ENERGY USE IN THE ENERPLEX OFFICE BUILDINGS: A PROGRESS REPORT

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ABSTRACT

A full year of energy-use data is now available for two new, heavily instrumented office buildings which incorporate a variety of technologies designed to reduce energy consumption. We present monthly, disaggregated energy use in both buildings. One building, fully occupied, has exceeded its target energy budget by a factor of three, due to unanticipated and large electricity use by computers and a cafeteria; the need to remove the heat generated by this equipment and the inability to use the heat in winter; a failure to take advantage of the daylighting features designed in the building envelope; and limitations in the design and operation of the HVAC controls. Our study of the heat pumps and ventilation system in the other, partially occupied building has pinpointed fan and heat pump performance which is both somewhat less than predicted and difficult for the building superintendent to detect. We identify modifications the superintendent has made to the controls, in some cases reducing energy use and in others, particularly in overriding night setback, greatly increasing energy use. The superintendent's need for more information in adjusting the controls is highlighted.

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INTRODUCTION

The Enerplex buildings are a pair of all-electric, speculative office buildings located in Plainsboro, New Jersey. Designed in the late 1970's and occupied for about two years, these buildings incorporate a number of energy saving architectural and engineering features (Norford et al. 1984). We have heavily instrumented the buildings as part of a multiyear effort, begun in 1982, to assess their performance. While influenced by the startup woes experienced by most buildings, data to date indicate that reaching the frontier of low-energy commercial buildings has proved to be a task more challenging than initially anticipated (Norford et al. 1985).

Consider that in Enerplex North, fully occupied in contrast to the 40% rented South building, measured site-energy use exceeds predicted by a factor of 3.3, taking the building from 35,000 to 118,000 Btu/y ft^2 (400 - 1330 MJ/y m^2). The key factor driving the increase is occupant energy use; the tenant embraces the computer but shuns the building's daylighting potential. HVAC controls have failed to perform properly as well, where failure is broadly defined to include a lack of information provided to the building superintendent and a lack of flexibility in permitting adjustment. And recent measurements reveal that such major equipment as fans and heat pumps/chillers may not be living up to specified performance and, more importantly, do not readily indicate their efficiency to the operator.

The evidence compels us to conclude that the team involved in achieving the energy efficiency promised by the technology embodied in the buildings must include more players than the design architect and engineers. The owner, the operator, the tenant, those who plan the layout of the tenant's rented space - all have a role. While this conclusion hardly breaks new ground, especially for speculative buildings, the data and analysis presented in this paper provide important and generalizable insights into particular problems faced by such buildings and those involved in their design, operation and use.

SITE ENERGY DISAGGREGATION - FOCUS ON ENERPLEX NORTH

Annual energy use for both buildings is disaggregated and compared to prediction in Tables 1 and 2; Figures 1 and 2 show monthly disaggregation. Predictions, made with DOE-2 and a microcomputer-based daylighting calculations (Norford et al. 1984; Princeton Energy Group 1984), yielded results in good agreement with predictions made by an independent firm hired by the building mechanical engineers (Nall 1981). Disaggregation is that permitted at reasonable cost by the building wiring; for example, we measure electric service to tenant space in the North building, but cannot separate lights and office equipment. Much of the North building computer center could have been monitored with a single meter but this facility was planned after our meters were in place and we have relied on spot measurements.

Occupants

Our data acquisition system, supplemented by spot measurements with a portable power meter and an occupant survey (Petrini and Krufka 1985), sheds light on how the North building tenant used energy in August, 1985. As indicated in Figure 3, the tenant's computer center, with its dedicated chillers, used 60 kW around the clock, or 13,800 Btu/y ft^2 (157 MJ/y m^2); absent additional data, we have considered this figure to be relatively constant, varying perhaps 10-20% with the volume of tenant business. (In the South building, a computer facility has been nearly shut down as a tenant's business has changed, pointing to the need for frequent measurements or observations.) Similar measurements of kitchen equipment yielded 6,100 Btu/y ft^2 (69 MJ/y m^2). Predicted equipment energy use for office space of the same areas, at 0.5 W/ft^2 and 50 hours per week, was only 3% of the measured value.

Realizing that the modern tenant lives by both bread and bytes, one does not approach the enormous measurement-prediction difference for tenant energy use by sanctifying a prediction made just prior to the electronic-office era and labeling the tenant as a profligate energy consumer. But the difference is more than an artifact of an outdated model and yields at least two lessons:

1. Energy used by computers and kitchens tends to shift the base from which the efficacy of the building envelope and HVAC equipment should be judged.

2. The Enerplex buildings, like other speculative buildings, lack the built-in flexibility to make use of large, unanticipated, internal heat sources. Heat recovery from central computer facilities is common when such a facility is anticipated, as in a building designed for a particular client. Enerplex North has electric-resistance heating coils located in ventilation duct terminal boxes throughout the building, and it is hard argue for heat recovery as a retrofit measure, given this investment. A more flexible system at the design stage might be based on a water loop throughout the building, with local heat pumps withdrawing or adding heat to the loop as needed. Such heat pumps could supply year-round process heat for kitchens as well as winter space heat for offices. This system has been used in an ASHRAE award-winning building (ASHRAE 1986) and is currently subject to EPRI-directed research.

Energy use in the tenant's general-purpose office areas is driven by lights and personal computers. Lighting is a far cry from what the building designers anticipated: very little of the planned 25-30% annual reduction in overhead lighting due to daylighting has been achieved and overhead lights are supplemented by task lighting. The transformation from design to practice - tenant plans not in harmony with those of the architect - has been difficult for us as energy analysts to trace but seems to include less-than-ideal communication with the tenant and perhaps unrealistic expectations as well.

