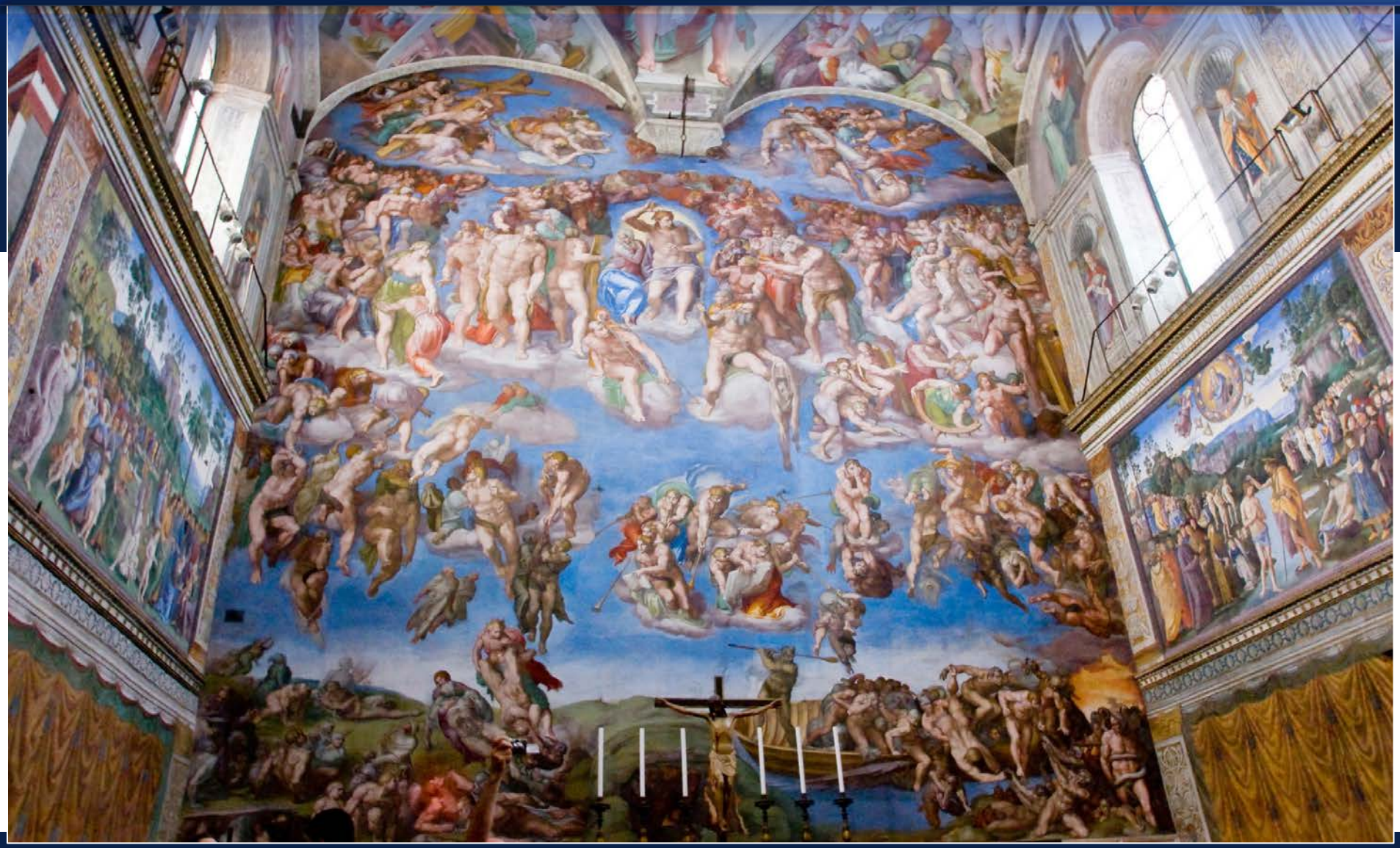
Occupancy Sensing Technologies:

Historical perspective, current state,
and value proposition

Hayden Reeve
United Technologies Research Center

Moving the world’s population every 4 days

Providing critical humidity control solutions



Integrating systems in 80% of aircraft

INTELLIGENT BUILDING TECHNOLOGIES

At United Technologies, we design, develop and manufacture many intelligent products. Each of our solutions brings to market innovations that enhance value, efficiency, comfort, mobility, safety, access and environments in nearly all types of buildings and applications, all over the world.

