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ABSTRACT

Many industries have begun to recognize that the projected efficiency gains resulting from the sequential production of heat and power by cogeneration equipment can be translated into financial rewards via capital investments in this equipment. These individual investment decisions, moreover, have been the object of Federal policies designed to encourage the use of these technologies since the co-generation of these energy forms conserves scarce natural resources. Whether the commercial sector will be successful in contributing to this national goal is complicated by many factors.

The technical and economic characteristics of a successful cogeneration system can be easily outlined; analyzing the opportunities for such systems in commercial buildings, however, is complicated by the number of interdependent trade-offs that must be made in any given application. One general statement of the problem is that an understanding of the net impact of the trade-offs requires an engineering/economic analysis that can capture the dynamic relationships between the thermal and electrical requirements of commercial buildings, the operating characteristics of the cogeneration equipment, and the utility interface to this operation.

The DOE-2 building energy analysis tool is used to analyze the returns to cogeneration systems for two building types located in five US cities. For these systems, the effects of system sizing and operating strategies on these returns are examined using actual rate schedules. Finally, conclusions are drawn regarding the relative importance of the engineering and economic components of cogeneration systems in commercial buildings.

KEYWORDS: Commercial Buildings, Cogeneration, Economics

INTRODUCTION

Significant opportunities can exist for the owners of commercial buildings to reduce their energy bills by investing in cogeneration equipment. From a societal standpoint, these investments are desirable because the reductions in energy bills are achieved by increasing the efficiency by which the end-uses for energy in buildings are met and because commercial buildings account for a significant fraction of US primary energy use. These investments, beyond generating direct returns, may also represent an important opportunity for building owners and managers to exercise a measure of internal control over an item of operating cost that has recently grown to substantial proportions. The importance of such control is under-scored by the wide-spread perception that these costs are inherently unstable (subject to the control of exogenous forces). Displacing future payments for energy with capital investments today, however, requires that certain criteria of cost-effectiveness be met.

The technical and economic characteristics of a successful cogeneration system can be easily outlined; analyzing the opportunities for such systems in commercial buildings, however, is complicated by the number of interdependent trade-offs that must be made in any given application. Electricity bills with substantial charges for peak demands, for example, may have to be weighed against relatively longer amortization periods for cogeneration equipment in an establishment that only operates forty hours per week. Similarly, economies of scale in plant sizing may have to be tempered by the fluctuating nature of the thermal and electrical loads in commercial buildings. One general statement of the problem is that an understanding of the net impact of these trade-offs requires an engineering/economic analysis, which has a time-step that captures the dynamic relationships between the thermal and electrical requirements of commercial buildings, the operation of the cogeneration equipment and the utility interface to this operation.

The economics of cogeneration in commercial buildings have not been studied as thoroughly as that for industrial applications. Many studies correctly recognize the analytical complexities introduced by the subject matter but do not address them directly (SRI International et al. 1980; Battelle Pacific Northwest Laboratories 1983, vol. II). Some attempts have been made to analyze commercial building loads but then rely on simplifying assumptions, particularly regarding utility rate structures (Office of Technology Assessment 1983; Cummings et al. 1982). Several studies have attempted detailed hourly simulations of commercial building cogeneration the New York City region this approach (Bright, Davitian, and Martorella 1980; Entek Research 1983 ;Rodberg et al. 1984). In summary, the problems presented by analyzing the opportunities for cogeneration in commercial buildings have been only unevenly addressed, with respect to the details of the physical interactions of the systems being studied or geographic scope of analysis.

For the present study, we employ the DOE-2 building energy analysis program to examine how the economics of cogeneration are affected by commercial building loads, regional variations in energy prices, equipment sizing, and strategies for operation. We do not pretend be more comprehensive in our treatment of the entire subject than other studies; indeed, we intend to slight the environmental considerations and the intricate details of project finance. We do illustrate the value of a simulation tool to one phase of such a comprehensive study by using our results to identify and determine the relative importance of the simultaneous processes taking place.

