MicroTurbine Economics in Commercial and Institutional Buildings

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Abstract: - A study that combines the technical and economical parameters has been conducted to assess microturbines' applications in Vermont State (US). A variety of scenarios have been investigated for different commercial and institutional buildings in order to identify the economically most attractive conditions of operation. In this context, an emphasis has been put on energy rate structures, installed capacity, threshold for base load and peak shaving applications, and control strategy. Results show that the technology is viable with today's prices in buildings using exclusively electricity as a source of energy. Economic indicators such as internal rate of return and system's break even cost are less interesting for applications in buildings where gas is used to fulfill space and water heating requirements.

Key-Words: - Microturbine, distributed generation, cogeneration, profitability, economic assessment

1 Introduction

Distributed generation (DG) refers to several technologies and application types, some being well-established and others being at the laboratory stage. Currently, the main drivers supporting the technology and market developments are renewable energy targets defined by different government levels and some policies in specific geographic areas. In the later case, distributed generation is often viewed as a long term mean to alleviate generation or distribution constraints.

Cogeneration is a type of application that yields a very efficient use of fossil fuels when properly designed and implemented. It can then be beneficial to the site owner, the utility and the society, and as such it is included in some of the renewable energy portfolio. Microturbine is an emerging technology now available commercially which can offer several technical advantages for applications involving a few tens of kilowatts to less than about 1 MW of electric output. Based on actual field experience, it has the potential to achieve high reliability and very low maintenance intensity which are key features when the owner doesn't have in-house technical support [1].

The potential savings from DG can be viewed from the perspective of the electric utility or the customer. From the utility's perspective, the capacity and energy output of distributed generators are generally not competitive with other sources of generation at the wholesale level. However, from the customer's perspective, the value of the electrical output of a distributed resource is measured by the retail rate that the customer can avoid paying less any special charges for standby, back-up, or similar services. In many high energy cost regions DG resources may be profitable if measured in this way.

The main objective of this study is to explore the long-term commercial market opportunity for microturbines and to determine the conditions under which they might compete with the alternative of purchased power in US market namely in North Eastern states. The potential savings from using a microturbine are viewed from the perspective of the customer. Results are presented for the state of Vermont.

2 Building electric power demand profile

Several operating modes have been considered in this study: continuous and intermittent operation (base load), demand following and peak shaving operation. To assess the impact of the microturbine output, one needs some reference time profile of the electric demand for the different kinds of buildings to be studied. This information was derived from the data collected in Quebec via communicating meters at a frequency of 15 minutes during a period of one year. Since Quebec province (Canada) and Vermont State (USA) are adjacent areas, the mentioned profiles are assumed to be representative of the latter region. These profiles have been used to estimate the space heating and water heating for all the segments under consideration: Office, Mercantile, Education, Warehouse, Lodging and Healthcare Buildings.

The Office Building segment is chosen as an example to present the methodology. The corresponding power demand profiles are displayed in figures 1a and 1b, respectively for an Office building using electricity for all end uses (type I) and gas to fulfill thermal requirements such as space heating and domestic hot water (type II).

