The DSR Potential of University of New Mexico's District Energy System

A. Mammoli[1,*], D. Lincoln[1], H. Barsun[2], L. Schuster[2], M. Ortiz[1] and J. McGowan[3]

[1]Dept. of Mechanical Engineering, the University of New Mexico
MSC 01-1150, Albuquerque, NM 87131, USA

[2]Physical Plant Department, the University of New Mexico
MSC 07-4200, Albuquerque, NM 87131, USA

[3]Energy Control Inc.,
2600 American Rd. SE, Suite 110, Rio Rancho, NM 87124, USA

[*]mammoli@unm.edu

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Abstract

Eighty-six of the University of New Mexico's (UNM) main campus buildings are serviced by a district energy system which receives electricity and natural gas from the local utility company. UNM's Physical Plant Department recently installed a metering, monitoring and verification (MMV) system which collects information about campus energy use. The MMV was designed with several features which allow for future interoperability with other building system services such as DDC, industrial controllers, security, and fire alarm systems. The design includes programmable logic controllers (PLC's) that communicate using MODBUS, native BACnet, BACnet IP, security and fire alarm protocols on the building side and MODBUS IP and BACNET IP on the network side. Furthermore, one building (Mechanical Engineering) is being instrumented to collect information about the energy use of individual systems within the building (fans, pumps, chillers etc.). The building has thermal storage tanks and a solar assisted heating and cooling system, which allow substantial flexibility in the building energy consumption profile, and a digital control (DDC) system which allows for automated decision making based on inputs from external IT systems. We analyze the electrical energy usage of campus for the purpose of estimating the potential of the UNM campus to respond to grid status information, by altering its energy consumption characteristics. Possible response (reactive and predictive) strategies are discussed in light of inputs from various IT systems, such as scheduling databases, weather forecasts, utility data. We estimate a potential 3 MW response, with more if several IT and physical systems are put in place.

1. INTRODUCTION

The vision of interoperability outlined by the GridWise Architecture Council's 2005 white papers [1,2] enables the integration of diverse participating subsystems in a larger system which can operate optimally, while freeing the medium- and long-term evolution of the system from *a priori* decisions which may become superseded and counterproductive in the future.

In 2001, UNM began a utility infrastructure investment program intended to reduce the use of energy associated with campus lighting, heating and cooling. The core of the investment was the renovation of the Ford Utilities Center, including the installation of a 6 MW co-generation turbine, boilers, and chillers, serving a 650 acre campus inhabited by over 25,000 people. The co-generation plant is currently operated when it is cheaper to produce electricity than to buy it (also accounting for heat recovery). The co-generation plant currently meets ~40% of the campus electricity needs and 65% of the heating needs (in terms of total energy). A new Energy Management and Control System (EMCS) was installed in the renovation, with the capability of monitoring and controlling energy use on campus from a remote location. Currently, the EMCS operates as a Metering, Monitoring and Verification (MMV) system, with no control function, with meters located at the boundary of each building.

Refurbishment and modernization of the Mechanical Engineering (ME) building began in 2006. The ME building is characterized by load-dominated high-thermal mass construction, by the capacity for thermal storage and by solar-assisted heating and cooling. For this building, monitoring is implemented on a finer scale, allowing for external intervention on the operation of individual systems. This building is viewed as a prototype of a grid-cooperative building of the future, and its potential will be compared to that of more conventional buildings on campus.

Because of these features, the University of New Mexico's central campus was identified as an ideal example on which to base a demonstration of interoperability concepts. While electricity consumption and production on UNM campus is currently managed based on real-time internal needs for lighting, cooling and heating, with the only external consideration being gas and electricity prices, we envision a future where interaction with the grid is bi-directional and real-time. In this study we analyze the overall electricity consumption patterns of the UNM central campus, and of a set of individual buildings therein in more detail. The possibility of altering the electricity use and production patterns based on external requests from the grid is investigated, while ensuring conditions necessary for fulfilling UNM's academic mission. As a consequence, it is necessary for the EMCS to interrogate other relevant IT systems, such as scheduling, security and weather services. We also consider the possibility of automatically responding to information such as curtailment signals, price signals, or energy "quality" signals (e.g. intermittent renewable resources such as the wind farm near Fort Sumner, New Mexico).

