Metering, Monitoring, and Verification – Part 1

APPA Institute for Facilities Management
Indianapolis, IND
September 12, 2023

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Purpose of Today's Presentation

- To provide a broad understanding of:
  - How to pick a meter
  - How to collect the meter outputs
  - How to convert data into information

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Agenda

- Metering
  - Definitions
  - Basic Applications
- Monitoring
  - Manual
  - Automatic
- Verification
  - Converting data into information
  - Metrics

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WORDS OF WISDOM

You *can* manage what you don't measure, but

If you don't measure, you're just guessing

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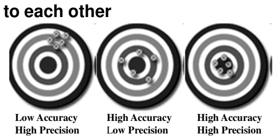
Terminology

- Sensor: An instrument for monitoring, measuring, or recording of a measured variable, e.g., volumetric flow, pressure, temperature, amperage, voltage, etc.
- Meter: A sensor, or group of sensors, used to measure a calculated variable, e.g, mass flow, BTU, tons of refrigeration, KW, etc.
- Resolution: The smallest change in a measured value that the instrument can detect, also known as sensitivity.
- Accuracy: How close a measured value is to the **actual (true) value**. (% of RATE, % of FULL SCALE)
- Precision (Repeatability): How close the measured values are **to each other**



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Terminology (cont.)

- Error: The disagreement between a measurement and the true or accepted value
- Bias: A systematic (built-in) error which shifts all measurements by a certain amount.
- Instrument Range: The interval between the minimum and maximum values of the measured variable in which the instrument is accurate
- Volumetric Flow Rate: The flow of the fluid measured as:

  q = A x V
  where:
  q = volumetric flow, ft^3/min, m^3/sec, gal/min, etc.
  A = area of the pipe, in^2, cm^2 , etc
  V = velocity, ft/min, m/sec, etc.
- Mass or Energy Flow Rate: The actual quantity or energy of fluid, i.e. pounds per hour, BTU/min. tons, etc. Requires knowledge of fluid and its properties. For example:

Mass
A cubic foot of air weighs about .075 lbs.; a cubic foot of water weighs about 825 times as much, 62 lbs.

Energy
A pound of propane contains about 21,000 BTU; a pound of hydrogen is about 3 times greater; 61,000 BTU

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Terminology (cont.)

- Turndown Ratio: Flow instrument range expressed as:

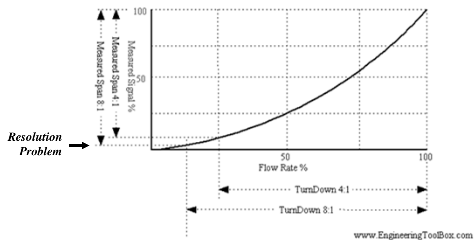
  $TR = q_{max} / q_{min}$

  where:

  TR = Turndown Ratio

  q_{max} = maximum flow

  q_{min} = minimum flow



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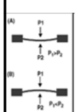
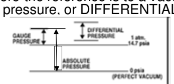
Simple Devices

- Electric Meters: Should measure KW, KWh, Φ-to-Φ voltage and amps, Φ-N voltage at a minimum. Should have connectivity capability (RS-485, Ethernet, Wireless)
- Pressure Sensors:
  - Measure the difference in pressure on two sides of a diaphragm. Depending upon the relevant pressure, we use the terms ABSOLUTE, where the reference is to a vacuum, GAUGE, where the reference is to local atmospheric pressure, or DIFFERENTIAL, where the sensor measures two different pressures.





  - Deformation of the diaphragm can be measured using various technologies such as strain gauges, piezoresistors, or capacitors
- Temperature Sensors:
  - Thermocouple: The junction of two dissimilar metals produces a temperature dependent voltage
  - Resistance Temperature Detector (RTD): RTDs are manufactured from metals whose resistance increases with temperature.
  - Thermister: Thermisters are manufactured from semiconductors whose resistance decreases with temperature.
- Transmitters associated with each of these sensors convert the sensor signal (voltage, ohms, etc.) into an output signal proportional to the sensed value, e.g. 4-20 mA, 0-10 V.

