Test Facility for Determining the Seasonal Performance of Residential Fuel Cell Systems

Mark Davis and Hunter Fanney

National Institute of Standards and Technology
Building and Fire Research Laboratory
Gaithersburg, MD USA

Outline

- Outline mission and goal for fuel cell research
- Introduce proposed seasonal performance standard
- Discuss background on existing standards for fuel cells
- Compare and contrast existing and proposed fuel cell standards
- Describe test facility for seasonal performance
- Conclude

NIST/BFRL Mission and Goal

- BFRL Mission:
  - The source of critical tools - metrics, models, and knowledge - used to modernize the Building and Fire Safety communities
- Project Goal:
  - Develop a consumer-oriented test procedure and rating methodology to accelerate the widespread commercialization of fuel cells in residential and small commercial applications

Proposed Seasonal Rating Standard

- Purpose:
  - To provide test methods and calculation procedures for determining the seasonal performance of residential fuel cell systems, including all electrical and thermal energy, which result in a single metric for annual performance.

- Scope:
  - Residential or small commercial applications
  - All types of fuel cells (PEMFC, PAFC, SOFC, etc.)
  - Any fuel source (Hydrogen, natural gas, propane, etc.)
  - Steady state and transient electrical operation
  - Optional use of thermal energy output for domestic water heating

Existing Fuel Cell Standards

- ASME PTC 50
- ANSI Z21.83 (CSA FC 1)
- IEC TC 105

} Performance

- IEEE P1547 → DC / AC Inverter
- NFPA 853 → Safety (> 50 kW)

Existing vs. Proposed Standards

- Existing:
  - Govern performance of fuel cells at single environmental condition
  - Designed to quantify performance of systems
  - Provide electrical efficiency and thermal effectiveness
- Proposed:
  - Determine performance of residential fuel cells on seasonal basis
  - Designed for economic comparison by residential consumers
  - Provide combined metric for electrical and thermal performance

Possible Tests Proposed Seasonal Standard

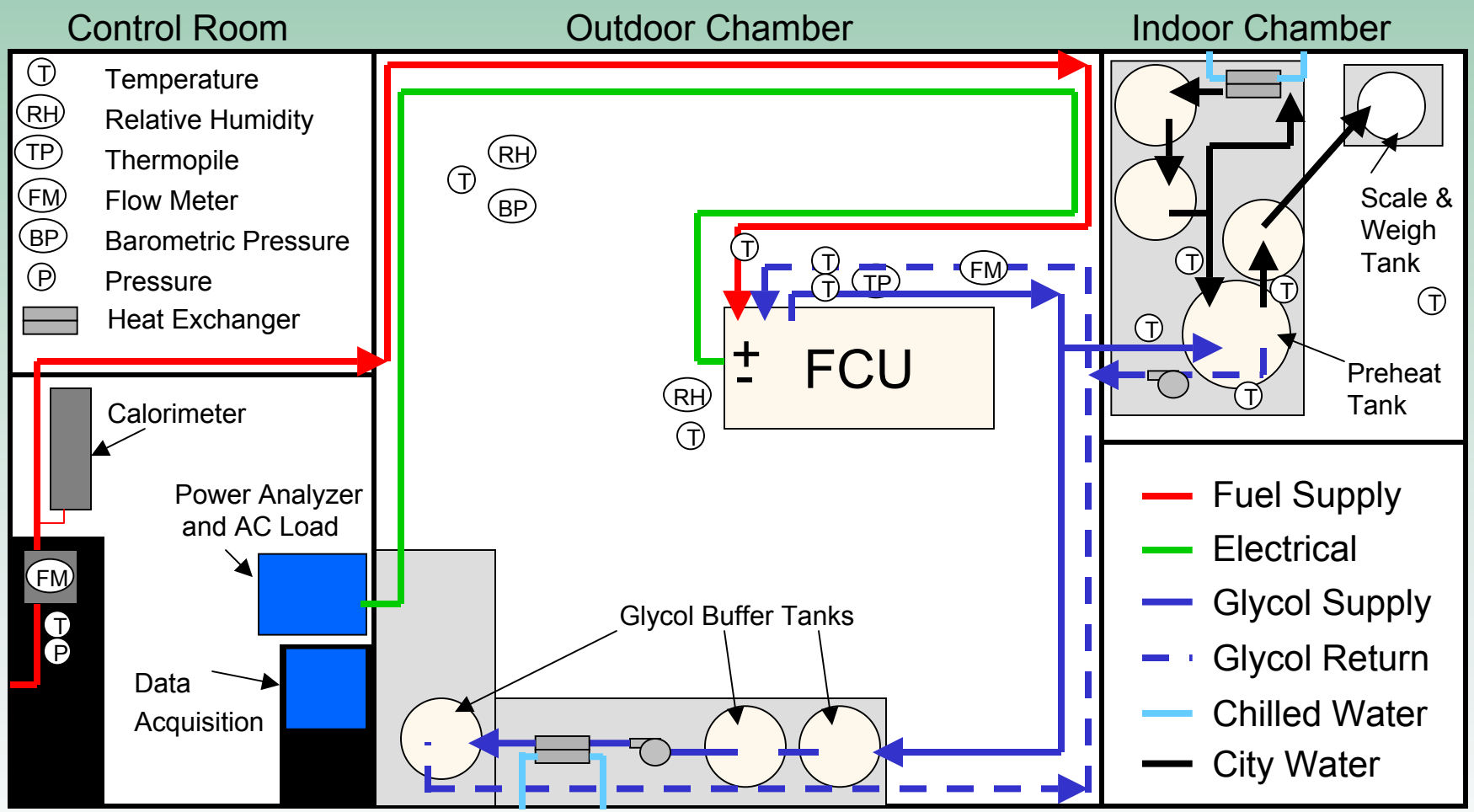
- Steady state electrical load
  - No thermal load
  - Steady state thermal load
  - Transient thermal load
- Transient electrical load
  - No thermal load
  - Steady state thermal load
- Startup electrical performance