2. SUMMER ELECTRICITY CONSUMPTION

Summer is the period of highest grid stress. The peak loads reported by the Public Service Company of New Mexico (PNM) in the period studied of July to September 2006 coincided exactly with the highest temperatures. Because grid interoperability should be pro-active rather than just reactive, and because the response time of many grid operators (e.g. buildings) can be measured in hours, a predictive ability which can extend from one to a few days is valuable. In the response strategies discussed later, the ability to forecast the probability of curtailment requests will be assumed.

2.1. Campus electricity consumption patterns

UNM purchases electricity from PNM at rates described in the Advice Notice No. 318 [3]. The metered electricity consumption rate for August of 2006 is shown in Fig 1. Weekday consumption is approximately 4 MW higher than on weekends. The sharp spikes in purchased power visible on weekday mornings are due to building startup after nightly and weekend system shut-off. The downward part of the spike is a consequence of achievement of setpoints in the buildings and the start-up of the co-generation plant. The demand spike is higher on Mondays, as a consequence of building conditions having fallen further away from the setpoint during the weekend. The on-peak period is 8:00AM to 8:00PM on weekdays. The energy rate for on-peak operation is $0.046/kWh, with an on-peak demand charge of $7.022/kW for demand above 8,000kW. Off-peak, the energy charge is $0.026/kWh. The monthly customer charge is the on-peak period demand charge applied to the 8,000 kW minimum demand. Thus, the rate of purchased energy is maintained above 8,000 kW and rarely falls below this value.

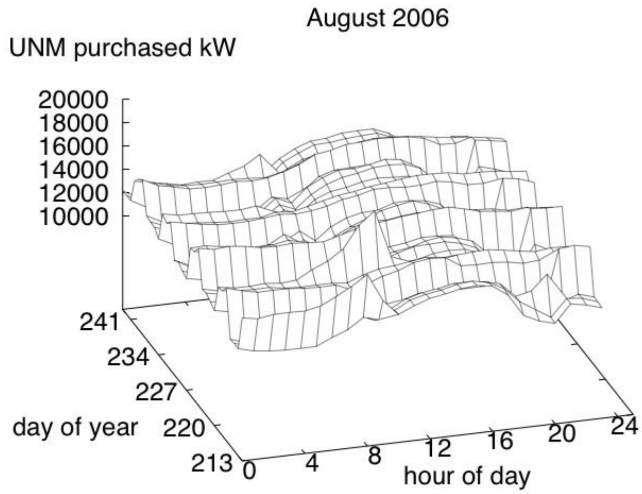

Figure 1: Metered electricity purchased by UNM central and North campusin August 2006.

2.2. Co-generation plant operation

The operation of the co-generation plant for the week containing the PNM peak load in August is shown in Fig. 2. The plant can achieve full power (6 MW) in less than 30 minutes. The overall cycle efficiency for the co-generation plant is on the order of 70%. Moreover, the combustion of natural gas results in lower greenhouse gas emissions relative to coal. Thus, from a thermodynamic and environmental point of view, there is considerable advantage in producing electricity locally, however now economic considerations only decide plant operation.

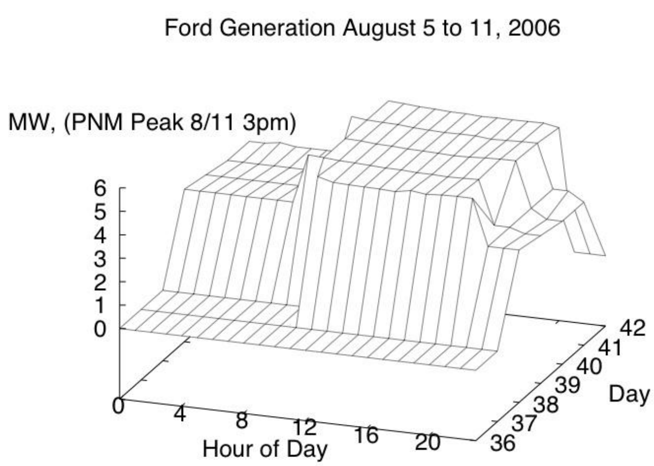

Figure 2: Electricity generation at the UNM Ford Utilities plant for the week of August 5-11, 2006.

