ENERGY AND BUILDING AUTOMATION

A WHITE PAPER ON ITS POTENTIAL FOR THE CITY OF FLINT AND GENESEE COUNTY

AltEnergy Inc.

A. What is "Building Automation" and how does this effect Energy Efficiency and Conservation for Flint government-owned facilities?

A.1 What is Building Automation?

Building automation (BA) describes the functionality provided by the control system of a building for the purpose of energy savings and optimization. A building automation system (BAS) is an example of a distributed control system (DCS). The control system is a computerized, intelligent network of electronic devices, designed to monitor and control the mechanical and lighting systems in a building. The BAS core functionality keeps the building climate within a specified range, provides lighting based on an occupancy schedule, and monitors system performance and device failures and provides email and/or text notifications to building engineering staff. The BAS functionality reduces building energy and maintenance costs when compared to a non-controlled building. A building controlled by a BAS is often referred to as an intelligent building system.

The typical facilities that can benefit from building automation include:

- Large urban, full-service hospitals
- Commercial, privately owned buildings
- Government buildings (e.g., municipal facilities)
- Research facilities (e.g., laboratories)
- Large data or information processing centers
- Large residential units (high rises)
- Large, indoor shopping malls
- Movie theaters, casinos, auditoriums, and other entertainment venues
- Grocery stores
- Aquariums
- Convention centers
- Hotels
- Airports
- Correctional institutions.

The main benefits of building automation include:

- Lower energy usage
- Optimization of energy usage
- Security and privacy
- Control over energy resources
- Control of operating conditions:
    - humidity
    - air volume
    - temperature

Figures 1 and 2 show installations where building automation technology has been successfully deployed.

Figure 1. Building automation on a commercial building.

Figure 2. Building automation on an apartment building.

Figure 3. The topology of a Building Automation System.

Building Automation System Topology

Perhaps the most distinguishing characteristic of building automation systems is that they rely on standardized network protocols. The most common BA protocols in use are:

- LonWorks
- BAC-net
- KNX/EIB
- Internet based
    - Wired
    - Wireless

Most building automation networks consist of a *primary* and *secondary* bus (see Fig. 3) which connect high-level controllers (generally specialized for building automation, but may be generic programmable logic controllers) with lower-level controllers, input/output devices and a user interface (also known as a human interface device). The primary and secondary bus can be a wired or a wireless network.

Most controllers are proprietary. Each company has its own controllers for specific applications. Some are designed with limited controls: for example, a simple Packaged Roof Top Unit. Others are designed to be flexible. Sensor inputs are used to read a variable measurement. Examples are temperature, humidity and pressure sensors or from wireless sensors. A digital input indicates if a device is turned on or not. Analog outputs control specific actuators that effect changes on the air temperature of the building and on its energy management system (EMS). An example is a hot water valve opening up 25% to maintain a setpoint. Digital outputs are used to open and close relays and switches. An example would be to turn on the parking lot lights when a photocell indicates it is dark outside.

A.2 Building Automation Components

1. Controller

Controllers are essentially small, purpose-built computers with input and output capabilities. These controllers come in a range of sizes and capabilities to control devices commonly found in buildings, and to control sub-networks of controllers. Inputs allow a controller to read temperatures, humidity, pressure, current flow, air flow, and other essential factors. The outputs allow the controller to send command and control signals to slave devices, and to other parts of the system. Inputs and outputs can be either digital or analog. Controllers used for building automation can be grouped in 3 categories. Programmable Logic Controllers (PLCs), System/Network controllers, and Terminal Unit controllers. However an additional device can also exist in order to integrate 3rd party systems (i.e. a stand-alone AC system) into a central Building automation system).

