National Aeronautics and Space Administration

Integrated Systems Health Management for Sustainable Habitats
(Using Sustainability Base as a Testbed)

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Outline

- Overview of Sustainability Base
  - Introduction
  - Research objectives and thrust areas
  - Energy metering capabilities
  - Systems of interest to Sustainable Habitats
- Integrated System Health Management for Sustainable Habitats
  - Motivation
  - Overall Goals
  - Challenges

Sustainability Base

- 50,000 sq. ft. high-performance office building
- ~220 occupants
- LEED Platinum certified

Sustainability Base

- Reduce impact on environment
- Minimize energy use
- Minimize potable water use
- Create an evolving sustainability research testbed
- Apply NASA + Partner technologies to improve performance

Sustainability Base

Systems Health Management

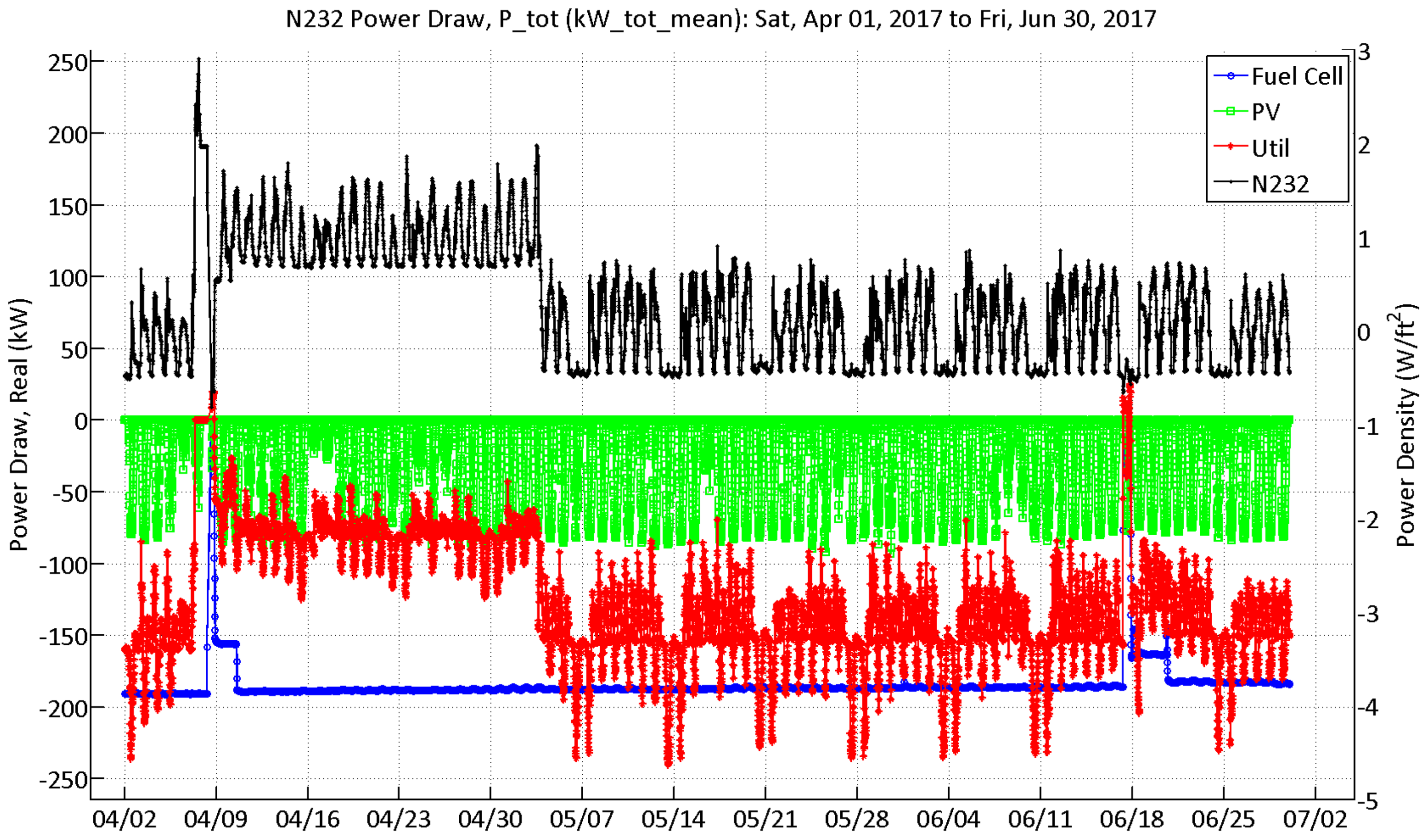
- Investigate methods to determine
  - ✓ Anomalous conditions (“Detection”)
  - ✓ Faulted state (“Diagnostics”)
  - ✓ Time to failure (“Prognostics”)
  - ✓ Response to take (“Mitigation”)
- Hypothesis: Systems health management leads to more cost effective building maintenance and operations (e.g. CBM – Condition-Based Maintenance)