★ All tests performed at various ambient temperatures and relative humidities

NIST Residential Fuel Cell Test Facility

- Designed to determine seasonal effects on residential fuel cell performance
- Measure electrical energy output, thermal energy output, fuel energy and usage, and environmental conditions
- Control ambient temperature and relative humidity
- Plug Power Gensys 5c installed in facility

Test Facility Schematic

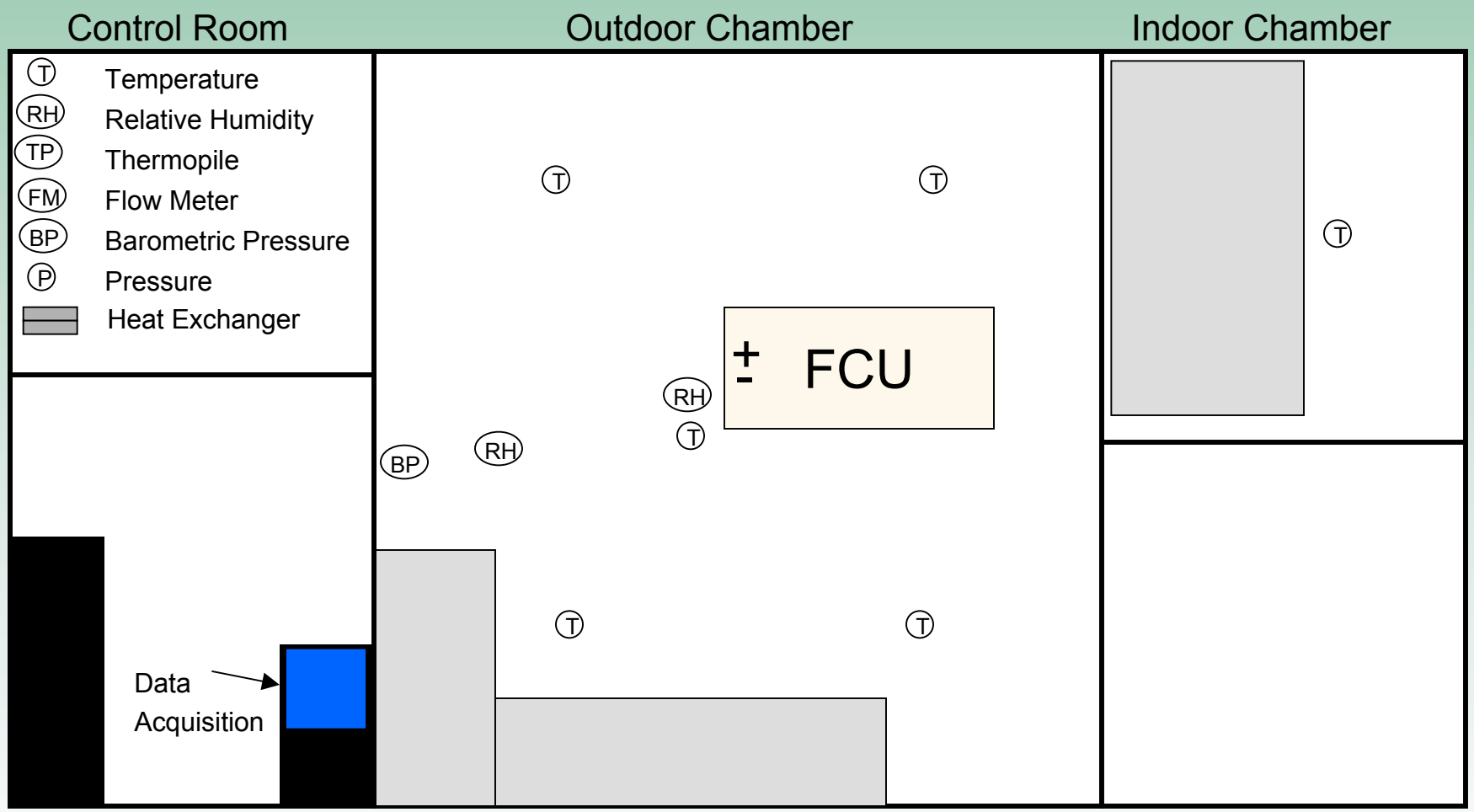


Environmental Condition Measurement and Control

- Ambient temperature
  - Controlled by environmental chamber (-18°C to 40°C)
  - Measured by 4 thermocouples spread throughout chamber
  - Air temperature measured as it enters fuel cell
- Relative humidity
  - Controlled by environmental chamber (20% to 95%)
  - Relative humidity transducer at intake to fuel cell and center of chamber
- Barometric pressure
  - measured by pressure transducer
  - not controlled