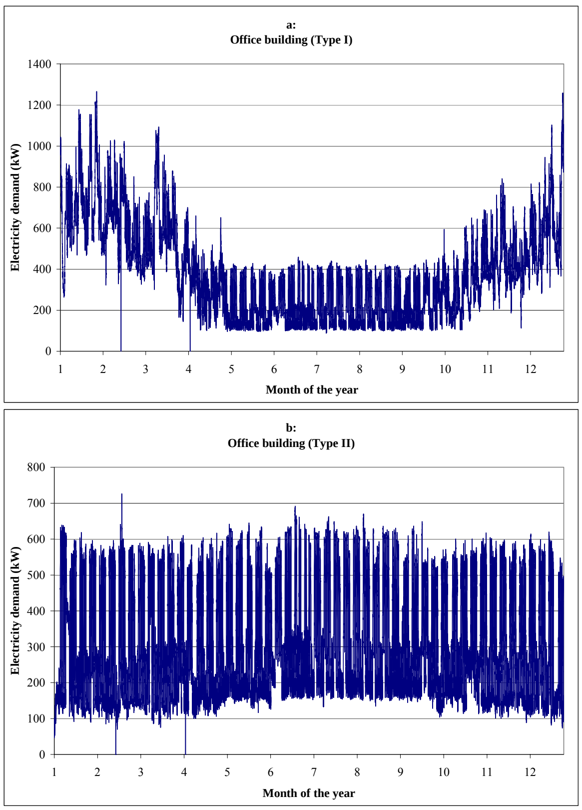


Fig. 1 Power demand profiles in Office Buildings.

The space-heating load has been estimated for each segment from the corresponding total electric demand using the PRISM method [2]. This method provides three parameters: the global loss factor (UA), the equilibrium temperature (τ) and the base load (α). The two first parameters are used to estimate the space-heating load while the third one represents the base load that includes plug loads and hot water requirements.

The energy required to maintain a constant indoor temperature is obtained from the following balance where the thermal inertia is neglected:

$$\dot{Q}_{SH} = UA(T_{in} - T_{out}) - \dot{Q}_g \quad (1)$$

where UA is the total heat loss coefficient (kW/°C), $\dot{Q}_{SH}$ is space-heating load (kW) and $\dot{Q}_g$ is internal gain (kW) while T_{in} and T_{out} represent the indoor and the outdoor temperature (°C) respectively.

The first term of the right hand side of equation 1 represents the heat loss of the building while the second term on the same side of the equation corresponds to the indoor heat gains due to lighting, solar gains, household appliances and occupancy. Hence, there exists an equilibrium temperature so that the quantity $\dot{Q}_{SH}$ equals zero. When the outdoor temperature is below the equilibrium point, heat should be supplied to the building to maintain a set point temperature. By introducing the equilibrium temperature, the heat balance becomes as follows:

$$\dot{Q}_{SH} = \begin{cases} UA(\tau - T_{out}) & \text{if} \quad T_{out} < \tau \\ 0 & \text{if} \quad T_{out} \geq \tau \end{cases} \quad (2)$$

with

$$\tau = T_{in} - \left(\dot{Q}_g / UA\right) \quad (3)$$

The total consumption for a type I building can be deducted from the following expression:

$$\dot{Q}_{tot} = \begin{cases} \alpha + UA(\tau - T_{out}) & \text{if} \quad T_{out} < \tau \\ \alpha & \text{if} \quad T_{out} \geq \tau \end{cases} \quad (4)$$

Knowing the total electric demand $\dot{Q}_{tot}$, the base load is obtained from equation 4.

The schematic representation of the PRISM estimation of the three parameters defined above is shown in figure 2. It can be seen that the PRISM model represents an acceptable estimation for space heating load and base load when the temperature is less than τ. In fact, the linear curve with UA slope is a good approximation for the weekly average of the electricity demand. However, the approximation is less accurate when the outdoor temperature is more than 18^0C (i.e. mid-season and summer). This is probably due to the air conditioning load. In fact, the base load represented by the constant α does not include seasonal load such as air-conditioning.

Concerning type II buildings, the model calculates the energy required for both space and water heating using equation 2 and the DOE data (see table 1) respectively. Efficiencies of the gas fired equipments are taken into account by the model. The efficiency is fixed at 75% for gas water heaters, furnaces and boilers.

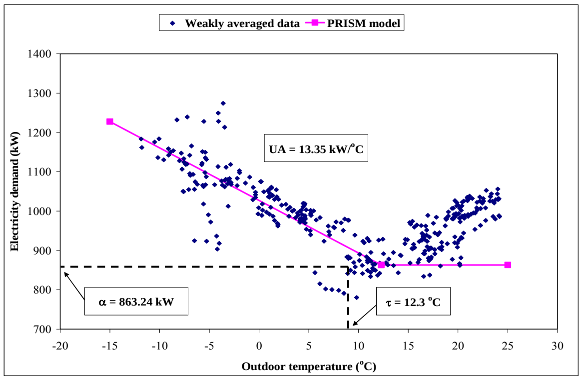


Fig. 2 Power demand versus outdoor temperature.