WATER
Smart meters, use/flow sensing

FIRE
Functionality checks, detector service

Automation and Monitoring
Building automation and control
Facility monitoring

ACCESS/SECURITY
Badge in, cameras, integration perimeter, doors, floors, occupancy

HVAC
Fans, variable air, volume, air quality

LIGHTING
Occupancy sensing

ENERGY
Smart meters demand response

ELEVATORS
Maintenance, performance

EDWARDS, Kidde, DET-TRONICS, AutomatedLogic

Chubb, AutomatedLogic

Carrier, AutomatedLogic, NORESCO

OTIS, AutomatedLogic

LENEL, Onity, interlogix, Chubb, AutomatedLogic

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UTRC Technology Demonstration Experience

Tsinghua – Occupancy comfort and estimation

Berkeley

East Hartford

Cork

Rome

Shanghai

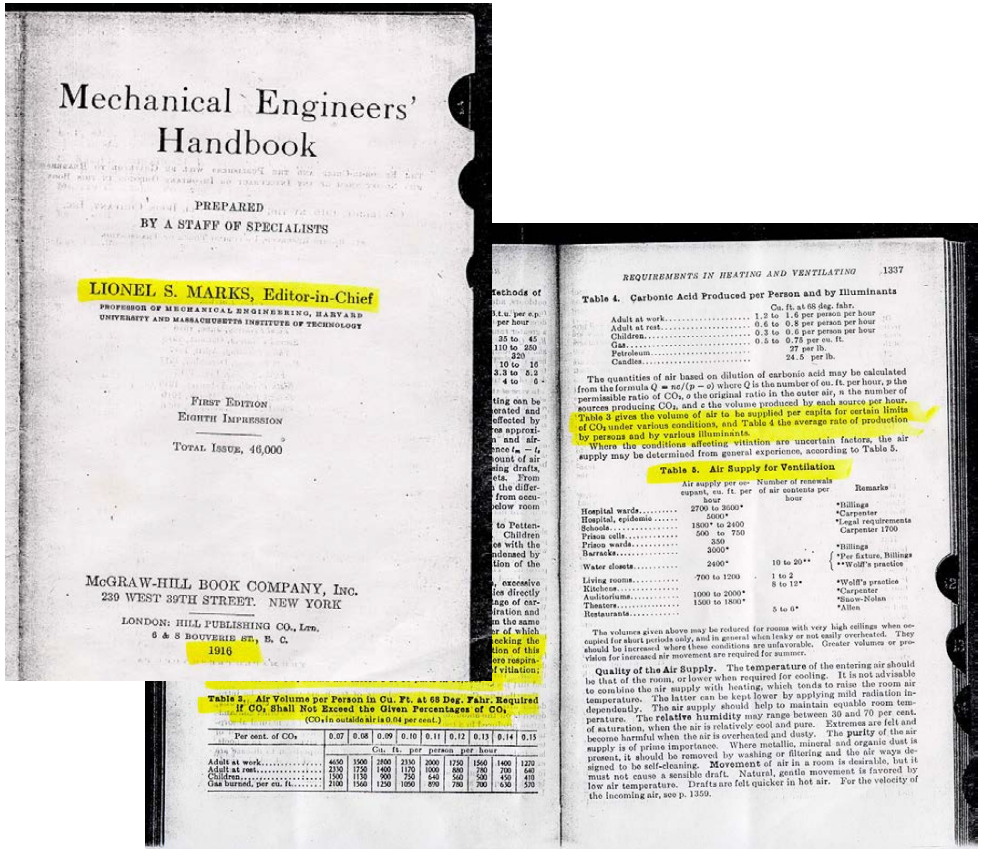
UTRC Test Bed

CCS Europe

CCS Asia

Sensing for Ventilation Control

History: CO2 Ventilation Control



Mechanical Engineers' Handbook

PREPARED BY A STAFF OF SPECIALISTS

LIONEL S. MARKS, Editor-in-Chief
PROFESSOR OF MECHANICAL ENGINEERING, HARVARD UNIVERSITY AND MASSACHUSETTS INSTITUTE OF TECHNOLOGY

FIRST EDITION
EIGHTH IMPRESSION

TOTAL ISSUE, 46,000

McGRAW-HILL BOOK COMPANY, INC.
239 WEST 39TH STREET, NEW YORK
LONDON: HILL PUBLISHING CO., LTD.
6 & 8 BOUVERIE ST., E. C.
1916

REQUIREMENTS IN HEATING AND VENTILATING 1337

Table 4. Carbonic Acid Produced per Person and by Illuminants

	Cu. ft. at 68 deg. fahr.
Adult at work	1.2 to 1.6 per person per hour
Adult at rest	0.6 to 0.8 per person per hour
Children	0.3 to 0.6 per person per hour
Gas	0.5 to 0.75 per cu. ft.
Petroleum	27 per lb.
Candles	24.5 per lb.

The quantities of air based on dilution of carbonic acid may be calculated from the formula $Q = ne/(p - o)$ where Q is the number of cu. ft. per hour, p the permissible ratio of CO_2, o the original ratio in the outer air, n the number of sources producing CO_2, and e the volume produced by each source per hour. Table 3 gives the volume of air to be supplied per capita for certain limits of CO_2 under various conditions, and Table 4 the average rate of production by persons and by various illuminants.