Test Facility Schematic

Environmental Conditions



Fuel Energy Measurement

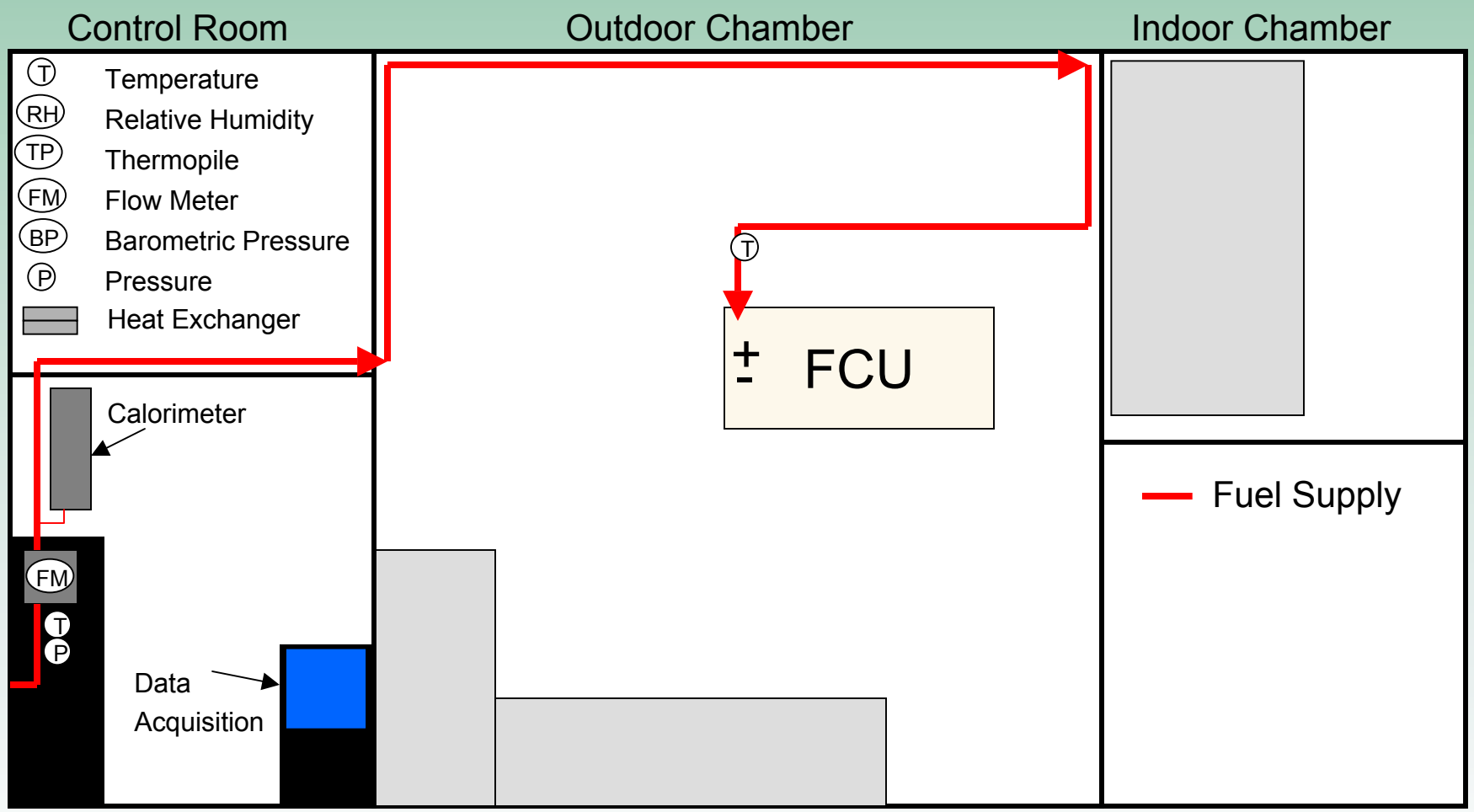
- Natural gas is primary fuel
  - Slight modification to accommodate other fuels
- Fuel energy rate calculation:

$$\dot{E} = \dot{V}_{STP} \cdot e_{STP}$$

- Energy content of fuel
  - Calorimeter measures specific energy of fuel @ STP
- Volumetric flow rate
  - Dry-type positive displacement natural gas flow meter
  - Proximity sensors on dial record every ¼ L of gas consumed
- Fuel properties
  - Fuel temperature - thermocouple
  - Fuel pressure - pressure transducer (0-15 in. w.c.)
  - Convert actual volumetric flow rate to flow rate @ STP