Data Mining

- Use computer algorithms to find anomalies
- Build knowledge bases of system behavior
- Hypothesis: Data mining identifies subtle changes in building performance missed by simple threshold-based detection schemes
- Active Learning: facilitate incorporation of human feedback on the operational significance of statistical anomalies

Energy Metering Capabilities

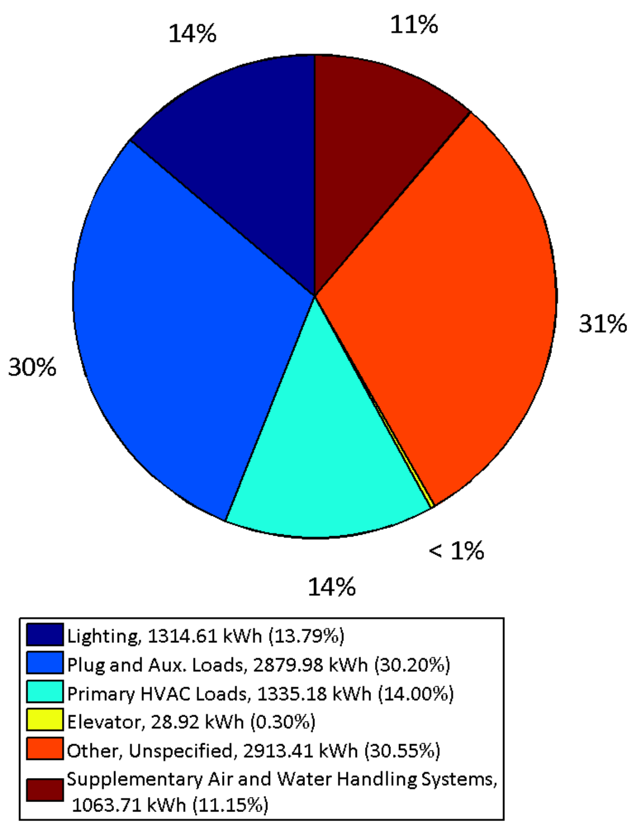
- APMS (Ames Power Monitoring System)
  - Provides whole building energy consumption
  - Also provides on-site generation capabilities (SOFC, PV array)