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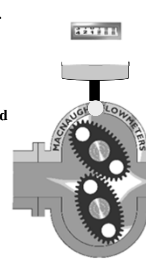
Flow Meters

Positive Displacement meters

The positive displacement flow meter measures process fluid flow by precision-fitted rotors as flow measuring elements. Known fixed volumes are displaced between the rotors. The rotation of the rotors are proportional to the volume of the fluid being displaced.

The number of rotations of the rotor is counted by an integral electronic pulse transmitter and converted to volume and flow rate.



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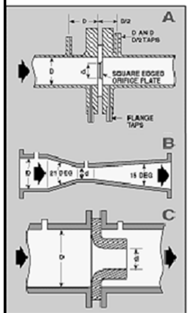
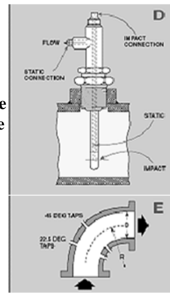
Flow Meters



Pressure Differential

In a pressure differential device the flow is calculated by measuring the pressure drop over an obstruction inserted in the flow. The differential pressure device is based on <u>Bernoulli's Equation</u>, where the flow velocity is a function of the square root of the pressure drop.



A. Orifice
B. Venturi
C. Flow nozzle
D. Pitot Tube
E. Elbow Tap

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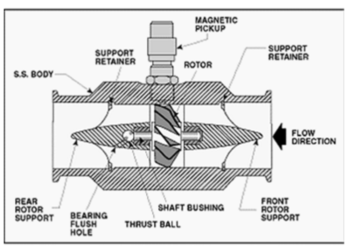
Flow Meters

Turbine



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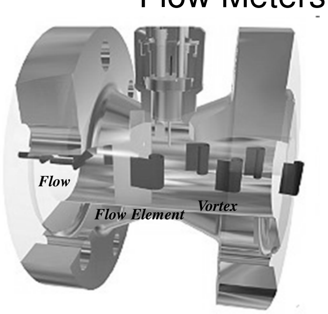
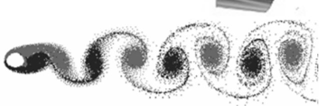
Flow Meters



Vortex

Vortex meters operate on the principle that when a non-streamlined object is placed in the middle of a flow stream, a series of vortices are shed alternately downstream of the object (Von Karman vortex street). The frequency of the vortex shedding is directly proportional to the velocity of the fluid flow.



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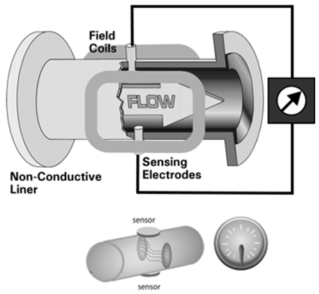
Flow Meters

Electromagnetic



Ions generate voltage when traveling through the magnetic field.

Magnetic flow meters are based on Faraday's Law of Magnetic Induction. In a magnetic flow meter, the liquid acts as a conductor as it flows through the pipe. This induces a voltage which is proportional to the average flow velocity - the faster the flow rate, the higher the voltage. This voltage is picked up by sensing electrodes mounted in the meter tube and sent to the transmitter which takes the voltage and calculates the flow rate based on the cross sectional area of the meter tube.

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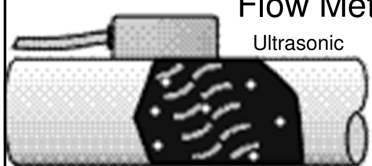
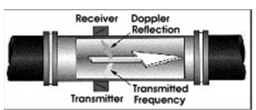
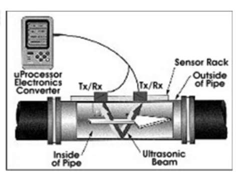
Flow Meters

Ultrasonic





Doppler ultrasonic flowmeters operate on the Doppler effect, whereby the transmitted frequency is altered linearly by being reflected from particles and bubbles in the fluid. The net result is a frequency shift between transmitter and receiver frequencies that can be directly related to the flow rate.