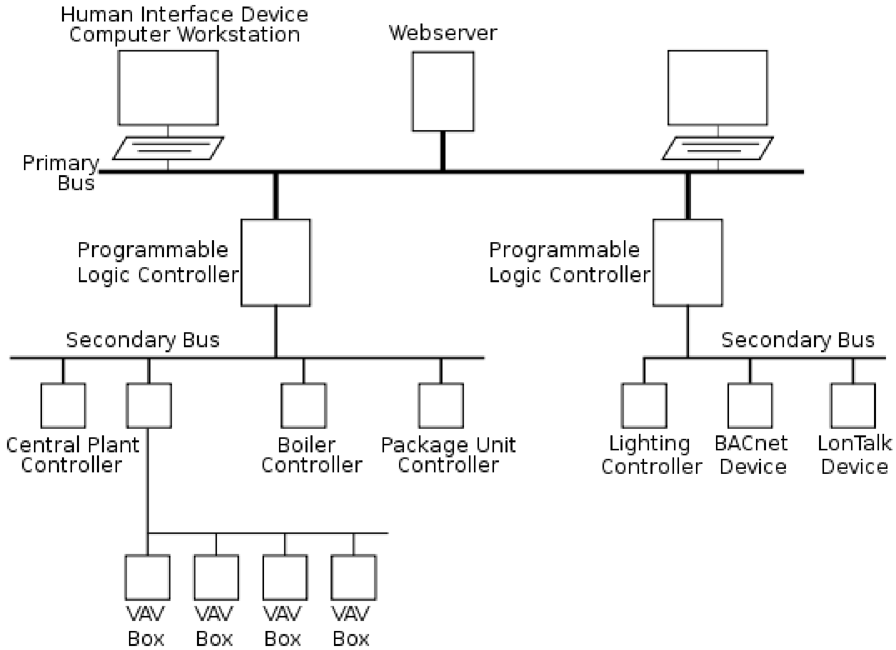

Figure 3. System topology of a Building Automation system.

PLC's provide the most responsiveness and processing power, but at a unit cost typically 2 to 3 times that of a System/Network controller intended for BAS applications. Terminal Unit controllers are usually the least expensive and least powerful. PLC's may be used to automate high-end applications such as clean rooms or hospitals where the cost of the controllers is a lesser concern. In office buildings, supermarkets, malls, and other common automated buildings the systems will use System/Network controllers rather than PLC's. System/Network controllers may be applied to control one or more mechanical systems such as an Air Handler Unit (AHU), boiler, chiller, etc., or they may supervise a sub-network of controllers. In the diagram above, System/Network controllers are often used in place of PLCs. Terminal Unit controllers usually are suited for control of lighting and/or simpler devices such as a package rooftop unit, heat pump, VAV box, or fan coil, etc. The installer typically selects 1 of the available pre-programmed personalities best suited to the device to be controlled, and does not have to create new control logic.

2. Occupancy

Occupancy is one of 2 or more operating modes for a building automation system. Unoccupied, Morning Warm-up, and Night-time Setback are other common modes. Occupancy is usually based on time of day schedules. In Occupancy mode, the BAS aims to provides a comfortable climate and adequate lighting, often with zone-based control so that users on one side of a building have a different thermostat (or a different system, or sub system) than users on the opposite side. A temperature sensor in the zone provides feedback to the controller, so it can deliver heating or cooling as needed. If enabled, Morning Warmup (MWU) mode occurs prior to Occupancy. During Morning Warmup the BAS tries to bring the building to setpoint just in time for Occupancy. The BAS often factors in outdoor conditions and historical experience to optimize MWU. This is also referred to as Optimized Start. An override is a manually-initiated command to the BAS. For example, many wall-mounted temperature sensors will have a pushbutton that forces the system into Occupancy mode for a set number of minutes. Where present, web interfaces allow users to remotely initiate an override on the BAS. Some buildings rely on occupancy sensors to activate lighting and/or climate conditioning. Given the potential for long lead times before a space becomes sufficiently cool or warm, climate conditioning is not often initiated directly by an occupancy sensor.

