

Recommissioning Energy Savings Persistence

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Synopsis

Utilities, administrators, or turnkey providers in many areas around the country offer recommissioning (RCx) based demand side management (DSM) programs. Because RCx is a newer and largely unevaluated DSM offering, there have been significant concerns surrounding the persistence of the RCx measures and resulting demand and energy savings. These concerns can become a barrier to the acceptance and implementation of RCx as a DSM program.

Because of the interest in RCx as an approach to DSM and the accompanying concern over measure persistence, we have conducted a case study evaluation of RCx and persistence in a facility from 1995 to 2003.

The project was published and presented as a case-study at the 7th Annual NCBC conference in 1999 (HVAC Commissioning in an Existing Building: A Case Study at a Large Office Building in Colorado, Bradford, Brandemuehl). As presented in the original paper, the original RCx project resulted in verified savings of 14% in electrical demand, 25% in electrical use, and 74% in gas use.

Despite significant changes in building mission, complete turnover of building operating staff and several changes to the HVAC systems, the 2003 RCx effort found that the original 1996 measures were still in place and performing as intended. The 2003 RCx effort, however, did identify additional measures that reduced demand by another 80 kW.

The case study demonstrates that the persistence of savings resulting from RCx activities depends on the type of modifications made, the level of interaction of the service providers with the building engineer and owner, and the degree of support provided to the building staff by management.

About the Authors

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Introduction

Recommissioning is gaining recognition for its ability to deliver demand savings, but skepticism still remains regarding the ability of the savings achieved through RCx to continue delivering savings for many years. Buildings are dynamic systems, with operations staff, property management firms, space uses, and even building equipment changing over time. These changes and their effect on building equipment operation and energy consumption can present a significant challenge to the ability of low-cost energy conservation measures (ECM) to deliver consistent and long-lasting savings. However, if the ECMs are carefully chosen and implemented correctly, the energy savings can be expected to persist for many years. This paper will show that depending on the above factors, some ECMs have a higher likelihood of remaining unchanged for many years, while others may fail to deliver savings after a short time.

Furthermore, the method employed to document persistence can have a significant effect on the apparent persistence. While a detailed discussion of measurement and verification (M&V) of energy savings is beyond the scope of this paper, it is necessary to understand that application of the correct M&V methodology is essential to achieving an accurate assessment of persistence. For this study, two approaches were used: whole building utility analysis, and ECM isolation. In the former case, the monthly utility usage was adjusted for weather, occupancy, and significant changes in space use. The latter method was used for selected ECMs that affect isolated HVAC components.

The subject building for this analysis is a commercial office building in Boulder, Colorado. The building was the subject of an RCx study in 1995-1996, during which time many ECMs were implemented, resulting in significant electric and gas savings. The building was again recommissioned in 2003, resulting in savings of 3.5% in electrical demand and 5% in electrical use (no effort was made to reduce gas use).

The energy and demand savings between 1995 and 1996 that were attributable to recommissioning are shown in Table 1. The savings resulting from the 2003 study that are attributable to the correction of measures implemented in 1996 are also shown. The savings shown for 1996 is with respect to 1995, and the savings in 2003 is compared to 2002 usage. A direct comparison of these savings, to assess savings persistence, will be discussed later in this paper.

Table 1. Recommissioning Savings Summary

	kW	kWh	Elect Cost	Gas CCF	Gas Cost
1996 Savings	14%	20%	20%	74%	83%
2003 Savings	3.5%	5%	5%	n/a	n/a

The results from the RCx effort undertaken in 1996 are impressive, but were the benefits transitory, or did the savings persist over the last 10 years? To answer this question, which is on

the minds of many engineers, commissioning agents, building owners and DSM program administrators, some analysis is required. Because savings cannot be measured directly – there is no such device as the “negawatt meter” – sound performance measurement and verification procedures are necessary.

Regardless of the M&V methods used, the savings is calculated by subtracting the actual use during the performance period from the use that would have occurred had the ECMs not been installed (the “Adjusted baseline”). This basic formula is shown in Equation 1.

$$\text{Savings} = \text{Adjusted baseline usage} - \text{Post-retrofit usage} \quad (\text{Eq. 1})$$

In the measure-by-measure M&V analysis (Option B of the FEMP M&V Guidelines), the savings attributable to the RCx work in both 1996 and 2003 effort is done using measure-specific engineering calculations.