The study begins with a brief review of the major technical and economic issues facing cogeneration projects as a means for setting the stage for the complexities that a simulation tool can address. Next, computer simulations of energy performance and costs are performed for a large office building and a large hotel, located in five climatic/economic regions of the country. In these buildings, two cogeneration systems operating under three different strategies are examined. Finally, simple economic statistics are prepared to compare the worth of the systems and these results are discussed in terms of the effects of the key variables used in the analysis.

TECHNICAL AND ECONOMIC ISSUES FOR COGENERATION SYSTEMS

Cogeneration equipment consists of no more than a traditional prime mover (gas turbines, reciprocating piston engines, or steam turbines), which has been equipped to recover heat as input or an output of the conversion of fuel to mechanical or electrical energy. The efficiency gains of cogeneration equipment result from the sequential production of thermal and electrical energy in a single process that requires less energy than producing these energy forms independently. Large central station power plants, for example, could be considered cogeneration plants, if the heat rejected in the process of making electricity were recovered to some useful end.

Cogeneration technologies vary significantly with respect to their suitability for applications in commercial buildings. Bottoming cycles, where heat is recovered as an input to the energy conversion process, lack a source of high temperature heat in commercial applications. Topping cycles, where heat is recovered as an output of the conversion process, are much more attractive because of the relatively lower temperature thermal requirements in commercial buildings and higher electrical conversion efficiencies.

Within the range of available topping cycle technologies, too, there are wide variations in energy conversion efficiencies, part-load fuel consumption and, of course, installed cost. Natural-gas fired reciprocating piston engines are often cited as the preferred technology for commercial building applications (Office of Technology Assessment 1983; Cummings et al. 1982). These engines offer high electrical conversion efficiencies through a broad range of operating loads and are backed by a large supporting infrastructure. Open-cycle gas turbines are also frequently mentioned as candidates for use in commercial cogeneration systems (Cummings et al. 1982; Kimball and Cohoe 1983). A greater fraction of the fuel consumed in a gas turbine can be recovered in the form of high temperature heat for use in highly efficient absorption chillers, but electrical conversion efficiencies are not as high in the relevant range of sizes (100 kW - 10 MW), part-load performance is often poor, and installed costs are typically higher. For both of these technologies, the development of packaged systems, where the prime mover, heat recovery equipment and controls are sold as a pre-engineered unit, promises to reduce the up-front costs of these systems.

The opportunities for cogeneration in commercial buildings are influenced by many considerations. We outline some of the major issues below in order to give additional background to the issues addressed by the computer simulations.

Thermal energy requirements are the primary constraint that must be addressed in sizing and operating cogeneration equipment. Since the efficiency gains from co-generating thermal and electrical power result from recovering and utilizing energy that would otherwise be wasted and since the utility grid can serve as a sink for excess electrical energy, the benefits of cogeneration depend on the amount of co-generated thermal energy that is utilized. In this sense, recovered thermal energy can be thought of as an additional credit to be applied with the electrical energy and demand charges that are off-set by the on-site generation of power. The value of this credit is often expressed as a net heat rate for the production of electricity (Joskow and Jones 1983)

With respect to the thermal energy requirements of commercial buildings, it is important to note that chilled water for cooling can be produced by heat-driven absorption chillers. Using these chillers, a poor load factor for heat can be improved by including summer demands for cooling.

An important issue for investments in cogeneration equipment that we do not explore is whether less expensive investments in other energy conservation measures exist to reduce the thermal energy requirements of these buildings. Clearly there can be tension between the two in that they compete for investment dollars to address the same thermal end-uses.

Electrical energy requirements are less of a constraint to plant sizing and operation due to the passage of laws permitting electricity to be sold to the utility at fair rates (U. S. Congress 1978). The magnitude of these requirements, however, are very germane since their relationship in time to the thermal energy requirements determines the value of on-site electricity generation; co-generated electricity can either off-set internal needs or be sold to the grid. Additionally, a cogeneration investment has the potential to reduce demand charges, which are typically driven by cooling requirements, by reducing these requirements simultaneously with both outputs of the conversion processes.