The pattern of operation is similar for all summer weeks. The generator is shut off on weekends. During weekdays, it operates between 3 MW and 4 MW until 8 AM, when it is ramped to approximately 6 MW. The power is reduced to 3-4 MW again after 8 PM. This pattern leaves little opportunity for using the generator for campus load shedding during peak hours, when the turbine is already operating at peak capacity. It could be used in conjunction with other strategies, for example for pre-cooling of buildings off-peak, however doing so would be economically detrimental with current rate structures, as purchased electricity off-peak is cheaper than locally generated electricity, even accounting for added efficiencies resulting from heat recovery. Factors other than economics may be taken into account if this or additional co-genration plant is to take part in real-time energy markets.

3. BUILDING-WISE CONSUMPTION PATTERNS

The UNM central and north campus is the object of this study, as it is monitored and can potentially be controlled by the central EMCS. In 2001, there were a total of 231 buildings, with a collective surface area of 590,536 m^2. A subset of these buildings (86) are connected to the District Energy System and 65 are metered through the ECMS, and constitute 70% of the total building area. For this study, 5 representative buildings, representing a cross-section of building type, mechanical equipment and end-use, and collectively constituting ~10% of the total DES-served space, are considered. These buildings will be utilized to determine the curtailment strategies that may be implemented. Based on the results, the response characteristics of the entire campus will be extrapolated.

3.1. Mechanical Engineering

The Mechanical Engineering (ME) building is composed of research laboratories, classrooms, and offices and contains 6530 m^2 gross floor space. It has 6 supply fans and 2 return fans totaling 122 kW. The building is heated by the campus steam system with additional heat supplied by a roof mounted solar thermal system. The cooling coils draw chilled water (CHW) from thermal storage tanks, supplemented by an absorption chiller operating from the solar heating system. The storage tanks are recharged using a heat exchanger connected to campus chilled water.

The Mechanical Engineering building in the first week of semester in 2006 displayed an electric load varying from 150 kW to 250 kW during weekdays (Fig. 3). The added load, compared to weekends is caused by lights, computers and occupants (approximately 75 faculty, staff and graduate students, and up to 200 students attending class). The energy consumption for this building in 2006 matched the average campus consumption per unit area. In 2006, a four-stage electric chiller consuming up to 100 kW was used to meet the thermal load as required. In addition, fans consuming about 100 kW were constantly in operation. The restoration of the thermal storage tanks, the addition of the solar water-fired absorption chiller, and the installation of fan speed controls will return the energy consumption to its 1981 pattern (Fig. 4).

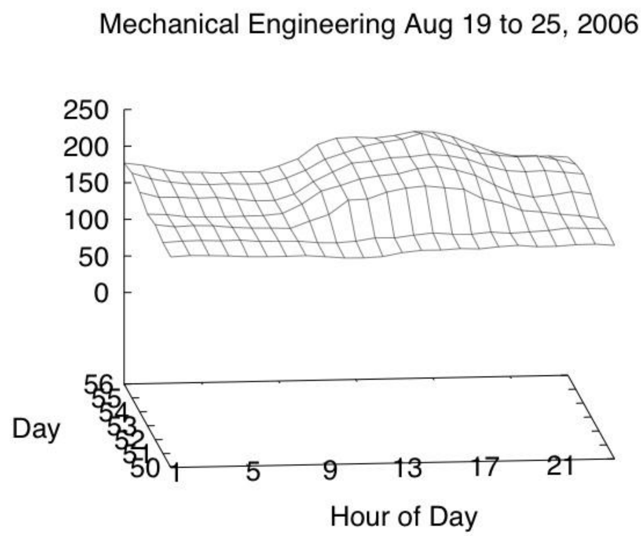

Figure 3: Electrical load for ME building in August 2006.

