X3D Sensor-based Thermal Maps for Residential and Commercial Buildings

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Outline

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- Thermal Comfort
- Humidity and Temperature Monitoring System
- Data Acquisition
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- Scalability and Validation

Motivation

- Sustainable methods of construction - zero-carbon passive heating technologies
- Thermally deficient western methods of construction - huge potential of applying energy-efficiency improvements
- Sub-tropical climate zones which have entirely different requirements when it comes to designing energy-efficient and low-carbon houses

- The proposed system:
  - Cost effective solution for seasonal thermal monitoring
  - Simple, Scalable, Web-based visualization of 3D Thermal Maps
  - Facilitates decision making in terms of architectural modifications for energy-efficiency improvements from residential to commercial buildings
  - Independent of proprietary software packages and their integration solutions.

Thermal Modeling – Brief Review (1)

- Conventional models of thermal representations are in use by: construction professionals and HVAC engineers.
- National Institute of Building Sciences are proposing baseline standards [NIBS 2015] for thermal performance of building enclosures with measurement and verification for design and construction of enclosure assemblies.
- California lays the groundwork for adoption of a Zero Net Energy (ZNE)-ready code by 2020
- Thermal analysis software products: SolidWorks Simulation, Ansys Advantage, Ansys CFX and many others that support CAD-based models integration.

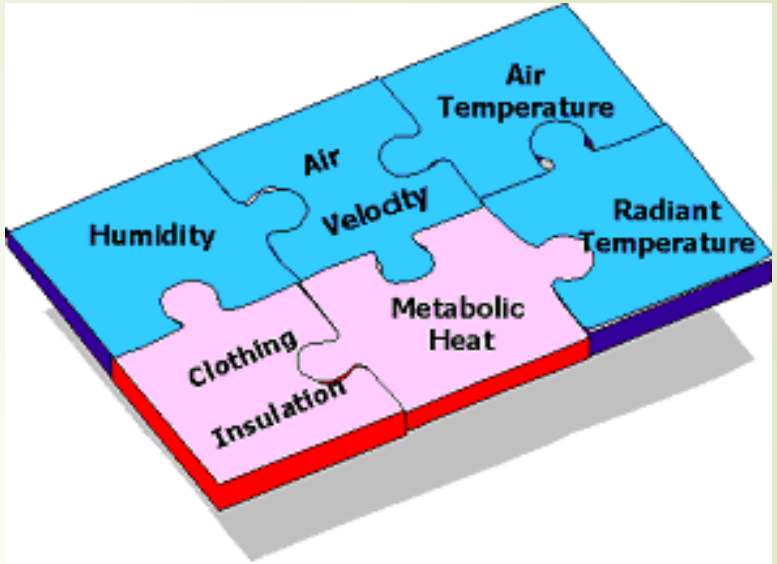
Thermal Modeling – Brief Review (2)

- Complex computational fluid dynamics (CFD) simulations used for the past 20 years to model the flow of air in buildings.
  - simulation systems presented are proprietary
  - too complex to be applied in conjunction with real-time data.

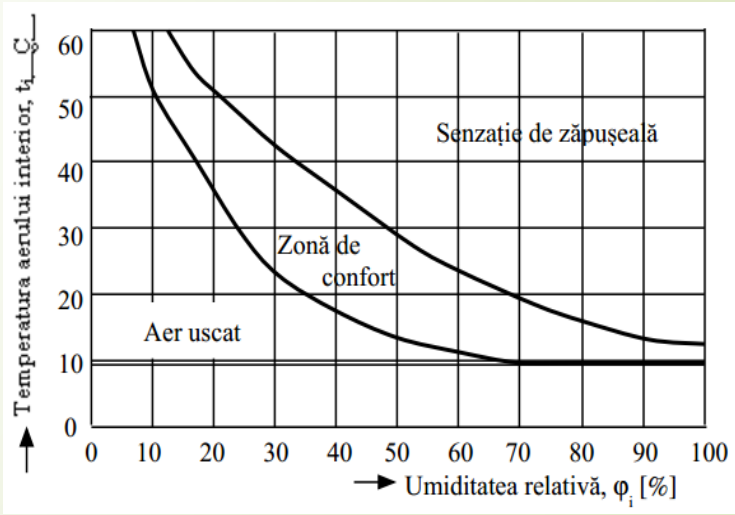
- Ham et al. [2014] presents a thermography-based (IR cameras) method to visualize the actual thermal resistance and condensation problems in buildings.

- Lee et al. [2014], measured the impact of three newly developed dynamic clothing insulation models using EnergyPlus, version 6.0.