Transit-time flowmeters measure the difference in travel time between pulses transmitted in a single path along and against the flow. Two transducers are used, one upstream of the other. Each acts as both a transmitter and receiver for the ultrasonic beam.

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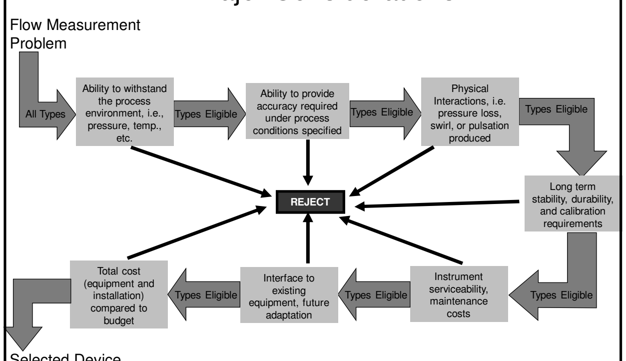
Selecting Flow meters Major Considerations



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Flow meter Characteristics Comparison Sheet							
Flow meter Element	**Recommended Service**	**Turndown**	**Pressure Loss**	**Typical Accuracy(%)**	**Required Upstream pipe diameters**	**Viscosity Effect**	**Relative Cost**
Orifice	Clean, dirty fluids; some slurries	4 to 1	Medium	±2 to ±4 of full scale	10 to 30	High	Low
Venturi tube	Clean, dirty and viscous fluids; some slurries	4 to 1	Low	±1 of full scale	5 to 20	High	Medium
Flow nozzle	Clean and dirty fluids	4 to 1	Medium	±1 to ±2 of full scale	10 to 30	High	Medium
Pitot tube	Clean fluids	3 to 1	Very low	±3 to ±5 of full scale	20 to 30	Low	Low
Elbow meter	Clean, dirty fluids; some slurries	3 to 1	Very low	±5 to ±10 of full scale	30	Low	Low
Target meter	Clean, dirty viscous fluids; some slurries	10 to 1	Medium	±1 to ±5 of full scale	10 to 30	Medium	Medium
Variable area	Clean, dirty viscous fluids	10 to 1	Medium	±1 to ±10 of full scale	None	Medium	Low
Positive Displacement	Clean, viscous fluids	10 to 1	High	±0.5 of rate	None	High	Medium
Turbine	Clean, viscous fluids	20 to 1	High	±0.25 of rate	5 to 10	High	High
Vortex	Clean, dirty fluids	10 to 1	Medium	±1 of rate	10 to 20	Medium	High
Electromagnetic	Clean, dirty, viscous conductive fluids and slurries	40 to 1	None	±0.5 of rate	5	None	High
Ultrasonic (Doppler)	Dirty, viscous fluids and slurries	10 to 1	None	±5 of full scale	5 to 30	None	High
Ultrasonic (Transit Time)	Clean, viscous fluids	20 to 1	None	±1 to ±5 of full scale	5 to 30	None	High
Mass (Coriolis)	Clean, dirty viscous fluids; some slurries	10 to 1	Low	±0.4 of rate	None	None	High
Mass (Thermal)	Clean, dirty, viscous fluids; some slurries	10 to 1	Low	±1 of full scale	None	None	High

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Metering Compound Values for reference

Some commonly metered values require multiple inputs and must be calculated, e.g.