Where the conditions affecting vitiation are uncertain factors, the air supply may be determined from general experience, according to Table 5.

Table 5. Air Supply for Ventilation

	Air supply per occupant, cu. ft. per hour	Number of renewals of air contents per hour	Remarks
Hospital wards	2700 to 3600*		*Billings
Hospital, epidemic	5000*		*Carpenter
Schools	1800* to 2400		*Legal requirements Carpenter 1700
Prison cells	500 to 750		
Prison wards	350		
Barracks	3000*		*Billings
Water closets	2400*	10 to 20**	*Per fixture, Billings **Wolff's practice
Living rooms	700 to 1200	1 to 2	
Kitchens	1000 to 2000*	8 to 12*	*Wolff's practice
Auditoriums	1500 to 1800*		*Carpenter
Theaters			*Snow-Nolan
Restaurants		5 to 6*	*Allen

The volumes given above may be reduced for rooms with very high ceilings when occupied for short periods only, and in general when leaky or not easily overheated. They should be increased where these conditions are unfavorable. Greater volumes or provision for increased air movement are required for summer.

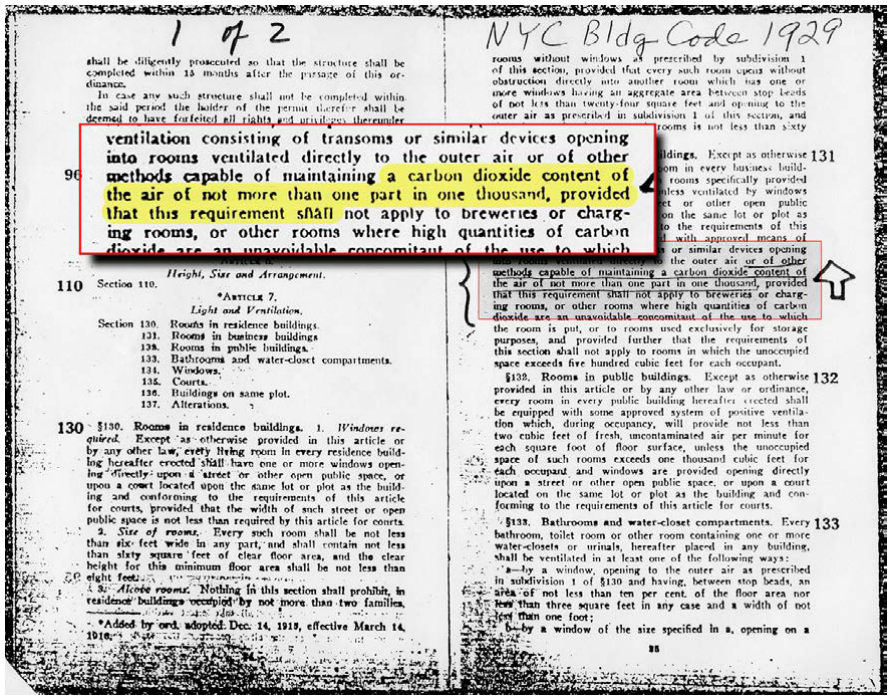
Quality of the Air Supply. The temperature of the entering air should be that of the room, or lower when required for cooling. It is not advisable to combine the air supply with heating, which tends to raise the room air temperature. The latter can be kept lower by applying mild radiation independently. The air supply should help to maintain equable room temperature. The relative humidity may range between 30 and 70 per cent. Extremes are felt and of saturation, when the air is relatively cool and pure. Extremes are felt and become harmful when the air is overheated and dusty. The purity of the air supply is of prime importance. Where metallic, mineral and organic dust is present, it should be removed by washing or filtering and the air ways designed to be self-cleaning. Movement of air in a room is desirable, but it must not cause a sensible draft. Natural, gentle movement is favored by low air temperature. Drafts are felt quicker in hot air. For the velocity of the incoming air, see p. 1359.

Table 3. Air Volume per Person in Cu. Ft. at 68 Deg. Fahr. Required If CO_2 Shall Not Exceed the Given Percentages of CO_2
(CO_2 in outside air is 0.04 per cent.)

Per cent. of CO_2	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
	Cu. ft. per person per hour								
Adult at work	4650	3500	2800	2350	2000	1750	1560	1400	1270
Adult at rest	2150	1750	1400	1170	1000	880	780	700	640
Children	1500	1150	900	750	640	560	500	450	410
Gas burned, per cu. ft.	2100	1560	1250	1050	870	780	700	630	570

1916 Mechanical Engineers Handbook:

CO_2 not to exceed 800-1,000 parts per million



1 of 2

NYC Bldg Code 1929

shall be diligently prosecuted so that the structure shall be completed within 18 months after the passage of this ordinance.