	Building type	Office	Mercantile	Education	Warehouse	Lodging	Healthcare
Energy intensity (Btu/ft^2)	I and II	8700	5100	17400	2000	51400	63000
Floorspace (ft^2)	I	104012	52259	64400	47932	n/a	n/a
	II	160888	31743	176291	103904	147067	384315
Space heating (kWh/year)	I	1554986	443196	958308	466518	n/a	n/a
	II	2994479	314557	3107146	1177446	2615778	8869556
DHW (kWh/year)	I	265212	78113	328420	28096	n/a	n/a
	II	410237	47447	899024	60905	2215493	7096082
Others (kWh/year)	I	1686876	1667727	354589	589989	n/a	n/a
	II	2940787	1183665	1149694	1489073	1768526	8561104
Electricity consumption (kWh/yr)	I	3507074	2189036	1641317	1084603	n/a	n/a
	II	2940787	1183665	1149694	1489073	1768526	8561104
Annual peak (kW)	I	1262	518	598	273	n/a	n/a
	II	726	248	559	429	445	1557
Gas consumption (MMBtu/yr)	I	0	0	0	0	n/a	n/a
	II	15483	1641	18219	5628	21972	72624

Table 1 Energy break-down by segment.

3 Model overview

A mathematical model that estimates the profitability of the microturbines in the commercial sector has been developed. The model has a modular architecture that allows the implementation of new modules without major modifications.

3.1 Operation and control

The model developed offers a great flexibility to cover many scenarios of microturbine operation. In fact, it allows simulating the operation of up to 10 units in parallel configuration. Two type of control strategy can be used [3]. The first one is a sequential control that allows the micro-turbine to operate only at full load. With this type of control, the system cannot operate for a demand below its nominal capacity to avoid any extra production of electricity. It should be noted here that this condition is used because electric storage and buyback are not considered in this study.

The second strategy consists in a continuous control where the microturbine follows the load. The electric and the thermal efficiencies vary with the load and are determined consequently. When more than one microturbine is used, the units operate in sequence depending on the demand. The number of units in operation is determined according to the following relationship [4]:

$$N = \frac{P_d - P_{th}}{P_{MT}} \tag{5}$$

where P_d is the building demand, P_{th} is the threshold level for control strategy and P_{MT} represents microturbine's nominal capacity. For instance, if the control is continuous, the second unit starts up when the demand exceeds the nominal capacity of the first unit. The third unit will be on when the demand is over the sum of the two first units' capacity and so on up to 10 units. However, the number of units in operation can be set to a maximum number less than 10. On the other hand, base or peak shaving can be simulated for both control strategies no matter is the number of microturbines. The base shaving is achieved by setting the threshold to the minimum value. Peak shaving is simulated for higher values.

Concerning the heat recovery system, the thermal efficiency of the microturbine is set to 45% at full load. For example, a unit of 28 kW electric capacity delivers a 42 kW thermal output when the unit runs at 100% capacity. In the case of continuous control where the unit can run at part load, the thermal efficiency is determined according to the variation of the electric efficiency. The heat recovered from the hot exhaust of the microturbine is transmitted via a gas to water heat exchanger to the water heater first. The remaining heat is supplied for space heating end-use. If the heat generated is insufficient to cover the thermal load of the building, the deficit is supplied by a back-up connected to the utility.

The heat recovered from the co-generation system is included in the calculation of the microturbine's overall efficiency given by:

$$\eta = \eta_{el} + \eta_{th} \times \frac{Q_r}{Q_a} \tag{6}$$

where Q_r is the heat recovered and Q_a represents the available heat.