- Chilled water: Tons or BTU/hr; requires volumetric flow, supply and return temperatures (ΔT), density compensation generally not required
- Hot Water: BTU/hr; same as chilled water
- Steam Flow: Pounds/hr or BTU/hr; requires density compensation using temperature, pressure, and heat content. Some meters can do this dynamically, but most use static values.
- Liquid Fuel Mass or Energy Flow: Natural gas or fuel oils; requires density compensation using temperature, pressure, and heat content.
- Solid Fuel Mass or Energy Flow: Coal or wood; requires mass and heat content

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Monitoring

Collecting and organizing the data for use

- Manual Data Collection
  - Assign responsibility (who)
  - Locate all meters to be read (where)
  - Learn how to read the meters (how)
  - Determine the frequency of data collection (when)
  - Create data collection forms (what)
  - Plan for future automated collection, i.e. use tablets, netbooks, Microsoft Excel or Access.

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Monitoring

- Automated Data Acquisition
  - ***The automated retrieval of field data from remote locations to a centralized data storage location.***
  - ***Components include both hardware and software***

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Monitoring – for reference

- Automated Data Acquisition **Hardware**
  - Programmable Logic Controllers (PLCs): Devices located near the sensors that have the capability to collect and process local data for download to a central storage location
  - “Smart” Meters: Devices that contain software that allow them to process, connect and download data directly to the network
  - Network Connection Devices: Interface between the various field device data transfer protocols (Modbus, ControlNet, BacNet, TCP/IP, etc) and the network (phone, wireless, ethernet, etc.)
  - Database Servers: computer(s) used to store the data for real-time, historical, and archival use.
  - Firewalls: computer(s) used solely to limit access to the servers and data collection network
  - Workstation(s): other computers that can connect to the database servers to disseminate and process collected data
  - Wiring: between field devices internal to building, between buildings. 4-20 mA, Cat5e, RS485, etc. Need to chose whether to use campus WAN or install dedicated network

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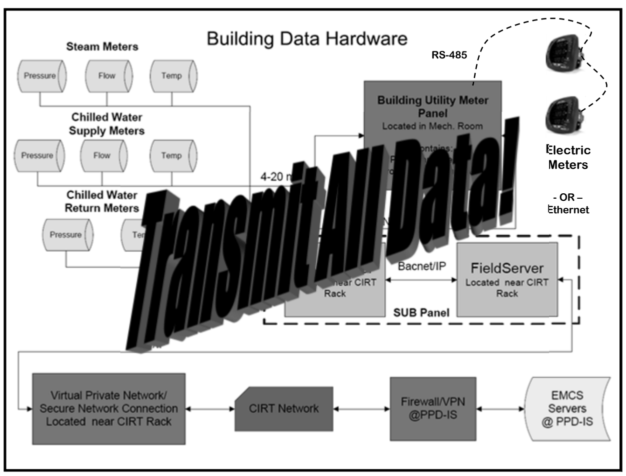

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Monitoring
Transmit All Data!

- Chilled Water BTU = 0
  - ***Flow = 0***
  - ***Supply Temp = 0***
  - ***Return Temp = 0***
    - ***Both = 0***
  - ***Supply Pressure = 0***
  - ***Return Pressure = 0***
    - ***Both = 0***

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Monitoring – for reference

- Automated Data Acquisition **Software**
  - PLC Programming: software necessary to program PLCs to process data, e.g. convert flow and temperature into BTU's, read field input terminals, load data into storage registers, upload data to other devices, etc.
  - Device Calibration: software required to configure field sensors and devices, e.g. pipe size, fluid properties, etc.
  - Protocol Converters: software interface modules to convert between the various field device data transfer protocols (Modbus, ControlNet, BacNet, TCP/IP, etc)
  - Database Manager: software used to organize and relate the data for end-use, e.g. MSSQL, MySQL, Oracle, etc.
  - Firewall: software used to set up authorized access to the database manager, e.g. Kerio, Cisco, etc.
  - Workstation: software used to disseminate and gather the field data, e.g. web server, visualization, scheduler, etc.