3. Lighting

Lighting can be turned on and off with a building automation system based on time of day, or the occupancy sensors and timers. One typical example is to turn the lights in a space on for a half hour since the last motion was sensed. A photocell placed outside a building can sense darkness, and the time of day, and modulate lights in outer offices and the parking lot.

4. Air handlers

Most air handlers mix return and outside air so less temperature change is needed. This can save money by using less chilled or heated water (not all air handling units use chilled/hot water circuits). Some external air is needed to keep the building's air healthy. Analog or digital temperature sensors may be placed in the space or room, the return and supply air ducts, and sometimes the external air. Actuators are placed on the hot and chilled water valves, the outside air and return air dampers. The supply fan (and return if applicable) is started and stopped based on either time of day, temperatures, building pressures or a combination.

5. Constant volume air-handling units

The less efficient type of air-handler is a "constant volume air handling unit," or CAV. The fans in CAVs do not have variable-speed controls. Instead, CAVs open and close dampers and water-supply valves to maintain temperatures in the building's spaces. They heat or cool the spaces by opening or closing chilled or hot water valves that feed their internal heat exchangers Generally one CAV serves several spaces, but large buildings may have many CAVs.

6. Variable volume air-handling units

A more efficient unit is a "variable air volume (VAV) air-handling unit," or VAV. VAVs supply pressurized air to VAV boxes, usually one box per room or area. A VAV air handler can change the pressure to the VAV boxes by changing the speed of a fan or blower with a motor or (less efficiently) by moving inlet guide vanes to a fixed-speed fan. The amount of air is determined by the needs of the spaces served by the VAV boxes. Each VAV box supply air to a small space, like an office. Each box has a damper that is opened or closed based on how much heating or cooling is required in its space. The more boxes are open, the more air is required, and a greater amount of air is supplied by the VAV air-handling unit. Some VAV boxes also have hot water valves and an internal heat exchanger. The valves for hot and cold water are opened or closed based on the heat demand for the spaces it is supplying. These heated VAV boxes are sometimes used on the perimeter only and the interior zones are cooling only.

7. VAV hybrid systems

Another variation is a hybrid between VAV and CAV systems. In this system, the interior zones operate as in a VAV system. The outer zones differ in that the heating is supplied by a heating fan in a central location usually with a heating coil fed by the building boiler. The heated air is ducted to the exterior dual duct mixing boxes and dampers controlled by the zone thermostat calling for either cooled or heated air as needed.

8. Central plant

A central plant is needed to supply the air-handling units with water. It may supply a chilled water system, hot water system and a condenser water system, as well as transformers and auxiliary power unit for emergency power. If well managed, these can often help each other. For example, some plants generate electric power at periods with peak demand, using a gas turbine, and then use the turbine's hot exhaust to heat water or power an absorptive chiller.

9. Chilled water system

Chilled water is often used to cool a building's air and equipment. The chilled water system will have chiller(s) and pumps. Analog temperature sensors measure the chilled water supply and return lines. The chiller(s) are sequenced on and off to chill the chilled water supply.

10. Condenser water system

Cooling tower(s) and pumps are used to supply cool condenser water to the chillers. The condenser water supply to the chillers has to be constant so, speed drives are commonly used on the cooling tower fans to control temperature. Proper cooling tower temperature assures the proper refrigerant head pressure in the chiller. The cooling tower set point used depends upon the refrigerant being used. Analog temperature sensors measure the condenser water supply and return lines.

11. Hot water system

The hot water system supplies heat to the building's air-handling unit or VAV box heating coils, along with the domestic hot water heating coils (Calorifier). The hot water system will have a boiler(s) and pumps. Analog temperature sensors are placed in the hot water supply and return lines. Some type of mixing valve is usually used to control the heating water loop temperature. The boiler(s) and pumps are sequenced on and off to maintain supply.

