

Energy Efficiency Potential at UTK

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1 Introduction

1.1 Past activities

The University of Tennessee-Knoxville campus has an active program in integrating energy efficiency into its buildings and activities. Current actions, according to the *2005 UTK Environmental Progress Report* (UTK 2005) include:

- Improvements in the UTK steam plant
- Lowering steam distribution pressures
- Maintaining high rates of condensate return
- Air conditioning efficiencies
- Turning off heating, ventilating, and air conditioning (HVAC) systems during unoccupied periods
- Lowering temperatures in hot water systems
- Better insulation and better windows in new buildings
- Low-E retrofits to the windows of some older buildings
- Low-flow shower heads and water faucets in new and retrofitted buildings
- More efficient lighting systems
- Motion-sensing lighting systems
- Energy-conserving behavioral training
- “Green Power” purchase from KUB
- Solar panel and wind turbine demonstration
- Student Environmental Progress grants
- Request for a Long-Term Energy Plan

As can be seen by this list, the university has actively pursued currently available technologies for energy efficiency improvements. Looking toward the future, what technologies may become available that would further improve the energy efficiency of operations at UTK over the next twenty-five years?

1.2 Future

The purpose of this white paper is to identify and analyze the application of innovative technologies and methods for energy efficiency, on both the supply side and the demand side, that will be available within the next twenty-five years and that could have practical application on the UTK campus. The paper will begin with information on current source and use of energy at UTK. It will then detail several recent studies that included technologies that UTK may employ to change energy use or production on the campus. In chapter 4 it will provide more detail on technologies most likely to have an impact. Chapter 5 will briefly describe other technologies, focusing on transportation, that while not installed directly by UTK may nevertheless influence the shape of the campus.

2 Energy Use Breakdown

The *2005 UTK Environmental Progress Report* gives a breakdown of energy use on the campus between electricity, coal, natural gas, and steam. This list is a mixture of primary and intermediate energy forms, since UTK generates their steam and a portion of their electricity needs from coal and natural gas (Table 1). (Energy values are approximate based on conversion factors.) Coal and natural gas combined provided between 910 and 1030 TJoule, creating roughly 780 TJoule of steam in boiler, for an efficiency between 75% and 86%. Electricity is likely mostly from separate purchase from KUB rather than internal generation and represents about the same end-use energy demand as from steam.

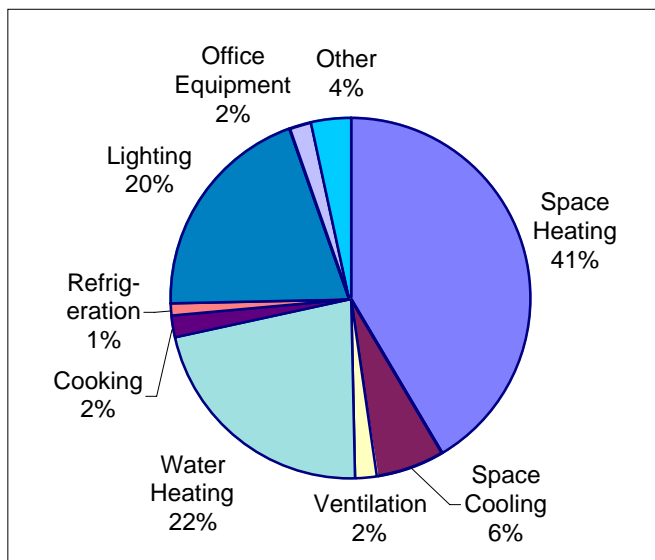
Table 1. 2003-2004 Primary and Intermediate Energy Use at UTK

	Units	TJoule	10 year change
Coal	26,624 ton	580- 700*	-22%
Natural Gas	3,137,317 therms	331	+533%
Electricity	223,331,935 kWh	804	+18%
Steam	661,615,271 lb	775-785	+29%

* Based on 20.8 – 24.9 mmBtu/ton and 1055 Joule/btu

The UTK information does not differentiate the energy by end-use. However, some insight can be gained from the Department of Energy's *2005 Buildings Energy Data Book* (DOE 2005). The reference includes a table showing the end-use energy intensity in btu/sqft for educational facilities, including both higher education and K-12 facilities across the country (Figure 1). The actual data is from a 1995 survey of commercial facilities and energy use may have changed somewhat since that time, such as an increase in electronic equipment. Energy use at UTK is also likely somewhat different because of its location in the southern U.S. (meaning proportionately more cooling and less heating needs) and a broader array of facilities (e.g., dormitories, laboratories) than the average educational institution.

