance with geographical scope of this project (state of New Jersey), building’s load data is simulated using New Jersey weather data2. An overview of these customer segments along with their energy consumption characteristics is provided in the following table:

Table 3- Customer segments information

Segment	Floor area	# floors	Electricity		Natural Gas	
			Annual consumption (kWh)	Peak load (kW)	Annual consumption (Therm)	Peak load (Therm)
Hospital	241,351	5	6,500,906	1,262	97,684	38
Large hotel	122,120	6	1,886,223	447	102,459	38
Supermarket	45,000	1	1,649,429	364	28,470	22
Strip mall	22,500	1	290,780	89	8,150	9
Stand-alone retail	24,960	1	325,740	101	7,531	9.8
Large office	498,120	12	5,580,000	1,580	37,290	78
Midrise Apt	22,740	4	234,300	65	6,590	4.7
Secondary school	210,887	2	2,320,900	1,098	70,112	111
Outpatient	40,940	3	486,280	201	44,770	10.5
Full service restaurant	5,500	1	314,700	68	9,914	6.5
Warehouse	52,045	1	258,474	88	8,068	9.7

b) CHP technology / Prime mover

Four different technologies and prime movers are considered across the use cases in this study:

a. Fuel cell (SOFC) without heat recovery
b. Fuel cell with heat recovery
c. Micro turbine
d. Reciprocating engine

Different technologies/prime-movers have different operation and financial characteristics. Following table summarizes the parameters and characteristics of these technologies.

Table 4- CHP prime mover characteristics

Prime mover	Average electric. efficiency	Average heat to power ratio	Average total efficiency	Average installation and maintenance cost over lifecycle ($/kW)	ITC[3] (%)

[2] EnergyPlus co-simulation software is used for this purpose
[3] https://energy.gov/savings/business-energy-investment-tax-credit-itc

FC	47%[4]	0.87	87.9%	9,500	30%
Micro Turbine (MT)	30%	2	90%	6,000	10%
Reciprocating Engine (RECIP)	38%	1.3	87.4%	5,500	10%

c) Location (NJ Electricity and Gas providers)

Different locations based on major Electricity and Gas providers' territories in NJ are defined for core cases. Different Electricity and Gas provider companies have different rating structure for electricity and gas, which affect the calculation in financial evaluation process.

Three Electricity Distribution Companies (EDC) and two Gas Distribution Companies (GDC) in NJ are defined for core cases. EDC billing components considered for analysis are delivery and supply charges. For supply charges, it is assumed that all customers have elected Rider BGS-CIEP indicating that they will be charged according to PJM hourly LMPs for commodity. These three EDCs have completely different rating structures for delivery charges (both energy and demand charges). While EDC1 and EDC2 have seasonal tiered demand charge structure according to customer's peak shared level (PSL), EDC3's seasonal demand charge structure is not sensitive to customers' PSL. Moreover, EDC1 assigns time-of-use (TOU) demand charge for their customers with PSL > 150kW. Table 2, summarizes the rating structure across the three EDCs.

Table 5- EDCs rate structure

EDC1	EDC2	EDC3
Customer differentiation factor: - PSL (150KW)	Customer differentiation factor: - PSL (750KW)	Customer differentiation factor: -
Supply demand charge structure: - BGS CIEP	Supply demand charge structure: - BGS CIEP	Supply demand charge structure: - BGS CIEP
Supply energy charge structure: - BGS CIEP (real-time PJM LMP)	Supply energy charge structure: - BGS CIEP (real-time PJM LMP)	Supply energy charge structure: - BGS CIEP (real-time PJM LMP)
Delivery energy charge structure: - Seasonal - Flat	Delivery energy charge structure: - Seasonal - Tiered	Delivery energy charge structure: - Seasonal - Flat
Delivery demand charge structure: - Seasonal - Tiered - TOU for PSL > 150KW	Delivery demand charge structure: - Seasonal - Tiered	Delivery demand charge structure: - Seasonal - Flat
Aggregated KWH and KW charges ranking - KWH: EDC3 > EDC2 > EDC1 - KW: EDC1 > EDC2 > EDC3		

GDC billing components considered for analysis are delivery and supply charges. For supply charges, it is assumed that all customers have elected Rider "A" for Basic Gas Supply Service

[4] http://www.nyiso.com/public/webdocs/media_room/publications_presentations/Other_Reports/Other_Reports/A_Review_of_Distributed_Energy_Resources_September_2014.pdf

(BGSS). GDCs have completely different rating structures for delivery charges (energy charges, demand charges and balancing charges). Following table 3 summarizes the rating structure across two GDCs.

Table 6- GDCs rate structure

GDC1	GDC2
Customer differentiation factor: - Monthly consumption peak (3000Therm)	Customer differentiation factor: - DG installation - Annual consumption (5000Therm)
Supply charges structure: - Rider "A" BGSS	Supply charges structure: - Rider "A" BGSS
Delivery charges structure: - Energy: Seasonal - Demand & balancing: Flat	Delivery charges structure: - Energy: Seasonal - Demand & balancing: Flat
Aggregated per Therm, per demand Therm and per balancing Therm charges ranking - Per Therm: GDC1 > GDC2 - Per demand therm: GDC2 > GDC1 - Per balancing therm: GDC1 > GDC2 - **** GDC2 incentivizes distributed generation (DG) owner by assigning lower charges**	

d) CHP sizing

Two different sizing approaches are considered across the use cases:

I) **Sizing based on the thermal demand:** Heat demand values are sorted in decreasing order and placed in a load-duration diagram. Then the dimensioning method (which is based on "biggest rectangle" method) has been applied on it. The intersection of this biggest rectangle with the vertical axis represent the useful thermal output of CHP system (Figure 6).

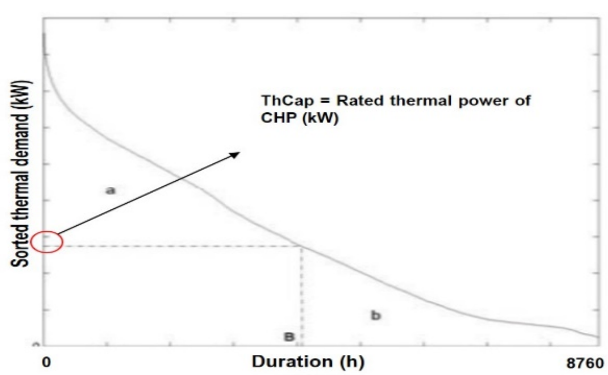


Figure 8-load-duration diagram - Biggest rectangle method for CHP sizing

II) **Sizing based on the electricity demand:** Electricity demand values are sorted in decreasing order and placed in a load-duration diagram. Then the dimensioning method has been applied on it. The intersection of this biggest rectangle with the vertical axis represents the electricity output of CHP system.

4- Modeling methodology

The operation of CHP-FC systems is formulated as a mixed-integer optimization problem. The objective of operation model is to simulate optimal operation of facilities with CHP-FC installations over a period of time (a year). The rigorous operation model is used to estimate the value generated from CHP-FC installation compared to the base-line (without distributed generation (DG)). This value, along with the other cost elements such as project installation cost, will feed to a rigorous cost-benefit analysis model to determine the cost-effectiveness of the project. The model will account for statistical nature of loads and various technology features and operational conditions of CHP. The model also accounts for different application scenarios. Detailed description of mathematical programming formulation including objectives and constraints for each CHP-FC application is provided next.

a. Electric Bill Management (EBM) in normal operation

The objective of EBM optimization is to maximize the cash flow by reducing total energy cost and monthly demand charges (as well as increasing net metering revenue to model cases where the use of a NJ Class I RE biofuel is proposed). The objective function and operational constraints are as follows:

Objective function

1- Minimizing total energy cost a) Electricity cost b) Gas cost	2- Minimizing monthly demand charges	3- Minimizing CHP-FC operation cost a) Regular operation cost (fuel cost) b) Start up cost c) Shutdown cost

Operational Constraints

1- Constraints of power balance a) Meet electrical demand completely b) Meet thermal demand completely	2- Constraints on CHP-FC devices a) Upper and lower boundaries for the rate of changes in the CHP-FC output power b) Upper and lower limit on CHP-FC output power

b. Backup system during the outage events (Resiliency)

The objective is to serve the critical load (CL) during outage hours. A penalty structure in the form of $/kWh of unserved CL is specified to minimize the unserved critical load to the extent possible. A review of the results of a sensitivity analysis around the penalty may result in a recommendation for optimal incentive level for an islanding equipment adder. Net metering is disabled since the system is disconnected from the grid. The operational constraints are as follows:

Objective function	
1- Maximize the served critical load * The unserved critical load will be penalized by a big number	2- Minimizing CHP-FC operation cost a) Regular operation cost (fuel cost) b) Start up cost c) Shutdown cost
Operational Constraints	
1- Constraints on critical demands a) Critical electricity demand b) Critical gas demand	2- Constraints on CHP-FC devices a) Upper and lower boundaries for the rate of changes in the CHP-FC output power b) Upper and lower limit on CHP-FC output power

5- Detailed results for customer segments

In this section, load profiles, evaluation scenarios along with detailed results in the form of graphs and tables for all eleven (11) customer segments are provided. The following sets of results are presented:

- Project annual value for two sizing configurations and all technologies of prime-movers (Note that results illustrated in this section is for EDC3 and GDC2);
- Emission reduction measure for different sizing configuration and technologies; and
- Resiliency evaluation across different sizing configurations;

a) Hotel

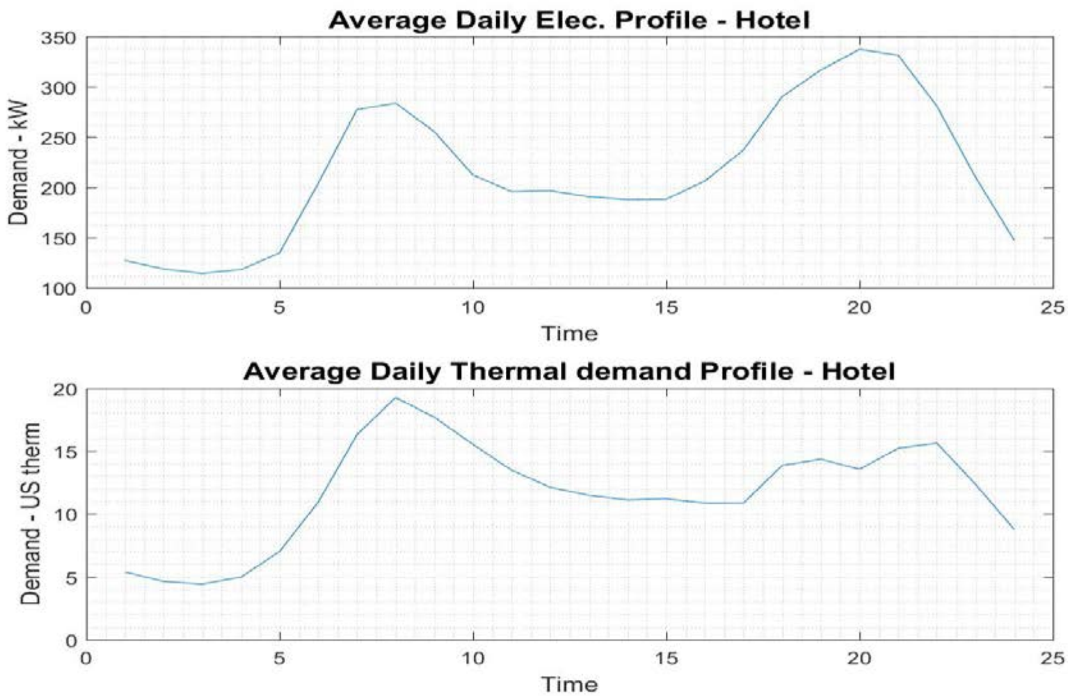


Figure 9- Average daily energy profiles - Hotel

Table 7- Project financial & emission reduction measures - Hotel

Technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	150	158,598.54	1,054.31	9.01	6.31	750.46	1.74	0.89
FC WO HR	150	150,939.32	1,003.40	9.97	6.98	668.91	1.74	0.89
MT	150	176,530.70	1,173.52	5.11	4.60	940.25	1.74	0.90
RECIP	150	156,641.68	1,041.30	5.28	4.75	729.14	1.74	0.89
FC W HR	742	187,882.98	253.13	37.53	26.27	775.86	2.30	1.17
FC WO HR	742	170,992.97	230.37	43.41	30.39	595.65	2.30	1.17
MT	185	201,423.70	1,085.49	5.53	4.97	1,090.56	2.03	1.04
RECIP	315	230,790.04	731.62	7.52	6.77	1,077.48	2.57	1.32

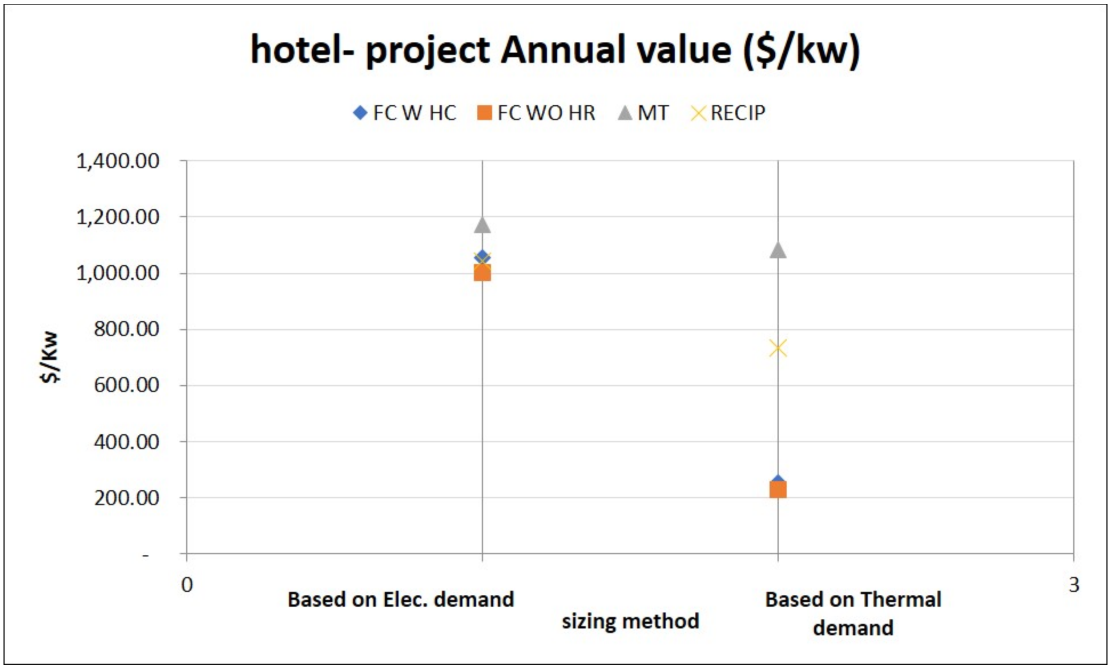


Figure 10 -Project annual value - Hotel

Table 8- Resiliency measure - Hotel

Technology	cap class	capacity	Average percentage of served critical load
FC W HR	**1**	**150**	**0.92**
	2	**742**	**1.00**
FC WO HR	**1**	**150**	**0.92**
	2	**742**	**1.00**
MT	**1**	**150**	**0.92**
	2	**185**	**0.98**
RECIP	**1**	**150**	**0.92**
	2	**315**	**1.00**

b) Hospital

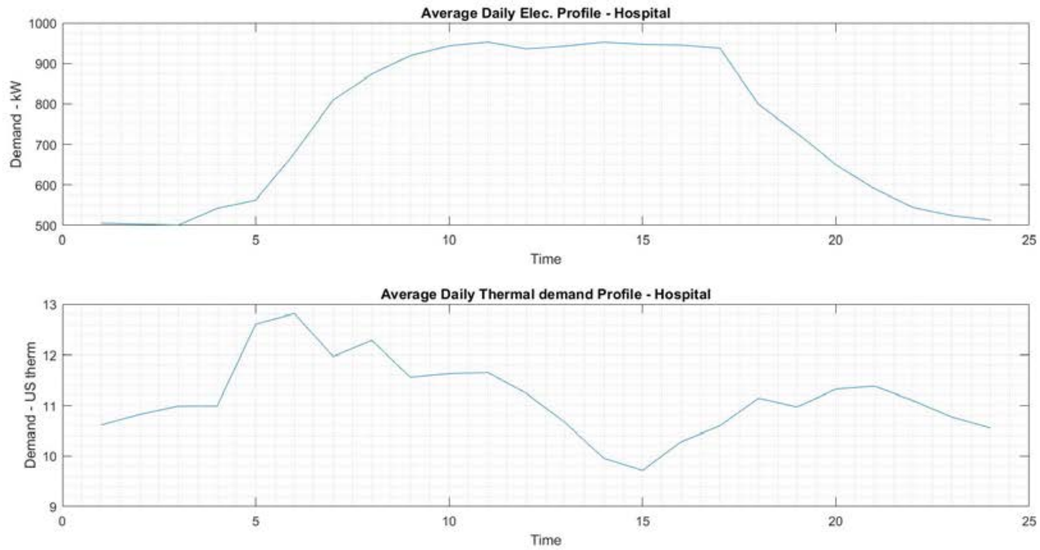


Figure 11-Average daily energy profiles – Hospital

Table 9-Project financial & emission reduction measures - Hospital

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	504	453,105.44	898.00	10.58	7.41	2,586.99	6.00	3.07
FC WO HR	504	426,956.39	846.18	11.82	8.27	2,308.40	6.00	3.06
MT	192	221,786.34	1,149.24	5.22	4.70	1,271.15	2.34	1.21
RECIP	328	305,769.50	932.01	5.90	5.31	1,658.76	3.98	2.04
FC W HR	771	601,290.98	778.94	12.20	8.54	3,378.41	7.94	4.07
FC WO HR	771	566,140.37	733.40	13.64	9.54	3,003.23	7.94	4.06
MT	504	475,380.25	942.15	6.37	5.73	2,797.59	6.00	3.08
RECIP	504	436,210.92	864.52	6.36	5.73	2,393.77	5.99	3.06