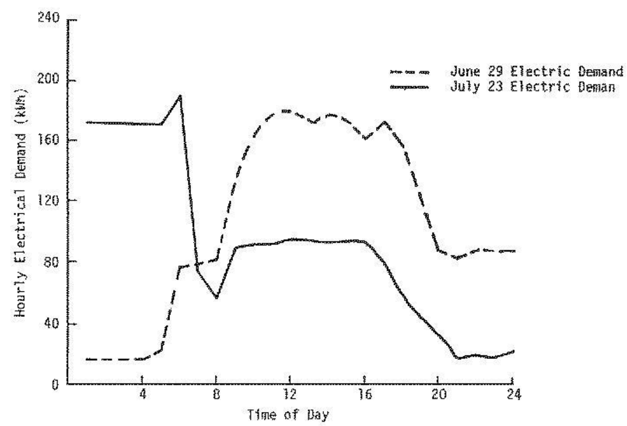

Figure 4: Measured electricity consumption for the ME building with thermal storage (July) and without thermal storage (June) in 1981.

With the new fan controls, we estimate the ability to run the ME building at approximately 100 kW at peak, and to reduce the load to approximately 70 kW following a curtailment request. Using the monitoring system, including flow meters and temperature sensors at appropriate locations in the hot and cold water storage system, the solar system and the heat exchanger interfacing ME with Ford DES, we will be able to experiment with various load shedding strategies, and measure the response in real time. We will also determine whether the additional level of information allows a greater degree of interoperability in comparison with other buildings where energy use is only monitored at the building boundary.

3.2. Electrical, Electronic and Computer Engineering

The Electrical, Electronic, and Computer Engineering (EECE) building is composed of research laboratories, classrooms, offices, and the Centennial Engineering Library (16,630 m^2 of gross floor space). The 9 air handling units contain 9 supply fans and 3 return fans totaling 201 kW. The three largest air handling units have variable frequency drives (VFD) for their fans (146 kW). The air handling units include dual and single duct systems. Cooling is supplied by the campus chilled water system.

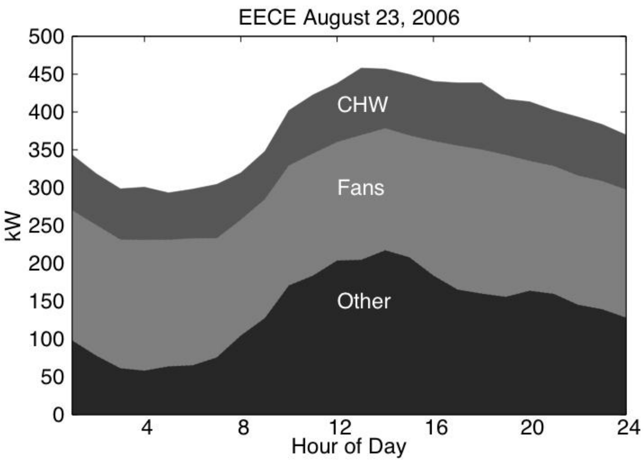

Figure 5: Total electricity usage (metered and CHW) for the EECE building on August 23. Note the large baseload due to the constant operation of fans which however could be set back if space sensors were installed.

The EECE building experiences a metered base load of approximately 200 kW, increasing to a peak of 375 kW which extends through the afternoon (Fig. 5). The baseload is due largely to fans that are not set back or shut down due to lack of space sensors. There is little difference between operation with and without students. The small effect of student occupancy is not surprising, due to the small fraction of the building dedicated to classrooms. It is difficult to account for the effect of library occupancy, as data are not available. However the library entry and exit gates could be used to log statistics and real-time data.

For this building, we estimate a load shedding capability of 50kW for chilled water and 50kW for fans, with current capabilities or small additions (space sensors informing the DDC).

3.3. Dane Smith Hall

Dane Smith Hall is composed of classrooms and contains 9084 m^2 of gross floor space with six air handling units. These air handling units contain six supply fans totaling 93 kW, each with VFD speed control. Each system is single duct with heating from the campus steam and cooling fromcampus chilled water. The electricity consumption is typical for a load-dominated building, in which the principal load is due to student occupancy, and where setpoints are raised at night. There is a metered baseload of about 70 kW, with an afternoon peak of about 175 kW. Student occupancy data reconstructed from the scheduling database (Fig. 6) show a daily student count between 800 and 1600 for the period 8 AM to 4 PM, and a secondary peak from 5 PM to 8 PM corresponding to evening classes.