The tenant, working with an architect other than the building designer, chose to put managers in individual, enclosed offices along the exterior walls and other employees in areas bounded by head-high partitions. Many of the latter areas border the glazed walls which separate office space from the sky-lighted corridors and were intended by the designer to receive natural light. The partitions and associated shelving, furnishings which the tenant brought from his previous building, severely restrict daylighting at the work surface and in most cases require task lighting as well. Partitions and blinds have also been used to enhance privacy by blocking off the glazing bordering the corridors and the atrium and, in fewer cases, the glazing in outside walls. Privacy is compromised in offices used by managers through the use of glass walls separating the offices from the general work areas. These walls were installed because the offices are 12 ft (4 m) deep and natural light was estimated to be effective as far as 15 ft (5 m) from the exterior windows.

With daylighting benefits keyed to an open office plan and a small number of photocells (one per facade per floor), and with the tenant's interior layout so different, it is not surprising that the tenant elected not to install the larger number of photocells which would be required to achieve a savings less than predicted at the design stage. As a result, displacement of electric lighting is due only to limited manual control. What remains are two tradeoffs and one unqualified technology winner:

1. Reduced privacy, where it is not combated with opaque walls, gives office space an airy, spacious feeling that has appeal even without lighting savings.

2. The skylights above the corridors greatly reduce lighting requirements in the corridors and make for a very pleasant space, even without displacing office electric lighting. However, modeling in the very similar South building showed that even the full daylighting benefit from the skylights was only enough to balance the thermal penalties due to using glazing rather than opaque, insulated roofing (Norford 1984).

3. Efficient light fixtures, with 32 W fluorescent tubes, parabolic reflectors and solid state ballasts, were installed. They are rated at 1.4 W/ft^2, about 2/3 the level achieved with 40 W bulbs and less efficient ballasts. This technology has proved to work well.

We have recently mapped tenant general-purpose office electricity use throughout a week, with the results shown in Figure 4. Only 56 percent of the electricity use occurs during the 7 am - 6 pm weekday time period, followed by weekends, weekday evenings, and weekday mornings. The profile of hourly weekday electricity use on the electrical risers serving the tenant can be used to semi-quantitatively separate lights from personal computers and other office equipment. Tenant use approaches 3 W/ft^2 during business hours. Lights account for about 1.5 W/ft^2, leaving the remainder for personal computers, copying machines, and other equipment. In contrast to the sharp rise in electricity use at 7 am, the decline in the evening gradually occurs over 5 hours. This reflects the 5:30 pm departure time for many employees and the arrival of the cleaning crew, who keep many of the lights on and don't turn them all off until about 10 pm. What remains during the night is a combination of equipment, some task lights which may have been left on, and a few overhead lights which are energized for safety reasons.

Electricity used by personal computers and other equipment appears to be less than 1.5 W/ft^2 during business hours. We estimate that most of the night energy use (after the cleaners depart) comes from these machines, and not from lights. The data suggest, and our own experiences confirm, that the computer revolution contributes not only to daytime electricity peaks, but has boosted off-hour consumption as well. Dealing with the information age's energy bill may involve making it easier to turn off equipment at night and on weekends (by making it faster to turn on a machine in the morning, with features like clock/calendars) as well as looking harder at how a computer uses electricity. We have not yet shared our data with the tenant but plan to do so and monitor the response, via meters and interviews.

Cooling

Measured cooling energy consumption of 17,000 Btu/y ft^2 (193 MJ/y m^2) exceeds the 6,500 Btu/y ft^2 (74 MJ/y m^2) prediction by 10,500 Btu/y ft^2 (119 MJ/y m^2). Measured energy includes the benefit of the ice pond, a seasonal cold storage system used in series with the chillers (Kirkpatrick et al. 1986). The ice pond, partially filled in its first year of operation, provided 200 MWh (thermal) of cooling at a COP of 8; in its absence the chillers would have provided this cooling, stretching the gap between measurement and prediction. The difference in cooling energy is primarily due to the increased heat generated by the tenant's equipment. Secondary effects include a chiller COP possibly lower than the COP of 2.4 used in our predictions (a full power COP of 2.8 was specified during the building design stage); and fan energies greater than predicted, thereby generating more heat. The weather in 1985 closely followed the long-term average: at base 65 F (18 C), 1985's cooling degree days were 1% larger than the long-term average, while the heating degree days were 3% lower. If we account for the increase in occupant and fan energy use, and credit the ice pond and the computer center's dedicated chillers, we estimate a 1985 seasonal chiller COP of 2.1. We have measured a wide range of chiller COPs this year (0.6-2.3), when the ice pond has been running in series with the chillers and serving as a peak shaver. The upper end of this range corresponds to conditions comparable to what the chillers experienced last year, running alone: large chiller cooling loads and relatively high evaporator inlet temperatures.

Heating - An Argument for Smarter Controls

With increased internal loads, it is surprising that the heating energy also exceeds prediction. Two factors were at work in the 1985-86 winter: the tenant favored a 72 F (22 C) indoor temperature in lieu of the 68 F (20 C) used in the prediction, and the building was heated to 72 F (22 C) around the clock for nearly three months. Constant winter heating was implemented in both buildings by the superintendent, who overrode the night setback controls.