The **operating hours** of the facility are the final component of the equation that determines the direct benefits of a cogeneration investment. Unlike many industrial applications, which have continuous needs for thermal energy, the energy requirements of commercial buildings are largely a function of the businesses that operate within them. The highly efficient conversion of energy by cogeneration equipment, if performed only sparingly, may result in an un-acceptably long amortization period for the investment.

The **cost and availability of competing forms of energy** represents the opportunity cost of a cogeneration investment. Cogeneration can be properly thought of as a fuel-switching strategy in which fuel is being purchased to off-set the need for power from the utility. In this framework, the relative cost of utility power to that of co-generated power (credited for recovered thermal energy) determines the returns for the investment. Since, in most cases, natural gas or another gaseous fuel will be used to run the cogeneration equipment, the cost of this fuel must off-set the cost of the fuel and electricity used to run a conventionally-equipped building. These costs, moreover, exhibit wide regional variations.

There remain at least two further contributing issues that are not addressed in this study: the **environmental quality impacts** of and the **availability of space** for cogeneration equipment. The first issue is of particular concern because there are substantial air pollution impacts created by the prime movers. The second issue, while less of concern for buildings that are still in the design stage, does have associated with it an opportunity cost in the form of foregone revenues for rental space. Also contained in this issue and related to the first are the acoustical and vibrational impacts associated with siting a cogeneration plant within a building. A convenient device for treating these issues is to attach a premium to the first cost of the systems.

The foregoing discussion has been motivated by the hypotheses that an understanding of opportunities for cogeneration in commercial buildings must recognize the time-varying processes involved. These include the thermal and electrical energy requirements of the buildings, the energy conversion properties of cogeneration equipment and the utility rate structures with which the performance of the systems will be measured, and that a computer simulation can capture them. We turn now to a discussion of this simulation methodology.

SIMULATION PROCEDURE AND ASSUMPTIONS

The simulations that form the basis of the present analysis consist of four components: The simulation tool, the building types, the climatic/economic regions in which they operate and the proposed cogeneration systems.

The simulation tool used in this study is a modified version of the DOE-2.1 building energy analysis program. The hourly time-step of the program permits a level of detail in the engineering and economic calculations that is essential for developing an understanding of the interactions described in the previous section. The specific modifications (to be incorporated into DOE-2.1C) permit the simulation of advanced cogeneration operating strategies and a detailed accounting of the utility interface, particularly with respect to demand charges and the sale of electricity to the utility (Building Energy Simulation Group 1984).

Two distinct building proto-types are simulated to span a range of thermal and electrical loads. An office building represents one extreme with short operating hours, highly concentrated electrical demands during the peak hours of most utilities and low thermal requirements. The other extreme is represented by a hotel with near continuous operation, relatively constant electrical demands and large thermal requirements. Both proto-types are based on actual buildings constructed in 1981 but have been modified to meet Standard 90-75 (The American Society of Heating, Refrigeration, and Air-conditioning Engineers, Inc. 1975). Detailed descriptions of the building structure, air-side HVAC systems and operation are contained in Battelle Pacific Northwest Laboratories 1983, vol. III.

Five geographic locations are used to represent diversity in both climatic regimes and utility rates/structures for the US. The cities selected for this study are El Paso, TX, Seattle, WA, Washington, DC, Houston, TX and Milwaukee, WI. An extended discussion of the selection methodology is contained in the previous reference and the details of the rate schedules are contained in Battelle Pacific Northwest Laboratories 1983, vol. III, app. A) The effects of these variations are reflected in the the resulting end-uses energy requirements for the buildings and energy costs of operating a conventional central plant to meet these requirements.

The energy requirements for the central plants of each building proto-type are presented on Table I in the form of load factors for each of the three end-use energy requirements of the buildings. Load factors relate peak demands to the average demand in order to capture the relative magnitudes of the time-varying nature of these energy requirements. The climates distinguish themselves by the variations in load factors for the thermal energy requirements, while the electric load factors are nearly constant. As expected, the load factors for the hotel are uniformly higher than those for the office building, indicating a much closer relationship between the average demand and the peak demand stemming from longer hours of operation.