12. Alarms and security

Many building automation systems have alarm capabilities. If an alarm is detected, it can be programmed to notify someone. Notification can be through a computer, Internet, cellular phone, or audible alarm.

- Common temperature alarms are: space, supply air, chilled water supply and hot water supply.
- Differential pressure switches can be placed on the filter to determine if it is dirty.

- Status alarms are common. If a mechanical device like a pump is requested to start, and the status input indicates it is off. This can indicate a mechanical failure.
- Some valve actuators have end switches to indicate if the valve has opened or not.
- Carbon monoxide and carbon dioxide sensors can be used to alarm if levels are too high.
- Refrigerant sensors can be used to indicate a possible refrigerant leak.
- Current sensors can be used to detect low current conditions caused by slipping fan belts, or clogging strainers at pumps.

At sites with several buildings, momentary power failures can cause hundreds or thousands of alarms from equipment that has shut down. Some sites are programmed so that critical alarms are automatically re-sent at varying intervals. For example, a repeating critical alarm (of a uninterruptible power supply in 'by pass') might resound at 10 minutes, 30 minutes, and every 2 to 4 hours there after until the alarms are resolved. Security systems can be interlocked to a building automation system. If occupancy sensors are present, they can also be used as burglar alarms. Fire and smoke alarm systems can be hard-wired to override building automation. For example: if the smoke alarm is activated, all the outside air dampers close to prevent air coming into the building, and an exhaust system can isolate the alarmed area and activate an exhaust fan to move smoke out of the area. Life safety applications are normally hard-wired to a mechanical device to override building automation control.

A.3 How does Building Automation effect Energy Efficiency and Energy Conservation for Flint government-owned facilities?

From the above summary of Building automation, it can be seen that a building automation system installed on Flint government-owned facilities will allow energy to be used more efficiently and reduce energy consumption. Whether or not a building automation system will reduce energy costs, depends on the size of the facility. If the facility is too small, the energy savings may not offset the investments in the building automation system during the lifetime of the system.

B. What specific activities are included in Building Automation?

Most of the activities happen when the system is being designed and installed. After the system is installed there is minimum monitoring and maintenance as the system is highly automated. The specific activities are:

- Economic feasibility analysis
- Funding search activities
- Building automation system design
- Vendor selection, installation, and system integration
- Building automation system testing
- On-going monitoring and maintenance

C. Provide analysis of City of Flint Information and Technology services in relation to Building Automation.

The COF currently has 23 servers and 517 PCs to support information technology. At approximately 250 Watt per workstation, this is equivalent to 135 kW. It is expected that the number of workstations will increase proportionally in the next few years. In addition, there is communication and network equipment that needs to be taken into account. It is not a good idea to make detailed energy savings calculations on actual loads as these change frequently. Instead, per unit calculations are preferred because they can be used to calculate actual figures once the actual system load is known. All of the equipment to support information technology in a given organization is known as a data center. Thus, for the purpose of this analysis we will use a generic data center of 200 kW which in fact will be the actual size of the COF information technology capacity, including communications and networking, in the next few years.

To discuss potential economic benefits and initial cost advantages of building automation and using Smart Grid technologies such as distributed generation, a power flow model is necessary. In the following, we present a model to estimate the power flow in a traditional data center and in a data center with building automation and also with distributed energy sources to compare power losses in the various power conversion devices.

All power devices are not ideal, they dissipate energy and the power losses can be characterized by the efficiency of the device. The traditional data center, shown in Fig. 4, typically involves a UPS (uninterruptible power supply) and power distribution unit (PDU) in the NCPI (network-critical physical infrastructure) which delivers AC to the IT equipment (e.g., PCs, servers, etc.) The most noticeable feature of the data center with renewable sources, shown in Fig. 5, is that the IT equipment is powered from a DC bus, rather than AC as is the case of the traditional data center. Thus a UPS in the NCPI and power supplies in the IT equipment is not needed. However, other power converters are needed.