Thermal Comfort

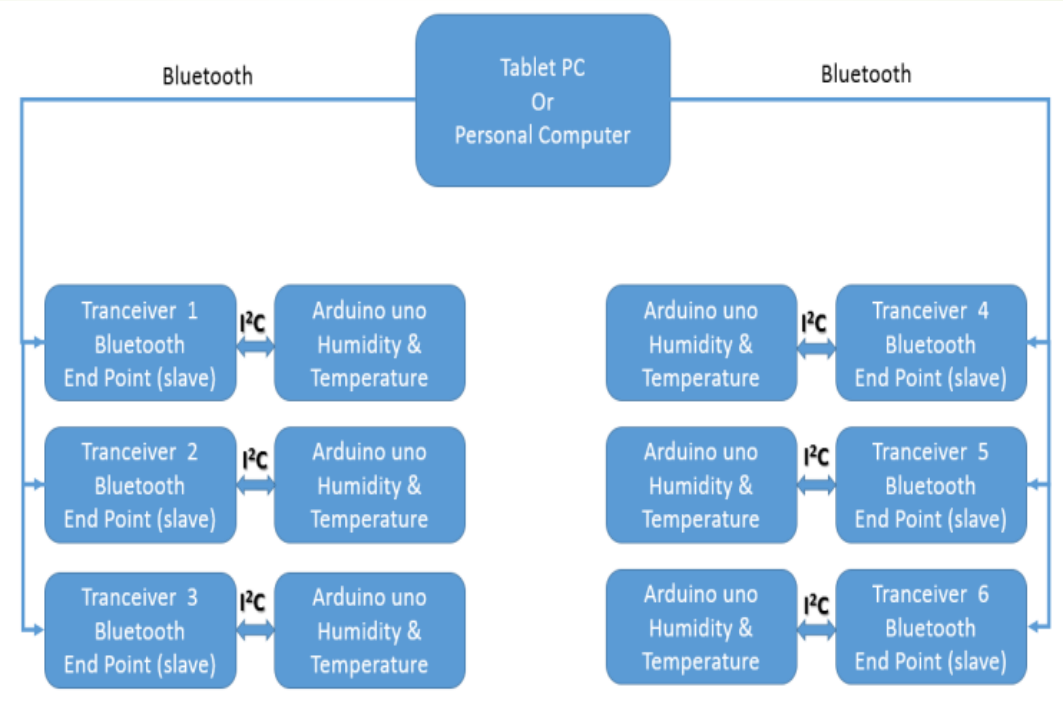


- A complex problem: 6 major factors (environmental & personal)
- Rijal et al. [2014] - conducted a thermal comfort and occupant behavior survey in 30 living rooms during the hot and humid season in the Kanto region of Japan. Residents adapt to the hot and humid environments by increasing the air movement using behavioral adaptation such as window opening and fan use.
- Pitts [2013] deals with transition spaces like entrance foyers, circulation zones, lift lobbies, stairways and atria, and thermal comfort experiences.
- Opportunities to reduce environmental conditioning and therefore energy use in such spaces.



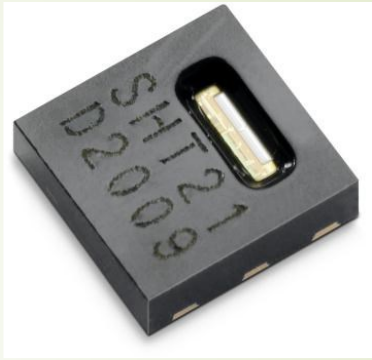
Humidity and Temperature Monitoring System (1)

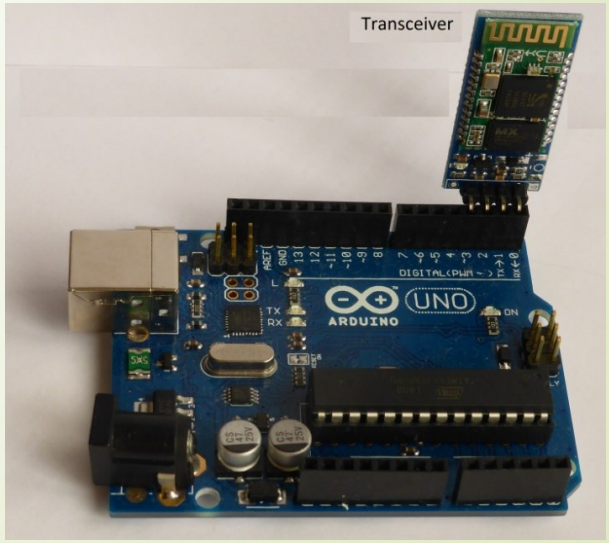
- Arduino Uno [Arduino 2015] based on ATmega328 microcontroller