It can be deducted from equation 6 that the overall efficiency varies between two limits. On one hand, when the heat is not recovered (no co-generation), the overall efficiency coincides with the electric efficiency. On the other hand, the overall efficiency is represented by the sum of the electric and thermal efficiencies when all the recoverable heat is used for thermal end-use. In the case of sequential control the lower and the upper limits are respectively 30% and 75%.

For the case of continuous control, the electric efficiency (actual and future values) is determined according to the following equation:

$$\eta_{el} = a \left(\frac{P_d}{P_{MT}} \right)^b \tag{7}$$

where a and b are the fitting coefficients given by:

- actual: a=24.97 and b=0.3098
- future: a=29.96 and b=0.3098

Equation 6 is obtained by fitting the experimental data obtained from the monitoring of 28 kW unit. In order to normalize the equation so that it can be used for any microturbine's capacity, the equation has been derived in a dimensionless form. The quantity between brackets is the ratio of the demand and the nominal capacity of the system. Hence it has no dimension and varies between 0 with no load and 1 at full load. The future electric efficiency η_{el} is obtained by majoring the actual efficiency by 20%. Figure 3 shows that the future efficiency at full load is 30% while it is currently 25%. These values are in accordance with those available in the literature [4].

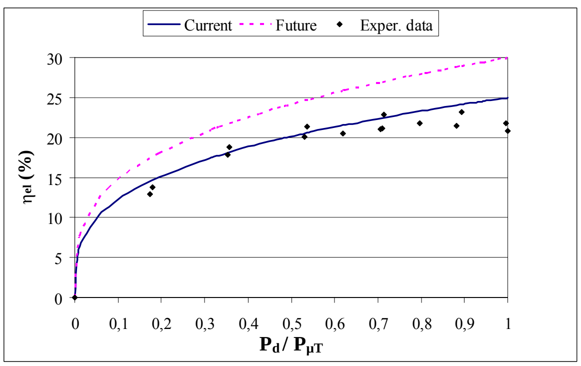


Fig. 3 Electric efficiency at part-load.

3.2 Economic analysis

Equal periodic payments approach is adopted in this study to allow comparison of annual costs of different scenarios. The economic analysis covers a period of 15 years beginning from the date of investment. The costs considered are included in the following expression:

$$C_{tot} = C_i + C_e + C_m + C_r \tag{8}$$

where C_{tot} is the sum of all costs: investment capital C_i , energy bills C_e , maintenance C_m and finally major replacement (overhaul) C_r.

For a given market discount rate *i* and a system lifetime *n*, the annual equal periodic payment (AEP) is such as:

$$AEP(i,n) = \left[\sum_{y=1}^{n} \frac{(C_{tot})_y}{(1+i)^y} \right] \cdot \left[\frac{i}{1-(1+i)^{-n}} \right] \tag{9}$$

The microturbine economic viability to the customer is determined by comparing the AEP (i.e. units operating costs) with the utility cost of delivered energy (electricity and eventually gas) represented by the reference annual payment (AEP_{ref}). Money savings are generated if the difference between these respective quantities is negative. However, the project will go forward only if money savings are large enough relative to the investment required to meet the costumer's investment-return criteria.

The payback period is used as an indicator for profitability. An expression (Eq. 10) that takes into account the effect of the market discount rate is used instead of the well-known ''simple payback'' [5].

$$Payback = \frac{Ln\left(\frac{CRF}{CRF - i} \right)}{Ln(1+i)} \tag{10}$$

CRF is the capital recovery factor defined as:

$$CRF\ (\%) = \frac{annual\ \ savings}{investment} \tag{11}$$

Energy cost escalation rates and inflation are not considered in this study.