Figure 1. Proportion of Energy End-Use of Educational Facilities by Building Activity (DOE 2005)



As can be seen by Figure 1, the vast majority of energy use is for HVAC, water heating, and lighting. Improvements in these areas will provide the most savings to the university. Furthermore, electrical uses have both higher cost per Btu and require significantly more amounts of primary energy to provide the end-use energy (since generation on average is around 33% efficient.) Energy savings in electrical end-uses such as lighting or office equipment will have an appreciably larger impact on total energy savings.

3 Previous Studies

Depending on the how far into the future one looks and how widespread in the market the technologies should be to be considered “available” there are a number of technologies that could change the energy use for buildings. A recent workshop and study attempted to identify technologies that could play a large role in future years.

3.1 Basic Energy Sciences Workshop

In October 2002, a workshop was held to assess the basic research directions that will assure a secure energy future (DOE 2003). Its goal was to look at basic research directions that could have a long-term impact on energy production or utilization. Over 100 scientists and engineers from academia, industry, and federal laboratories and agencies participated in the workshop. As a resource for the workshop participants, a factual document was compiled that summarized the state of energy sources and use at a national and international level.

3.1.1 Factual Document Assessment

Major transformations are possible in the energy features of buildings as the result of applied technology R&D and in the underlying basic sciences. In as much as most of these are best applied to new construction, their market penetration will probably occur after the year 2020.

Equipment and Appliances: By definition, the energy used in buildings is consumed by equipment that transforms fuel or electricity into end-uses, such as delivered heat or cooling, light, fresh air, vertical transport, cleaning of clothes or dishes, information management, or entertainment. The overall efficiency of this transformation depends largely on the efficiency of the equipment itself.

Numerous opportunities exist to develop equipment that is much more efficient than that currently available.

- It may be possible to virtually eliminate space heating in many climates by means of building shells with very high resistance to heat loss or gain involving high insulation walls, ceilings, and floors and triple pane windows with transparent heat-reflecting films; wide use of passive designs; and mass-produced components (walls, ceilings) with very low infiltration rates.
- Microtechnology could greatly increase heat and mass transfer rates, with highly efficient applications to chemical and thermal systems. One potential buildings application, microheat pumps, could be distributed throughout the building as part of the walls or

window. This distributed approach would allow selected rooms or even parts of rooms to be heated or cooled as needed.

- Multifunctional equipment and integrated systems offer the opportunity for a significant increase in efficiency improvement. For example, an integrated water heating/space cooling system that uses heat pumping to meet space heating, air conditioning, and water heating needs could be 70% more efficient than the combined efficiencies of systems in use today.
- Dramatic declines in the energy consumed by supermarket refrigeration systems could be achieved with distributed system designs. Such systems of the future would locate compressors close to display cabinets thereby avoiding the loss of refrigerant charge. Use of the waste heat by heat pumps for space conditioning would lead to further efficiency gains.
- As energy conversion technologies evolve, many buildings could become net producers of energy as roofs incorporate photovoltaic panels and fuel cells and microturbines generate more power than is required on site. In addition, fuel cells and microturbines produce waste heat that can be employed to serve building thermal loads. These power technologies could transform the entire demand and supply chain in terms of energy generation, distribution, and end-use.
- Building control systems of the future will likely incorporate smart technology to closely match energy and water supply and ambient conditions with the needs of building occupants. Building loads and central plants supplying the loads will be more integrated and optimized to enhance the efficient use the energy streams into and out of the building.

The Building Envelope: The building envelope provides fundamental thermal load control for a building. Walls, roofs, and floors block or delay the flow of heat between a building's interior and exterior. Windows can also block heat flow, provide daylight, transmit solar energy, and provide a view of the outside. High capacitance internal walls, ceilings, and floors can provide thermal storage that reduces energy use by storing solar energy and reduces peak loads by balancing energy use over a 24-hour period. Improvements in the energy performance of these building elements reduce energy use in buildings and thereby reduce Green House Gas (GHG) emissions.