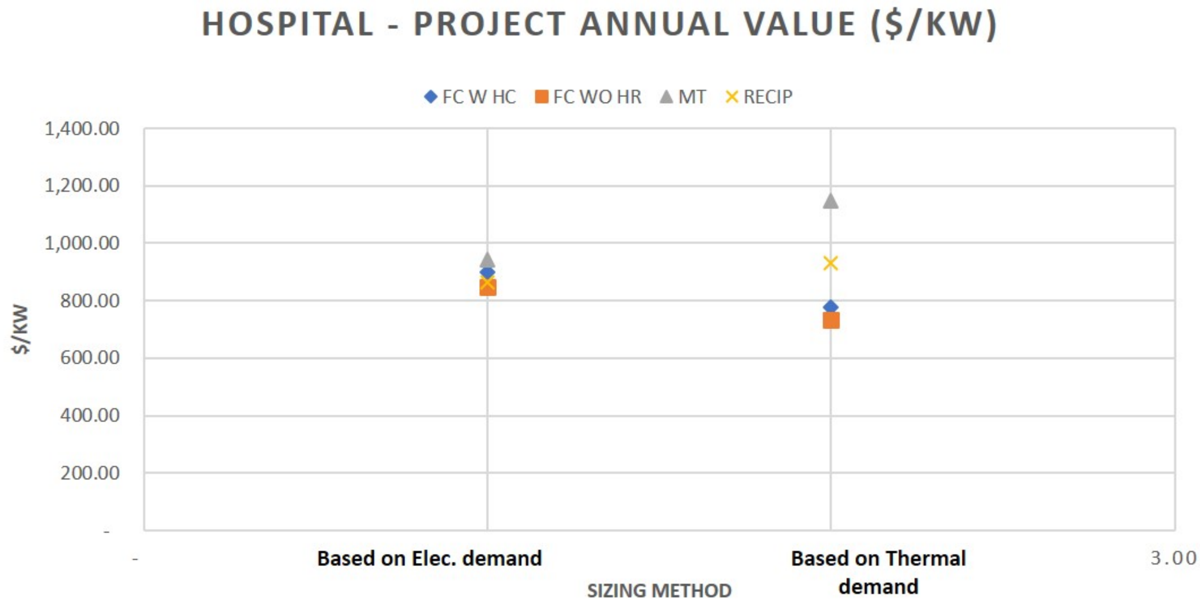


Figure 12-Project annual value - Hospital

Table 10-Resiliency measure - Hospital

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	504	0.83
	2	771	0.99
FC WO HR	1	504	0.83
	2	771	0.99
MT	2	192	0.36
	1	504	0.83
RECIP	2	328	0.60
	1	504	0.83

c) Full-service restaurant

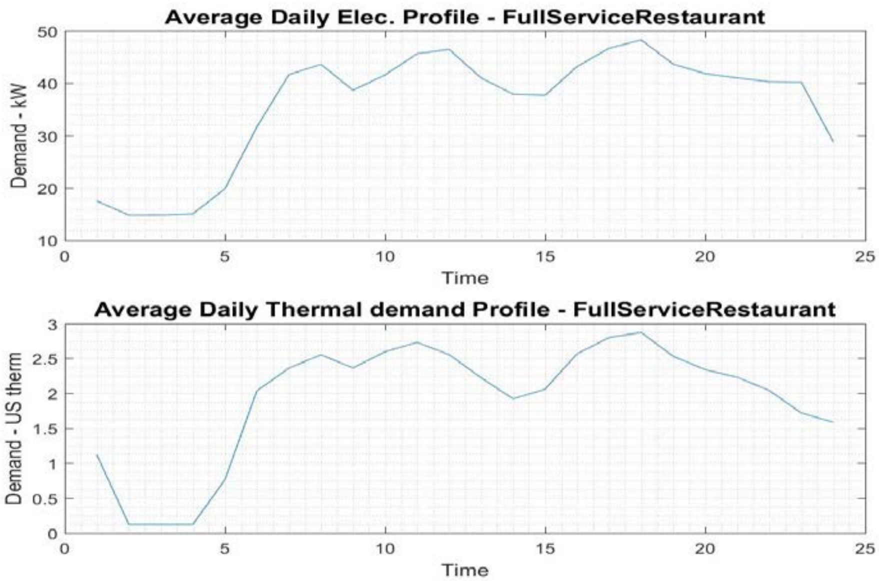


Figure 13-Average daily energy profiles – Full-service restaurant

Table 11-Project financial & emission reduction measures - Full-service restaurant

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	34	32,720.72	976.13	9.94	6.96	155.25	0.36	0.19
FC WO HR	34	31,154.17	880.36	10.98	7.69	138.63	0.36	0.19
MT	34	36,105.78	1,055.05	5.69	5.12	190.78	0.36	0.19
RECIP	34	32,175.69	940.21	5.85	5.26	149.34	0.36	0.19
FC W HR	176	23,875.26	135.31	70.21	49.15	82.33	0.33	0.17
FC WO HR	176	20,867.42	118.26	84.56	59.19	50.34	0.33	0.17
MT	44	41,383.11	938.10	6.40	5.76	219.01	0.42	0.22
RECIP	74	36,466.26	486.26	11.31	10.18	171.38	0.42	0.21

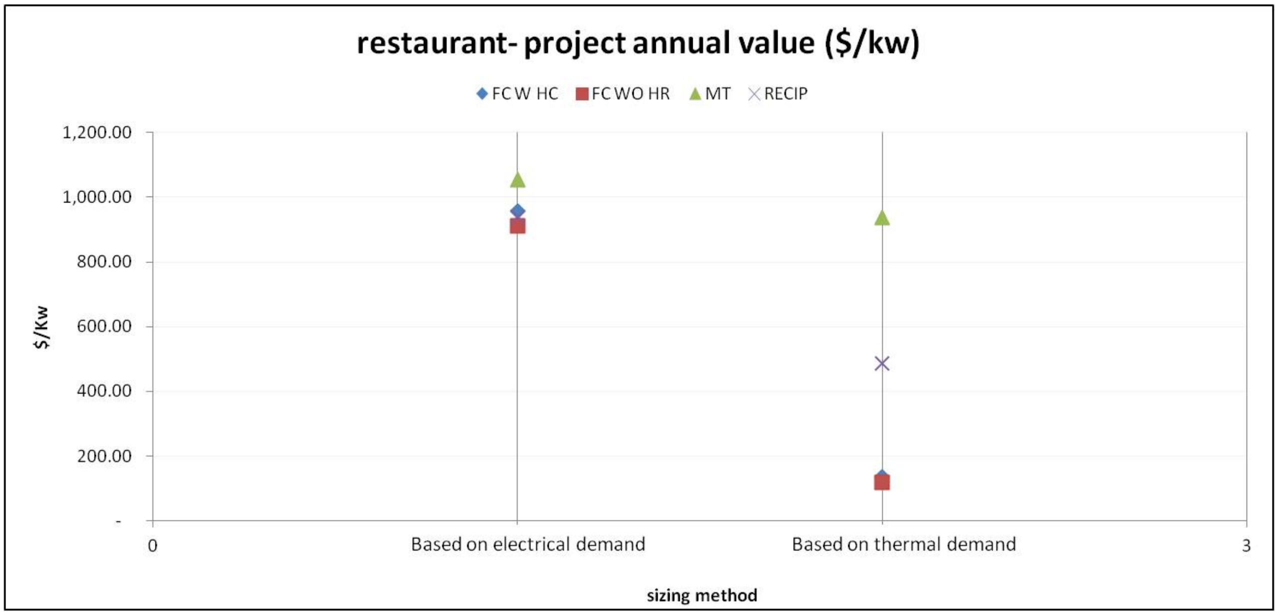


Figure 14Project annual value - Full-service restaurant

Table 12-Resiliency measure – Full service restaurant

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	34	1.00
	2	176	1.00
FC WO HR	1	34	1.00
	2	176	1.00
MT	1	34	1.00
	2	44	1.00
RECIP	1	34	1.00
	2	74	1.00