In case any such structure shall not be completed within the said period the holder of the permit therefor shall be deemed to have forfeited all rights and privileges thereunder

ventilation consisting of transoms or similar devices opening into rooms ventilated directly to the outer air or of other methods capable of maintaining a carbon dioxide content of the air of not more than one part in one thousand, provided that this requirement shall not apply to breweries or charging rooms, or other rooms where high quantities of carbon dioxide are an unavoidable concomitant of the use to which

Height, Size and Arrangement.

Section 110.

*ARTICLE 7.
Light and Ventilation.

Section 130. Rooms in residence buildings.
131. Rooms in business buildings.
132. Rooms in public buildings.
133. Bathrooms and water-closet compartments.
134. Windows.
135. Courts.
136. Buildings on same plot.
137. Alterations.

§130. Rooms in residence buildings. 1. *Windows required.* Except as otherwise provided in this article or by any other law, every living room in every residence building hereafter erected shall have one or more windows opening directly upon a street or other open public space, or upon a court located upon the same lot or plot as the building and conforming to the requirements of this article for courts, provided that the width of such street or open public space is not less than required by this article for courts.

2. *Size of rooms.* Every such room shall be not less than six feet wide in any part, and shall contain not less than sixty square feet of clear floor area, and the clear height for this minimum floor area shall be not less than eight feet.

3. *Alcove rooms.* Nothing in this section shall prohibit, in residence buildings occupied by not more than two families,

*Added by ord. adopted Dec. 14, 1918, effective March 14, 1919.

rooms without windows as prescribed by subdivision 1 of this section, provided that every such room opens without obstruction directly into another room which has one or more windows having an aggregate area between stop beads of not less than twenty-four square feet and opening to the outer air as prescribed in subdivision 1 of this section, and rooms is not less than sixty

dings. Except as otherwise 131
om in every business build-
rooms specifically provided
nless ventilated by windows
et or other open public
on the same lot or plot as
o the requirements of this
d with approved means of
s or similar devices opening
rooms ventilated directly to the outer air or of other methods capable of maintaining a carbon dioxide content of the air of not more than one part in one thousand, provided that this requirement shall not apply to breweries or charging rooms, or other rooms where high quantities of carbon dioxide are an unavoidable concomitant of the use to which the room is put, or to rooms used exclusively for storage purposes, and provided further that the requirements of this section shall not apply to rooms in which the unoccupied space exceeds five hundred cubic feet for each occupant.

§132. Rooms in public buildings. Except as otherwise 132
provided in this article or by any other law or ordinance, every room in every public building hereafter erected shall be equipped with some approved system of positive ventilation which, during occupancy, will provide not less than two cubic feet of fresh, uncontaminated air per minute for each square foot of floor surface, unless the unoccupied space of such rooms exceeds one thousand cubic feet for each occupant and windows are provided opening directly upon a street or other open public space, or upon a court located on the same lot or plot as the building and conforming to the requirements of this article for courts.

§133. Bathrooms and water-closet compartments. Every 133
bathroom, toilet room or other room containing one or more water-closets or urinals, hereafter placed in any building, shall be ventilated in at least one of the following ways:

a—by a window, opening to the outer air as prescribed in subdivision 1 of §130 and having, between stop beads, an area of not less than ten per cent. of the floor area nor less than three square feet in any case and a width of not less than one foot;

b—by a window of the size specified in a, opening on a

1929 NYC Building Code:

Specifies ventilation systems capable of achieving 1,000 ppm CO2

Credit: Mike Schell, AirTest

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CO_2 Sensor Development

Circa 1890 - 1935

Circa 1992

Telaire 1050
1st CO2 Sensor for Demand Controlled Ventilation

Circa 2014

TR9299-WiFi CO2 & Temp

Credit: Mike Schell, AirTest

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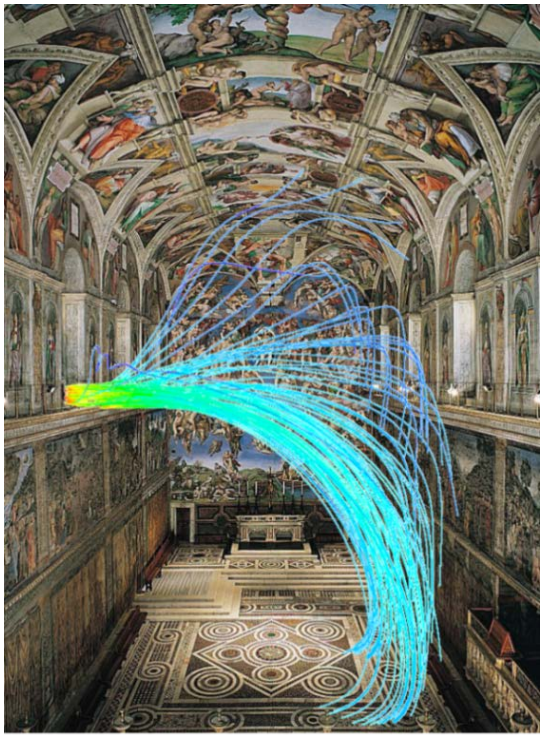
Video Detection Case Study