Decreasing the building thermal load reduces the need for heating and cooling energy. The following emerging building envelope technologies will significantly reduce building energy use:

- super insulation, based on vacuum principles
- new-formula high-efficiency foam insulation that uses no chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons
- advanced gas-filled, multiple-glazing, low-emittance windows and electrochromic glazing

- roof systems that promote self drying, thereby preventing moisture from degrading its insulation
- passive solar components
- durable high-reflectance coatings
- advanced thermal storage materials

Intelligent Building Systems: The process of designing, constructing, starting up, controlling, and maintaining building systems is very complex. If it is done properly, the final product delivers comfort, safety, and a healthy environment and operates efficiently at reasonable cost. If any part of this process breaks down, the product fails to deliver these benefits. The lost health and productivity in office environments alone costs U.S. businesses hundreds of billions of dollars each year. In addition, operating these “broken” systems is estimated to cost at least 30% of commercial building energy use (more than \$45 billion). The key to designing and operating buildings efficiently is the ability to manage information, deliver it in a timely manner to the proper audience, and use it effectively for building design and operation. More intelligently designed and operated buildings use energy more efficiently and thus reduce GHG emissions.

Sensors and Controls: To best optimize the energy efficiency, air quality, and personal comfort of an entire building, monitoring of the interior space is critical. An essential requirement for effective monitoring will be the development of low-cost, low-power sensors. Poor office environments cost U.S. businesses more than \$400 billion a year in productivity losses and increased health care costs. To achieve maximum energy efficiency, a whole-building perspective is needed that integrates sensors, controls, and communications to anticipate changes in the environment and respond dynamically while maintaining comfort and air quality. First-order estimates indicate that such an approach will reduce annual energy consumption by 2.1 EJ (2 quads), reducing energy costs by \$55 billion and carbon emissions by 35 MtC (Christian 2002).

3.1.2 Workshop Conclusions

The discussions at the workshop presented a sense of urgency for the need for basic research to assure the energy supply for the nation and the world. An underlying theme in the discussions was the need for low carbon energy while adding 13 TW (13 TJ/s) of world-wide energy generation capability (a true grand challenge that was compared to the race for the moon in the 1960s), perhaps more critical in terms of security of the U.S. There were many scientific and technological challenges across the energy spectrum. Currently there are no viable ways of meeting these challenges. Non-carbon energy sources have daunting difficulties that need innovative solutions for these to become a high percentage of the energy pool. Fossil fuels have equal challenges relative to environmental concerns, as well as the ability to use non-traditional reserves.

The workshop discussions produced a total of 37 proposed research directions; four concerning residential, commercial, and industrial energy consumption:

- Sensors
- Solid State Lighting
- Innovative Materials for New Energy Technologies

- Multilayer Thin Film Materials and Deposition Processes

3.2 NCEP Study

In 2004, the National Commission for Energy Policy issued a report on possible energy policies (NCEP 2004). As an appendix to the report, a number of papers by different groups presented information on energy efficiency potentials. One paper was written by ORNL staffers listing example building technologies that could reduce energy use by 2025 (Hadley et al 2004). The five technologies described in the paper and achievable energy savings by 2025 were:

- **Solid state lighting**
 - Inorganic and organic light emitting diodes that replace incandescent and fluorescent lighting in a broad variety of end-uses (1.2-3.5 Quads),
- **Advanced geothermal heat pumps**
 - Selective water sorbents and other technologies that greatly reduce the capital cost and land requirements for geothermal heat pumps in residential and commercial sectors (0.2 Quads),
- **Integrated energy equipment**
 - Multi-function (cooling, heating, hot water, dehumidification) and packaged combined heat and power technologies that integrate multiple energy services into single pieces of equipment to lower cost and increase efficiency (0.3 Quads),
- **Efficient operations technologies**
 - Information technologies to improve the functioning of energy-using equipment on an ongoing basis within buildings (0.1 Quads), and
- **Smart roofs**
 - Nano- and micro-technologies that change the reflectance and infra-red emissivity of roof materials as a function of temperature to retain heat in winter and reflect heat in summer (0.1 Quads).

These example technologies may be applicable to some segments of the UTK campus.

4 UTK Buildings Applications

On the UTK campus, some of the likely candidate technologies for improved energy use (beyond those already being utilized) are:

- Solid-State and Hybrid Lighting
- Biomass cofiring of boilers
- Integrated Energy Equipment (e.g., CHP systems)
- Advanced Geothermal Systems
- Desiccant Systems
- Smart Roofs
- Improved Energy Management Software and Sensors

4.1 Lighting

4.1.1 Solid-State Lighting

Solid-state lighting (SSL) has the potential to revolutionize the lighting market through the introduction of highly energy efficient, longer-lasting and more versatile light sources. Advancements in SSL technology over the last two decades have contributed to a gradual market penetration in colored and some specialty white-light markets. As industry and government investment continues to improve the performance and reduce the costs associated with this technology, SSL is expected to start competing with conventional light sources for market share in general illumination applications. The scientific and research communities forecast that as the performance of light emitting diodes (LEDs) and organic light emitting diodes (OLEDs) improves, their costs will simultaneously decrease. Energy savings will result from consumers choosing SSL sources in general illumination (white-light) applications such as offices, retail establishments and homes.