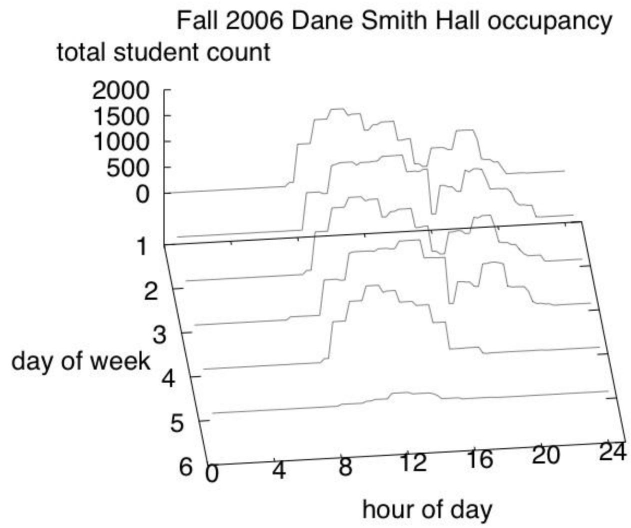

Figure 6: Reconstruction of student occupancy for the Fall 2006 semester, from scheduling database.

The break-up of energy consumption (Fig. 7) for a typical day in late August shows no CHW or fan load at night. During the day these become significant, closely following the shape of the occupancy. Overall, this building offers substantial flexibility but also requires a high level of systems interoperability (scheduling, occupancy sensors, lighting controls) for complete optimization.

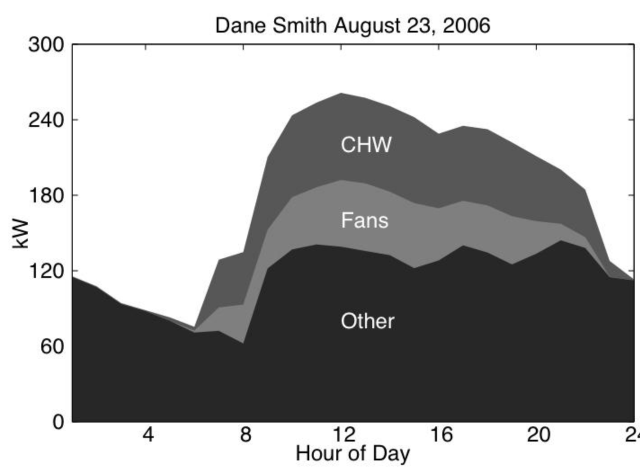

Figure 7: Break-up of electricity consumption for Dane Smith Hall on August 23, 2006.

With current capability, we estimate a load shedding capacity of 70 kW with minimal loss of comfort. More aggressive automated load shedding could take place if the scheduling database could be queried for current and predicted occupancy.

3.4. Cancer Research Facility

The Cancer Research Facility is composed of research laboratories and offices and contains 7592 m^2 of gross floor space with three air handling units. The main air handling units contain 4 supply fans and 4 exhaust fans with a total fan capacity of 298 kW. The facility is a significant energy user in that it uses 100% outside air. The facility contains 4 biohazard laboratories with a dedicated exhaust fan each and a common standby exhaust fan with a total capacity of 15 kW. The main exhaust fans have VFD speed control and the supply fans have econo disk speed controls. The system operates continuously. The air handling units are single duct with heating from the campus steam system and cooling from campus chilled water system. We estimate a combined load shedding capacity of 150 kW for this building.

3.5. Fine Arts Center and Popejoy Hall

The Fine Arts Center and Popejoy Hall operate on a common set of controls and contain 22,940 m^2 of gross floor space with 13 separate air handling units. The facility contains classrooms, offices, practice studios, and a large public performance hall. The air handling units contain 17 fans totaling 220 kW. None of the fans have speed control equipment. The air handling units include dual and single duct systems. With the exception of one system, heating is from campus steam and cooling is from campus chilled water. The Popejoy backstage system is a package unit with natural gas for heat and an electric A/C compressor.