3.3 Utility rates

The energy bills are calculated according to the Green Mountain Power (GMP) commercial rate 63 and Vermont Gas G4 commercial rate. Commercial customers of GMP who are on rate 63 are power demand billed (Table 2). The power demand is recorded every 15 minutes (average power). The demand charges are determined on the basis of the highest recorded power demand during the month. The most expensive power demand and energy charges are in the peak period (6:01 a.m. to 10:00 p.m. Monday to Friday). In contrast, the lowest rate is during the off peak hours regardless of the day in the week.

On the other hand, GMP rate has a ratchet clause. The customer is billed on a minimum of 50% of the highest power demand recorded during the previous 12 months.

Monthly Charge	Demand Charges		Energy Charges	
	kW		kWh	
	Peak	Off-peak	Peak	Off-peak
$64.69	$13.25	$2.64	$0.05834	$0.05076

Table 2 GMP utility electricity rate 63.

Gas bill is calculated according to an annual rate (no difference in summer or winter). The used rate corresponds to G4 commercial rate of Vermont Gas utility:

Monthly charge:	48.69	$/month
Energy consumption:	0.64636	$/ CCF[1]

3.4 Scenarios and parameters

Many scenarios of microturbine application in segments mentioned previously have been examined in order to cover a variety of possible mode of operation for this technology. The situations considered are summarized in table 3.

	Capacity	Control	Threshold (kW)
case 1	28 kW	Sequential	28,40,50,100 and 150
case 2	28 kW	Continuous	0,50,100,150 and 200
case 3	60 kW	Sequential	60,70,80,100 and 150
case 4	60 kW	Continuous	0,50,100,150 and 200
case 5	75 kW	Sequential	75,100,125,150 and 175
case 6	75 kW	Continuous	0,50,100,150 and 200
case 7	100 kW	Sequential	100,125,150,175 and 200
case 8	100 kW	Continuous	0,50,100,150 and 200

Table 3 Scenarios of operation.

The technical and the economic parameters have been selected in the present study as follows:

- Electric efficiency: 30% LHV
- Thermal efficiency: 45%
- System cost (including installation) [6]:
  - 15 000$ per unit for a 28 kW
  - 22 000$ per unit for a 60 kW
  - 28 000$ per unit for a 75 kW
  - 40 000$ per unit for a 100 kW
- Maintenance cost:

$$\underbrace{200\$/\mathrm{yr}}_{\text{base cost}} + \underbrace{0.003\$/\mathrm{kWh}_{\text{electric}}}_{\text{variable cost}}$$

- Major replacement cost: 50% of the initial investment each 40 000 hours of operation
- Market discount rate: 10%
- System lifetime: 15 years
- Availability: 98% (annual shut down from 23/07 to 30/07 for maintenance purpose).

4 Results and discussion

This section describes the results of the economic analysis obtained from simulations performed on buildings using microturbines for co-generation.

As mentioned in a previous section, the simulations considered two different control methods. The first was a sequential technique (i.e. On-Off technique) where the systems were operated only at full load when the building electrical load was greater than the threshold. At this point, the units would start one by one as the load increases until all ten are operating. The second control method assumed that the system would run at part load whenever possible in an attempt to maximize the annual run time.