SSL uses the emission of semi-conductor diodes to directly produce light, rather than resistance heating of a wire as in incandescent lamps or excitation of a gas as in fluorescent lamps. Electrons and holes are injected into a solid-state semiconductor material. When these recombine, light is emitted at around the wavelength corresponding to the energy bandgap of the material. Once the light is created internally, a high fraction of it must reach the surface and escape rather than be absorbed; this is done either through the shape of the LED or the type of material used. Because these lights can concentrate their emissions in the visible spectrum, they can be very efficient. Different wavelengths can be easily created by using different materials. However, SSL faces the problem that a single LED does not fill the full spectrum and appears colored. Creating a white, general-purpose light causes additional complexity and/or lower efficiency.

Lighting has a wide variety of end-uses, from high-quality task lighting in residential buildings, to factory lighting for a large area, to street lighting, to warning signals and headlights in transportation, among others. Initial end-uses for LED lighting have been in areas where long life has been especially desirable while high flux is not necessary (i.e., the light needs to be visible itself, but not necessarily illuminate other objects.) Examples include traffic lights, exit signs, and automobile taillights. In addition, these end-uses are generally single-color applications rather than white light so that the color rendition index (CRI) is not important. Future applications will expand as the technology provides increased brightness, better CRI, longer life, and lower cost. Initial applications will likely be in areas with little requirement for a high CRI such as outdoor and warehouse lighting. As the technology develops, with improved lighting quality and lowered cost, additional end-uses will be feasible. Eventually, most major end-uses could be supplied by LEDs.

OLEDs are most suitable in the near term for displays such as computer monitors or televisions. They may also be used for commercial accent lighting such as signs. In the longer term, they may be replacements for area lighting such as ceiling lights. However, the research priorities for the near-term end-uses (brightness, responsiveness) do not necessarily match the improvements needed for broader markets (efficiency, cost).

4.1.2 Hybrid Lighting

When sunlight is plentiful, the fiber optics in the luminaires provide all or most of the light needed in an area. Unlike conventional electric lamps, HSL systems produce little waste heat. During times of little or no sunlight, sensor-controlled electric lamps operate to maintain the desired illumination level. “It is a very cool light — you can touch the fibers with your hands,” says Dr. Duncan Earl, Oak Ridge National Laboratory. This is because the collectors remove the infrared light — the part of the spectrum that generates a lot of the heat in conventional bulbs. Hybrid light fixtures do use artificial means to generate light. Photosensors automatically adjust how much electric current is needed to keep a room uniformly bright. According to Earl, “On a sunny day [HSL] can pull in enough sunlight to offset 80 percent of the artificial light.” If the sun is blocked by a dark thundercloud, the piped-in sunlight will drop to only about five percent of a room’s lighting needs. The optical fibers also lose light the longer they are. Therefore, it only makes sense right now to use HSL in rooms with direct roof access. The current optimal fiber length is 50 feet or less. Typically this translates to the top two floors of a commercial building. (ORNL 2005)

4.2 Biomass Cofiring in Boilers

When compared with coal, biomass feedstocks (agriculture residues, dedicated energy crops, forest residues, urban wood waste, and wood mill wastes) have lower emission levels of sulfur or sulfur compounds and can potentially reduce nitrogen oxide emissions. In a system where biomass crops are raised for the purposes of energy production, the system is considered carbon neutral since crops absorb carbon during their growth process. Thus, the net emissions of the CO₂ are much lower compared with coal-firing. (English 2005).

Cofiring biomass has been successfully demonstrated as a supplementary fuel source in a number of high-efficiency boilers -- pulverized coal (PC) boilers, coal-fired cyclone boilers, fluidized-bed boilers, and spreader stokers. Field validation tests have shown that biomass can be substituted up to 15% of the total energy input by adjusting burner and feed intake systems. Biomass cofiring at levels up to 15% results in little or no loss in combustion efficiency.