Airflow and system analysis ensures flawless 'day one' operation

Crowd monitoring ensures peak loads are meet with no CO_2 excursions

Sistine Chapel, Vatican City, Rome

Preserving cultural icons through feed-forward control

http://global.ctbuh.org/paper/2404
https://youtu.be/wfFppqDDeRU

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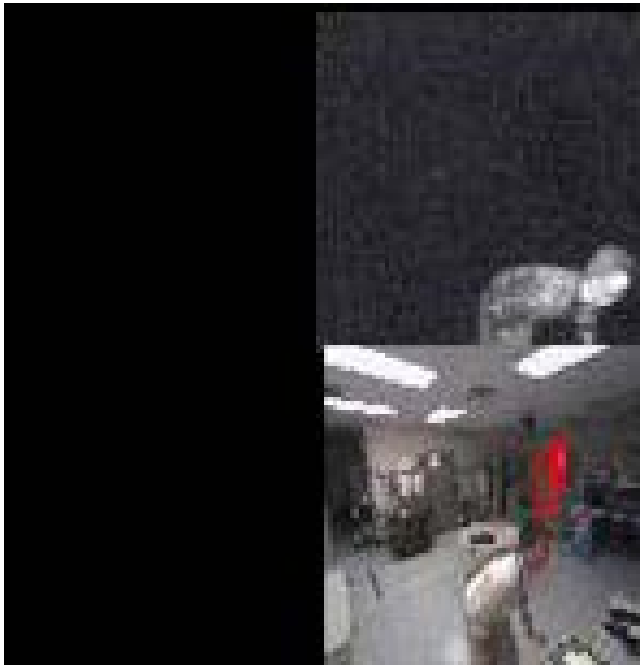
Occupant Presence Detection

Current limitations and emerging trends:

- Temperature and CO2 are lagging indicators of occupancy and resulting HVAC load and are prone to drift
- Traditional single point IR sensors have high missed detect rates. Video has high false alarm rates.
- IR FPA sensors offer potential for cheap and accurate presence detection, people counting, and ancillary load detection.

SOFRADIR-EC

Sofradir EC 80x80 aSi Array



Side by side comparison video

- False Detection in RGB
- 80x80 images down-sampled from Axis IP camera images

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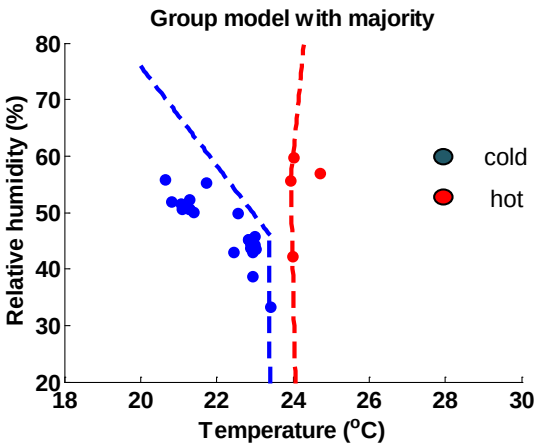
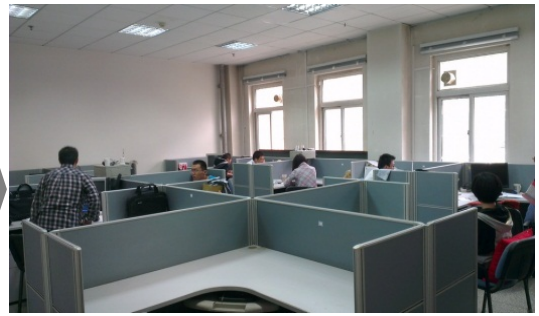
Occupant-Centered Comfort Control

Supported Tsinghua investigation of group comfort dynamics and benefits:

User input on comfort



Dynamic group comfort map created



HVAC controls to comfort map

- UTRC/Tsinghua[1,2]: Satisfaction-based control can save up to 15% energy than setpoint control under similar outdoor temperature condition. Develops custom comfort regions for groups of occupants based on user input.