Tenants in both buildings complained about a lack of heat caused by poorly adjusted ventilation duct terminal boxes which were supplying too much cool air to the offices. The boxes are a key feature of a variable-air-volume (VAV) system, a technology used for the past 10-15 years to reduce fan power and simultaneous heating and cooling. Figure 5 shows a schematic of the box and its intended winter operation in the South Building. The flow of 55 F (13 C) supply air is throttled to a minimum as the indoor temperature drops. A further temperature decrease causes the thermostat to open the hot water valve supplying the heating coil. Conversely, if indoor temperature increases, first the valve closes and then the supply air damper opens. Damper adjustment involves setting the stops for the minimum and maximum positions. The contractor who adjusted the dampers misread the engineer's plans and set the minimum stop too high, thwarting the potential benefit of the technology and increasing the simultaneous heating and cooling.

This problem was slowly corrected over the winter; 100 boxes in each building required readjustment. The building superintendent, aware of the impact of the problem, yet sensitive to occupant needs, overrode the controller which both allows the building to cool off during unoccupied periods and schedules the startup of the heating plant at a time which should increase indoor temperatures to a comfortable level by the beginning of the workday. He felt that if the building were allowed to cool down the controls would not start the heating plant in time, partly because the fans brought cool air into the offices making it more difficult to boost the temperature.

A homeowner, faced with a nighttime temperature setback which seems too severe, might respond by reprogramming his thermostat to decrease the setback, rather than eliminating setback completely. The Enerplex superintendent could not as easily choose that option, because each building has 100 thermostats. Changing individual thermostats requires intruding into occupied offices or working when the building is unoccupied, and requires record-keeping as well (when was a given thermostat adjusted? how much? what was the effect?)

The decision to continuously condition the buildings had a significant impact on total building energy use. Figure 6 displays daily total building energy use versus average outdoor temperature. Here 24-hour operation has been distinguished from normal conditions, when the controls automatically schedule the heat. The difference in weekday energy use, about 4 MWh/day, can be explained primarily by the fans: while the indoor-outdoor temperature difference increases slightly, it's the fan-induced increase in the total heat-loss coefficient (conduction plus airflow) which dominates. Continuous conditioning means throwing a single switch which informs the control system that the building is to be considered occupied at all times. Not only are the central fans activated but, without changing the control logic, outdoor air is brought in as well. The outdoor air is needed for ventilation but not, of course, when the building is in fact unoccupied. Even the minimum flow of outdoor air into the building can increase the heat-loss coefficient by 50 percent over the value appropriate for conduction and infiltration.

Figure 6 does not include indoor temperature and it is necessary to determine whether the controls worked properly before the superintendent overrode them. Figure 7 shows indoor temperatures, measured at five locations in the return air plenum on the second floor, for a week in December, 1985. The workday thermostat setpoint was 72 F (22 C). Only on Monday mornings, after the building had cooled over a weekend, did the controller fail to raise the temperature in time. Morning warmup performance for these and other days is quantified in Table 3.

It is probable that our data do not include the hottest or coldest offices. Our sensors showed a 3-4 F (2 C) spread even when the building was conditioned 24 hours a day. Fine tuning the building by adjusting individual thermostats would be far more efficient than continuously conditioning the entire building and may well be more effective in dealing with local problems. Again, thermostat adjustment is more time-consuming and intrusive than changing the central controls. The superintendent of one of the multifamily apartment buildings we are studying has also favored adjustments to central rather than local controls in response to complaints.

Based on our data, a better response to cold Mondays would have involved starting the warmup earlier after a weekend, or programming the controller to treat Sunday as a work day. Because the data were not analyzed and shared with the superintendent until late February, 1986, what we consider to be unnecessary 24-hour/day conditioning occurred for most of the winter. This action cost 75 MWh in the South building and 400 MWh in the North building; the latter amounts to about 9 percent of the annual energy consumption and is worth at least $20,000. The potential energy-savings embodied in the Enerplex night setback controls has not yet been realized. The lack of real-time information provided by the controls and their inflexibility in permitting prompt local adjustments has hampered the superintendent and has placed the building shakedown period on a yearly rather than monthly time scale. Next winter the superintendent plans to use the controls and adjust them as necessary. In addition, digital control of HVAC startup, offering improved communication and control, may soon be installed in the North building.

SOUTH BUILDING - HVAC TECHNOLOGIES EXAMINED

The South Building uses the same VAV fan system as the North Building and incorporates groundwater-coupled heat pumps for both heating and cooling. Our analyses to date show that both technologies have not yet been as effective as predicted and that the superintendent is in a poor position to evaluate them.

The fan system varies the flow of nearly constant-temperature air, a clear improvement over fixed flow systems. Variable-pitch vanes attached to the inlets of centrifugal fans regulate the flow. Table 4 shows the predicted (from long-term average weather) and measured central fan monthly energy use. Even in warm weather, fan energy significantly exceeded prediction. In summer we expected the differences to be small, because the internal loads in the building are comparable to what was predicted, because predicted central fan energy use varied weakly with weather, and because the fan operating schedule was similar to that used in the predictive model. The large difference in winter months is due in part to continuous operation of the fans.

Based on the building specifications for maximum fan airflow and fan motor size and efficiency, and the DOE-2 part-load fan efficiency curves, we expected the performance shown in Figure 8. This figure also shows what we've measured; the fans flow is typically 10-12 m^3/s (21,000-26,000 cfm), where the ratio of measured to predicted power is 1.7, in good agreement with the ratios of monthly energy use. It is not yet known how pressure drops in the ventilation system, which linearly influence fan power at a fixed flow rate and fan and motor efficiency, compare with the building specifications. Figure 8 also includes the DOE-2 part-load curve for variable-speed-motor-drive fan control. Using the DOE-2 variable-inlet-vane and variable-speed-drive curves, a VSD retrofit was predicted to save 66 MWh/year, or 47 percent of the annual central fan energy consumption; the payback period, including engineering costs, is 3-5 years. While VSD control may not in practice match the DOE-2 part-load curve, the fan curve we have measured suggests that the benefits from a VSD retrofit may well be larger than estimated.