In the whole-building analysis of the RCx savings (Option C of the FEMP M&V Guidelines), adjustments are made to the post-RCx usage to account for changes in the energy use that are not a result of the degradation of the 1996 RCx measures. This was done by constructing a timeline that includes approximate dates of changes in space uses, occupancy, and weather, and the estimated demand and energy load increases that resulted.

Building Description

The building, in Boulder, Colorado was constructed in 1990 and consists of 3 stories of office space, with a total facility area of approximately 270,000 square feet. The building is used primarily as offices and a research and development laboratory, but also includes a cafeteria, computer lab, a large conference room, and has large glass-ceiling open atria.

The building is generally occupied from 8:00 AM to 5:00 PM, and the HVAC equipment generally operates between 5:00 AM and 6:00 PM. The building engineer estimated occupancy in 2003 at 450 to 500 people.

Mechanical Equipment

The air handling systems include 10 variable air volume (VAV) air handling units (AHUs) serving 352 series fan powered VAV boxes. A multizone AHU serves the conference room, and several fan coil units (FCU) and Liebert units (served by chilled water) serve the computer and other labs. Numerous small fans exhaust air from the atrium, restrooms, and other miscellaneous spaces. The central cooling plant is located on the ground floor, and consists of two centrifugal chillers (630 and 800 Ton capacity), primary and secondary chilled water pumps, and a flat-plate heat exchanger (450 Ton capacity as a water-side economizer). Two induced-draft cooling towers are located adjacent to the mechanical room in the service yard, and can be valved in any combination to serve the chillers. The plant piping is set up such that the flat-plate heat exchanger (FPHX) is dedicated to the larger chiller. The building load rarely if ever exceeds 800 Tons.

Two firetube hydronic boilers generate hot water, which is distributed to heating coils in the AHUs and perimeter fan-powered VAV boxes. Both the hot water and chilled water distribution systems are primary/secondary systems with constant speed primary pumps and variable speed secondary pumps. All equipment, including zone thermostats and VAV boxes are controlled and monitored by the direct digital control (DDC) building automation system (BAS).

1995-1996 Recommissioning Activities

In 1995-96, the building was the subject of a comprehensive RCx project and optimization study that resulted in the *ASHRAE Research Project 823-RP, Implementation of On-line Supervisory Control of Cooling Plants Without Storage*. The results of the RCx study were presented at the 7th Annual National Conference on Building Commissioning, (1997) as *HVAC Commissioning in an Existing Building: A Case Study at a Large Office Building in Colorado*. The RCx work was part of an academic study, and no cost was incurred to the building owner for the investigative portion of the work. The study scope included the central cooling and heating plants, AHUs, and air distribution systems. The changes made during the RCx study are summarized below.

Supply air system modifications

Several changes were made to the air distribution systems to improve control and reduce energy consumption.

- The PI loop control parameters were tuned to stabilize fan speeds.
- The supply air temperature setpoint at the AHUs was lowered to reduce fan power consumption. Generally, the temperature was reduced from about 55°F to 50°F.
- The chilled water temperature setpoint was set to 43°F.
- A reset strategy was applied to the supply air duct static pressure setpoint. This strategy ensured that only enough pressure was supplied to the VAV boxes to meet requirements, without unnecessary pressure drop across VAV box dampers. Before implementation, the duct pressures were controlled to a constant 1.5" w.g. or higher. The new strategy allowed the duct pressures to drop as low as 0.6" w.g. under low load conditions.
- The supply air temperature logic was changed to eliminate "fighting" between the cooling and heating systems.

Building pressurization control changes

Initially, the building static pressure was out of control, resulting in some areas manifesting negative pressures, while other spaces were over pressurized. This resulted in uncontrolled infiltration, and doors standing open.

- Set points were changed to more appropriate values.
- Exhaust air damper motors were repaired to permit actuation through the full operating range.
- The PI loop control parameters were changed to eliminate exhaust, return, and outside air damper position hunting.
- The control logic for the exhaust fans and dampers was changed to establish proper control precedence. The strategy implemented controlled the exhaust damper to maintain building static pressure, and the return fan to maintain static pressure downstream from the return fan and ahead of the exhaust and return dampers.