The complex displays a fairly flat energy consumption profile, varying from 250 kW to 300 kW. The scope for load reduction is limited. An increase in the temperature setpoint would produce a reduction in the flow rate of chilled water, but no decrease in fan speed. A few large air handling units (Popejoy, Keller, Rodey) could be shut off completely if no performances or rehearsals were scheduled. This should be done automatically, regardless of grid-related curtailment requests, based on information from the scheduling database. Careful consideration should be given to ensuring that thermal inertia of the building is accounted for and that the cooling system is capable of absorbing the load from eventual large audiences in the performance spaces as well as the load related to cooling the building structure. The electric load is dominated by lighting and equipment, a substantial amount of fan power, and a relatively small electric load required for CHW production. The relatively small CHW-related electric load is due to the extremely efficient chillers in the UNM District Energy System. We estimate a curtailment capacity of 85 kW for the complex.

4. BUILDING-LEVEL CURTAILMENT

We consider the following curtailment strategies, in order of preference:

1. Curtail HVAC for non-occupied areas. This is best done in coordination with scheduling information, both taking advantage of `thermal inertia' and avoiding discomfort caused by it. Also, scheduling software should take HVAC zones into consideration.

2. Raise cooling set point by specified amounts, depending on level of curtailment required. This can only be done where DDC controls are available down to the individual zone, such as in Dane Smith Hall. Where zone controls are antiquated or otherwise non-existent, some curtailment may be achievable by adjusting the AHU supply air temperature setpoint, but the balance between fan energy and CHW energy will need to be carefully monitored to see any savings.

3. Reduce VFD control on fans by a set amount, which could be related to curtailment request. This is simple to accomplish for some of the buildings in this study by lowering the duct static pressure requirement which will cause the VFDs to slow. Pre-cooling may take place during off-peak hours or before likely curtailment requests.

To obtain a quantitative measure of the effect of strategies (2) and (3), a building similar to Dane Smith Hall was simulated in a building simulation code (TRNSYS 16). In particular, a section of the building was modeled in detail, including a fan and a cooling coil. The supply air to the fan is a mixture of return and outside air, which can be varied to ensure that adequate fresh air is supplied for low fan speeds.

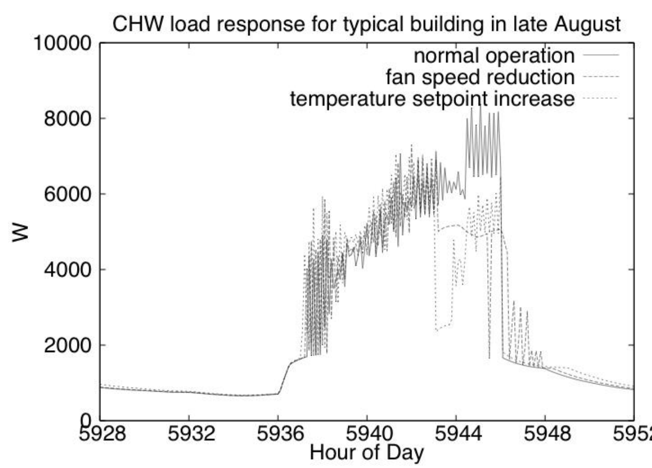

Figure 8: Electric load due to production of chilled water for an 875 m^2 section of a classroom building, under various curtailment strategies. Curtailment signal at hour 5943.

When the temperature set point is increased by 2°C, following a hypothetical curtailment request, a fast increase in temperature to the new set point results. The power required to produce chilled water initially drops sharply (Fig. 8) then begin to rise after 1hour, to reduced levels. The fan power behaves similarly. If direct control over the fan VFDs is possible, then the maximum speed can be re-set. In the simulation, the maximum fan speed was set to 1/3 of its normal maximum value. The result is a gradual increase in temperature which may be less perceptible to the occupants than a sudden one. The chilled water power is reduced to a level moderately below the normal (Fig. 8) while the fan power remains constant at approximately 1/4 of the "no-curtailment" level (Fig. 9). This strategy would be most suitable in conjunction with thermal storage, as in the case of the Mechanical Engineering building, or where the thermal inertia of chilled water system is large enough that central chilled water production can be curtailed independently of the actions taken in individual buildings.