Our analysis is not complex but the generation of part-load curves and their use in evaluating potential retrofits is not part of a building superintendent's normal routine. This kind of information could be provided by an energy management system capable of logging airflow and fan power. Airflow measurement is already needed for VAV control; the benefit stemming from a Watt transducer amply justifies its installation.

The heat pumps, based on the engineer's specifications, were expected to perform with a COP of 4.0 in the winter and 5.4 in the summer, with little variation as a function of load above very low part-loads. Figure 9 indicates that the measured winter performance has not fully matched expectation. The typical winter COP of 3.3 shows a small variation as the condenser outlet temperature varies over even a 1-2 F (1 C) range and plummets under low loads, when the heat pump runs during setback periods and delivers very little heat. The COP drops to about 2.7 when the power for well, condenser and evaporator pumps is included; this is the COP is for delivered heat that can be compared with the COP of 1.0 for the North Building electric resistance heat. It is not yet known why the measured COP values for winter only reaches 80-85 percent of the expected values. Recent summer data yield a COP of 4.2-5.3. The lower COP values have been been noted for higher cooling loads when the condenser inlet water temperature has been higher than the specified setpoint.

As with the fans, heat pump performance is normally not measured in a meaningful way by the building operator. Key parameters are delivered heating or cooling and electrical input; ignorance of their values can be expensive. If a building overheats in summer and the chillers are running at peak electrical input, does the building superintendent conclude that internal loads are so large that another chiller is needed? The building operator should be able to easily assess the performance of the installed cooling equipment before reaching such a conclusion.

In examining the factors leading to continuous winter conditioning, we identified a need for the kind of communication between superintendent and local HVAC units which would permit easy measurement of local temperatures and easy adjustment of local controls. Such communication, which was recently suggested by others as well (Int-Hout 1986) would permit the superintendent or an automatic controller to better adjust the central fans and heat pumps. For example, the heat pumps are designed to provide very cool (55 F (13 C)) air to all offices throughout the summer. Each VAV box adjusts the flow as required to maintain the thermostat setpoint. Warmer, unconditioned air is adequate if it provides sufficient cooling when the VAV box is wide open. The building superintendent turns off the heat pumps off in mild weather, using outdoor air alone, or outdoor air cooled by well water, to cool the building. A similar strategy has been estimated to reduce annual cooling energy by 13% (Norford et al. 1986). However, such actions may penalize individual offices which are subject to overheating. The superintendent uses the temperature of the air returned from the offices - an average over all offices - as a measure of when mechanical cooling is required. Feedback from individual offices would provide a better basis for control: if an office is hot, and the VAV box is wide open, then the temperature of building supply air needs to be reduced.

CONCLUSION

Our experiences to date with the Enerplex structures lead us to conclude that making a speculative office building as energy efficient as is consistent with tenant needs and the designers' skills is a challenge which must be met by a team which includes building users and operators. Legitimate tenant needs in Enerplex North are exacerbated by significant energy use during unoccupied periods, an unwelcome characteristic of the information era, and by a lack of teamwork which could have made the daylighting features appealing to the tenant. The installed controls have been difficult for the building superintendent to tune. Lacking sufficient and easily obtainable information about office temperatures and the performance of the night setback and setback recovery controls, for example, the superintendent responded to lack-of-heat complaints by overriding the controls and conditioned the building continuously. The performance of the central fans and the heat pumps has been both less than expected and not apparent from the building control system; better information appears to be key in making the superintendent and building owner more effectively involved in making buildings more resource-respectful.

ACKNOWLEDGMENT

We are grateful for funding made available through the establishment of the New Jersey Energy Conservation Laboratory at the Center for Energy and Environmental Studies, Princeton University; major funding agencies are all seven of the New Jersey gas and electric utilities, the New Jersey Department of Energy, and the Prudential Insurance Company. We thank Diane Brongo and Andy Bose for their investigation of tenant energy use in Enerplex North.

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Table 1
Site Energy Use in Enerplex North

March 1, 1985 - February 28, 1986

Category	Predicted(1) $\frac{Btu}{y\ ft^2}$	($\frac{MJ}{y\ m^2}$)	Actual(2) $\frac{Btu}{y\ ft^2}$	($\frac{MJ}{y\ m^2}$)	Actual / predicted
Occupants	10,200(3)	(116)	61,900(4)	(703)	6.1
Services(5)	2,600	(30)	5,900	(67)	2.3
Heating	8,900	(101)	12,800(6)	(145)	1.4
Cooling	6,500(7)	(74)	17,000	(193)	2.6
Fans	6,900	(78)	19,900	(226)	2.9
Total	35,100	(398)	117,500	(1,334)	3.3

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1. Energy use was predicted with the DOE-2 computer program, using TMY weather for Newark, NJ. Predicted energy use and more information on the Enerplex buildings can be found in Norford et al. 1984.

2. Actual energy use is based on a combination of measurements and estimates: metered total building electricity; submetered supply and return fans, chillers; submetered electrical users serving tenant offices, fan-powered induction boxes and heating coils; and spot measurements and estimated operating hours for kitchen equipment, computer room equipment, and some miscellaneous equipment.