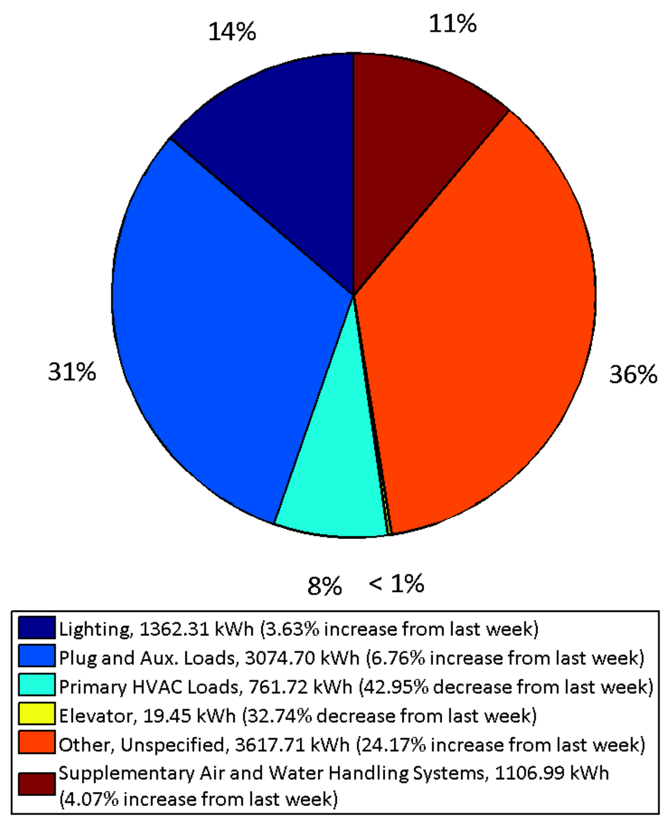
Energy Metering Capabilities

- DEMs (Digital Energy Meters)
  - Panel-level consumption monitored centrally through Siemens FMCS software

For week of 02-Jul-2017,
N232 Energy Consumption = 9535.82 kWh



For week of 09-Jul-2017,
N232 Energy Consumption = 9942.89 kWh
(4.27% increase from previous week)



partnerships

Energy Metering Capabilities

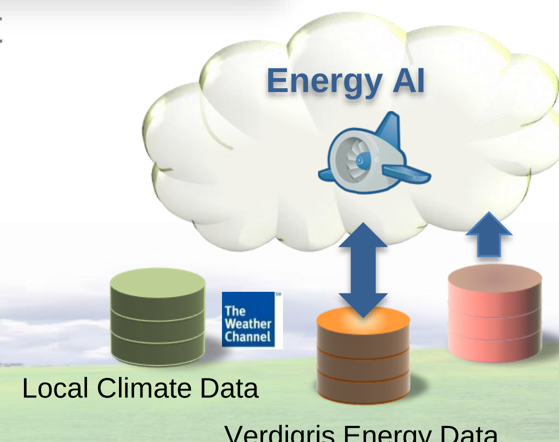
NASA Ames Sustainability Base

Verdigris Technologies

VERDIGRIS TECHNOLOGIES

Combining Ames' expertise in Prognostics and Health Management technologies with Verdigris focus on energy point-of-use demand sensing and control

- Developing advanced power management sensing and systems control technologies
  - ✓ Electric power demand sensing
  - ✓ Subsystem load identification and operational assessment
  - ✓ Intelligent power load control



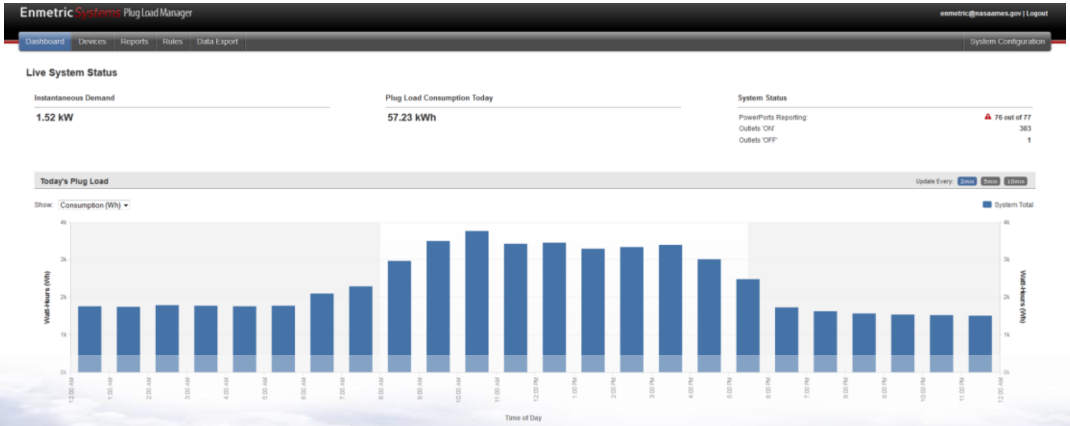
Energy Metering Capabilities

NASA Ames Sustainability Base

partnerships

EnmetricSystems

- Electrical plug loads are the fastest growing segment of commercial energy demand
- Enmetric plug load management system allows turning off loads when not being used, eliminating wasted electricity
- Occupants will be able to view and control personal energy usage