Humidity and Temperature Monitoring System (2)

- Data acquisition module
  - Sensor (Sensirion) dimensions and energy consumption is minimized;
  - The hardware components are cost-effective;
  - High accuracy for temperature .01°C, relative humidity ±2%
  - High reliability (99.9%) of the network;
  - Simple command and control communication protocol tunneled through Bluetooth wireless.
  - 1 Hz update – real time monitoring



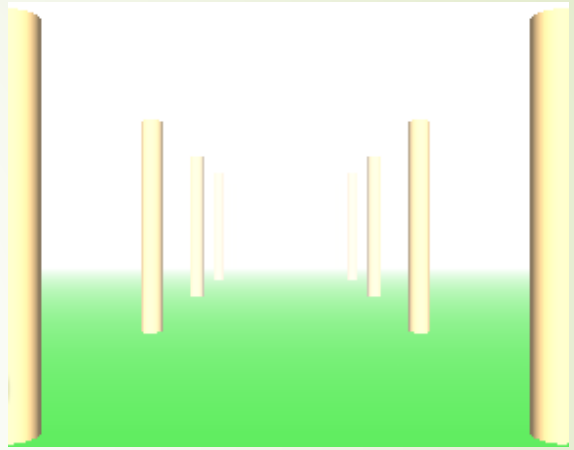


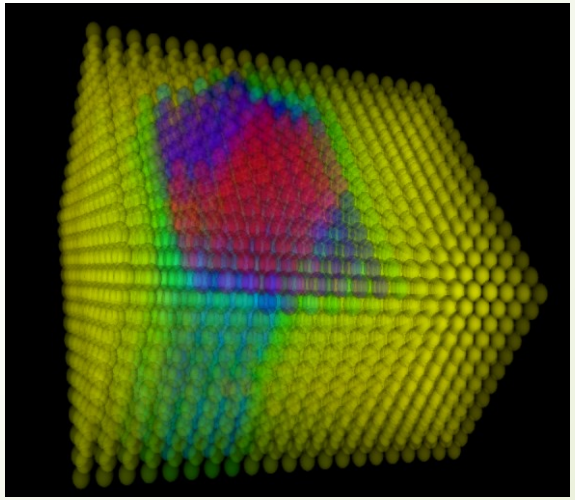
Data Acquisition

- The wireless sensors are producing measurement values every second in the data buffer.
- The data buffer is consumed by the data acquisition client (DAQ) that plays the role of the master (e.g. a tablet, smartphone or PC)
- Data is saved on permanent storage for later use (e.g. playback of sensor data for extended periods of time)

X3D Data Representation

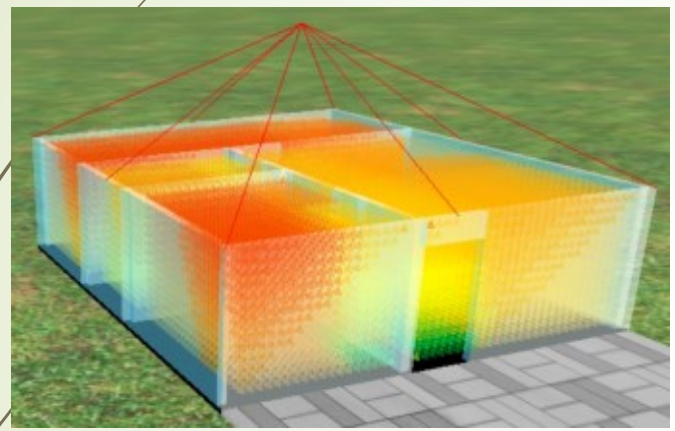
- X3D nodes explored:
  - X3D Fog
  - X3D Primitives