d) Large office

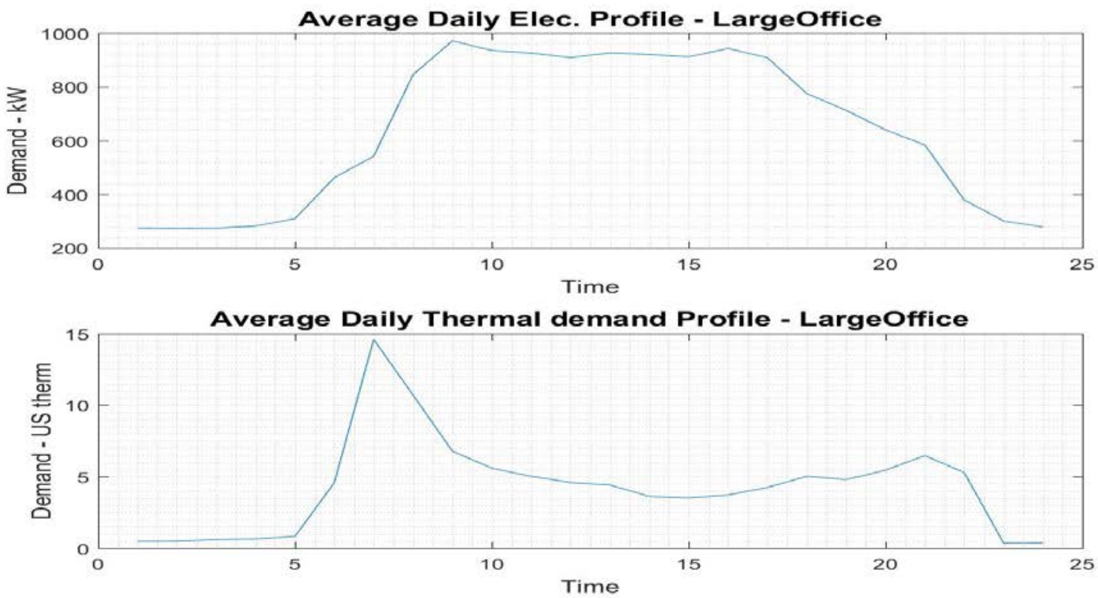


Figure 15-Average daily energy profiles - Large office

Table 13-Project financial & emission reduction measures - Large office

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	898	515,810.82	574.03	16.55	11.58	2,577.46	6.85	3.50
FC WO HR	898	503,846.90	560.71	17.83	12.48	2,467.92	6.85	3.50
MT	254	225,280.07	885.79	6.77	6.10	1,272.64	3.06	1.56
RECIP	432	301,302.56	696.89	7.89	7.10	1,516.93	4.46	2.27
FC W HR	1,017	551,313.21	541.93	17.53	12.27	2,686.41	7.24	3.70
FC WO HR	1,017	538,807.34	529.64	18.88	13.22	2,572.38	7.24	3.69
MT	898	529,146.74	588.87	10.19	9.17	2,705.02	6.85	3.50
RECIP	898	485,973.78	540.82	10.17	9.15	2,249.35	6.85	3.49

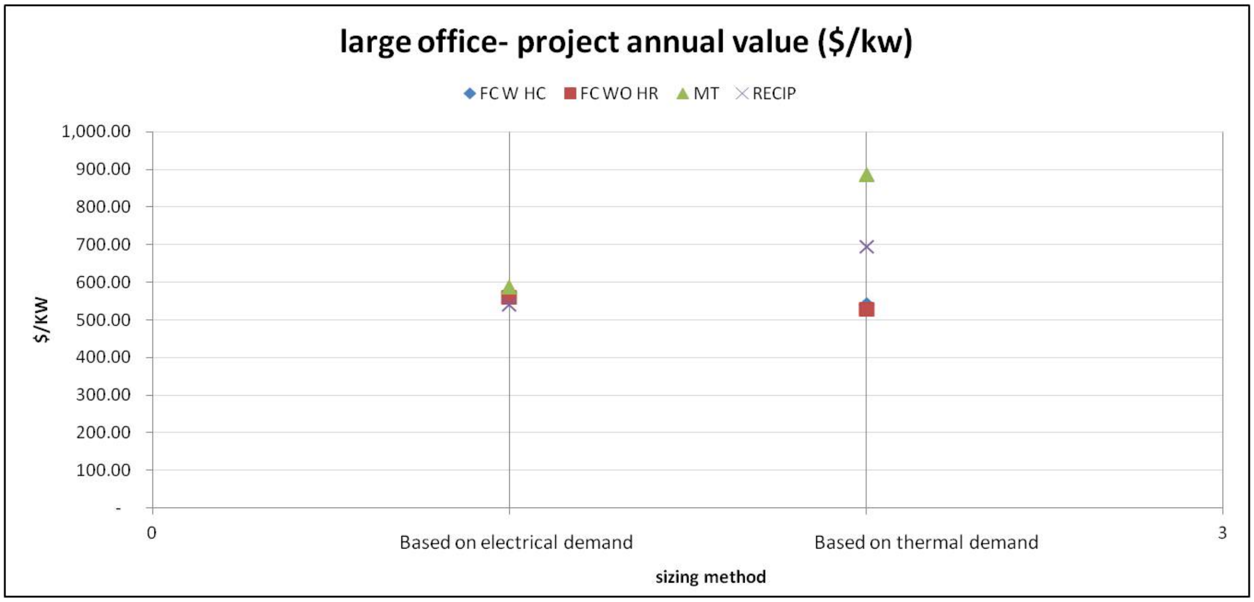


Figure 16-Project annual value - Large office

Table 14-Resiliency measure - Large office

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	898	1.00
	2	1,017	1.00
FC WO HR	1	898	1.00
	2	1,017	1.00
MT	2	254	0.63
	1	898	1.00
RECIP	2	432	0.83
	1	898	1.00

e) Midrise apartment

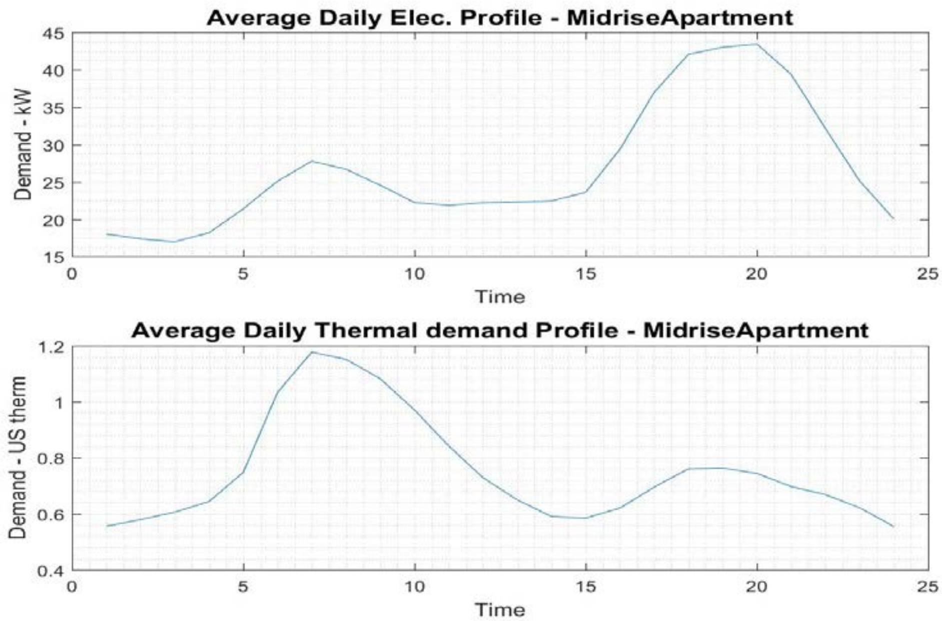


Figure 17-Average daily energy profiles - Mid-rise apartment

Table 15-Project financial & emission reduction measures - Mid-rise apartment

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	15	16,385.54	1,030.47	9.22	6.45	82.31	0.19	0.10
FC WO HR	15	15,613.46	981.92	10.18	7.13	74.16	0.19	0.10
MT	30	25,530.18	851.01	7.05	6.35	135.09	0.29	0.15
RECIP	30	23,184.69	772.82	7.12	6.41	111.31	0.29	0.15
FC W HR	108	18,003.86	166.55	57.04	39.93	62.72	0.24	0.12
FC WO HR	108	16,330.19	151.07	66.19	46.34	45.36	0.24	0.12
MT	30	25,530.18	851.01	7.05	6.35	135.09	0.29	0.15
RECIP	45	26,921.16	585.99	9.39	8.45	120.76	0.32	0.16

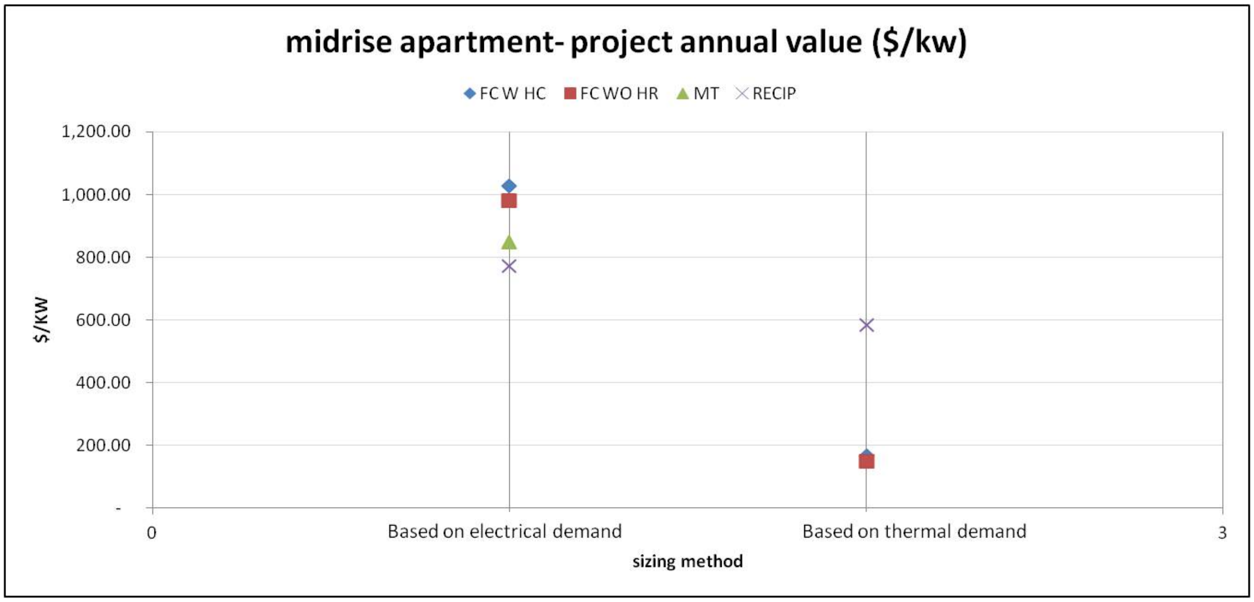


Figure 18-Project annual value - Mid-rise apartment

Table 16-Resiliency measure - Mid-rise apartment

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	15	0.89
	2	108	1.00
FC WO HR	1	15	0.89
	2	108	1.00
MT	1	30	1.00
	2	30	1.00
RECIP	1	30	1.00
	2	45	1.00