Power Port


Bridge

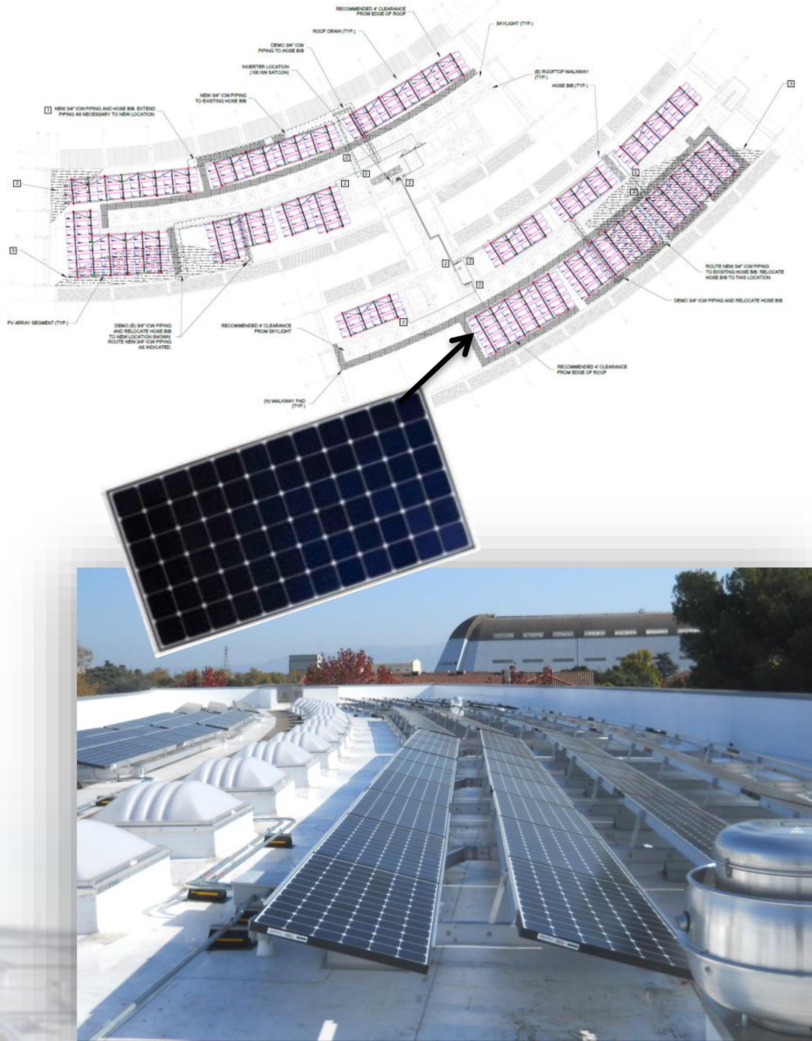
Systems of Interest to Sustainable Habitats

NASA Ames Sustainability Base

electrical

SunPower™ Photovoltaic Panels

- 432 panels in 24 strings of 9 modules on each wing (North and South)
- Generates 30% of annual building energy demand
- Conversion efficiency of 19%
- Energy data available through Draker software web interface system
- Possible relevance to SACE–like technology advancements (Solar Array Constraint Engine)