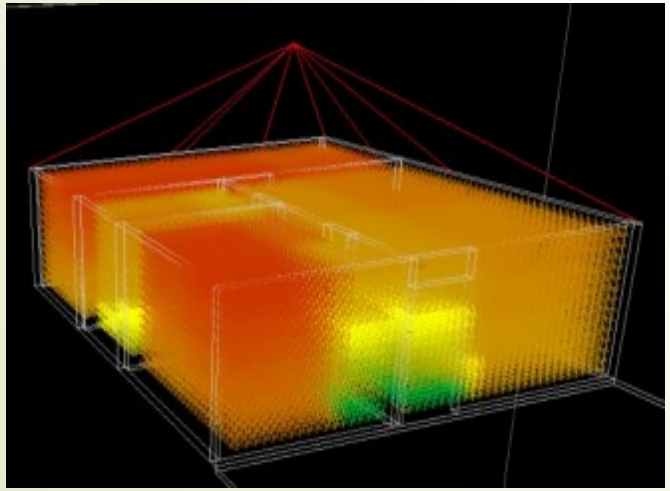


X3D Data Representation

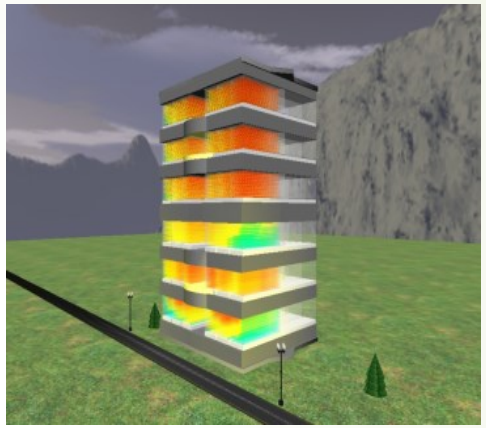
Semi-transparent walls

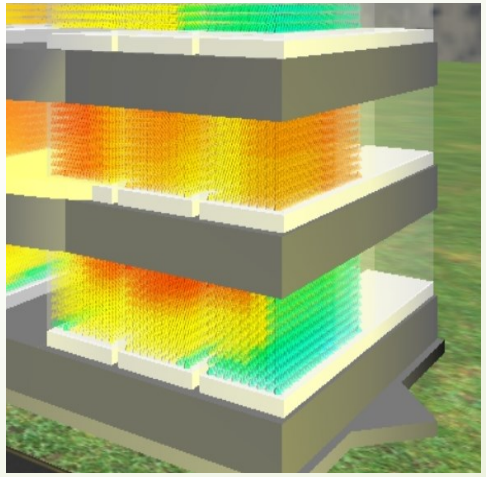


Wire-frame rendering



Scaling to Large Commercial Buildings





Results that are representative of the actual interior physics assuming a laminar air-flow, non-turbulent steady-state condition of airflow

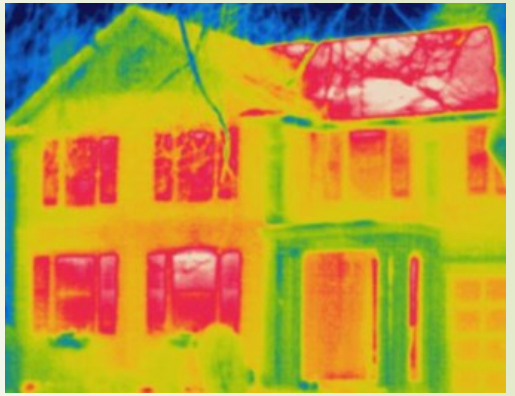
Scalability

- Scalability to large commercial buildings is possible using simple polygonal elements – billboards => 15+ FPS
- Scalability to city regions is possible – algorithms are under implementation, keeping framerate above 15
  - Fully interactive
  - Partially interactive i.e. predefined view points
  - Non-interactive - animation

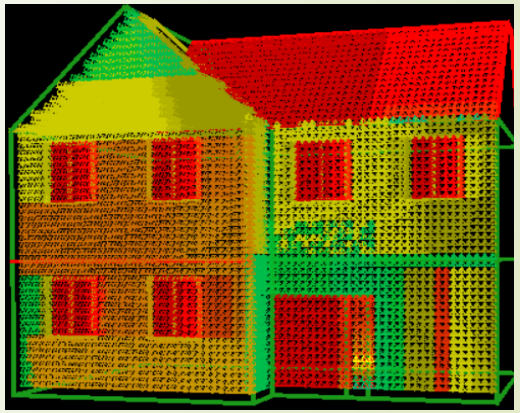
Validation

- Validation method for the simulation system using infrared (IR) thermography with a thermal imaging camera
  - Mockup X3D model
  - Sensor data simulated through dynamic arrays
- Automatic validation through image analysis – under development.

Image based on IR Camera System



X3D Thermal Map



Conclusions

- Basic and cost effective system for temperature/humidity data acquisition
- Scalable X3D system for 3D Thermal Maps representation
- Building energy modeling can be applied early in the design development phase, as a collaborative effort between the energy consultant and the architect.
- Initial energy modeling scenarios may use forward simulation models to predict approximate values for annual energy consumption and energy costs.
- The type of early design impact analysis allowed by X3D sensor-based thermal comfort simulation may be one of the key aspects of sustainable design, pre-construction, construction and operation phases of the respective residential or commercial building.

- The study will be expanded for case studies dealing with various human comfort zones during year-round seasons as humidity plays a major role in heat transfer.

Acknowledgements

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