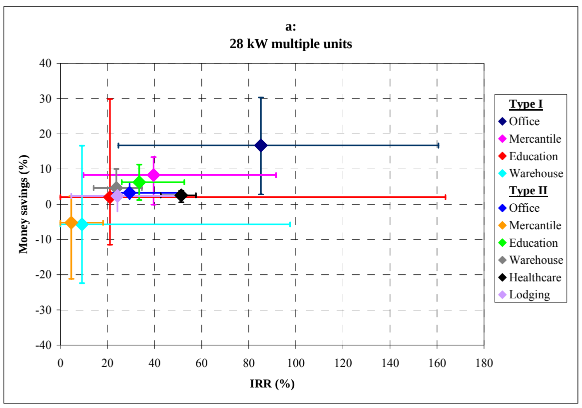
4.1 Money savings

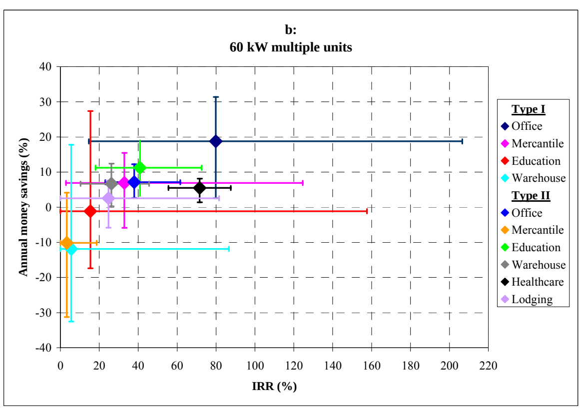
The relative annual money savings achieved by system of multiple microturbines of 28 kW to 100 kW are depicted in the figures 4a-d. The lozenges represent the mean values of both the internal rate of return (IRR) and the annual money savings. The branches in the horizontal and the vertical directions correspond to the span of the IRR and the relative money savings respectively.

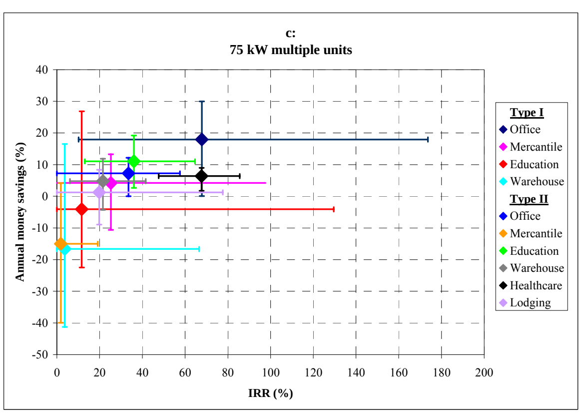
The examination of the results reveals that the lower the capacity of the microturbine the greater the mean relative annual savings in general. This can be explained by the fact that small units have a high seasonal efficiency. Indeed, most of the heat generated by these units is recovered. Contrary, large capacity units generates huge amount of heat that exceeds the thermal requirements of the building and heat waste occurs. Nevertheless, the effect of microturbine's capacity on the maximum value of the relative money savings remains insignificant for most of the segments. Indeed, the maximum relative savings are approximately 30% regardless the capacity of the microturbine.

[1] 1 CCF ≡ 1 Therms = 100 000 BTU

A similar trend is observed with the IRR: large capacity microturbines require more capital. Hence, the mean IRR is decreased. In fact, 28 kW units show a better profitability since most of the segments have a mean IRR higher than the market discount rate fixed at 10%. The IRR is very interesting especially for type I office building. The horizontal branches confirm that the IRR lowest value deceases when the microturbine's nominal capacity is increased. In the case of Office building of type I, the minimum value of IRR is approximately 17% with a 28 kW unit. This value decreases as low as 4% when a 100 kW microturbine is used.







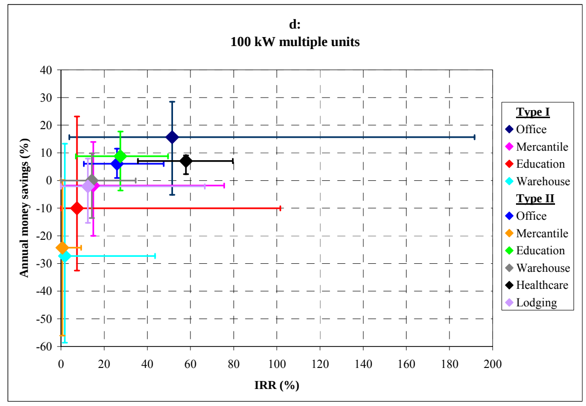


Fig. 4 Money savings versus internal rate of return.