In a much more dramatic fashion, the geographic regions and building types distinguish themselves by the energy bills resulting from operating a conventionally equipped central plant (see Table II). The differences are highlighted by the wide variation in average costs for natural gas and electricity, not only across utility territories, but between building types on the same rate schedule. In particular, high demand charges in Washington, D.C., and Milwaukee combined with a poor load factor for electricity result in significantly higher average electricity costs for the office building than the hotel. Also of note is the extremely low cost of electricity in

Seattle where natural gas is actually more expensive than electricity on a site Btu basis.

Information on buy-back rates for electricity was not available for Milwaukee, Houston, and Washington, D.C. and hypothetical low values were used, based on the actual rates used for Seattle and El Paso (Resource Dynamics Corporation 1983). In discussing our results, the effect of this assumption will be isolated by presenting the value of electricity sales separately.

The simulation of the cogeneration systems is composed of three components: technology, sizing and operating strategy.

Without pre-judging the merits of gas turbines and spark-ignition reciprocating engines, we have selected a natural-gas fired diesel engine for this study. The performance of this engine is derived from values that are typical for commercially available machines and is not intended to represent any one manufacturer's product. In operation, 70 % of the fuel consumed is converted to heat and power for use in meeting the energy requirements of the building. At full-load, 27 % of the fuel is converted to electricity, which translates to a net heat rate of 5846 Btu/kWh. Operating cost factors are derived from a OTA study of industrial and commercial cogeneration (Office of Technology Assessment 1983).

One and two identically sized 350 kW machines are examined so that the plant is sized to meet two different fractions of the thermal load. We know, *prima facie*, that thermal energy generated in excess of building demands will be wasted (barring the existence of thermal storage) and thereby reduce the value of the electricity produced. Hence, sizing to meet some part of the thermal load will ensure that recovered heat can be utilized. The trade-off is that sizing to meet a greater fraction of these demands will result in excess capacity more of the time.

There are three possible operating strategies for a cogeneration system: track electrical loads, track thermal loads or run full-out. The first and the third suffer from a potential to waste significant amounts of recoverable thermal energy. One may be economically justified in wasting thermal energy, however, if electricity rates, in particular demand charges, are high enough. Tracking thermal loads ensures that all recovered energy will be utilized but may result in the sale of excess electricity at rates that can not cover the incremental cost of operating. In this situation, one is better off not generating this extra electricity, even if some thermal needs are then met by a conventional boiler or chiller.

We examine three strategies for operating a cogeneration system. The first is to follow the thermal load, where some of that load is composed of heat-driven absorption chillers, which meet cooling requirements. The second is a hybrid strategy that tracks the lesser of the thermal and electrical demands, so that no electricity or thermal energy is generated in excess of on-site demands. The third is also a hybrid strategy; it tracks the greater of the thermal and electrical demands. Undersizing the machines has the effect of simply running the machines full-out when the load being followed is in excess of the capacity of the machines. Finally, for each strategy, no machine is allowed to run below 15 % of rated capacity.

The worth of a cogeneration plant is expressible as the value of the energy costs offset by system, net of the additional operating expense, compared to the cost of the investment. We turn now to a discussion of these results.

RESULTS OF THE SIMULATIONS

The results of the simulations indicate that, with few exceptions, the cost of co-generating heat and power can not compete with the cost of operating a conventional plant. In general, while electricity costs are reduced, the increased cost of natural gas tends to overwhelm any gains and where there are reductions in energy bills, the additional cost of operating a cogeneration plant usually serves to off-set them. In this situation, the value of the investment term is irrelevant since the returns are negative.