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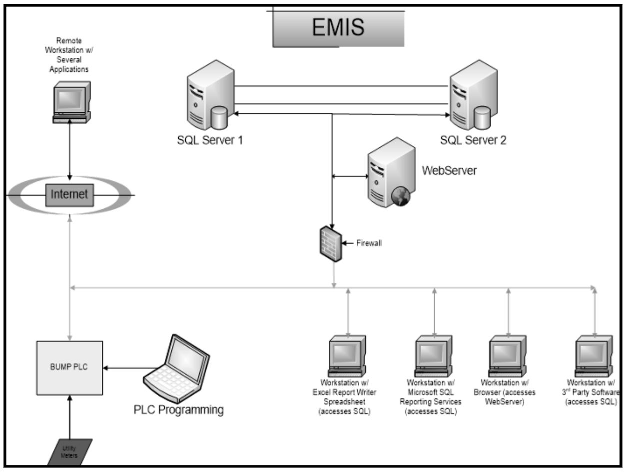
EMIS



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Verification

- Energy Management Information System (EMIS): Convert DATA into INFORMATION
  - Gather dispersed and disparate production, energy use (both billing and meter) and budget energy data from multiple sites, multiple energy suppliers and different types of energy suppliers.
  - Validate the data and manage missing or erroneous data.
  - Convert the raw data into usable management information, particularly meaningful Key Performance Indicators (KPIs).
  - Generate meaningful reports that include the analysis of trends and exceptions.
  - Distribute the analyses and reports across multiple sites, internally and externally, in a timely fashion.

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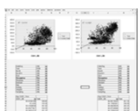
Verification

- Metrics Examples
  Convert INFORMATION into KNOWLEDGE
  - Example Applications

Data Analysis Report Writer

Statistical Analysis



Real-Time Web Viewer

Data Provisioning to 3rd Party Applications

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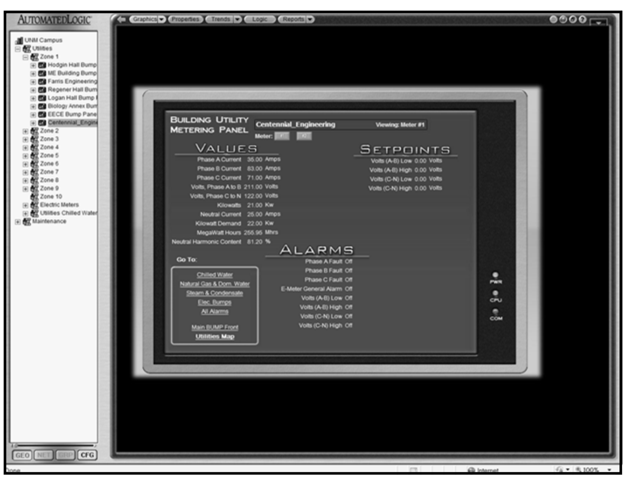

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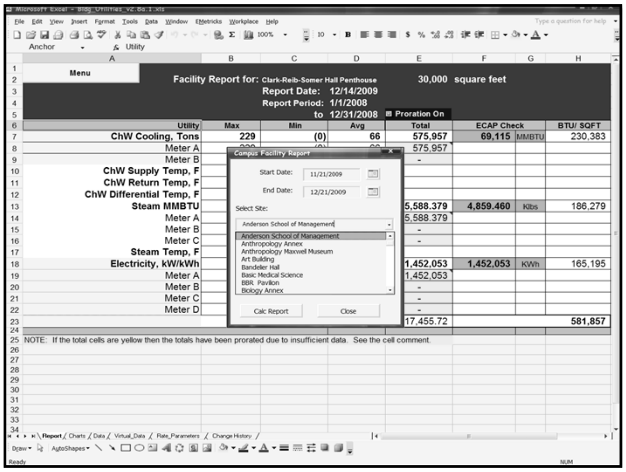
Menu
Facility Report for: Clark-Reib-Somer Hall Penthouse
30,000 square feet
Report Date: 12/14/2009
Report Period: 1/1/2008
to 12/31/2008
Proration On
Campus Facility Report
NOTE: If the total cells are yellow then the totals have been prorated due to insufficient data. See the cell comment.