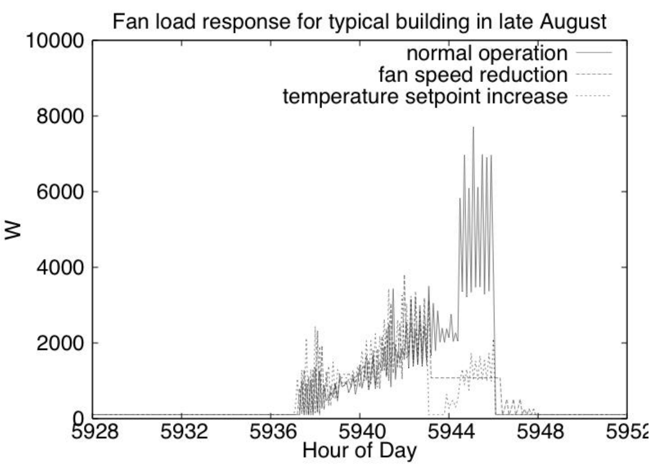

Figure 9: Fan electric load for a classroom building, under various curtailment strategies. Curtailment at hour 5943.

For both cases, the time-averaged response to a curtailment request is approximately 7.5 W/m^2, without significantly affecting comfort levels. If these response levels are taken to be representative of the average over all buildings on campus, then a total response of 3MW is possible. This level of response is achievable currently. However, increasing the use of information available could enable more aggressive curtailment, without the need for substantial capital investments. For example, if interrogation of the scheduling database reveals very low occupancy levels for a particular building for a period of several hours (e.g. Dane Smith Hall on a Friday, Fig. 6), then chilled water to the building could be cut completely. Weather forecasts, indicating the likelihood of curtailment requests, could also be used for this purpose. The structure of the building could be pre-cooled overnight, at low cost and efficiently due to the favorable thermodynamic conditions.

BACnet web-enabled control systems such as Delta allow inputs to be made realtime to adjust setpoints or change to operational strategies. Older control systems such as Inet can take an external input but it must be applied to the entire building (e.g., night or curtailment mode) due to bandwidth limitations in the systems routers. In most cases, DDC control systems are configurable with curtailment options, but they have not been used to date at UNM.

5. CONCLUSIONS AND RECOMMENDATIONS

There is a ~3MW curtailment potential with existing infrastructure, more if IT systems are fully integrated with ECMS or the energy portal. We recommend that discussions begin with UNM student representatives, faculty and staff to determine possible incentives (eg. partial refund of student fees from energy curtailment savings etc). PNM should propose incentive scheme for UNM. Physical infrastructure is necessary for full interoperability. A second turbine will be used to generate at peak. Capital improvement are necessary to allow these and additional strategies to be implemented. In order of technical preference, these are:

1. Zone-level DDC installed in concert with both lighting controls and fan VFDs to allow each space's entire energy usage to be modulated in response to load, occupancy and grid needs.
2. Photovoltaics in roofing systems to supplement the central cogeneration capabilities. While this cannot strictly be classified as curtailment, it would enable greater flexibility in the allocation of the co-generation resource, given that peak electricity production would generally coincide with peak use.
3. Central thermal storage may be feasible when City of Albuquerque abandons the 32,000 m^3 Yale reservoir. If used to store chilled water, it could satisfy campus CHW requirements for several hours daily, releasing approximately 2 MW of production capacity currently dedicated to operating the central CHW production. Furthermore, it could be used to absorb off-peak wind generated electricity.

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Author biographies

Andrea Mammoli obtained his Ph.D. in Mechanical Engineering at the University of Western Australia in 1995. He was a Postdoctoral Fellow at Los Alamos National Laboratory until 1997, when he joined the faculty of the Mechanical Engineering Department at the University of New Mexico. Prof. Mammoli's research interests are in computational mechanics, materials, and thermofluids. Since a sabbatical in Italy in 2004, he became interested in all aspects of building energy use, from passive solar design to high-tech solutions. He is currently PI on a project dealing with the restoration and modernization of UNM's mechanical engineering building thermal solar and storage system, on the UNM GridWise demonstration project, and on the development of utility-scale collectors for thermoelectric generation. Prof. Mammoli has authored or co-authored over 40 peer reviewed articles and conference proceedings.