Capital costs for retrofitting an existing coal-fired boiler are site specific and are affected by a host of factors – required boiler modifications, on-site processing requirements (e.g., size reduction, drying, etc.), and requirements for storage and handling. However, a key difference is whether the biomass will be blended with coal or fired separately. If biomass is blended, no separate feed system is required for the biomass. Blending biomass with coal tends to limit the amount of biomass that can be accommodated to about 2% of the total heat input. Separate feed systems are much more expensive, but the amount of biomass that can be burned increases to about 15% of a unit’s total heat input. Estimates are that the capital cost for blending up to 2% biomass would be \$50/kW (~\$6/lb/hr steam capacity) while for blending up to 15% would be around \$200/kW (~\$24/lb/hr steam capacity). (English 2005)

4.3 Integrated Energy Systems

Integration of systems is a powerful method to improve the functions provided by multiple systems. It can lower costs, improve efficiency, reduce space requirements, and make services that are otherwise unavailable attractive to users. Integration occurs in a large number of fields,

from combined inventory control/checkout in businesses, to cell phones with built-in cameras for consumers.

A major concept for improving energy efficiency is recognizing the synergy between energy forms needed by different energy end-uses or types of equipment. Integrating the equipment allows the exhaust of one to be supplied as an input energy source to another, lowering the overall energy consumed. In addition, integrated systems allow the common use of components for multiple purposes, which can result in lower first costs for systems.

Several of these concepts are already being implemented at UTK, most notably the generation of steam from electricity production, known as combined heat and power (CHP). As equipment has improved, smaller sizes of equipment have become economic. This allows utilization in individual buildings or elsewhere on campus that are not connected to the steam system and may not previously have proven suitable. Improved integration can lower the barriers and foster the acceptance of high efficiency technologies. Possibilities include:

- Combined heat pump space heating, cooling, water heating, and dehumidification
- Cool air from heat-pump water heating used for space cooling
- Exhaust heat from refrigeration and freezing used for space heating and/or hot water
- Exhaust heat from distributed electricity generation used for space heating, water heating, and other thermal energy needs

The highest and most consistent energy savings from distributed energy resources occur when the thermal exhaust from the electric generation is used for other purposes at the site such as heating, cooling, dehumidification, or steam. Total efficiencies from this combined cooling, heating and power (CHP) can easily exceed 70% (DOE 2004). Smaller individual integrated systems may also facilitate the use of biofuels. While the volume that would be necessary for cofiring in the steam boilers may be beyond the amount available locally, smaller systems may be able to use locally available biomass or provide a crucial demonstration system before expanding to a larger use of biofuels.

4.4 Advanced Geothermal Heat Pumps

Much of the UTK system uses district steam for heating and electric centrifugal chillers for cooling. Some facilities though may be suitable for using geothermal heat pump systems as an energy savings mechanism. Nationally and locally, heat pumps are used for heating (and cooling), but overall provide less than 10% of the heating needs in the country. A heat pump works on the same principle as an air conditioner except that it allows the functions of the evaporator and condenser (which absorb and reject heat) to be exchanged depending on whether heating or cooling is required.

Heat pumps have been around for many years, and the technology is quite robust. However, they suffer from one problem. The efficiency and capacity of heat pumps depends on the temperature difference across which the heat is to be pumped: the greater this temperature difference, the lower the efficiency and the lower the capacity. For an air-source heat pump, the temperature difference corresponds to the difference between outside air temperature and the desired indoor air temperature. Thus in the cooling season, both the cooling capacity and the cooling efficiency

decrease as the outdoor air temperature rises. Likewise, in the heating season, both the heating capacity and the heating efficiency decrease as outdoor air temperature falls. In most applications, supplemental heating is required during the winter.

A geothermal heat pump (GHP) solves the problem of decreasing efficiencies due to temperature extremes by eliminating the outdoor coil altogether, and replacing it with a heat exchanger that is coupled to the earth. Unlike outdoor air temperatures – which can vary by more than 100°F over the year – the temperature of the earth just a few feet below the surface is fairly constant. Absorbing and rejecting heat to the earth results in a heat pump with higher efficiency and more stable capacity throughout the year. Most applications do not require supplemental heating. The main disadvantages of the conventional GHP systems relative to air-to-air heat pumps are the extra expense of burying heat exchangers in the earth and the difficulty of locating and making repairs, if needed.