f) Out-patient

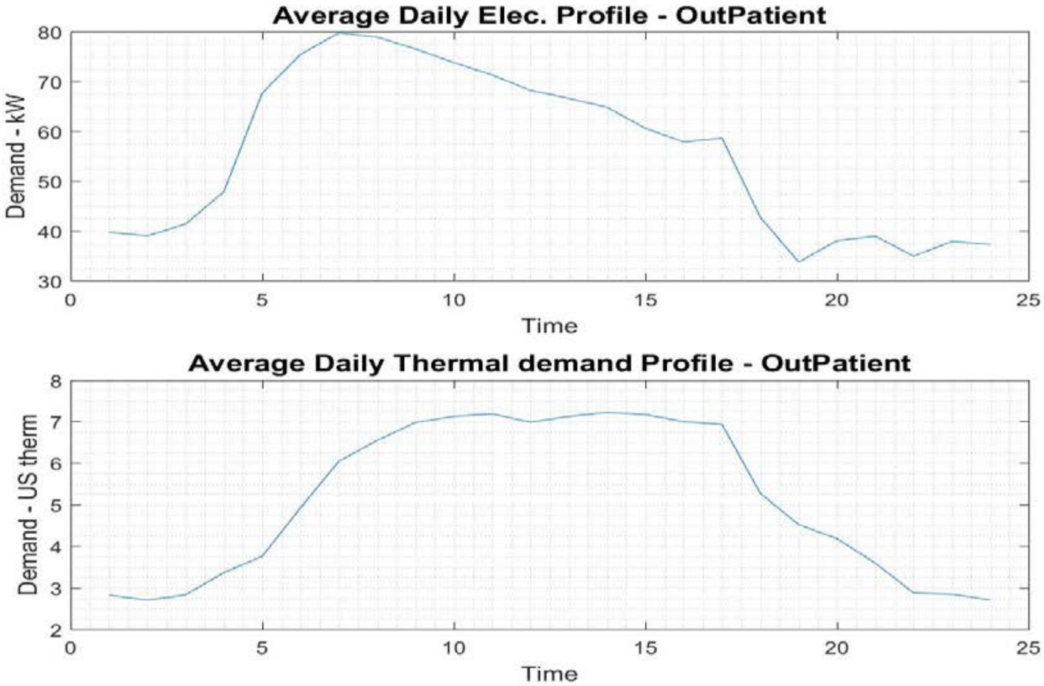


Figure 19-Average daily energy profiles – Outpatient

Table 17-Project financial & emission reduction measures - Outpatient

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	34	44,090.46	1,291.18	7.36	5.15	172.47	0.40	0.21
FC WO HR	34	42,342.44	1,239.99	8.06	5.65	153.81	0.40	0.20
MT	34	48,378.71	1,416.76	4.24	3.81	218.21	0.40	0.21
RECIP	34	43,659.12	1,278.55	4.30	3.87	167.73	0.40	0.20
FC W HR	303	38,056.93	125.55	75.67	52.97	61.04	0.39	0.20
FC WO HR	303	32,854.63	108.39	92.26	64.58	6.70	0.39	0.19
MT	75	71,175.30	939.25	6.39	5.75	347.95	0.64	0.33
RECIP	128	67,507.05	524.03	10.50	9.45	278.71	0.66	0.34

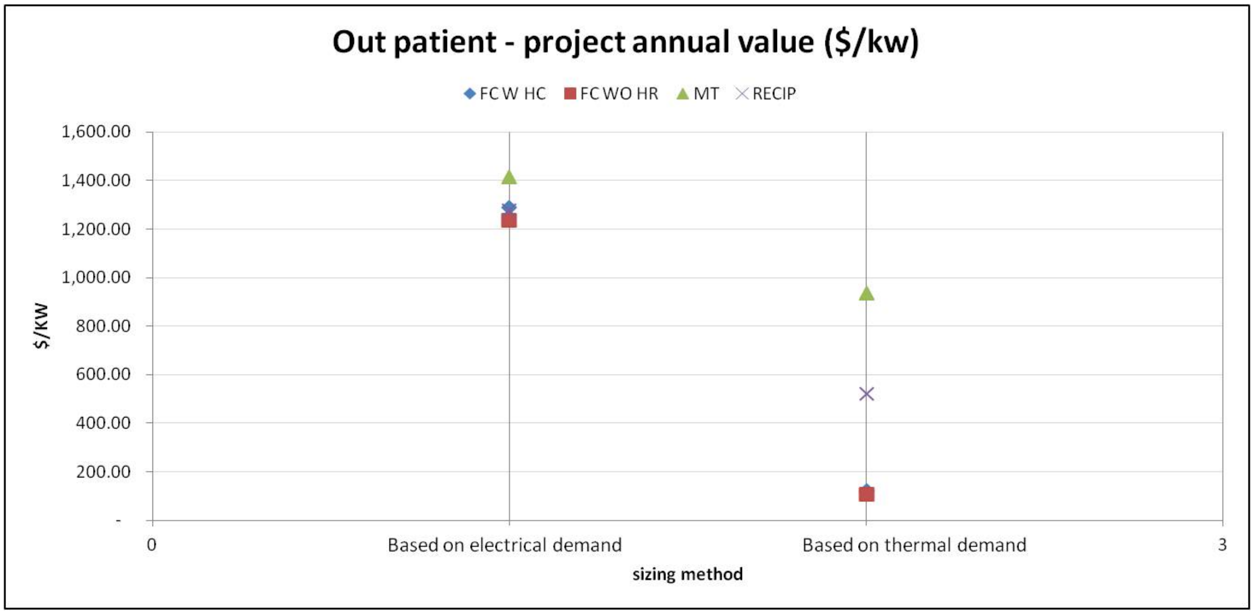


Figure 20-Project annual value - Outpatient

Table 18-Resiliency measure - Outpatient

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	34	0.79
	2	303	1.00
FC WO HR	1	34	0.79
	2	303	1.00
MT	1	34	0.79
	2	75	1.00
RECIP	1	34	0.79
	2	128	1.00

g) Secondary school

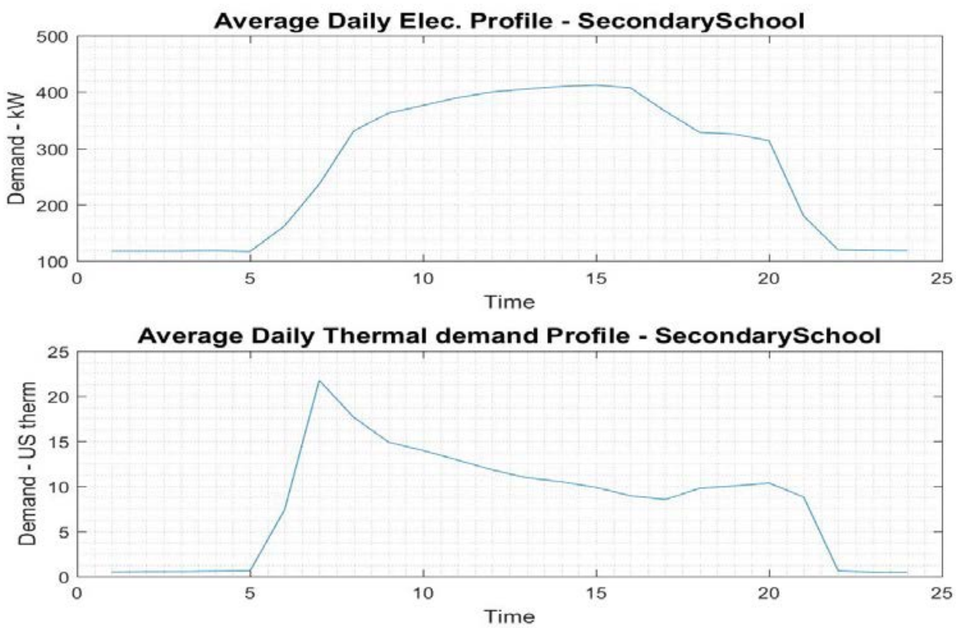


Figure 21-Average daily energy profiles - Secondary school

Table 19-Project financial & emission reduction measures - Secondary school

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	351	220,054.89	626.14	15.17	10.62	1,003.86	2.60	1.33
FC WO HR	351	212,814.40	605.54	16.51	11.56	931.09	2.60	1.33
MT	351	233,962.68	665.72	9.01	8.11	1,136.92	2.60	1.33
RECIP	351	212,767.27	605.41	9.08	8.18	919.10	2.60	1.33
FC W HR	1,098	202,487.71	184.27	51.55	36.09	529.35	2.34	1.18
FC WO HR	1,098	192,296.48	174.99	57.14	40.00	428.51	2.34	1.18
MT	721	261,321.55	362.34	16.56	14.90	1,073.74	2.47	1.26
RECIP	1,226	219,808.96	179.28	30.68	27.61	728.52	2.33	1.19