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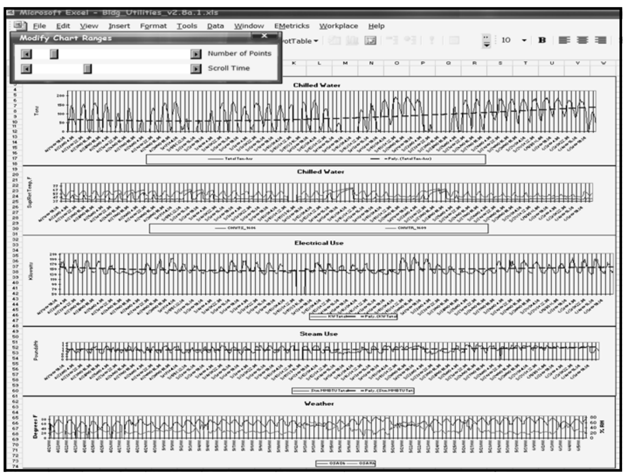
Modify Chart Ranges
Number of Points
Scroll Time
Chilled Water
Chilled Water
Electrical Use
Steam Use
Weather

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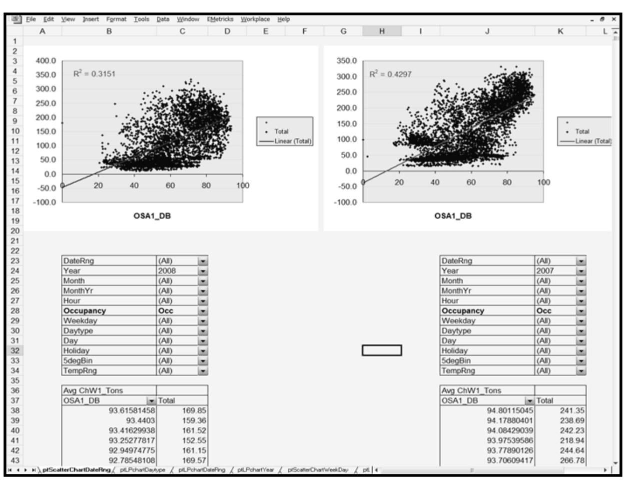
R² = 0.3151
R² = 0.4297
OSA1_DB
OSA1_DB
Total
Linear (Total)

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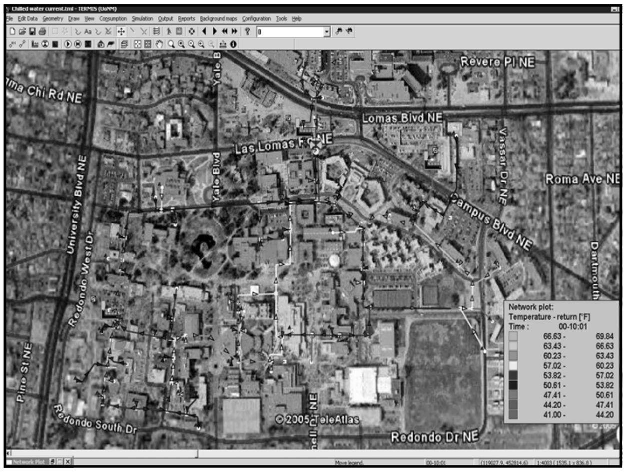

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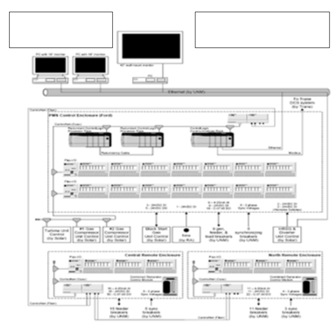
Questions & Answers

Thank You!



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