Air-side economizer and ventilation system changes

Changes were made to increase the availability of free cooling, and improve control of the outside air fraction. This resulted in reduced cooling loads under hot ambient conditions, due to the reduced outside air cooling load, and reduced chiller run hours, due to increased use of free cooling.

- The outside, mixed, supply, and return air temperature sensors were recalibrated.
- The mixed air temperature was established as the controlled variable, in place of the supply air temperature, to reduce hunting caused by slow system response to changes in the outside air damper position. The mixed air temperature setpoint was set a few degrees below the supply air setpoint, and the chilled water coil valves were forced closed when the outside temperature dropped below 48°F.
- The control logic for the air-side economizer was completely revised to maximize free cooling capability.

Water-side economizer recommissioning

The water-side economizer is a FPHX and piping allowing direct heat transfer from the AHUs to the cooling towers without operating the chillers. Because the air-side economizers are always the first stage of free cooling, they were recommissioned before checking the function of the water-side economizer. The following changes were made to the water-side economizer:

- Air-side economizers were recommissioned to reduce cooling load
- The automatic three-way valve actuator used to blend warm water exiting the condenser with cold water leaving the tower sumps during transition from economizer to chiller mode was replaced with a slower, but more reliable, actuator.
- Temperature sensors were calibrated.
- The control logic was revised and tested to verify smooth transition from water-side economizer mode to chiller mode. To ensure system stability during the transition from economizer to chiller operation, the condenser water setpoint was set at the minimum temperature allowed by the chiller manufacturer. This permitted the maximum possible water flow to the condenser bundle. Only proportional gain was used on the valve control to avoid integral “wind-up” common with slow-reacting systems.

Heating System Recommissioning

Several problems related to the heating system were found to be unnecessarily increasing energy consumption. The following changes were made to eliminate these problems:

- As described above, the air-side economizers were operating incorrectly, introducing high flows of cold air into the AHUs and resulting in increased heating loads on the boiler plant. This was resolved through the RCx of the air-side economizers and ventilation systems.
- Due to prior problems with freezing coils, the control logic had been set up to maintain a continuous minimum hot water flow through all coils. This resulted in an unnecessary preheating of air, and additional cooling load. The hot water coil valves at the AHUs were programmed to close completely when heating was not required.

- The existing control logic operated the large boiler as the lead, causing poor overall part-load performance. The logic was redesigned to set the smaller boiler as the lead, and to enable the boilers in a stepwise fashion to meet increasing heating loads.
- The primary hot water distribution pumps had originally been programmed to shut off as soon as the boilers were shut off, resulting in flash steam generation in the boiler box, which would escape via the air relief valves. To alleviate this problem, the pumps were set to run continuously, year-round. While this solved the immediate problem, it resulted in wasted pumping energy. Thus, the pump logic was changed to run the pumps only when boiler temperature is high, resulting in pump energy savings and improved boiler operation.
- Hardware problems in the primary/secondary pumping system caused 100% of the hot primary water to enter the secondary loop, even when such high temperatures were not required at the coils. A secondary loop temperature reset strategy was implemented to reduce the temperature of the loop, increasing system stability and reducing unnecessary heat losses in the distribution piping.

History of Changes

Significant changes to the property management and maintenance teams, space uses, and mechanical systems have been made since 1996. In the late 1990's, a new property management firm was hired, bringing with them a new building maintenance staff. At the same time, the controls contractor that had been with the building since construction was replaced with another local firm. In 2001, an original 450 Ton chiller was replaced with an 800 Ton centrifugal chiller, one cooling tower was replaced with a larger unit with a variable-speed fan, and the capacity of the FPHX was expanded from 150 Tons to 450 Tons to increase free-cooling capacity. Simultaneously, a new 5" diameter branch was added to the secondary chilled water piping system to serve new cooling loads imposed by a key tenant. Temperature and flow meters were installed on this branch to allow submetering of the cooling load. During 2002, all variable frequency drives (VFDs) on the AHU supply and return fans were replaced. In 2004, the control programming was revised to allow both cooling towers to run simultaneously. This allows the FPHX economizer to operate through a greater range of ambient temperatures. In 2003, the building was selected to participate in the Xcel Energy Recommissioning Program, whose goal is to achieve demand savings during the summer afternoon peak period. As a result of this study, about 56 kW of peak demand savings was identified, with about 30 kW of that savings resulting from correction of previously implemented ECMs, and the remainder from newly identified ECMs. These changes were implemented in late 2003.