Systems of Interest to Sustainable Habitats

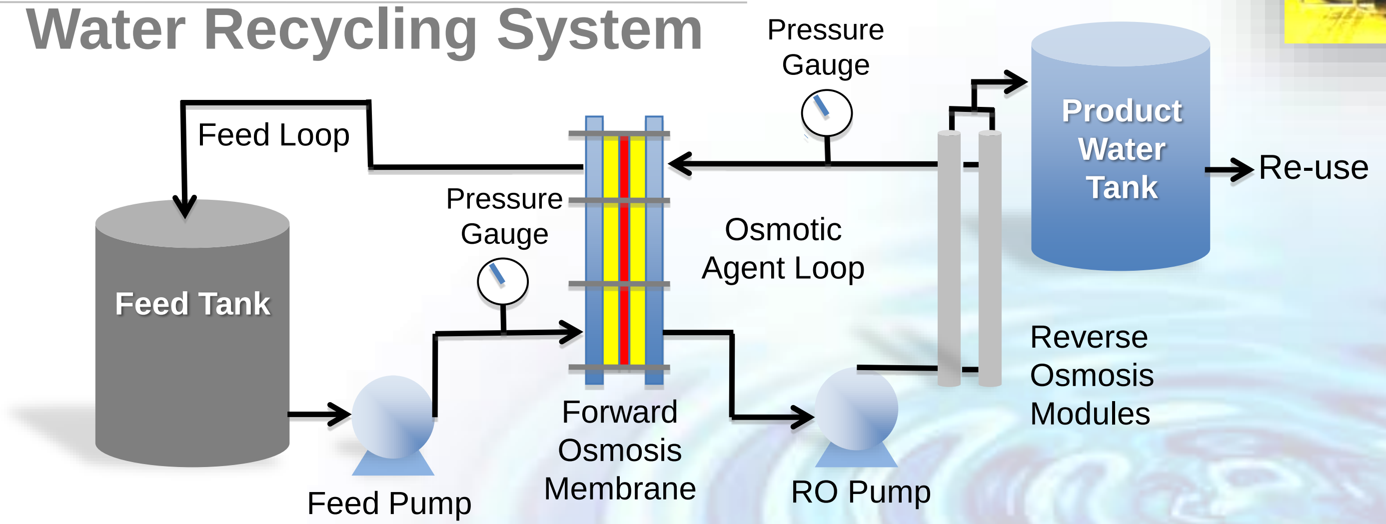
NASA Ames Sustainability Base

Grey Water Recycling System

- Reduce potable water requirements
- Provide a testbed for long duration water recycling technology applicable to space habitats
- Determine operating costs, cleaning requirements, and membrane life of Forward Osmosis process
- Relevant to ECLSS (Environmental Control and Life Support Systems)

Reverse Osmosis System (top)
Forward Osmosis System (bottom)

Water Recycling System



research

Systems of Interest to Sustainable Habitats

mechanical

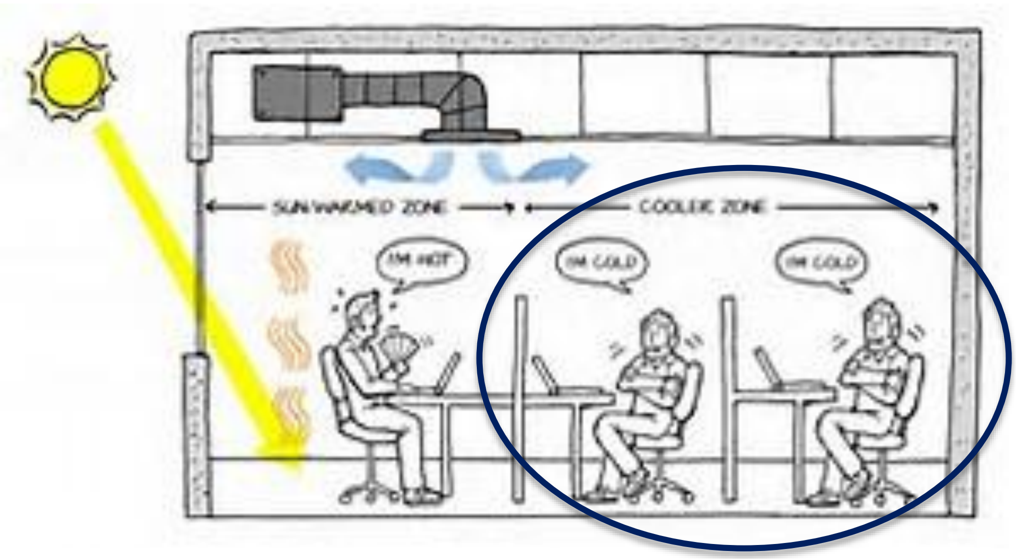
NASA Ames Sustainability Base

Ground Source Heat Pump System

- 106 well bores provide 58°F conditioned water year round
- Energy efficient heat exchangers heat water for wall mounted radiators or cool water for ceiling radiant cooling panels
- Floor radiant heating and cooling in foyer

- Fogg, Martyn J. (1997). "The utility of geothermal energy on Mars". Journal of the British Interplanetary Society. **49**: 403–22.