The returns are not uniform, however, and their differences can be used to determine the relative importance of the issues described in the second section. The primary statistic used in this discussion is the capacity factor of the cogeneration plant, which is a measure of plant's operation for the year and is defined as the ratio of the actual output of electricity by the plant to a hypothetical output given by the maximum rating of the plant multiplied by 8760. It is related to the concept of the load factor in that it compares the average demand to a maximum demand. In this case, the maximum demand is based on the rating of the plant rather than the highest recorded demand. The capacity factors and components of the net savings for each of the cogeneration plants are presented on Tables III and IV.

The value of the thermal credit created by recovering heat to some useful end is illustrated by the higher returns to the systems that track thermal demands. For either choice of plant size, tracking thermal demands yields consistently higher returns than tracking electrical demands. The results for tracking the lesser of the two demands are very similar to those for tracking thermal demands indicating that this strategy is tracking thermal demands most of the time. Hence, for the assumed plant sizes, tracking electrical demands results in the production of thermal energy that is not recovered. Under these circumstances, a high capacity factor for a strategy that tracks electrical demands is of little value when the thermal energy co-produced is not utilized.

Since electrical demands typically exceed those for thermal energy, most of the electricity produced by the cogeneration equipment is used on-site. Sales of electricity are consequently small and the bulk of electricity generated is being used to off-set purchases from the utility. With respect to the uncertainties in the buy-back rates that were assumed for the sales of electricity, only large increases in these rates would alter the trends in net savings.

Holding the operating strategies fixed to compare the results for the two plant sizes highlights the value of sizing the plant to meet only a fraction of the end-use energy requirements of the buildings. In all cases, the smaller plants have better returns than the larger plants. This result correlates well with the higher capacity factors of the smaller plants, for a given operating strategy. Higher capacity factors mean that the smaller plant uses more of its capacity a greater fraction of the time. This result can also be anticipated by referring to the low load factors for the end-use energy requirements of the two buildings (see Table I).

Comparing the results for the two building types begins to place the importance of the operation and sizing of these systems into the context of the larger driving force behind the operating losses. The cogeneration systems in the hotel have consistently higher capacity factors than those for the office building, yet the same systems, operated identically, in the office building have higher returns. Higher returns from lower utilization of the cogeneration equipment point to the dominating effect imposed by the rate differentials for electricity between the office building and the hotel. Co-generated electricity is off-setting purchases of electricity from the utility and the relative worth of these avoided purchases can be alluded to by comparing the average cost of electricity to the buildings, presented on Table II (the value is properly given by the incremental cost of electricity purchases for the building). The average cost of electricity to the office building is always greater than that to the hotel, while the average cost of natural gas is nearly identical for the two buildings. The effect of the differences in average electricity prices is to more than compensate for lower capacity factor of the cogeneration equipment.

The final step in the analysis compares the results across cities. The returns for the systems in Seattle are consistently the lowest, while those for Milwaukee are always the highest. Again, capacity factors do not correlate well with operating losses. For the smaller systems in the office building, the capacity factors are very close indicating similar levels of operation, despite the climatic variations between the cities.

Similar levels of operation for identical operating strategies indicate that the differences between these results stem from the relative costs of natural gas and electricity and that these differences are the driving force behind the net savings of cogeneration systems. From the standpoint of fuel-switching, it is clear that the value of substituting natural gas for electricity is given by the relative prices of the two energy forms. In Seattle, the average cost of electricity and natural gas are very close so that the effect of fuel-switching is to incur substantial operating losses. At the same time, the office building in Milwaukee is faced with the highest differential and the result is a much greater return.

The absolute level of the costs for natural gas and electricity, in addition to the cost differential between them, also serves to explain the differences between the cities. The cost differential for the office building in Washington, D.C. is nearly as great as that for Milwaukee but, for a given system and operating strategy with similar capacity factors, the results are much worse. Comparison of the electricity and natural gas purchases for these cities reveals that natural gas costs for Washington, D.C. are nearly twice that for Milwaukee.