Test Facility Schematic

Fuel Supply System

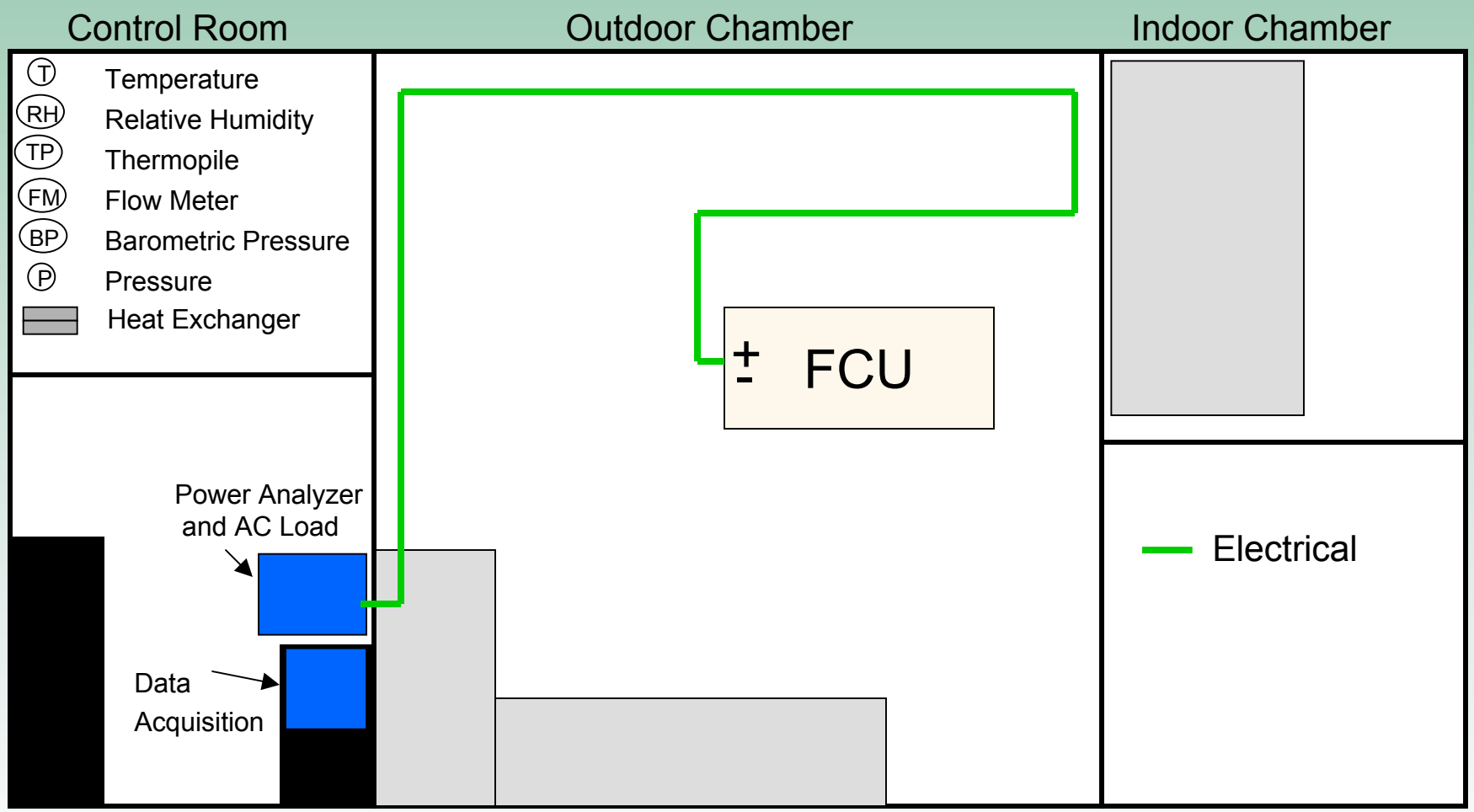


Electrical Energy Measurement

- 6 kW, 120/240 VAC capacity
- Interconnected to 60 Hz AC grid
- Power analyzer measures output to grid
  - True RMS voltage
  - True RMS current
  - Real power
  - Accumulated electrical energy
- Programmable AC load simulates auxiliary loads
  - Vary voltage, current, power, or resistance
  - Measure true RMS voltage and current, and real power
  - Accumulated energy measured using same power analyzer as grid interconnection

Test Facility Schematic

Electrical System



Thermal Energy Measurement

- 15 kW thermal capacity
- 35% Propylene Glycol / 65% Water
- Fluid conditioning loop
  - Develop thermal energy performance map
  - Vary flow rate between 3.5 and 35 L/min (~1 & 10 GPM)
  - Vary inlet temperature between 10°C and 60°C
- Typical residential system
  - Simulates fuel cell unit heating a preheat tank
  - Vary flow rate between 3.5 and 35 L/min (~1 & 10 GPM)
  - Measure electrical power used by main water heater drawing from preheat tank