Main Assumptions: For the purposes of this study, we assume a data center with a *power to data center* capacity of 200 kW. According to latest studies, the percentage of the total power to the data center that goes to the *power path* to IT and the *power to secondary support* is 53% and 47% respectively. This is illustrated in Figure 5. Building automation technology is considered a temporary energy consumption avoidance whereas more permanent solution, such as the Smart Grid are considered structural energy consumption avoidance. Figure 6 shows the economic benefits of saving one kW of electrical consumption in a typical data center .

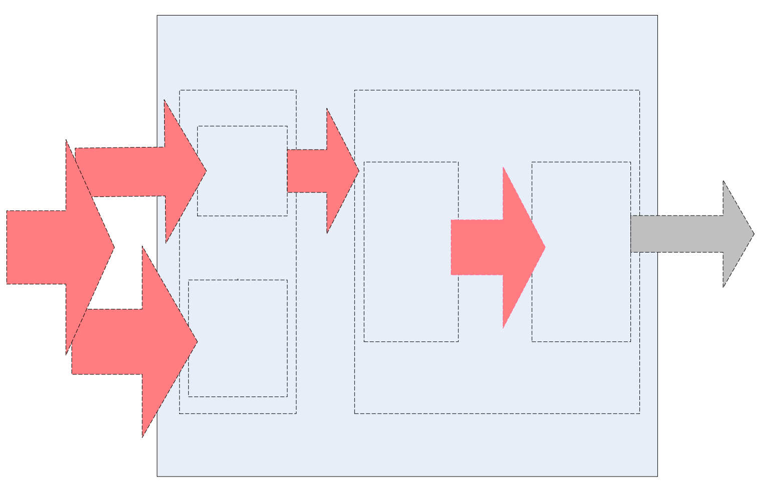

Figure 4. Power Flow in a Traditional Data Center.

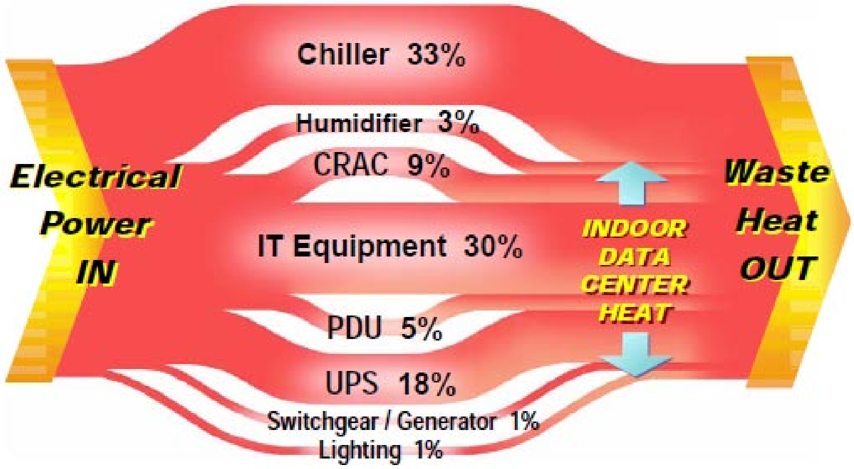

Figure 5. Power Flow in a Traditional Data Center.

	Temporary Consumption Avoidance	Structural Consumption Avoidance	Comment
Method of savings	Power Management Load shedding Economizer	High Efficiency Servers High Efficiency UPS Right-sizing	
1yr electrical savings	$960	$960	Assuming $0.12 per kW hr
10yr electrical savings (IT)	$9,600	$9,600	Typical design life of data center
10yr electrical savings (NCPI)	$960	$13,760	Structural avoidance allows reduction in capacity-related electrical consumption
NCPI CapEx Savings	$0	$13,300	Structural avoidance allows reduction in equipment capacity
NCPI OpEx Savings	$0	$6,600	Reduction in equipment reduces operating expenses such as maintenance
Total 10yr Savings per kW	$10,560	$43,260	