While the negative results of the simulations indicate that the prospects for cogeneration in commercial buildings are dubious, meaningful conclusions regarding the relative importance of the underlying processes can still be made. In particular, the importance of utilizing both outputs of the conversion process and sizing the system so that the rate of utilization is high can be noted. In absolute terms, however, this importance can only be measured in the context of the energy costs that are off-set by cogeneration investments and these costs can vary widely, even for the same rate schedule. The opportunities for cogeneration in commercial buildings, consequently, will be determined by the levels and relative prices of natural gas and electricity.

CONCLUSION

We have used a computer simulation to capture the individual effects of the time-varying processes that contribute to the economic worth of cogeneration systems in commercial buildings. These processes include the thermal and electrical energy requirements of the buildings, the operating characteristics of cogeneration equipment, and the utility interface to this operation.

We conclude that the utility interface is the dominant term in the equation. In particular, the level and relative cost of electricity and natural gas far outweigh the importance of the specific energy requirements of the buildings and the levels of operation of the equipment.

Cogeneration investments, then, are best thought of as a fuel-switching strategy in which natural gas substitutes for electricity and the value of this substitution is given by the prices for these two forms of energy. These prices show wide regional variations and, for electricity, similar variations due the structure of the rates. The opportunities for cogeneration in commercial buildings, therefore, depend on the local economics of the energy supply systems, as translated into effective rates for the potential cogenerator. Only when this constraint is satisfied do the intricacies of system sizing and operation become important considerations.

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Table I. Load factors for end-use energy requirements.

	Office Building			Hotel		
	Heat	Cool	Electric	Heat	Cool	Electric
Seattle	.12	.07	.34	.23	.12	.75
Milwaukee	.14	.09	.34	.22	.15	.76
Houston	.06	.16	.33	.21	.33	.77
El Paso	.08	.15	.33	.19	.30	.77
Washington, D.C.	.11	.11	.34	.21	.19	.76

$$Load\ Factor = \frac{Annual\ Demand\ /8760}{Peak\ Demand}$$

Table II. Energy costs for conventional central plants (k 1982$).

	Office Building				Hotel			
	Electricity		Natural Gas		Electricity		Natural Gas	
Seattle	191.44	(6.71)* ((.26))**	72.15	(6.04)	75.48	(5.28) ((.56))	95.95	(6.14)
Milwaukee	632.72	(21.44) ((.26))	61.72	(4.92)	218.91	(14.27) ((.55))	99.87	(4.92)
Houston	542.61	(17.22) ((.28))	25.06	(5.45)	320.31	(16.85) ((.60))	50.38	(5.43)
El Paso	330.54	(10.89) ((.27))	22.41	(3.92)	188.60	(10.94) ((.62))	44.04	(3.90)
Washington, D.C.	831.50	(26.83) ((.26))	112.96	(10.63)	302.71	(18.10) ((.56))	154.79	(9.97)

* Average cost in parentheses = $/mbtu

** Electric load factor in double parentheses

Table III. Results for the office building (k 1982$).