1. Experimental assessment of a satisfaction based thermal comfort control for a group of occupants, Zhao et al., 015 IEEE International Conference on Automation Science and Engineering (CASE),
2. Preliminary study of learning individual thermal complaint behavior using one-class classifier for indoor environment control, Zhao et al, Building and Environment 72 (2014) 201-211

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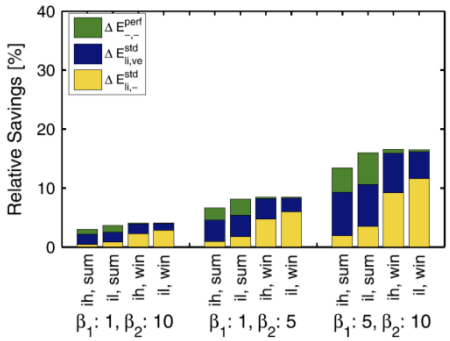
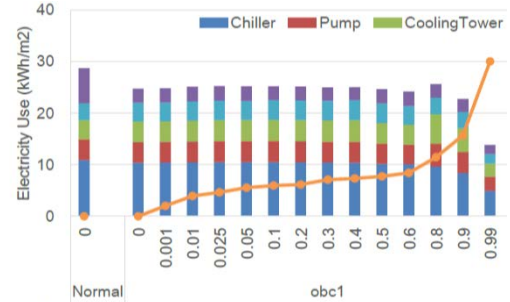
Advanced Occupant-Based Control

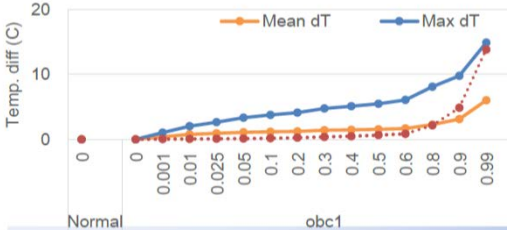
Benefits evaluated as a function of prediction horizon and sensor accuracy

- ETH Zurich[1,2] found adjusting lighting and especially ventilation to instantaneous measurement saved significant energy. However, using on top of that occupancy predictions did not provide a significant energy savings potential.

- UTRC/Tsinghua University[3]: Evaluated impact of OBC on energy savings and comfort violations as a function of sensor accuracy. Savings of 15-22%.







1. Sturzenegger, D. et. al "Importance of long-term occupancy information - a validation with real occupancy data." Pro. of the 11th REHVA World Congress Clima 2013, Prague, Czech Republic, June 16-19, 2013
2. Frauke Oldewurtel , David Sturzenegger, Manfred Morari, "Importance of occupancy information for building climate control", Applied Energy 101 (2013) 521–532
3. Professor (Samuel) Qing-Shan Jia, Tsinghua University, Unpublished work, 2015.

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Deployment Challenges

- Affordability: First cost dominated by installation and integration (data mapping) efforts. (i.e. packaging and installation usually account for >95% of node costs)

- Scalability: Must meet the requirements of heterogeneous building types, uses, and ages. (e.g. energy harvesting approaches would have to account for 6σ use-cases)

- Deployability: Seek plug and play solutions to address variable skill-sets in the field. (e.g. no onsite calibration or fingerprinting of building).

- Maintainability: Goal >10 year maintenance-free life. (e.g. no lifetime battery replacements).

- Acceptability: Complexity or poor performance will result in system being abandoned by building operator. (e.g. missed detect rates resulting in discomfort can result in call-backs or the system being turned off).