Results show that the technology is more profitable for all electric buildings (type I). In fact, the IRR can reach up to 200% for type I office building while it has a maximum of 60% for a type II building. In the latter buildings, the displaced loads are initially ensured by gas. Hence, the money savings generated are not as significant as those for type I buildings. However, buildings where gas is present could be profitable if there is a large need for heat all over the year such as for healthcare and education.

4.2 Economic viability

This section regroups the most profitable scenarios for all the segments studied including two types of buildings (type I and II) and both microturbine's control strategies (continuous and sequential modes). Two economic indicators have been used to select the most profitable scenarios: the highest IRR and the lowest payback period. The results are presented in terms of buildings energy requirements, economic results and scenario parameters. The electricity peak corresponds to the maximum demand during a year while the electric ratio represents the electric requirements divided by the sum of the electric and the thermal requirements. Hence, an electric ratio beyond 50% means that the electricity requirements are higher than the thermal requirements and vice versa.

Mode	Segment	Electricity consumption (kWh/year)	Gas consumption (MMBtu/year)	Electricity peak (kW)	Electric ratio (%)	Type of control	micro-turbine capacity (kW)	Threshold (kW)	Number of micro-turbines	money savings ($/year)	Return on investment (%)	Payback period (years)	Overall efficiency (%)
Type I	Office	3516585	0	1262	48	Continuous	60	50	4	102516	128	0,94	52
						Sequential	60	80	3	108516	176	0,66	57
	Service & mercantile	2194190	0	518	76	Continuous	60	100	2	27757	77	1,81	43
						Sequential	28	150	2	24441	94	1,37	54
	Education	1655517	0	598	22	Continuous	60	0	2	42704	109	1,14	57
						Sequential	60	60	1	14177	78	1,77	75
	Warehouse	1086129	0	273	54	Continuous	60	0	1	16118	87	1,54	50
						Sequential	28	28	2	11911	53	3,04	54
Type II	Office	2940791	15483	622	46	Continuous	60	200	8	44999	38	5,21	52
						Sequential	75	125	7	49611	38	5,27	55
	Service & mercantile	1183666	1641	248	77	Continuous	75	100	2	4467	19	n/a	40
						Sequential	75	100	2	6062	22	27,01	44
	Education	1149697	18219	559	22	Continuous	75	0	6	49146	42	4,39	62
						Sequential	75	75	6	53208	45	3,98	68
	Warehouse	1489075	5628	429	55	Continuous	60	150	5	22601	33	7,00	48
						Sequential	75	150	4	22206	33	7,36	54
	Healthcare	8561033	72624	1560	35	Continuous	60	0	10	93562	56	2,81	62
						Sequential	60	60	10	94030	57	2,80	62
	Lodging	1768526	21972	445	27	Continuous	100	0	1	21298	67	2,18	74
						Sequential	75	75	2	22029	53	3,08	68

Table 4 Summary of the most profitable scenarios.

Table 4 shows that the application of microturbines in type I buildings represents the most profitable scenarios when compared type II buildings. For instance, the IRR is more than 100% and the payback period is less than a year when the technology is used in a type I office building. If a gas fired equipment is used for both space heating and water heating in office building, the IRR drops to 38% and the payback is more than five years. This trend is valid no matter under which segment the building is classified.

It is interesting to mention here that the overall efficiency of the co-generation system is higher for segments where the electric ratio is relatively small such as in education, healthcare and lodging. In fact, these segments have an important thermal load associated to a high consumption of domestic hot water (see table 1) and also space heating. This contributes to valorize efficiently the energy contained in the exhaust namely when multiple microturbine's of high capacity are installed.

On the other hand, the sequential control is generally the mode that generates the highest money savings and increases the overall efficiency of the co-generation system for the same capacity and threshold. This can be explained by the fact that with this mode of control the microturbines operate at full load. Thus, the instantaneous electric and thermal efficiencies are not affected by the operation and remain equal to their respective maximum values as fixed in the technical parameters, say 30% and 45% respectively. In contrast, these two quantities vary with the demand when the continuous control is used: the efficiencies decrease when the microturbine operates at part load.