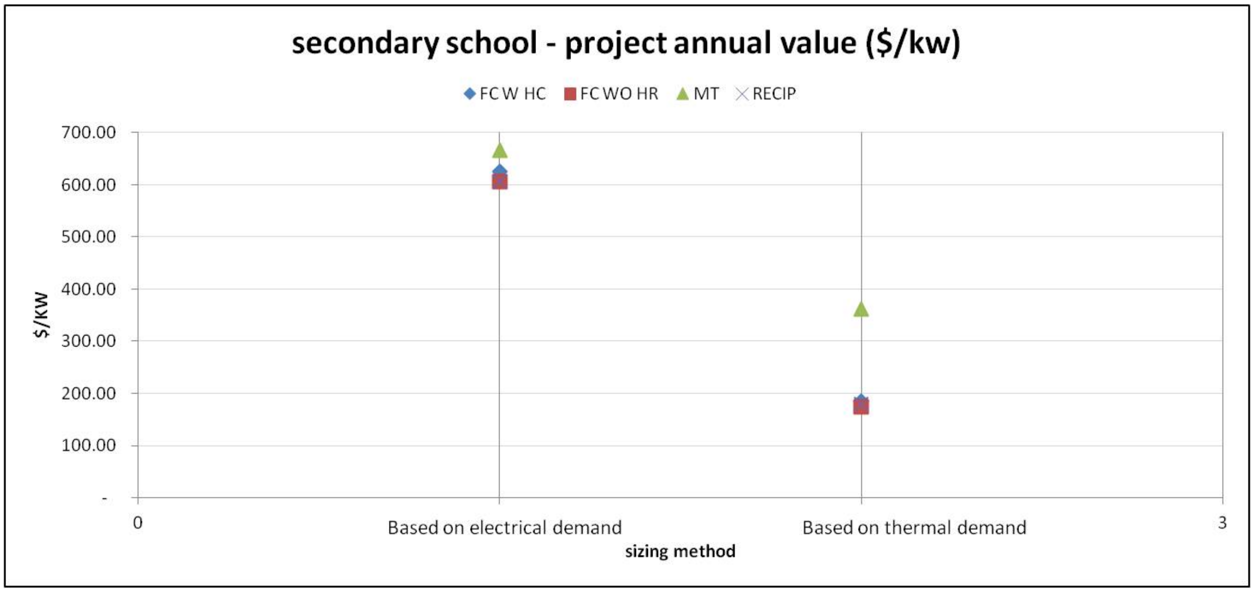


Figure 22-Project annual value - Secondary school

Table 20-Resiliency measure - Secondary school

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	351	0.99
	2	1,098	1.00
FC WO HR	1	351	0.99
	2	1,098	1.00
MT	1	351	0.99
	2	721	1.00
RECIP	1	351	0.99
	2	1,226	1.00

h) Stand-alone retail

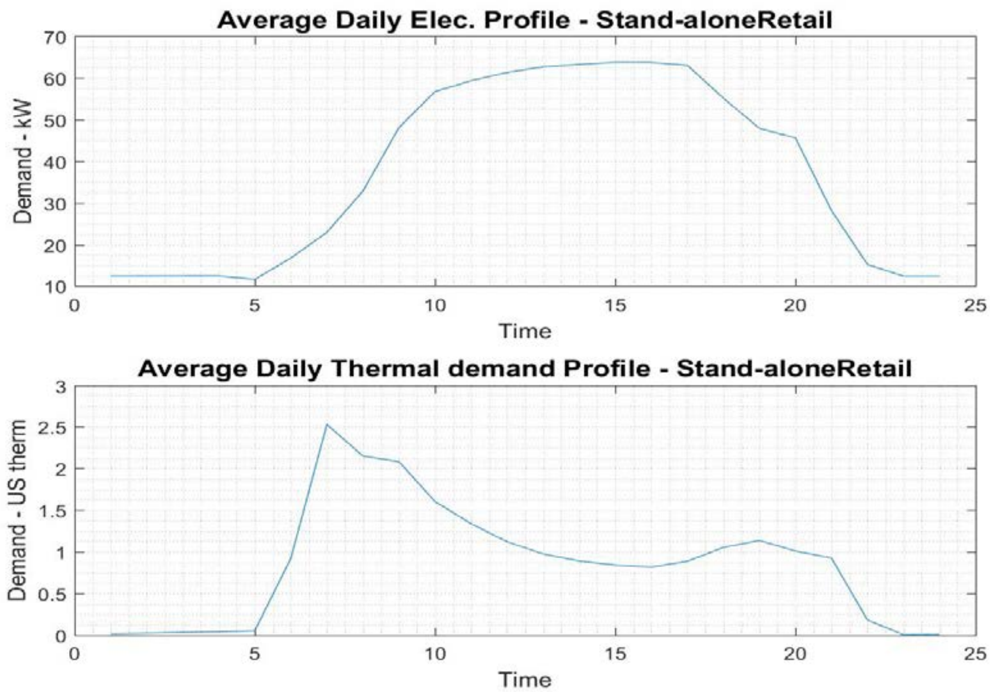


Figure 23-Average daily energy profiles - Stand-alone retail

Table 21-Project financial & emission reduction measures - Stand-alone retail

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	45	30,469.46	663.82	14.31	10.02	140.68	0.37	0.19
FC WO HR	45	29,685.92	646.75	15.46	10.82	133.30	0.37	0.19
MT	45	32,295.78	703.61	8.53	7.67	157.44	0.37	0.19
RECIP	45	29,329.96	638.99	8.61	7.75	127.30	0.37	0.19
FC W HR	101	32,962.18	326.35	29.01	20.11	126.77	0.39	0.20
FC WO HR	101	31,867.83	315.52	31.69	22.18	116.54	0.39	0.20
MT	63	35,899.28	568.81	10.55	9.49	165.10	0.38	0.20
RECIP	107	32,277.62	300.84	18.28	16.45	127.51	0.39	0.20

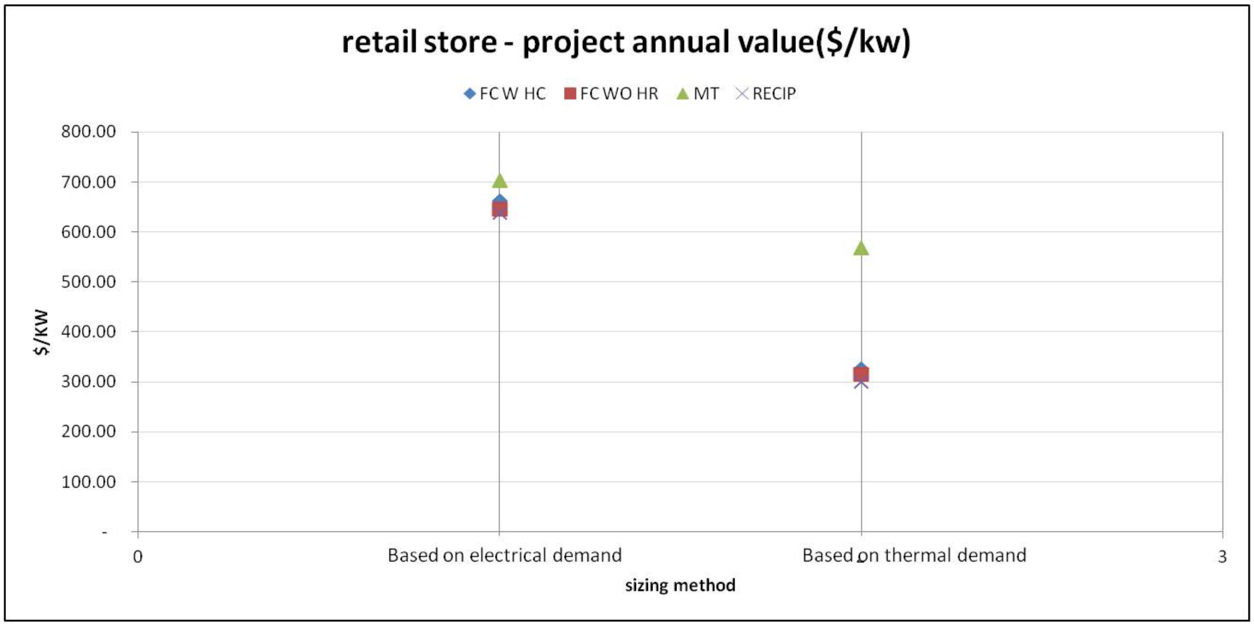


Figure 24-Project annual value - Stand-alone retail

Table 22-Resiliency measure - Stand-alone retail

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	45	1.00
	2	101	1.00
FC WO HR	1	45	1.00
	2	101	1.00
MT	1	45	1.00
	2	63	1.00
RECIP	1	45	1.00
	2	107	1.00