2003 Recommissioning Activities

In 2003, the building was recommissioned again as part of a program sponsored by the local electric utility. The cost of the study was borne by the utility, while the building owner paid to implement the improvements. The overall simple payback for the building owner's investment was less than one year. In that effort, the majority of the measures implemented in 1996 were checked, as discussed below. Some ECMs, not covered in the 1996 work, were also identified. These included revising lighting schedules and temporarily disabling fans in fan-powered boxes (FPB). The focus of this paper, however, is the status of the original 1996 ECMs.

Persistence Analysis

Procedure

The choice of M&V procedure employed to document the persistence of energy savings is an important factor in determining the “success” of a RCx project; use of an inappropriate procedure can result in the over or under-estimation of savings. The International Protocol for Measurement and Verification Procedures (IPMVP) offers guidelines for using four approved methods. The general procedures for calculating savings for the four options are as follows:

- Option A (Partially Measured Retrofit Isolation) – Engineering calculations using stipulated parameters and short-term or continuous post-retrofit measurements of parameters specific to the retrofit
- Option B (Retrofit Isolation) – Engineering calculations using short-term or continuous measurements of parameters specific to the retrofit
- Option C (Whole Facility) – Analysis of whole facility utility meter or sub-meter data using techniques from simple comparison to regression analysis
- Option D (Calibrated Simulation) – Energy use simulation, calibrated with hourly or monthly utility billing data and/or end-use metering

For this study, both Options B and C were used. Option B was used for individual ECMs for which independent variables are easily identified and measured. Option C was used to document the effect of more generalized operating strategies that result in significant changes in energy usage or demand. Of course, the analysis using Option C incorporates the savings for all ECMs, including those verified using Option B.

Measure Specific M&V

The ECMs discussed here are those that fell within the scope of the RCx study conducted in 2003. The Option B M&V procedure was modified slightly in that the independent variables driving the energy savings were monitored rather than the system or component energy use. The demand energy savings were then calculated using the engineering equations governing the electric demand of the component or system, with the measured parameters and typical meteorological year (TMY) weather data as inputs.

Air Handling Unit Operation

All of the AHUs were investigated to verify that the control sequences and set points put in place in 1996 were still operational. Trend data were collected and visual inspections made to document system operation. The control code was reviewed, and it was verified that all of the control sequences established in 1996 were still in place.

Air-side economizer operation and the minimum outside air fraction was evaluated for all AHUs through analysis of the mixed, return and outside air temperature trend data, as well as visual verification of damper positions. The results of the analysis indicated that the air-side economizers were functioning correctly. It is interesting to note, however, that on two AHUs the data trends indicated that the full economizer potential was not being achieved. After further

investigation, the cause was found to be failed fire/smoke damper actuators on one unit, and an undersized outside air plenum on the other. The minimum outside air dampers were also found to be operating correctly, though in five AHUs, the minimum outside air fraction was either higher or lower than the ideal. Again, the cause was found to be the failed fire/smoke damper actuators.

The potential for simultaneous heating and cooling at the AHUs or at the terminal units was investigated, but because the boiler plant was found to be disabled from May through September, there was no potential for heating during the peak cooling season. Furthermore, the annual gas usage documented in the Option C analysis shows that gas usage had remained at a minimum since 1996.

The supply air static pressure reset strategy put in place in 1996 was found to be present in the control code for all ten VAV AHUs. This reset strategy allowed the duct static pressure to drop as low as 0.6 in w.g. under low load conditions, or rise as high as 1.6 in w.g. under full load. In three AHUs, it appeared that the static pressure reset strategy was not functioning, but on further analysis, it was determined that the loads in those zones did not drop sufficiently to allow the static pressure set point to reset to lower values.

The supply air temperature set point was checked to confirm that it was still operating at the value established in the 1996 study. For all ten VAV AHUs, the supply air temperature was found to be the same as previously set (50°F).