Figure 6. Economic benefits of saving one kW of electrical consumption in a typical data center.E

Traditional Data Center: As depicted in Fig. 4, the data center draws all of its energy from the power grid. The total power to the data center is split into two parts, one that is intended for the IT equipment (*Power Path to IT*) and another path to power secondary support devices directly associated with the IT equipment such as computer room air conditioning (CRAC), cooling, etc. The devices in the IT path include uninterruptable power supplies (UPS), power distribution units (PDU), cabling etc. which dissipate some power. The actual IT equipment (e.g., a server) has a power supply that converts AC to DC. The actual power used to power the computing devices is called the "*useful power to IT*".

The typical efficiency representing the combination of the *UPS, PDU, and Cabling* power losses is 85% and the typical efficiency of the *IT equipment* power supplies is 75%.For a typical 200 kW data center, Table 1 lists the various power calculations at various stages of Fig. 4.

Table 1. Power calculations at several stages in a typical data center.

Grid Power, kW	**Power to Data Center, kW**	**Power Path to IT, kW**	**Power to Secondary Support, kW**	**Power to IT, kW**	**Useful Power to IT, kW**
214.82	**200**	**106**	**94**	**90.1**	**67.57**

Thus, the useful power for IT is 76.57 kW. The overall efficiency from grid to computing is 67.57/214.82 or 31.45%.

Data Center with Building Automation:
Building automation basically allows the optimization of energy required for the support functions of a data center as shown in Fig. 4. Thus we can expect a reduction of the Power to Secondary Support, in the above Table 1. We assume that building automation will enable the re-distribution of the percentage of the total power to the data center that goes to the *power path* to IT and the *power to secondary support* to be 58% and 42% respectively. The corresponding calculations for a data center with building automation technology is shown in Table 2.

Table 2. Power calculations at several stages in a typical data center with building automation technology.

Grid Power, kW	**Power to Data Center, kW**	**Power Path to IT, kW**	**Power to Secondary Support, kW**	**Power to IT, kW**	**Useful Power to IT, kW**
196.30	**182.76**	**106**	**76.76**	**90.1**	**67.57**

Note that the useful power to IT in Tables and 2 are the same thus the two situations are equivalent from the viewpoint of information technology. Yet, the first system draws 213.82 kW while the second draws 196.3 kW. Thus, a savings of (214.82 – 196.30) = 18.52 kW per data center is achieved; at a cost of $ 13c/kWh this implies a savings of $ 21,089/Year.

Data Center with the Smart Grid including Distributed Energy Sources:
There are several important differences between the data center with the Smart Grid that includes distributed energy sources as compared with the traditional data center. First, the power center with distributed sources draws power from three sources, from the grid, from solar panels, and from wind generators. Second, the three main sources generate AC and DC power, as opposed to just AC power in the traditional data centers, that feeds the overall data center. This DC power must be converted to AC via an inverter to power the secondary support equipment. Third, the IT equipment consumes DC power thus there is no need for power supplies, instead; a DC/DC converter is needed. Last, state of the art technology will be used to design all the power units thus leading to higher efficiencies in all power conversion devices.