3. The occupant prediction includes overhead lighting and office equipment. Lighting was modeled as 1.4 W/ft^2 installed capacity with a 30 percent daylighting reduction, and 2500 hour/year operation. Office equipment was modeled as 0.5 W/ft^2, also operating 2500 hours/year.

4. Occupant measurements include 13,800 Btu/y ft^2 (157 MJ/y m^2) for a computer facility and 6,100 Btu/y ft^2 (69 MJ/y m^2) for a kitchen.

5. Services include corridor, atrium and rest room lights, local exhaust fans, HVAC controls and alarms, elevators and miscellaneous equipment.

6. Because the electric heating coils are too numerous to separately meter and because the coils operate at varying power levels over irregular intervals, it is difficult to estimate their energy use. Therefore, heating is taken as the difference between the measured total and the remaining measured/estimated categories.

7. Chillers with a COP of 2.4 were used to predict cooling energy; no credit was taken for improved cooling performance stemming from the ice pond.

Table 2
Site Energy Use in Enerplex South

January 1, 1985 - December 31, 1985

Category	Predicted(1) $\frac{Btu}{y\ ft^2}$	($\frac{MJ}{y\ m^2}$)	Actual(2) $\frac{Btu}{y\ ft^2}$	($\frac{MJ}{y\ m^2}$)	Actual / Predicted
Occupants	10,200	(116)	11,900	(135)	1.2
Services(1)	4,400	(50)	9,300	(106)	2.1
Heating	4,100	(47)	8,300	(94)	2.0
Cooling	3,700	(42)	3,900	(44)	1.1
Fans	6,900	(78)	14,600	(166)	2.1
Total	29,300	(333)	48,000	(545)	1.6

1. For Enerplex South, the services category includes parking lot lights and exterior floodlights, estimated to be 1,800 Btu/y ft^2 (20 MJ/y m^2). This building is about 40% occupied, but the entire building has been conditioned.

Table 3
Morning Warm-up After Night Temperature Setback in Enerplex North

Date	heating start	Average interior temperature 7:00-8:00	8:00-9:00	Ambient temperature 8:00-9:00
Controls working				
Mon 16 Dec 85(1)	5:00	65 F	66 F	27 F
Tue 17 Dec 85	5:20	70 F	71 F	31 F
Wed 18 Dec 85	5:20	71 F	71 F	30 F
Thu 19 Dec 85	2:15	70 F	70 F	15 F
Fri 20 Dec 85	2:45	70 F	70 F	16 F
Mon 23 Dec 85(1)	0:40	68 F	68 F	31 F
Tue 24 Dec 85	4:00	71 F	72 F	28 F
Controls bypassed -- fans and heaters running 24 hours/day				
Mon 06 Jan 86	-	72 F	72 F	32 F
Tue 07 Jan 86	-	72 F	72 F	22 F
Wed 08 Jan 86	-	70 F	71 F	18 F
Thu 09 Jan 86	-	71 F	71 F	19 F
Fri 10 Jan 86	-	72 F	73 F	34 F
Mon 14 Jan 86	-	71 F	72 F	17 F
Tue 15 Jan 86	-	71 F	71 F	9 F
Wed 16 Jan 86	-	71 F	72 F	20 F
Thu 17 Jan 86	-	72 F	72 F	24 F

1. On Monday mornings only, the controls failed to bring the building close to the 72 F setpoint by occupancy time.

Table 4
Supply and Return Fan Energy Use in Enerplex South

	Month	Predicted kWh/day	Actual kWh/day	Actual / Predicted
1985				
	Jan	490	1560	3.2
	Feb	500	1340	2.7
	Mar	520	1210	2.3
	Apr	470	630	1.3
	May	350	440	1.3
	Jun	400	1000	2.5
	Jul	380	800	2.1
	Aug	390	800	2.1
	Sep	370	690	1.9
	Oct	340	650	1.9
	Nov	430	650	1.5
	Dec	520	1390	2.7
1986				
	Jan	490	1290	2.6
	Feb	500	1370	2.7
	Mar	520	810	1.6
	Apr	470	840	1.8

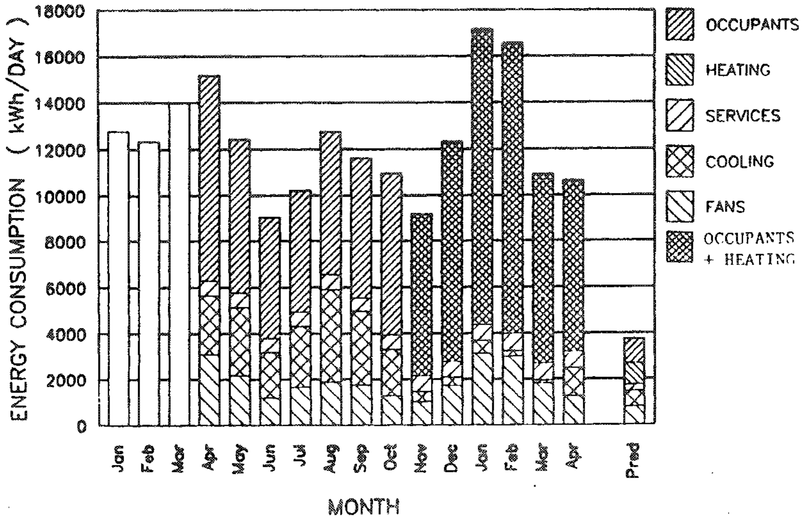


Figure 1. Enerplex North: Daily Energy Disaggregation (Jan 1985 - Apr 1986).