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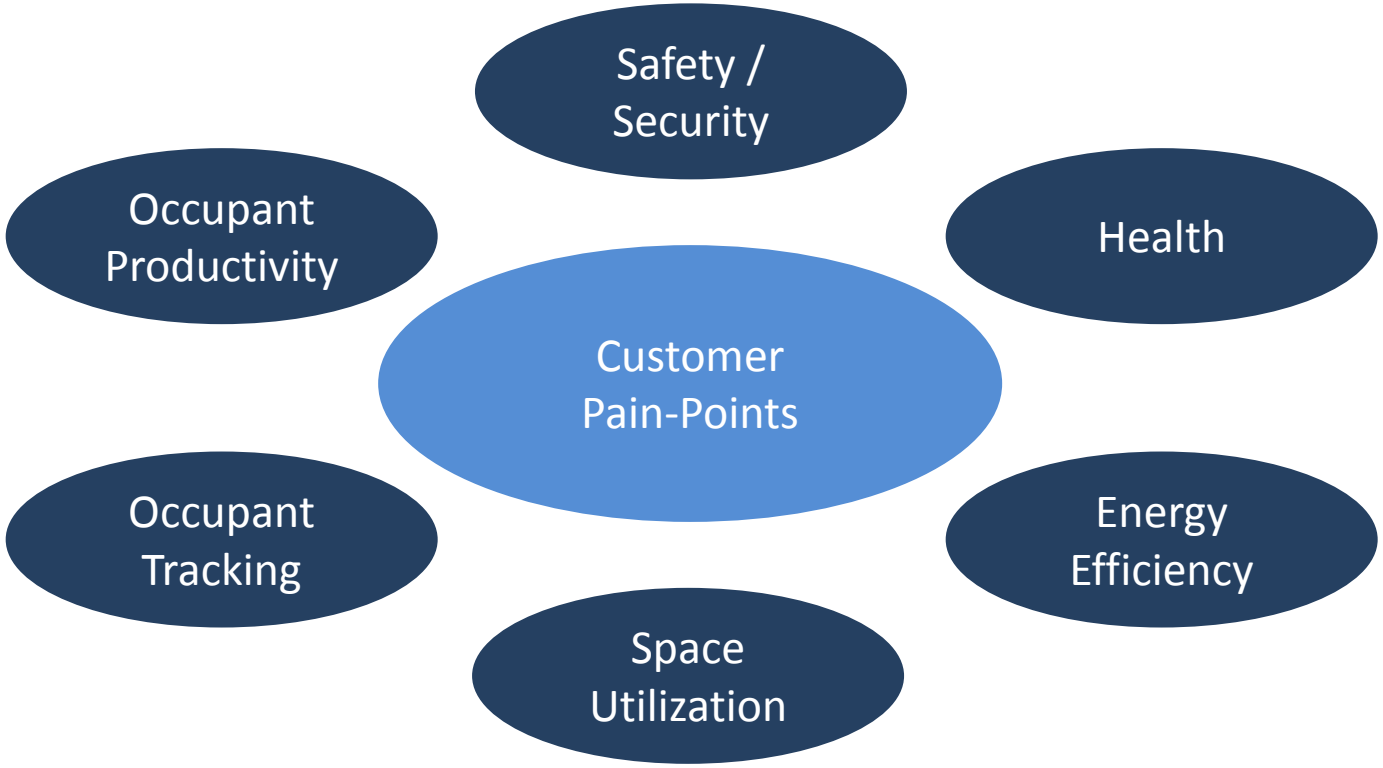
Beyond Energy: Occupant Experience

Adv. Occupant Based Operation

Advanced sensing and interaction enables range of value propositions:



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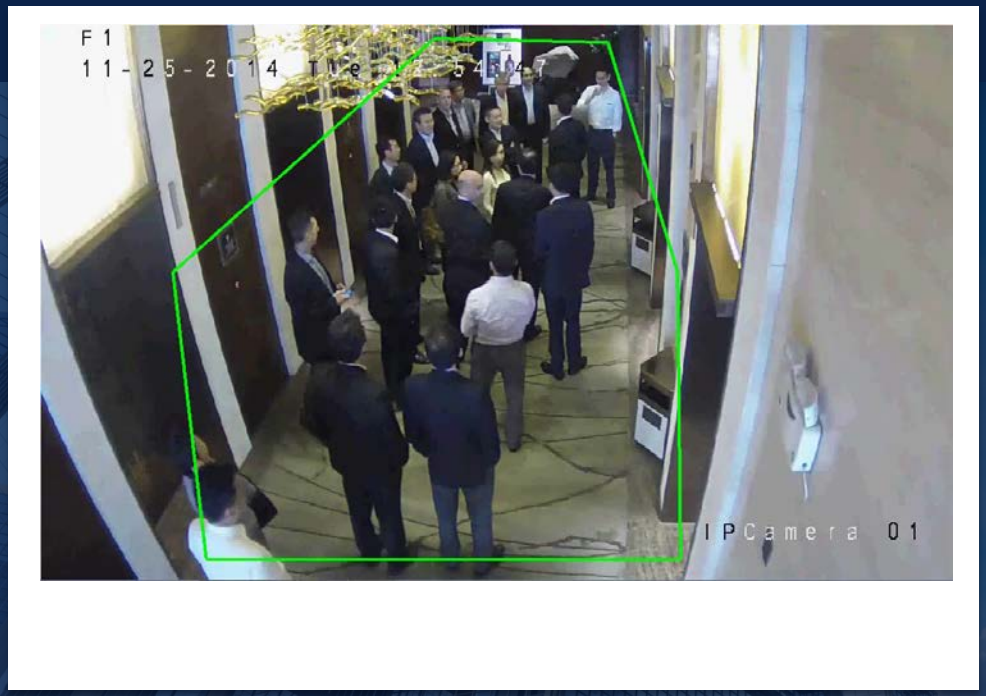
Vertical Transport Solutions