Several near- and long-term technologies could improve the cost-effectiveness of GHP systems. One way of reducing the cost of GHPs is to use a supplemental heat rejecter such as a dry fluid cooler. In this type of system – known as a hybrid – the ground heat exchangers are typically sized to meet the heating load only. During the cooling season, some of the heat that would have been rejected to the ground is rejected to the atmosphere through the fluid cooler.

Recent research has identified another process that can overcome more of the shortfalls in conventional ground-coupled heat pumps and offer even higher efficiencies and peak load reduction capability for residential and small commercial heat pumps. The expense of large underground heat exchangers is bypassed by a revolutionary new process of heat recovery that enables a small heat exchanger with a special desiccant-like material to exchange water naturally present in the environment either in the form of humidity or as adsorbed water. The process is termed selective water sorbents (SWS).

By absorbing water from the ambient surroundings (ground or air) during off-peak periods and desorbing water during peak periods, the overall energy profile can be changed to accomplish higher cooling efficiencies and simultaneously reduce peak electric demand. In a ground-coupled situation, the system would use a small, buried container that can rapidly exchange heat through a reversible process of exchanging water between the SWS and its environs. Since water has a large heat of vaporization, small quantities of water transport can move large amounts of energy across small thermal gradients.

Since water is environmentally benign, SWS technology offers both energy efficiency and environmental benefits. The dynamic sequence of water exchange reduces the footprint and physical size of a ground-coupled heat exchanger, lowering its initial and operating costs and increasing the potential market. Additional improvements may increase the likelihood of expansion of this energy efficient and green technology as the SWS technology is further developed.

4.5 Desiccant Systems

Oak Ridge National Laboratory researchers have for a number of years analyzed the value and technical feasibility for increased use of desiccant systems as a means to reduce the latent heat from moist air so that energy is saved. They have had ongoing demonstration projects at schools

and other facilities where high amounts of humidity can lower the indoor air quality. A description of some of their research follows (ORNL 2006).

Efforts to improve energy efficiency in buildings by tightening building envelopes and improving thermal insulation do not address indoor air quality (IAQ) issues or the issue of latent (moisture-related) cooling loads in buildings. Conventional air conditioners are not designed to handle the large ventilation rates needed to provide acceptable IAQ or overcome moisture buildup. The effects of the "sick building syndrome" on public health and productivity and of moisture damage are major incentives to develop energy-efficient space conditioning systems that provide high levels of humidity control.

Desiccants can improve the indoor air quality of all types of buildings. Desiccant cooling systems can be used as stand-alone systems or with conventional air-conditioning. In these systems, a desiccant removes moisture from the air, which releases heat and increases the air temperature. The dry air is cooled using either evaporative cooling or the cooling coils of a conventional air conditioner. The absorbed moisture in the desiccant is then removed (the desiccant is regenerated, or brought back to its original dry state) using thermal energy supplied by natural gas, electricity, waste heat, or the sun. Commercially available desiccants include silica gel, activated alumina, natural and synthetic zeolites, lithium chloride, and synthetic polymers.

Desiccant systems can supplement conventional air conditioners, reducing the need for vapor-compression systems to operate for long cycles and at low temperatures in order to handle temperature and humidity. By working together, conventional cooling systems and desiccant systems can tackle the temperature and humidity loads separately and more efficiently. HVAC engineers can then reduce compressor size and eliminate excess chiller capacity.

4.6 Smart Roofs

There have been a number of improvements to window, wall, and roof energy performance. Low-E windows, better insulation, reduced air infiltration, and high reflectance roofs have all served to lower the energy requirements for buildings. Many of these technologies have already been used at UTK on new buildings, as well as retrofits on some older buildings. New technologies may increase the amount of savings or create mechanisms for generating energy (e.g., photovoltaic systems.) Below is a description from the NCEP paper (Hadley et al, 2004) of one proposed technology to improve the overall energy savings from roofs, using nanotechnology to create temperature-dependent reflectance for roofs.

Today there is a great deal of discussion in the roofing industry about cool roofs, green roofs, garden roofs, vegetated roofs and other roof systems that are expected to be more energy efficient and ecologically friendlier than "conventional roofs". Cool roofs have received positive trade press, and some state and federal support for installation where cooling is the dominant building energy load. In mixed climates with both significant heating and cooling loads, the high reflectance that helps in the summer hurts in the winter by turning away solar energy that would otherwise heat the building. What the roof industry needs is a smart surface that changes reflectance with temperature.