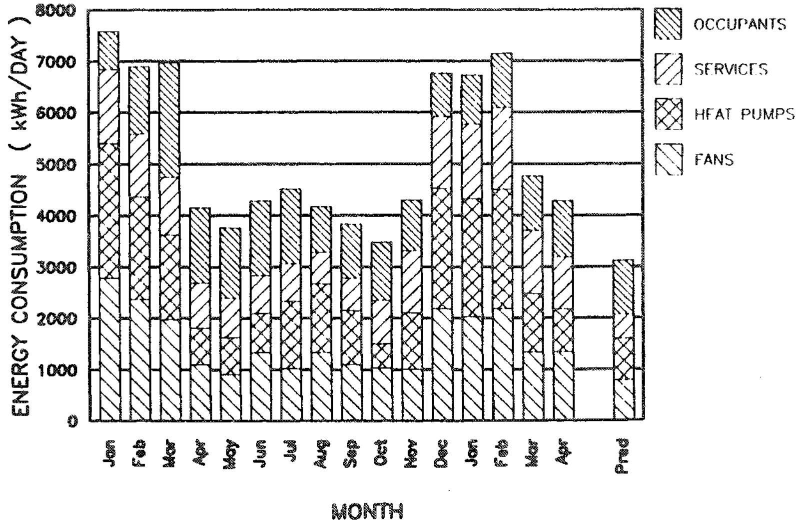


Figure 2. Enerplex South: Daily Energy Disaggregation (Jan 1985 - Apr 1986).

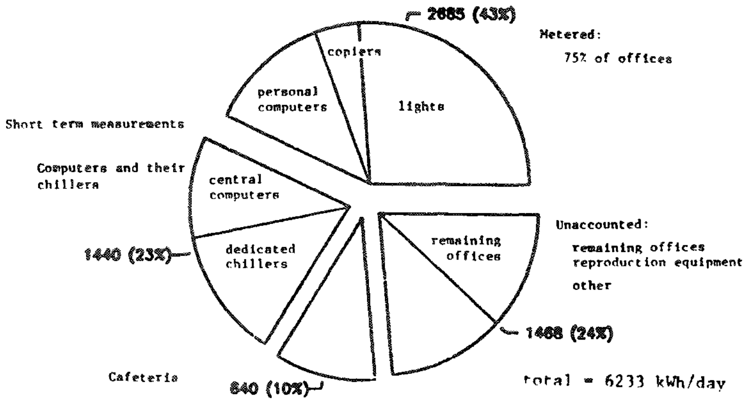
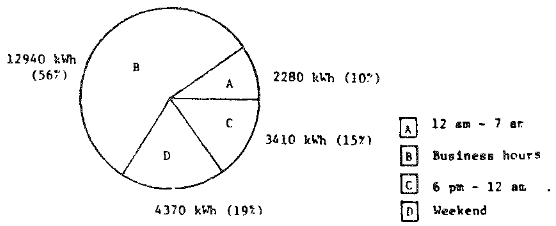


Figure 3. Occupant Energy Use in Enerplex North, August, 1985.

Weekly occupant energy use - typical spring week, 1986



Hourly occupant energy use - typical spring weekday, 1986

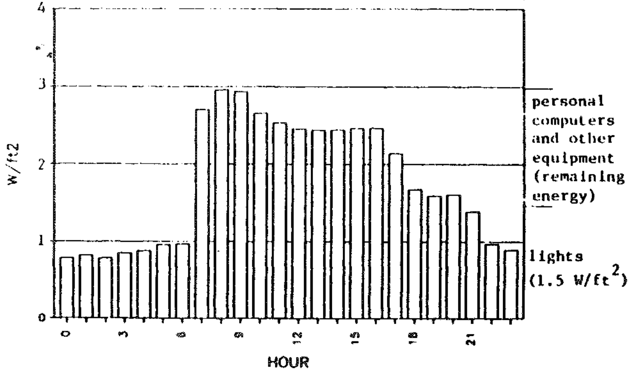


Figure 4. Occupant general-purpose office electrical energy use in Enerplex North, 1986. The central computer facility and the kitchen are excluded.