All AHUs were scheduled in 1996 to operate from 6:00 AM to 6:00 PM weekdays, and 8:00 AM to Noon on Saturday. In 2003, the units were scheduled to start between 5:00 and 5:35 AM and stop at 6:00 PM on weekdays, and operate from 7:00 AM to 1:00 PM Saturday. The building staff felt that these new schedules were necessary to satisfy the occupants. However, three AHUs were found to be operating continuously, contrary to the operator's desired schedule. While the desired schedule was indeed programmed in the BAS, further investigation found a problem in the control code that caused the programmed operating schedule to be overridden.

The chiller plant was verified to be operating according to recommendations made in the 1996 study. The equipment replacement in 2001 had no effect on the plant operating strategies. The chilled water supply temperature set point was set to 43°F in 1996, and was found in 2003 to be 44°F. This higher temperature would result in a small reduction (perhaps 3 kW) in chiller peak electric demand. The condenser water temperature set point was also unchanged from the old set point of 72°F. The boiler plant operation was not reviewed in detail in the 2003 study, but the utility bill analysis (FEMP M&V Guidelines Option C), presented later in this paper, shows minimal change in gas usage.

All of the ECMs discussed above were implemented in late 2003, and the presence of these deficiencies implies that degradation of the original RCx work had occurred. However, while the root causes of this degradation were shown to be problems outside the scope of the 1996 work, the savings is nevertheless broadly treated as degradation because the same systems are affected. To quantify the degree of degradation, or loss of persistence, the savings associated with these ECMs was calculated, as shown in Table 2. The calculations were done using the basic

engineering principles governing the affected system or equipment, using as inputs data collected through the building automation system, and typical meteorological year weather data. This savings is compared to the original savings value achieved in 1996 (discussed below) by calculating the percentage of that original savings that remained in 2003. The results of this comparison are shown in Table 3, with the result that for the ECMs implemented in 1996, the persistence was about 85%.

Table 2. Summary of 2003 RCx Savings

2003 RCx Measures	Demand (kW)	Energy (kWh)
Equipment Scheduling	0	242,797
OA & Economizers	22	20,685
Fan Control	7	18,809

Table 3. Electric Savings Persistence Summary

	Demand (kW)	Energy (kWh)
2003 RCx Savings Total	29	280,000
1996 RCx Savings	219	1,600,000
Persistence	86%	83%

Whole Building M&V

The savings persistence assessment presented above was augmented with a whole building approach, presented below.

Documented building internal load growth

It should come as no surprise that during the nine years since the original RCx project was completed, some changes have taken place. Some of the physical changes include: weather, changeover of space from standard office areas to laboratory areas, changes in occupancy, and a chiller retrofit.

In addition to the physical changes, there was a complete changeover of building executive, administrative and maintenance staff, and the building management company changed three times. In spite of the extended length of time between RCx and the significant building changes, the savings garnered in the first RCx effort have been largely maintained. Estimated internal load growth is documented in a timeline of events that had a significant effect on building load. The timeline is shown in Table 4.

Table 4: Approximate Timeline Of Load Changing Activities

Date	Activity	Remarks	kW change
May-96	Completed 1 st recommissioning	1996 minus 1994 peak demand	-219
Jun-98	North side offices increase density	Approximately 50 offices and people added	45
Jan-00	Heavy lab 24 hours and buildout	Served by existing Lieberts	10
Feb-00	First floor partial lab buildout	18 tons in 3 FCUs plus lab loads, 24 hr op	60
Nov-01	First and 2nd floor lab buildout	Includes 10T DX unit and fan coil units	220
Dec-01	Tenant 3rd floor buildout	50T of new FCUs and added load	40
Dec-01	Chiller replacement	450T chiller replaced with new 800T unit	-90
Oct-04	2nd floor 20,000 SF vacated		-54