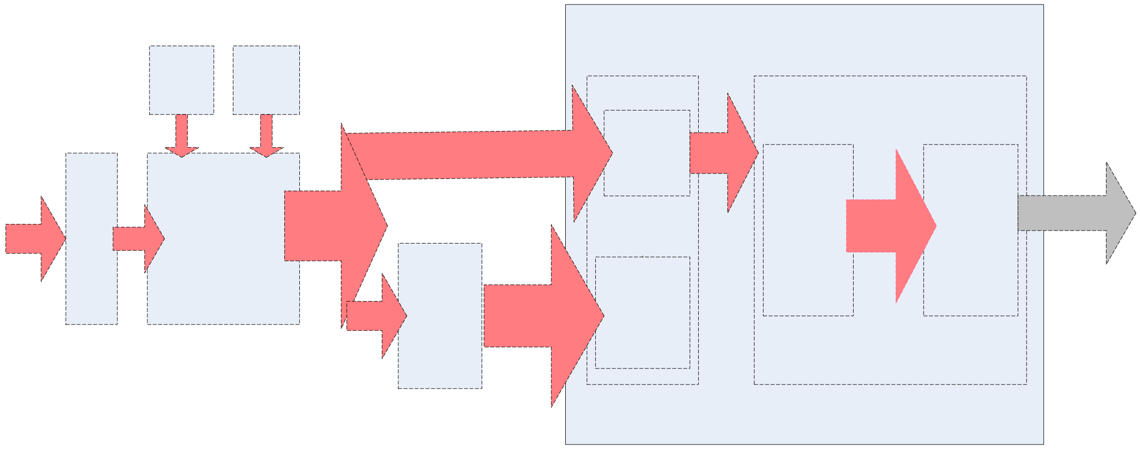

Figure 7. Power Flow in a Data Center with the Smart Grid and renewable energy.

The typical efficiency representing the PDU is 95% and the typical efficiency of the DC/DC converter of the IT equipment is 98%. On the power source side, the typical efficiency of the DC/DC converter is 98% while the efficiency of the various converters converting original source power to DC is 95%. As in the traditional data center, we assume the power to a typical data center to be 200 kW and that the contributions of solar, wind, and grid are 60%, 20%, and 20% respectively. Table 3 lists the various power calculations at various stages of the Fig. 7.

Table 3. Power calculations at several stages in a data center with Smart Grid technology.

Grid Power, kW	**Solar Power, kW**	**Wind Power**	**Power to Data Center, kW**	**Power Path to IT, kW**	**Power to Secondary Support, kW**	**Power to IT, kW**	**Useful Power to IT, kW**
42.96	128.89	42.96	200	106	94	100.7	98.68
29.41	88.26	29.42	136.95	72.58	64.36	68.95	67.57

Thus, the useful power for IT is 98.69 kW (first row of the table) and the total source power (the sum of grid, solar, and wind power) is 214.82 kW. However, to make appropriate benefit calculations, we use the second row of the table for the situation where the useful power to IT is the same for all configurations (i.e., 67.57 kW). For this case, the sum of the three energy sources is 147.1 kW and the overall efficiency from grid to computing is 67.57/147.1 or 45.93%. Thus there is an improvement in the energy efficiency over the traditional data center. However the most important advantage of the data center with distributed energy sources is that the energy consumption from the grid (and thus utility costs) can be adjusted, depending upon the sizes (and investments) of the solar and wind sources, from 100% to 0%. In the latter case, all of the energy into the data center would be coming from renewable sources. This implies a tradeoff between paying a fix rate to the utilities and incurring initial capital costs in exchange for a zero rate from renewable sources.

Conclusions: For the case of using Building Automation in a typical data center of 200kW capacity, the typical savings is 18.52 kW per data center; at a cost of $ 13c/kWh this implies a savings of $ 21,089/Year. Two potential benefits from using the Smart Grid with renewable sources include one fix and one variable. The fix potential benefits is due to the use of higher efficiency designs and the variable potential benefits is due to the use of renewable energy sources at the expense of initial capital costs. For example, for a typical 200kW data center, the fix energy savings is 214.82kW – 147.1kW = 67.72kW and the variable energy savings range from 0 to 147.1kW for an all energy from grid or an all energy from renewable sources situation respectively. Thus the initial capital cost advantage is the fix energy savings of 67.72kW and a variable energy savings from 0 to 147.kW per 200kW data center depending on the size of the renewable energy sources.

D**. Estimate the costs of implementing and continuance of a Building Automation program**

The costs basically involve the cost of performing the activities identified in section B above plus equipment costs. The following table shows an estimate of such costs for a typical building.