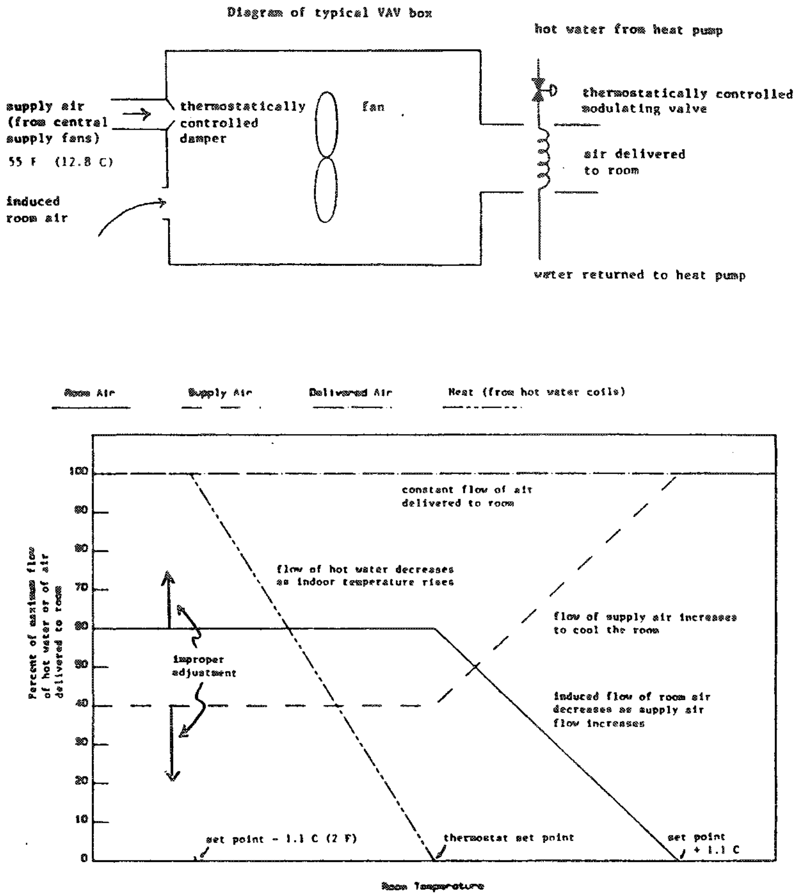


Figure 5. Winter operation of a VAV fan-powered induction box in the South building. Boxes in the building perimeter have heating coils; those in the interior do not. The North building uses electric resistive heating in lieu of hot water. The boxes in both buildings were improperly adjusted, so that the amount of cool supply air was increased and induced room air was decreased, making the buildings more difficult to heat.

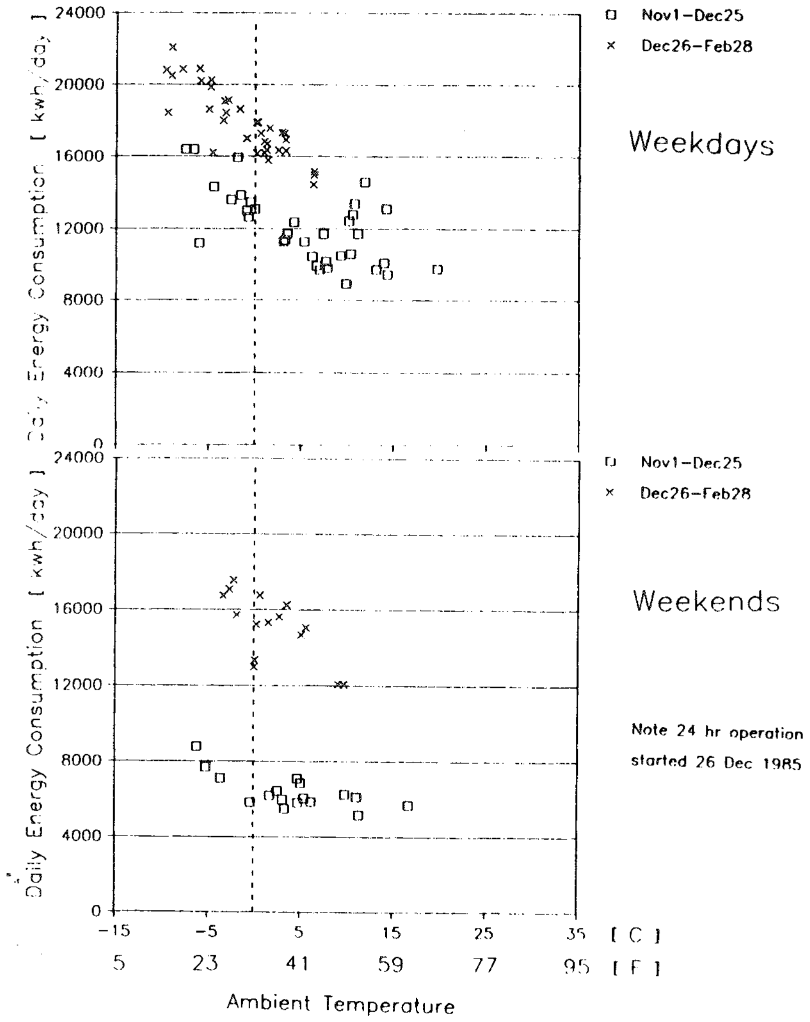


Figure 6. Daily energy consumption in Enerplex North. Through December 25, night setback and setback recovery were under HVAC microprocessor control; after this date, the building was continuously conditioned.

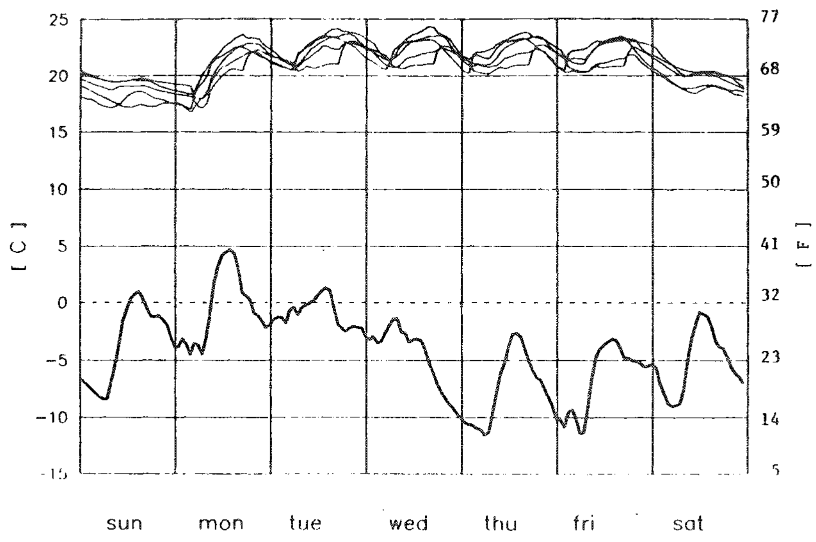


Figure 7. Enerplex North interior temperatures, with night setback and setback recovery controlled by an HVAC microprocessor. Note unsatisfactorily low temperatures following a weekend setback. Thermostat setpoint is 72 F (22 C).