An improvement in the roof's ability to modify heat flux based on air temperature has substantial potential for energy savings. Simulations have shown that a roof with a reflectivity of 85% above 65°F and 5% below 65° provides estimated energy savings of 5-10¢/sq ft-yr over the best available commercial roofing material and from 10-20¢/sq ft-yr over standard shingles in a wide variety of climates.

What would the smart roof concept look like? The product would consist of four layers. The first layer is the roof substrate whether metal, concrete, thermoplastic membrane or wood. The second layer is a customized polymer layer with a top surface that has a specially designed indentation pattern. The third layer is an opaque material used to fill the nanoscale indentations on the polymer surface. The fourth layer is a clear coating providing both physical and UV protection. The composite can be manufactured as a laminate that overlays the existing roof or that becomes part of the manufacturing process for the respective roof product. As a result, it is not expected to add any weight penalty versus existing roof materials.

4.7 Energy Management Systems Technology

Research has indicated many reasons why energy efficiency varies so much in commercial buildings. The causes of variation in efficiency can be categorized as variations in efficiency of operation, efficiency of systems, and efficiency of equipment. Of these three, about half of the potential improvement in energy efficiency for commercial buildings would result from operational improvements, with the remainder from equipment and system upgrades.

Many studies have shown the importance of operational improvements, with typical savings of 10–20% possible in a wide range of buildings (see Haas and Sharp 1999 for data and additional references). Effective operations provide one of the most cost-effective methods for achieving energy efficiency. Since the Oil Embargo of 1973, the improvement of building operations has been a key means of achieving energy savings. Despite the demonstrated opportunities, the “technology” for achieving higher-efficiency building operations currently is not based in hardware so much as in software and expert knowledge. Because of this current “soft”-ware dominance, transfer and wide distribution of knowledge is challenging.

Advances in information technologies such as diagnostic and monitoring software and hardware are still important for achieving improvements in building energy operations. Continued changes toward miniaturization of hardware and toward enhanced measurement and diagnostic capabilities emerge regularly and impact how building operations can be diagnosed and improved. The challenge is to move all phases of technology development, both hardware and software, toward specifically helping and improving building energy operations, especially in order to be able to conduct diagnostics and remediation on increasingly larger scales with fewer expert personnel required.

The technology includes components across the development spectrum. Expert knowledge on the systematic process of energy system evaluation of potential improvements is fairly well developed, although there are still major difficulties in managing the transaction between expert providers and non-expert procurers of such services. Development in sensors and controls is needed to improve their performance and lower their cost.

Energy Performance Rating Systems – The development of energy performance rating systems is, in certain ways, still in its infancy, as so little time has passed since these systems were first successfully developed (in 1999). In addition, the range of building types for which these tools are available is limited, and application in mixed-use buildings is often difficult. Oak Ridge National Laboratory has the only tool available for application in mixed-use buildings, and this tool has not been extensively tested. Significant R&D on these systems and their application is still important, although a major portion of commercial buildings is currently covered by the Energy Star tools.

Monitoring and diagnostic systems – The major gap in the technology results from the limited development to date of advanced monitoring and diagnostics systems. Advances in reliability and reductions in cost of hardware are needed. Expert knowledge must be codified and transferred to diagnostic and remediation recommendation algorithms.

With the high number of components in a commercial building, it is difficult for operation staff just to keep fully aware of equipment and system conditions. Without automated monitoring and fault detection, and the sensors and controls on which they rely, performance can degrade. The number and range of types of sensors installed in commercial buildings today is inadequate to provide sufficient automated (or even visual) monitoring. The primary impediment often cited to more and better sensing is the cost of additional sensors. Installed costs of sensors need to be reduced and decision makers need to become informed regarding the benefits they can derive from better sensing and control.

Automatic control needs to be developed that controls indoor conditions adequately that building staff build confidence in control systems. Control based on more plentiful sensors is required to control at the level desired by occupants and optimize energy use. Optimal control techniques at the system and whole-building level are needed to reach the level of performance where high-quality indoor conditions are provided at minimum net energy use. Control must be extended from individual independent loops to system level controls to achieve least-cost, highly efficient, building operation.

The BESAC workshop reported that a needed breakthrough is an information technology infrastructure that allows data from sensors to be collected, processed, and converted into useful information upon which action can be taken, thereby reducing energy use or providing other useful functionality. The new paradigm is a dense network of ubiquitous, wireless, self-powered sensors that can be networked to provide a complete and reliable picture of energy use and related parameters throughout a building and its equipment. Wireless communications protocols that are energy efficient will allow very long battery life or will support stand-alone operation using scavenged energy. Open protocols that are standardized across many business sectors will ensure interoperability of sensor and network components. Neural networks and adaptive logic can be utilized to adjust and fine-tune the operation of the building to meet changing occupant needs and external events, such as real time utility pricing.