Systems of Interest to Sustainable Habitats (HVAC Equipment Problems)



- Problems related to temperature fluctuations and subsequent thermal sensation complaints
- Leaking groundwater return/supply piping connections to heat pump
- Heat pump failures
- Critical alarms (e.g. hot water pump differential pressure)
- Relevant to ECLSS (Environmental Control and Life Support Systems)

Motivation/Requirements

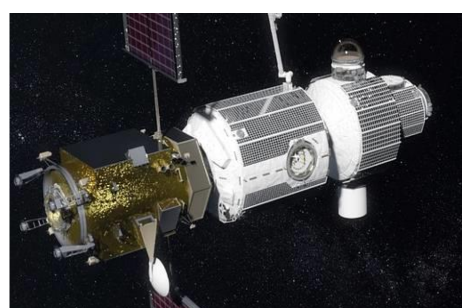
- Sustainable Habitats enable crews to live and work safely in deep space and are crucial to support long duration space missions
  - NASA has several terrestrial analogs
    - Habitat Demonstration Unit (HDU)
    - Deep Space Habitat (DSH) analog testing of the lunar environment called Desert Research and Technology Studies (D-RaTS)
    - Sustainability Base
- Innovative health management technologies are needed in order to increase the safety and mission-effectiveness for future space habitats
  - Off-nominal or failure conditions occurring in safety-critical life support systems may need to be addressed quickly by the habitat crew
  - Need to address adverse conditions without extensive technical support from Earth, due to communication delays
  - Crew must manage, plan and operate much of the mission themselves
  - Operations support must be migrated from Earth to the habitat
  - Need monitoring, tracking, and management capabilities on-board the habitat and related EVA platforms
  - Will require significant automation and decision support software

Overall Goals

- Integrated Systems Health Management technology advancement
  - Caution and warning systems are typically triggered by out-of-bounds sensor values
  - Can be enhanced by including machine learning and data mining techniques
  - New SBIR subtopic which covers this area
- Reduce the burden on the crew by providing tools to improve situational awareness
  - Provide highly accurate caution-and-warning alerts for known issues
  - Reveal latent, previously unknown failures conditions and ability to predict system degradation
  - Active learning: incorporation of human feedback on the operational significance of statistical anomalies

Open Challenges for Tech Transfer to Deep Space Gateway (DSG)

- Communication between Ground and Crew still required when presenting the Crew with anomalies
  - Ground-based Mission Control is still relevant for Habitat support
- Resource constrained environment for hosting active learning and other elaborate interfaces
  - Not feasible for hosting onboard computationally intensive processes and graphical applications.
- The DSG does not have a WRS
  - No need to recycle water since it only supports crew for 30 days
  - However, lessons learned can easily translate to best practices for companion systems (e.g. through "transfer learning")
  - Other target systems of interest besides the Water Recycling System for DSG ISHM technology include the following:
    - Radiation protection
    - Fire Safety/ Smoke Detection
    - Systems to reduce logistics and the need for resupply missions



Open Challenges for Tech Transfer to Deep Space Gateway (DSG)

- Challenges in reporting discrepancies to the Crew, and updating the models onboard
  - More automation needs to be built in to the Active Learning capability so that the operational impact on the Crew is minimized.
  - Possibility that the Ground Control will need to qualify/deploy the model.
  - For unknown anomalies, the onboard system can be transitioned to a "safe state" before the anomaly can be verified by the Ground and a "model update" is uploaded
  - Develop CONOPS for the right mix of Crew and Ground Control involvement during the model/information update process.
    - How is crew informed of changes in interpretability of results (explanations, etc.) when model is updated
    - Provisions on the Ground to V&V new model, ensure it has high fidelity, can be explained simply, etc.

Questions ?

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