Activity/Equipment	**Cost**	**Activity/Equipment**	**Cost**
Economic feasibility analysis	8,000	Equipment	50,000
Funding search activities	6,000	Building automation system testing	15,000
Building automation system design	15,000	On-going monitoring and maintenance	12,000 per Year
Vendor selection, installation, and system integration	80,000	Parts (for maintenance)	5,000 Per Year

E**. Estimate the short and long term energy and cost savings with Building Automation.**

The short term energy and cost savings are those of using a Building Automation system as described in section C above. The long term energy and cost savings are those of using building automation in conjunction with the Smart Grid with renewable sources also described in section C above.

SUMMARY

Building automation (BA) describes the functionality provided by the control system of a building for the purpose of energy savings and optimization. The typical facilities that can benefit from building automation include: Large urban hospitals ,Commercial buildings, Government buildings (e.g., municipal facilities), Research facilities (e.g., laboratories), Large data or information processing centers, Large residential units (high rises), Large indoor shopping malls, etc.

The main benefits of building automation include:

- Lower energy usage
- Optimization of energy usage
- Security and privacy
- Control over energy resources
- Control of operating conditions:
    - humidity
    - air volume
    - temperature

Building automation technology involves several computers, sensors, actuators, interconnected by one or more communication networks of type wired or wireless.

The city of Flint information and technology services currently draw approximately 136 kW from the grid. This power consumption is expected to increase in the next few years, so a study has been made for a typical 200 kW data center to calculate energy savings using building automation technology and smart grid technology. For the case of using Building Automation in a typical data center of 200kW capacity, the typical savings is 18.52 kW per data center; at a cost of $ 13c/kWh this implies a savings of $ 21,089/Year

RESUME OF DR. JUAN R. PIMENTEL

President & CEO, AltEnergy Inc.

EDUCATION:

Ph.D., Electrical Engineering, University of Virginia, 1980.
M.S. Electrical , Engineering, University of Virginia, 1978.
B.S., Electrical Engineering, National University of Engineering, Lima, Peru, 1975.

CURRENT POSITION AND RESEARCH:

Dr. Juan R. Pimentel founded AltEnergy Inc. in 2007 is acting as the current President & CEO. He is also a full Professor at Kettering University, Flint, Michigan. He has extensive research experience in the areas of control systems, dependable communication networks, automotive electronics, distributed energy, the Smart Grid, renewable energy, and hybrid electric vehicles. In 2007 he received the "Distinguished Researcher Award" from Kettering University for significant research involving hybrid electric vehicles, power electronics, distributed embedded systems, industrial communications, and safety critical systems. Dr. Pimentel is the developer of FlexCAN, an industrial communication network for safety-critical applications with high reliability, availability, and survivability requirements. FlexCAN has been successfully used in various prototypes and demonstration projects. At Kettering University, with the support of several industrial partners, he developed the Distributed Embedded Systems laboratory.

RELEVANT EXPERIENCE:

Dr. Pimentel is an experienced business executive, entrepreneur, and engineering Professor with over 10 years in start-up companies, and over 25 years in teaching and research & development. He has founded three other companies in the areas of industrial systems, multimedia systems, and industrial communications. Dr. Pimentel is a recognized international expert in the area of industrial communication networks with high reliability, safety, availability, and survivability requirements. He has performed extensive research at well known institutions such as INRIA-LORIA, Nancy, France, Fraunhofer Institute, Germany, University of Padova, Italy, Universidad Politecnica de Madrid, Spain, Universidad Carlos III de Madrid, Spain, and Universidad de los Andes, Bogota, Colombia. He has written three books on *Communication Networks for Manufacturing*, *Multimedia Systems*, and *Safety-Critical Automotive Systems*. Throughout his career, Dr. Pimentel has refined his expertise in the start-up business environment including small business administration, operations, team building, fund-raising, and strategic business development.