As mentioned before, the obvious prime markets will occur in utility areas that have customers using electricity for all end-uses (i.e. type I buildings) because of the short payback periods for all the segments studied. Furthermore, segments of type II buildings that require important amounts of hot water are economically viable according to their respective payback periods. The segments in question correspond to education, healthcare and lodging. Effectively, the number of units that could realistically be sold per year to a specifically defined market segment depends highly on the payback realized by potential owners. While owners may accept 2-3 year paybacks, landlords expect 1-2 years and institutions expect 4-5 years. However, some barriers could arise and make the technology unattractive such as interconnection requirements and power electronics that may be involved in the continuous control. These extra costs that may affect the viability of the technology have not been included in the present study.

4.3 Break-even cost

The break-even cost represents the system's cost that generates no money savings and does not lead to any loss of money. Thus, a break-even cost that is higher than the purchase cost per kW is seen as a good indicator for profitability.

The best break-even system cost obtained for each segment is displayed on figure 5. The examination of the figure reveals that the break-even point is very high for type I buildings. This quantity is less important for buildings where gas is present. However, all this segments must generate money savings since the purchase cost have been fixed between \$400 and \$500 per kW. This price coincides with the long term target (year 2010). On the other hand, one may see that the technology is economically viable in most of the segments, especially type I, even with today's price. The actual price of the technology is around \$900 to \$1000 per kilowatt without installation and cogeneration. An extra cost of 100-200 \$/kW is anticipated for cogeneration and similar for installation. The installation cost does not include interconnection cost which depends greatly on local regulation.

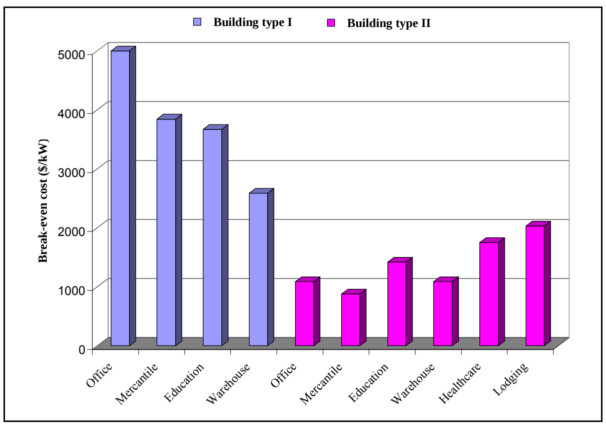


Fig. 5 Break-even cost by segment.

5 Conclusions

The influence of parameters such as the number of microturbines, their capacity, threshold and control strategy on profitability have been investigated for a variety of buildings using exclusively electricity or a combination of electricity and gas.

It has been shown that the technology is viable for most of the market segments. Buildings that use electricity as the only source of energy show a higher profitability. On the other hand, the economic performance is increased when the overall efficiency is enhanced. This situation occurs when the heat rejected by the microturbines is almost or fully recovered to displace thermal loads. In fact, buildings that require large amount of energy for space or water heating appear as more interesting candidates for microturbine cogeneration.

Concerning the control strategy, it has been observed that sequential control is more interesting than continuous modulation for the same installed capacity and threshold parameter. With the latter control, the electric efficiency deteriorates since the microturbines are allowed to run at part load.

The system break even cost shows that the technology is profitable with its today's price. The money savings will increase as the price is reduced in the future. Type I buildings show the highest economic viability.

In general, microturbines present potential savings in the commercial sector in Vermont State when the technology is viewed from the customer's perspective. Besides the attractive economics shown by the technology for most of the commercial market, the technical advantages of microturbines can act as an additional driving force for commercial acceptance.

According to the break-even system cost, some markets are already attractive namely type I buildings regardless the segment, other will become when microturbine prices will decrease.

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