Thermal Energy Measurement

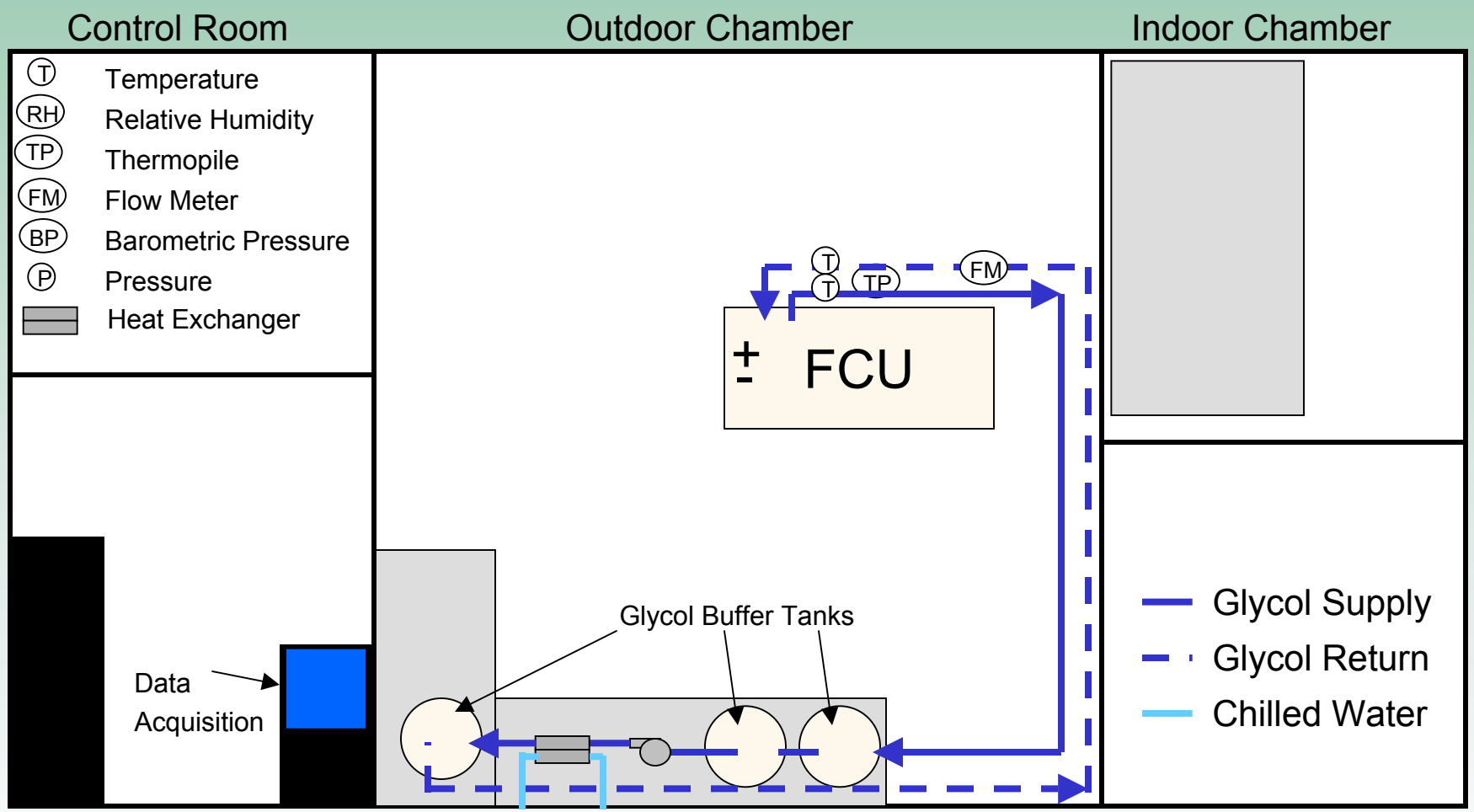
- Thermal power calculation:

$$\dot{q} = \rho(T) \cdot \dot{V} \cdot c_p(T) \cdot \Delta T$$

- Properties
  - Temperature dependent liquid density
  - Temperature dependent specific heat
- Volumetric flow rate measured by:
  - Turbine flow meter
  - Magnetic flow meter
  - Analog signal and pulse counter
- Temperature difference across fuel cell measured by:
  - Thermopile
  - PRTs
  - Thermocouples