Sensors and controls – Sensor and control needs for commercial buildings span a broad range of technical activities. Sensors at a sufficiently low cost are needed for a broad range of measurements that includes lighting quality, volumetric fluid flow rates, rotational position, wear, vibration, and power consumption, as well as the usual measurements of temperature and

humidity that are currently performed in commercial buildings. Sensor technology will require built in intelligence to ensure accuracy, self-diagnostics, and be easily integrated into existing systems. These emerging technologies should facilitate broader applications of sensors in buildings including automated diagnostics of HVAC and other energy systems, lighting, fire and safety systems, demand responsiveness and optimal control, indoor air quality, and counter measures against bio/chem attacks (building security).

In addition to possessing lower installed cost than today's sensors, R&D must lead to sensors with enhanced performance: longer lives, greater reliability, higher accuracy, persistent calibration. These enhancements will lead to higher, persistent, performance of building systems.

According to the BESAC workshop assessment, a breakthrough is needed in a new generation of smart sensors that can detect and measure a wide range of physical and chemical parameters. The sensors should be small, self-powered, low cost, durable, and robust in order to work under a wide range of physical environments, with detection capabilities that are specific to the parameter of interest, such as chemical species, particle size and/or shape, etc. Very low cost sensors allow redundancy that will improve accuracy. Sensors would be available to respond to a full range of stimuli, such as optical and radiant measurements, surface acoustic waves, airflow, chemical species, biological agents, inorganic particles, energy flows, magnetic fields, current, voltage, temperature, stresses, etc. On board, integrated electronics provide signal processing, conditioning and data compression, if needed.

Streamlined installation – In addition to improving the quality of sensors themselves, streamlined installation is required. One of the largest cost components for sensors is the cost of installation. Installation, particularly in retrofits, requires running cabling in spaces such as walls and ceilings that are frequently difficult to access, running up expenses for labor. Wireless network technology or communications over existing power wiring can significantly reduce installation costs in new or retrofit applications.

5 Other Applications

Besides energy efficiency-related measures directly installed on the UTK campus, there are likely to be broader changes in university life that could have a larger impact on energy use. Transportation energy use is a critical issue for our society, including UTK. However, transportation energy is a much smaller relative component of energy use for the university than buildings and equipment. There are a number of possible changes to transportation technologies and patterns that could have an impact on university life. Among these are:

- Hybrid technologies – Combined engine/battery-driven vehicles can increase the overall efficiency. Allowing the vehicle to also plug in to the electrical grid could provide a significant fraction of its energy needs from non-petroleum sources.
- Fuel cells – Vehicles using fuel cells for power could provide high-efficiency and low emissions, but there are many hurdles to their successful adoption including cost and fuel availability.

- Compressed natural gas – This alternate fuel is currently available for fleet vehicles but is not widely used. It provides an alternative to petroleum fuels, but natural gas itself is also becoming scarcer and higher priced.
- Ethanol – This alternate fuel is already widely used as an additive to gasoline, and many vehicles on the road could use up to 85% ethanol in their fuel mixture. The current source is mainly from corn, which is fairly energy-intensive in its planting and harvesting. Research is underway to develop economic methods to manufacture cellulosic ethanol, which could utilize a wider variety of plant sources.
- Biodiesel – This fuel can be manufactured from a number of plant or animal sources, with new methods available to broaden the types of materials that could be used.
- Batteries – Vehicles running solely on grid-supplied electricity by use of batteries have been under development for a number of years. Breakthroughs are needed in storage technologies before vehicles will have an adequate range at an affordable cost and lifetime.
- Public transit – The UTK campus currently has public transit available on campus as well as to and from the surrounding community. Increases in fuel prices may encourage switching from private vehicle to mass transit, which could alter the parking and traffic issues on campus. There may be market-based or other incentives from UTK to encourage the trend.
- Carpooling – Similar to public transit, increases in fuel costs may encourage the use of carpooling by students and staff. UTK may offer incentives or other policies to encourage the trend.
- Distance learning – With the increased availability of high-speed communication, more classes are being made available without physical attendance required. This lowers the need for transportation, classroom space, on-campus residence, and consequent energy requirements.

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