i) Strip-mall

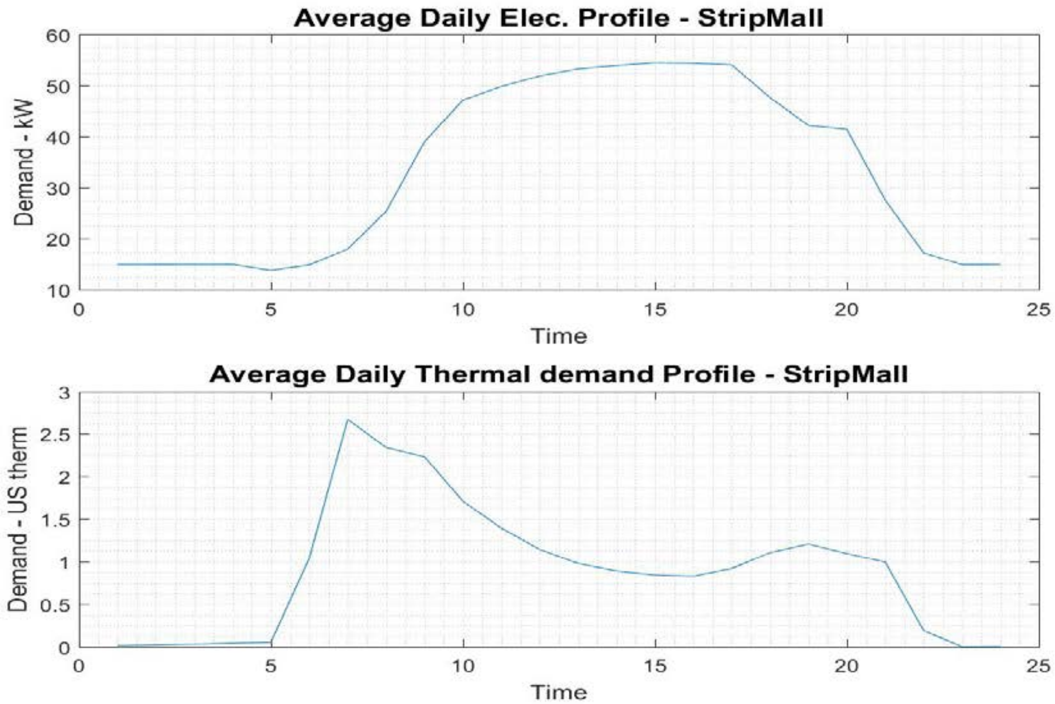


Figure 25-Average daily energy profiles - Strip mall

Table 23-Project financial & emission reduction measures - Strip mall

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	49	31,330.56	638.10	14.89	10.42	142.72	0.38	0.19
FC WO HR	49	30,547.38	622.15	16.07	11.25	135.35	0.38	0.19
MT	49	33,222.72	676.64	8.87	7.98	160.23	0.38	0.19
RECIP	49	30,215.38	615.39	8.94	8.04	129.63	0.38	0.19
FC W HR	89	28,434.35	319.48	29.73	20.81	55.85	0.33	0.17
FC WO HR	89	27,493.96	308.92	32.37	22.65	96.14	0.33	0.17
MT	63	35,460.85	558.65	10.74	9.67	166.16	0.39	0.20
RECIP	107	27,805.48	257.68	21.34	19.21	105.58	0.32	0.17

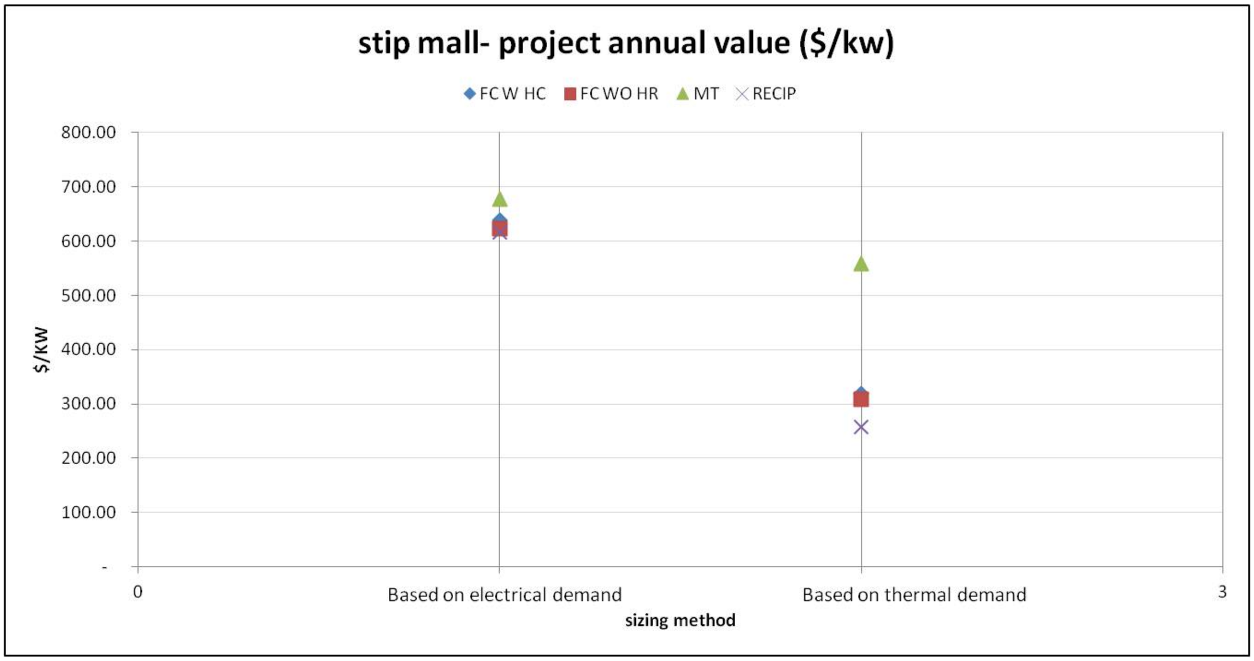


Figure 26-Project annual value - Strip mall

Table 24-Resiliency measure – Strip mall

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	49	1.00
	2	89	1.00
FC WO HR	1	49	1.00
	2	89	1.00
MT	1	49	1.00
	2	63	1.00
RECIP	1	49	1.00
	2	107	1.00

j) Supermarket

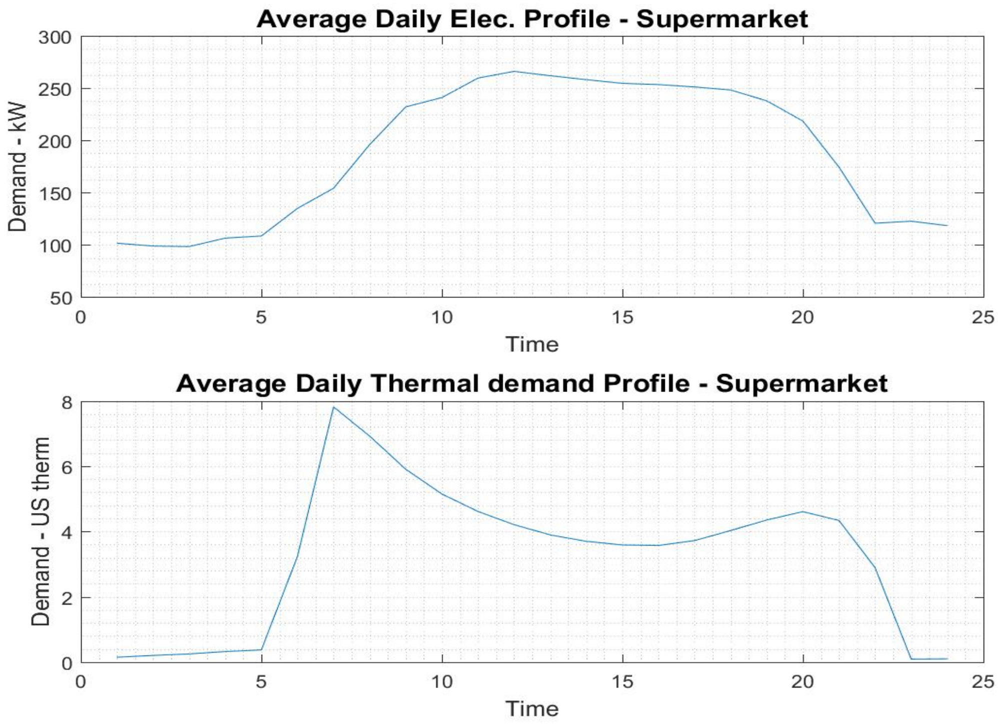


Figure 27-Average daily energy profiles - Supermarket

Table 25-Project financial & emission reduction measures - Supermarket

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	189	144,905.59	762.87	12.45	8.72	769.41	1.90	0.97
FC WO HR	189	139,764.76	735.80	13.59	9.51	717.25	1.90	0.97
MT	170	142,186.22	834.63	7.19	6.47	787.21	1.78	0.91
RECIP	189	137,791.85	725.42	7.58	6.82	687.80	1.90	0.97
FC W HR	681	120,462.79	176.78	53.74	37.62	514.40	1.85	0.94
FC WO HR	681	112,590.08	165.22	60.52	42.37	435.53	1.85	0.94
MT	189	152,553.24	803.13	7.47	6.72	839.28	1.90	0.98
RECIP	289	169,598.39	585.61	9.39	8.45	801.68	2.26	1.15