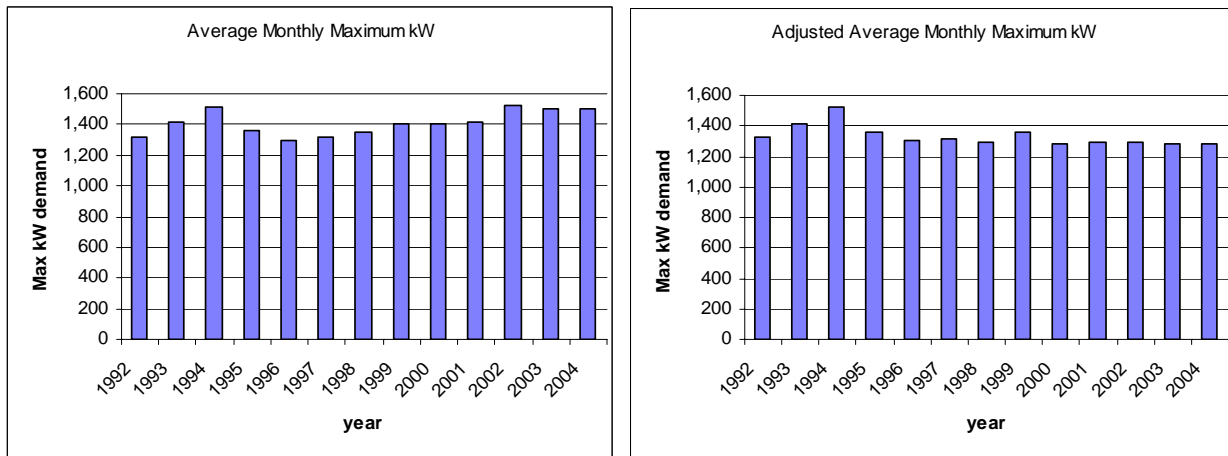


Figure 1: Average Annual Demand, Raw and Adjusted

Viewing the unadjusted utility demand data, shown on the left side of Figure 1, indicates that building demand has increased. Are the increased loads attributable to internal load growth, the decline of system performance, or was it a combination of both? The right graph in Figure 1 shows building demand adjusted for the increases in building internal load shown in Table 4. This graph shows that the electric demand would have remained nearly flat if the changes shown in Table 4 had not occurred. This relatively flat adjusted building demand alone may not convince the observer that the RCx savings persisted. However, because the results of the measure-isolation M&V method agree with the whole-building approach, some confidence that the ECMs have persisted is gained.

The left side of Figure 2 shows that the energy usage has also increased over the years. Again, these values were adjusted using the data in Table 4, where the demand was converted to energy using reasonable estimates of operating hours. Once adjustments are made for energy use growth, it can be seen in the right graph of Figure 2 that electric usage savings due to the original RCx use has, like the demand savings, persisted. It must be noted that the uncertainty inherently

associated with the whole building approach is significant. The energy usage spike in 2002 was not be explained by the available data.