	Capacity Factor	Electricity Purchases	Natural-Gas	Electricity Sales	Operation & Maintenance	Net Savings
Seattle						
One engine - 350 kW						
track thermal	.45	159.71	153.11	.02	19.57	-68.78
track lesser	.45	159.71	153.09	0.	19.55	-68.76
track greater	.74	147.62	223.79	.02	29.77	-137.57
Two engines - 700 kW						
track thermal	.37	137.01	203.68	.99	33.11	-109.22
track lesser	.35	137.10	201.87	0.	31.98	-107.36
track greater	.61	116.60	321.40	.99	50.33	-233.75
Milwaukee						
One engine - 350 kW						
track thermal	.46	541.55	125.74	.12	20.06	7.21
track lesser	.46	541.56	125.70	0.	20.01	7.17
track greater	.76	506.30	183.13	.12	34.90	-25.60
Two engines - 700 kW						
track thermal	.39	480.96	173.03	6.17	34.90	11.73
track lesser	.36	481.13	169.95	0.	32.56	10.80
track greater	.64	404.74	269.69	6.17	52.58	-26.40
Houston						
One engine - 350 kW						
track thermal	.45	446.13	120.84	.98	19.68	-17.90
track lesser	.45	446.17	120.74	0.	19.48	-18.72
track greater	.69	404.78	174.30	.98	28.15	-38.58
Two engines - 700 kW						
track thermal	.41	369.36	201.41	11.93	36.50	-27.67
track lesser	.40	369.58	199.40	0.	35.38	-36.69
track greater	.57	314.49	272.60	11.93	47.88	-55.37
El Paso						
One engine - 350 kW						
track thermal	.46	267.83	89.86	.54	19.93	-24.13
track lesser	.46	267.85	89.79	0.	19.83	-24.52
track greater	.72	238.67	130.00	.54	29.13	-44.31
Two engines - 700 kW						
track thermal	.40	224.16	142.02	7.54	35.76	-41.45
track lesser	.38	224.29	140.21	0.	34.35	-45.90
track greater	.59	181.91	200.30	7.54	49.10	-70.82
Washington, D.C						
One engine - 350 kW						
track thermal	.47	716.16	250.83	.06	20.33	-42.80
track lesser	.47	716.17	250.80	0.	20.30	-42.81
track greater	.74	682.58	351.42	.06	29.82	-119.30
Two engines - 700 kW						
track thermal	.41	621.30	351.27	4.17	36.14	-60.08
track lesser	.39	621.50	346.89	0.	34.59	-58.52
track greater	.62	566.44	512.75	4.17	50.97	-181.54

Table IV. Results for the hotel (k 1982$).

	Capacity Factor	Electricity Purchases	Natural-Gas	Electricity Sales	Operation & Maintenance	Net Savings
Seattle						
One engine - 350 kW						
track thermal	.58	40.23	194.69	.00	24.12	-87.61
track lesser	.58	40.23	194.68	0.	24.12	-87.60
track greater	1.00	21.08	285.03	.00	39.31	-173.98
Two engines - 700 kW						
track thermal	.33	36.80	212.28	.88	30.89	-99.65
track lesser	.32	36.81	210.51	0.	29.91	-105.80
track greater	.65	.04	363.06	.88	53.65	-244.44
Milwaukee						
One engine - 350 kW						
track thermal	.79	97.00	207.24	.41	31.80	-16.85
track lesser	.79	97.00	207.10	0.	31.65	-16.97
track greater	1.00	69.36	244.98	.41	39.73	-34.88
Two engines - 700 kW						
track thermal	.51	70.61	244.00	11.57	43.53	-27.79
track lesser	.47	70.67	239.79	0.	40.61	-32.29
track greater	.70	2.74	318.32	11.57	57.53	-48.04
Houston						
One engine - 350 kW						
track thermal	.87	135.59	230.76	1.12	34.75	-29.29
track lesser	.87	135.61	230.67	0.	34.65	-30.24
track greater	1.00	109.58	258.63	1.12	40.15	-36.55
Two engines - 700 kW						
track thermal	.67	50.14	330.32	35.64	55.05	-29.18
track lesser	.63	50.22	324.52	0.	51.71	-55.76
track greater	.80	3.62	383.91	35.64	64.34	-45.54
El Paso						
One engine - 350 kW						
track thermal	.83	75.12	162.40	.12	33.31	-38.07
track lesser	.83	75.13	162.39	0.	33.29	-38.17
track greater	1.00	54.14	186.88	.12	39.95	-48.21
Two engines - 700 kW						
track thermal	.59	40.38	211.85	20.93	49.06	-47.72
track lesser	.53	40.47	106.76	0.	45.09	-59.68
track greater	.76	.19	261.87	20.93	61.11	-69.60
Washington, D.C						
One engine - 350 kW						
track thermal	.82	140.82	382.07	.16	32.96	-98.19
track lesser	.82	140.83	382.00	0.	32.90	-98.23
track greater	1.00	119.17	449.43	.16	39.85	-150.79
Two engines - 700 kW						
track thermal	.56	81.23	460.74	7.32	47.00	-124.16
track lesser	.52	81.30	454.77	0.	44.26	-122.83
track greater	.74	12.82	603.66	7.32	59.68	-211.34

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