WESTIN PAZHOU, GUANGZHOU, CHINA



UP TO

40%

REDUCTION OF
MAX WAIT TIMES

THE IMPACT OF GREEN BUILDINGS ON **COGNITIVE FUNCTION**

United Technologies

24 PARTICIPANTS

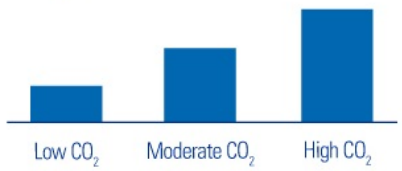
6 DAYS OVER **2 WEEKS**

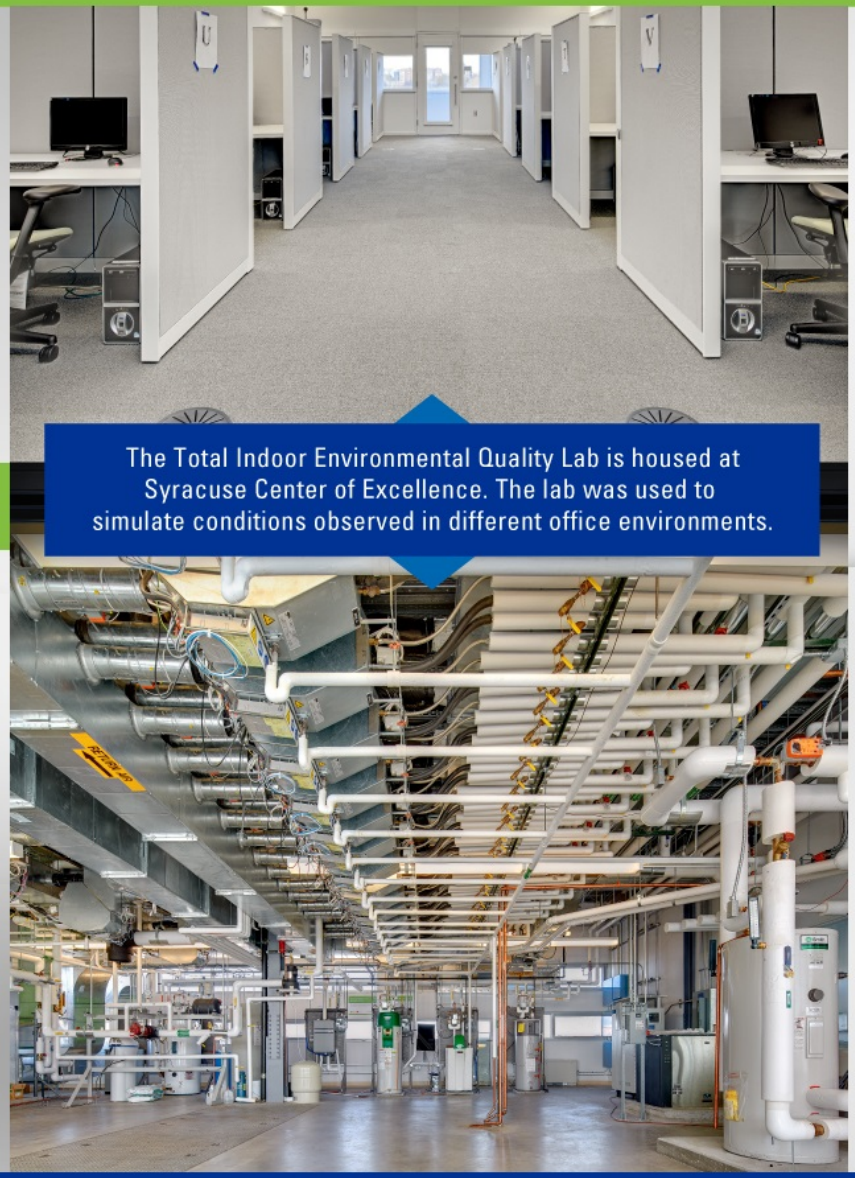
2 TESTS

1. **Multivariable test for building types:**

Conventional	Green	Enhanced Green
i.e., Typical Office	Low VOC	Low VOC and High Ventilation

2. **Single-variable test for carbon dioxide:**





The Total Indoor Environmental Quality Lab is housed at Syracuse Center of Excellence. The lab was used to simulate conditions observed in different office environments.

PARTICIPANTS EXPERIENCED

- SIGNIFICANTLY BETTER **COGNITIVE FUNCTION**
- FEWER HEALTH SYMPTOMS
- BETTER PERCEIVED INDOOR ENVIRONMENTAL **QUALITY**

BASED ON THE FOLLOWING COGNITIVE FUNCTION DOMAINS

- Basic activity level
- Applied activity level
- Focused activity level
- Task orientation
- Crisis response
- Information seeking
- Information usage
- Breadth of approach
- Strategy

1. #CogFX: http://thecogfxstudy.naturalleader.com/

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Future of Intelligent Buildings

INTELLIGENT BUILDING THEMES

SUPERIOR CUSTOMER EXPERIENCE

SCALABLE SOLUTION

SEEMLESS INTEGRATION

PERSISTENT OPTIMALITY

MOVING THE WORLD FORWARD

A global leader in building systems and aerospace industries

We invent new and better ways to keep people safe, comfortable, productive and on the move