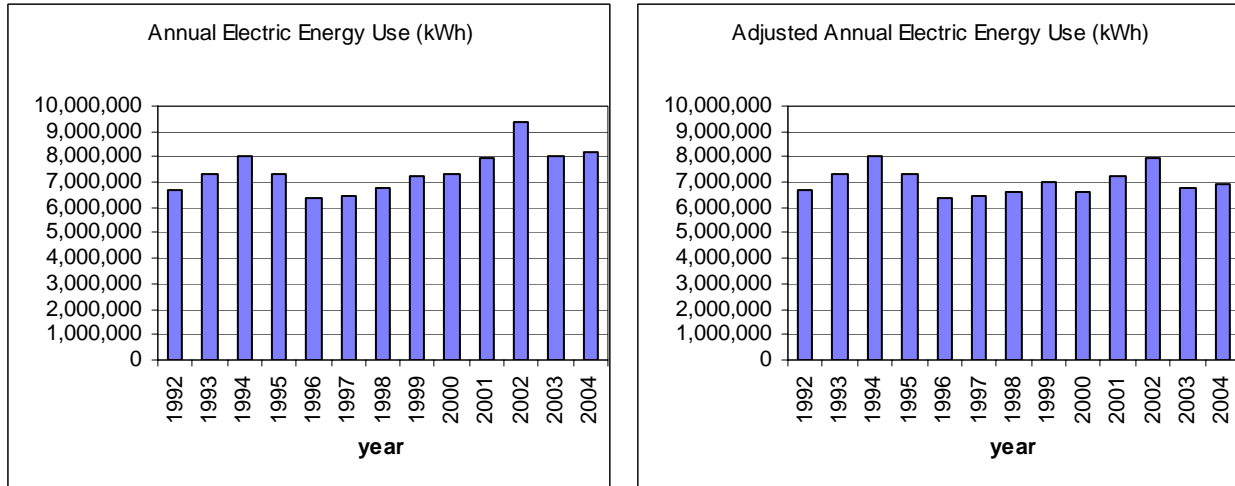


Figure 2: Annual Energy Use, Raw and Adjusted

In the 1996 RCx work, gas use was reduced significantly. As shown in Figure 3, gas use has remained low. Despite the fact that a commissioning agent didn't evaluate gas-using equipment for a period of nearly seven years, and after 2004 only analyzed after-the-fact, the usage reduction persisted.

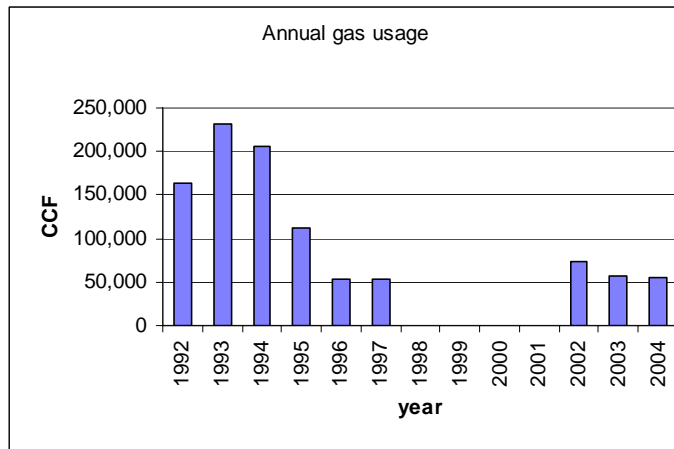


Figure 3: Annual Natural Gas Usage

Internal load growth as documented by main buss monitoring

Figure 4 shows two instantaneous snap-shots of kW demand for the building for days that are similar in temperature and time of day, but are nearly 8 years apart. This provides an illustrative example that the internal loads have grown in the facility. The main distribution service buss A

handles all of the HVAC loads, while buss B handles all of the lighting, plug and miscellaneous loads. In Figure 4, it can be seen that the internal loads have grown by approximately 200 kW, while the HVAC demand required to serve the loads has only grown about 10 kW. Because the outside air temperature was low and therefore the HVAC systems were in economizer mode, very little extra HVAC power was needed to serve the additional internal loads.

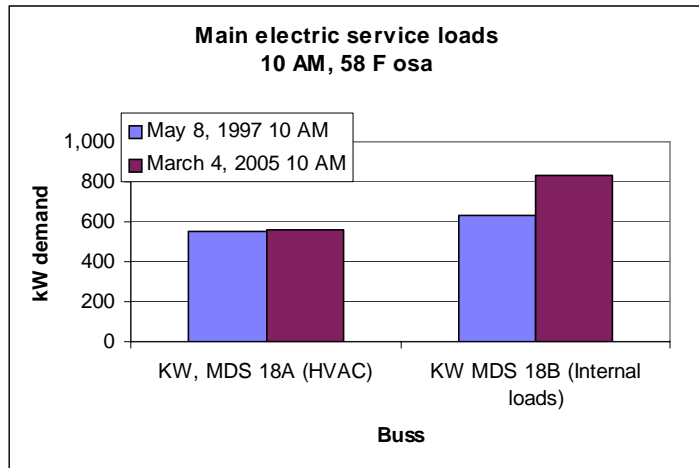


Figure 4: Comparison of Internal and HVAC Loads for Similar Days in 1997 and 2005

Conclusions

This paper demonstrates that RCx can generate long-term savings, even with limited ongoing support and significant building staff turnover, and that the types of ECMs implemented in this building can persist up to eight years and, presumably, beyond. However, new problems can crop up, compromising the ability of the ECMs to continue to deliver savings. Had ongoing support been provided to the building staff as part of the original RCx work, it is likely that no degradation in savings would have occurred. While the combination of different M&V methods can help bring the question of persistence into focus, the preferred method is the measure-specific approach because it provides better accuracy, often with less effort.

References

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