Don Lincoln is currently a PhD candidate in Mechanical Engineering at the University of New Mexico. He also functions as a consultant to the Facilities Management and Operations Center at Sandia National Laboratories. He has over 30 years of experience in the electric power generation engineering and maintenance fields. He was recently the Director of Commercial Utility Programs, for Alion Science and Technology (the former Illinois Institute of Technology's Research Institute). In that position he managed a process analysis group and developed a hydraulics test laboratory supporting the nuclear industry's pressurized water reactor (PWR) containment sump issue. With Alion, he managed international consulting projects in the Ukraine, Canada, France, Spain, and Japan. Mr. Lincoln holds a B.S. and M.S. in Mechanical Engineering from the University of Nebraska and is a registered professional engineer.

Hans Barsun is a facilities engineer with the UNM Physical Plant Department in the Engineering & Energy Services Division. One of his primary duties is to monitor the energy usage in buildings on the UNM campus and to identify opportunities for increased efficiency. He also is responsible for design oversight on new capital projects at the university and managing mechanical and energy conservation projects. One of the most interesting projects that he is involved with is the Gridwise Demonstration / Solar Revival project at the UNM's Mechanical Engineering building, which is updating an old solar thermal system installed in 1980. Prior to joining UNM, he spent 10 years as a facilities engineer at Intel where he worked with the cleanroom air handling systems along with exhaust and liquid waste treatment systems. He earned a Masters degree from UNM and earlier graduated from Purdue with a degree in Aeronautical Engineering.

Larry Schuster is currently the University of New Mexico Utilities Engineer. He manages the operation of the UNM energy management data system described in the paper. He was previously assigned to assist the C.E.O. of the University of New Mexico subsidiary charged with development of a utilities renovation project business plan and, during execution of the business plan, he was the Project Manager for all the Chilled Water System Improvement Projects and Director of the Utility Project Team responsible for the entire project. The data system was one component of the plan improvements. He has earned BSME and MSME degrees from the University of New Mexico, is an Association of Energy Engineers Certified Energy Manager and Green Building Engineer, and licensed professional engineer. He has taught in the UNM School of Architecture and Planning for 18 years, currently teaches in the UNM Mechanical Engineering Department, and has worked at the University of New Mexico for over 30 years in various capacities.

Mario Ortiz obtained his BS in Mechanical Engineering with an economics minor from New Mexico State University in 1998. He gained experience in the manufacturing environment through co-ops with Ethicon Endo Surgery in Albuquerque, New Mexico and Ethicon in San Angelo, Texas. He worked on waste measurement systems for BNFL Instruments in Los Alamos, New Mexico from 1998 to 1999. Worked on semiconductor process metrology systems for Bio-Rad in Albuquerque, New Mexico from 1999-2003. In 2003 he began pursuing a masters degree in ME and a career in the sustainable energy field at the University of New Mexico in Albuquerque, New Mexico.

Jack Mc Gowan is President & CEO of Energy Control Inc. (ECI), an Energy Service Company and System Integrator. ECI has been on the Flying 40 list of fastest growing technology companies in New Mexico for the past five years, and also won the Association of Commerce and Industry Viva Award in 2004 for Vision, Investment, Vitality and Action. SDM Magazine named ECI among the Top 100 System Integrators in North America for the past five years. Mc Gowan is Chairman of the U.S. Department of Energy GridWise Architecture Council. He is an author and has published 5 books including "Direct Digital Control" on Fairmont Press and over 125 articles. Mc Gowan was chosen by his peers as 2006 Visionary at the Builconn Intelligent Buildings and GridWise Expo. The Association of Energy Engineers admitted him to the "International Energy Managers Hall of Fame" in 2003 and named him "International Energy Professional of the Year" in 1997. He also sits on the Energy and Power Management Technical Advisory Board and is a Contributing Editor with WWW.Automatedbuildings.com, Engineered Systems and CABA's Intelligent Homes and Buildings.