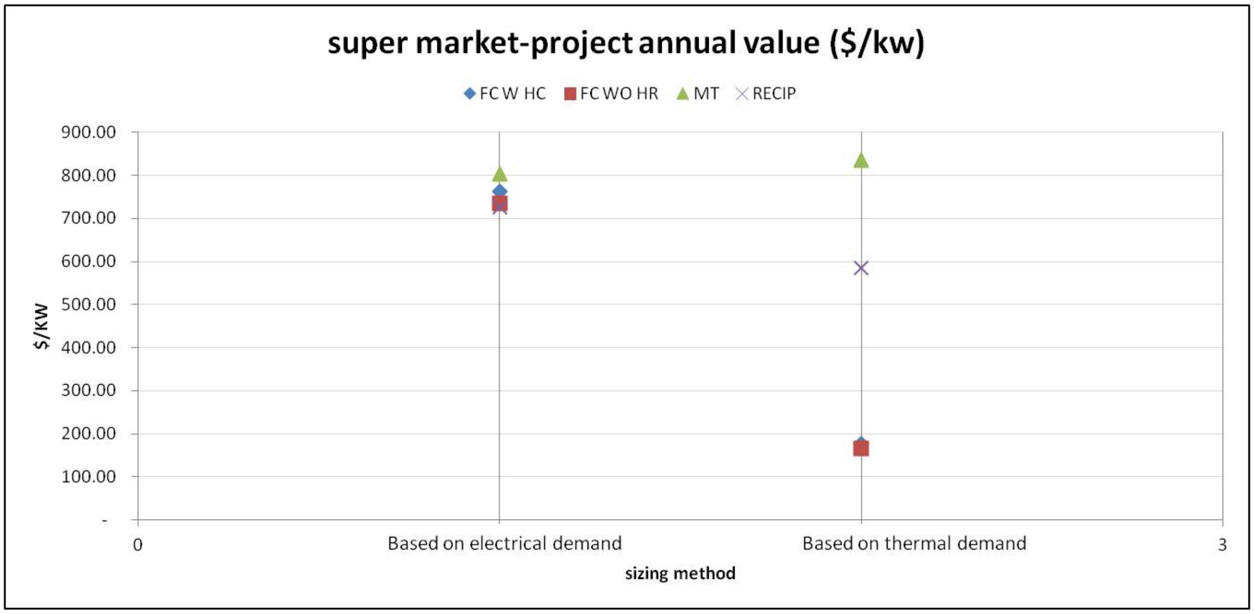


Figure 28-Project annual value - Supermarket

Table 26-Resiliency measure - Supermarket

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	189	0.99
	2	681	1.00
FC WO HR	1	189	0.99
	2	681	1.00
MT	2	170	0.98
	1	189	0.99
RECIP	1	189	0.99
	2	289	1.00

k) Warehouse

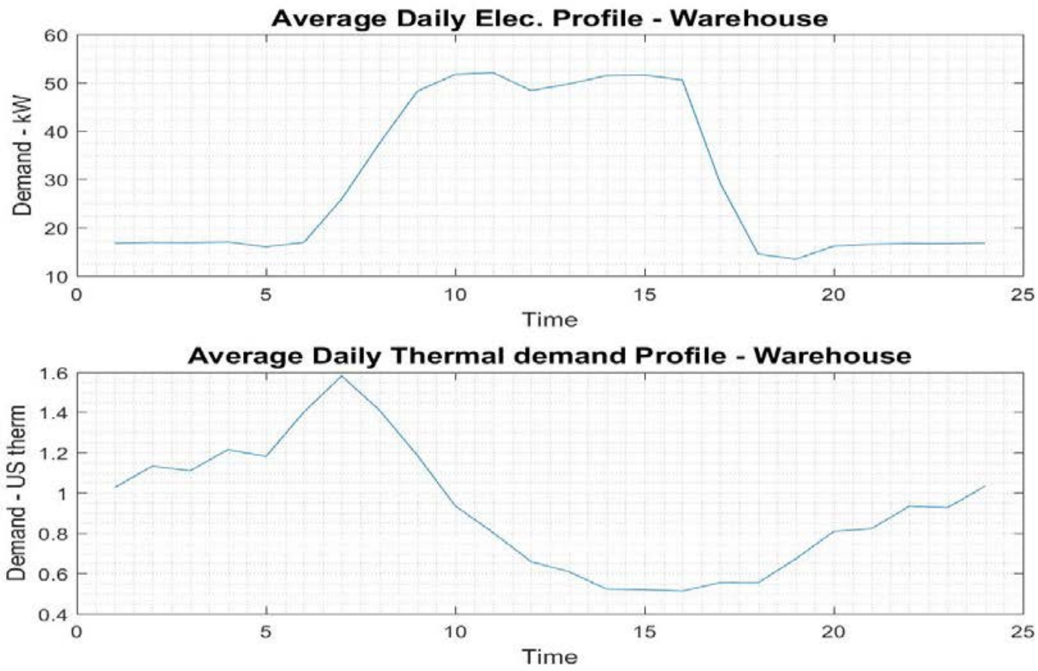


Figure 29-Average daily energy profiles – Warehouse

Table 27-Project financial & emission reduction measures - Warehouse

technology	Rated capacity (kW)	ENERGY COST SAVING ($)	Annual value ($/kW)	Pay-back-period W/O ITC	Pay-back-period with ITC	Annual CO2 reduction (Tons)	Annual SO2 reduction (Tons)	Annual NOX reduction (Tons)
FC W HR	54	28,017.10	510.15	18.62	13.04	113.18	0.31	0.16
FC WO HR	54	27,084.01	493.16	20.28	14.19	104.45	0.31	0.16
MT	40	25,969.59	637.23	9.42	8.47	119.71	0.27	0.14
RECIP	54	27,740.40	505.11	10.89	9.80	109.06	0.31	0.16
FC W HR	163	16,650.54	102.14	93.01	65.11	22.39	0.22	0.11
FC WO HR	163	15,269.41	93.67	106.76	74.73	9.54	0.22	0.11
MT	54	30,291.58	551.56	10.88	9.79	134.81	0.31	0.16
RECIP	69	29,998.39	432.99	12.70	11.43	118.17	0.34	0.17

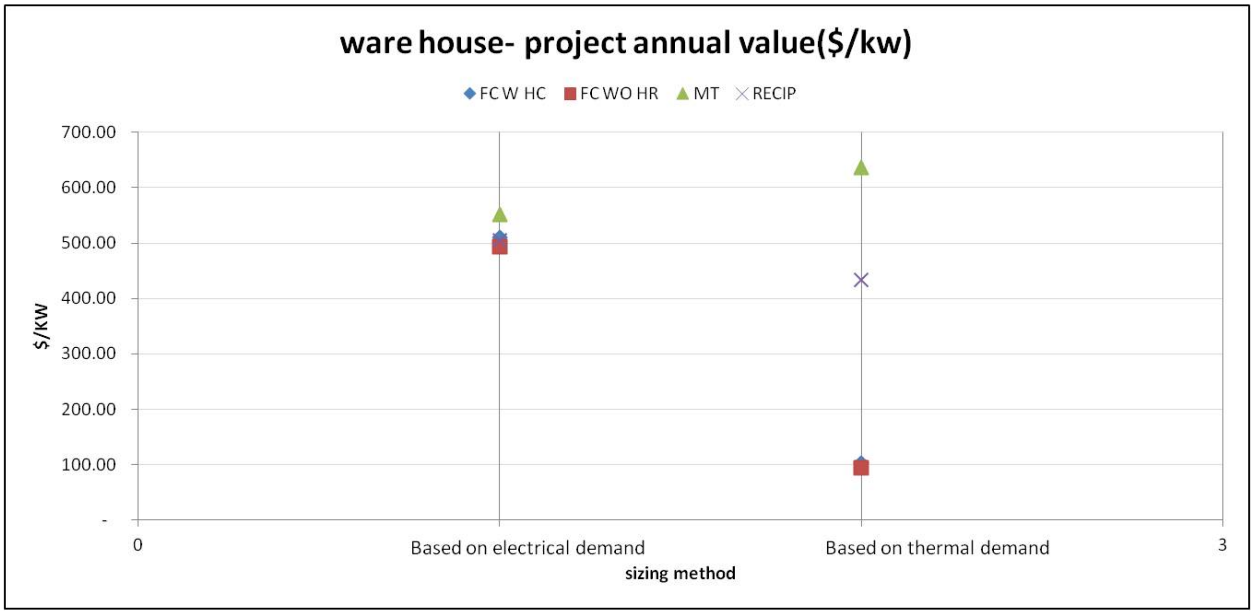


Figure 30-Project annual value - Warehouse

Table 28-Resiliency measure - Warehouse

technology	cap class	capacity	Average percentage of served critical load
FC W HR	1	54	1.00
	2	163	1.00
FC WO HR	1	54	1.00
	2	163	1.00
MT	2	40	1.00
	1	54	1.00
RECIP	1	54	1.00
	2	69	1.00