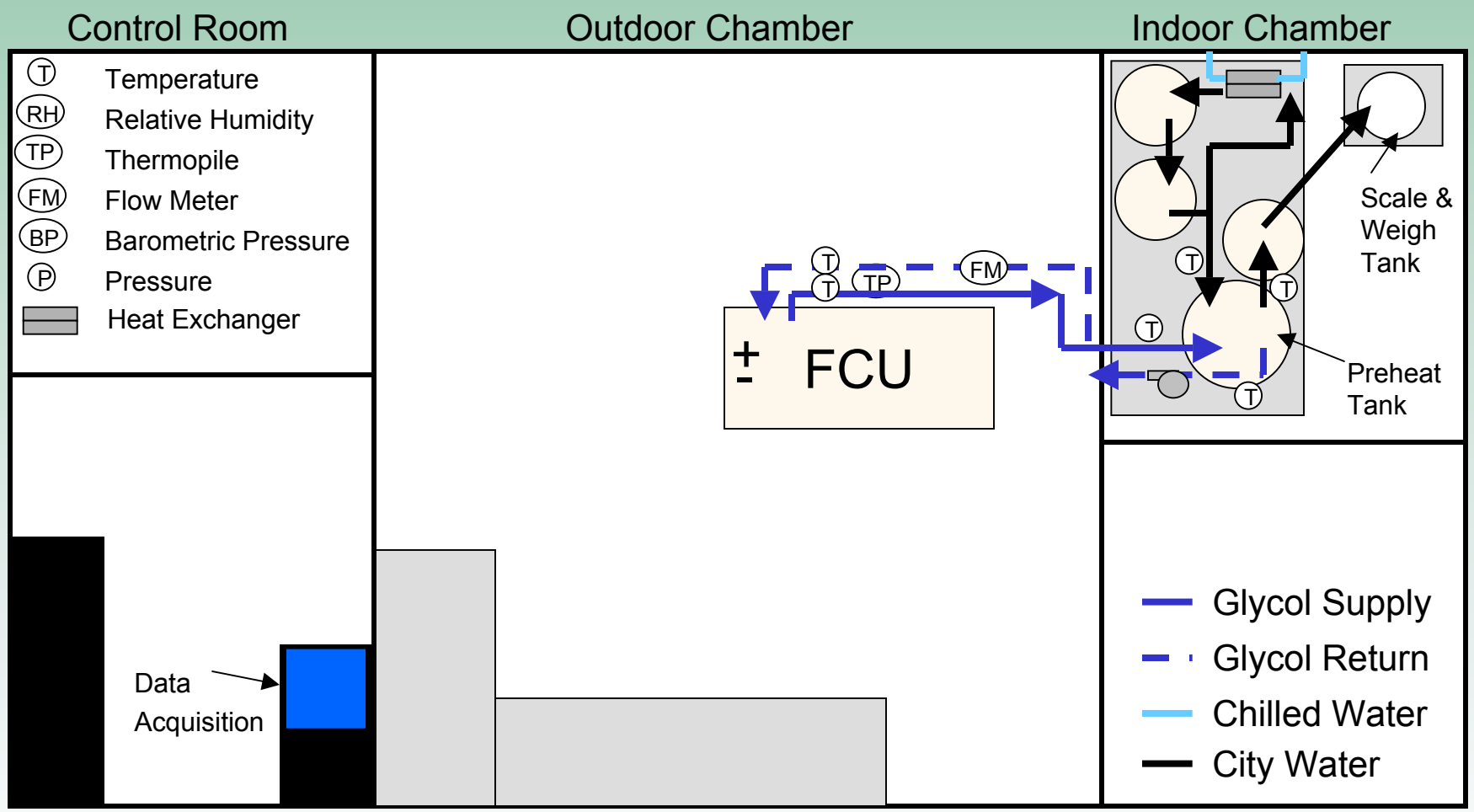
Test Facility Schematic

Thermal System – Fluid Conditioning Loop



Test Facility Schematic

Thermal System – Typical Residential Loop



Safety Systems

- Fuel supply solenoid
  - Computer and Manually controlled
  - Linked to gas detection system
- Gas detection system
  - Combustible hydrocarbons (>20% / >40% / >60% LEL)
  - Carbon Monoxide (>150ppm / >200 ppm / >250 ppm)
  - Oxygen (<14% / <18% / >25%)
  - 20% LEL HC and 150 ppm CO trip fuel solenoid
  - 40% LEL HC and 200 ppm CO start facility exhaust fan and open damper
- Combustible gas alarm near calorimeter

Conclusions

- NIST seeks to develop test procedure and rating methodology for seasonal performance of residential fuel cells
- Seasonal performance to be determined using newly constructed residential fuel cell test facility
- Test facility measures fuel energy consumed, electrical energy produced, and thermal energy produced at various environmental conditions