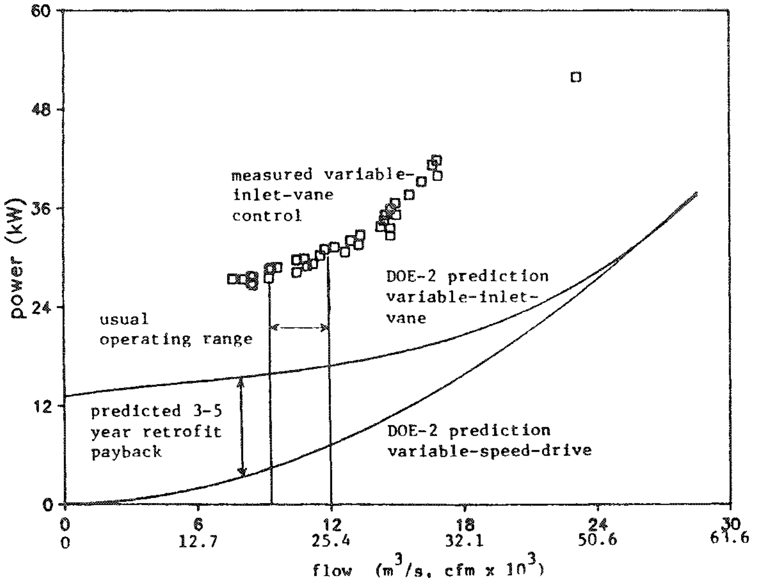


Figure 8. Part-load performance for one of the 50 hp, variable-inlet-vane controlled, centrifugal supply fans in Enerplex South. The difference between measured and predicted performance casts uncertainty on the energy savings associated with a variable-speed-drive retrofit but suggests that such a retrofit may be more effective than predicted.

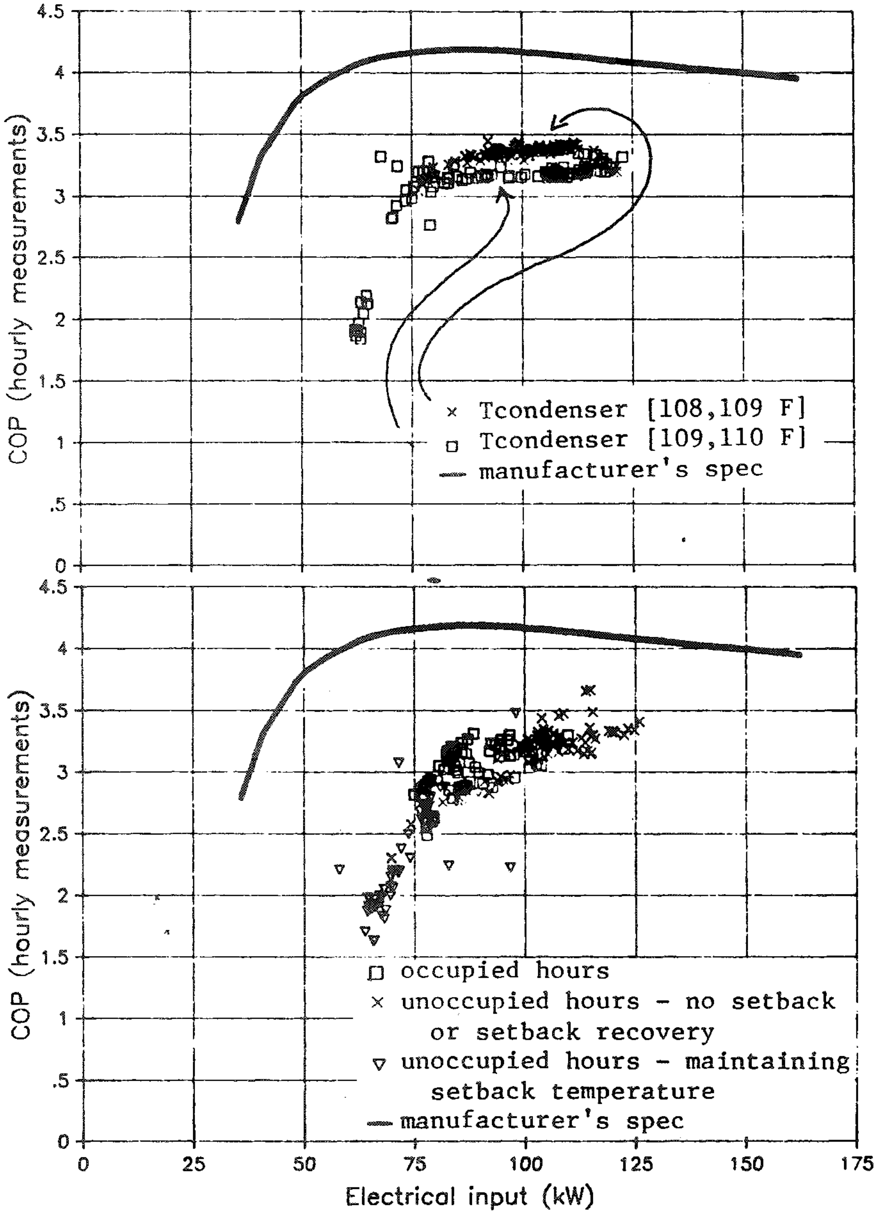


Figure 9. South building winter 1986 heat pump performance. Note the measurable change in COP when condenser water outlet temperature varies as little as 1-2 F (1 C). Also note low COP's when the unit is running under low loads, typically during unoccupied periods when thermostat setback was in effect.