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BCIT

Integrate Your Body: Human Physiological Responses as a Potential Driving Factor in IEQ Controls

Thermal Comfort in Health Care: The Need for Physiological Feedback

Rodrigo Mora, PhD., P.Eng.
British Columbia Institute of Technology
Rodrigo_mora@bcit.ca
(Member: SSPC-55)

Mike Meteyer, PE
ERDMAN
mmeteyer@erdman.com
(Member: SSPC-170, TC 9.6)

Marco Arnesano, PhD.
Università Politecnica delle Marche
m.arnesano@univpm.it
(Research collaborator)

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Overall Session Learning Objectives

- **Objective 1** - Understand the types of physiological factors that can more conveniently be monitored to assess thermal comfort in real-time.
- **Objective 2** - Understand the advantages of data-driven approach in comfort predictions of individuals.
- **Objective 3** – Learn about relevant research questions with regard to adaptive thermal comfort, and understand how to approach these questions experimentally in lab and field studies.
- **Objective 4** - Provide an overview of the principle of Human-Building Integration, and its potential use as a smart (end-user) control over HVAC systems.

Presentation Learning Objectives

- **Objective 1** - Understand the complexities in predicting and assessing thermal comfort in health care.
- **Objective 2** - Understand the types of human factors that can more conveniently be monitored to assess thermal comfort in health care.
- **Objective 3** - Learn the challenges & potential opportunities in using real-time physiologically-informed individual thermal comfort assessments to drive personalized & room indoor climate systems.
- **Objective 4** - Provide an overview of the types of wearable sensors that can practically be used.
- **Objective 5** - Understand the approaches to correlate sensors data to thermal comfort at individual and room levels.

Outline

1. Thermal Comfort in Health Care: Challenges
2. Background - Thermal Comfort Principles & ASHRAE Standard 55-2013
3. Physiological/Human Signals to be Monitored
4. Sensing & Monitoring Technologies
5. Issues & Requirements

1. Thermal Comfort in Health Care: Challenges

Diversity of Comfort Requirements *(Shipworth et al. 2016)*

Context

- Building type & characteristics
- Type of service / Type of medical procedure
- Sepsis requirements

- Transient (MET?)
- Gowning (CLO?)

Visitors
- Emotions
- Anxiety?
- Short stay

Patients
- Age group
- Medical condition
- Emotions
- Anxiety?
- Length of stay?
- Gowning
- Bedding

Staff
- Performance
- Arousal
- Mental stress
- Fatigue
- Workload

How to Capture this Diversity in Thermal Comfort Requirements?

1. Thermal Comfort in Health Care: Challenges

Factors Affecting Thermal Comfort of Patients: *(Mora and Meteyer 2017)*

Medical Condition

Healthy ← Disabled → Unhealthy

Intellectual
- Impaired perception
- Impaired emotion
- Impaired cognition
- Impaired temperament
- Impaired adaptation…

Physical/Physiological
- Impaired mobility
- Impaired thermal sensation
- Impaired thermoregulation
- Impaired metabolic functions
- …

Age Group
- Newborn
- Baby
- Toddler
- ….
- Elder

Type of Service/Medical Procedure
- Ward/Room type/location
- Medicine
- Anesthesia
- Activity/Posture
- Clothing/Gown
- Length of stay?

1. Thermal Comfort in Health Care: Challenges

People with Physical Disabilities

"Of particular importance is the use of the adaptive approach for people with physical disabilities. The present research has led to hypotheses that suggest that thermal comfort requirements for people with physical disabilities should take account of the restricted ability of people to adapt to the thermal environment. "

(Parsons 2002)

"For babies, children, the sick and the pregnant there is a need for systematic research into the interaction of the six basic parameters and thermal comfort. "

(Parsons 2002)

1. Thermal Comfort in Health Care: Challenges

Environment Effects on People (Assisted Living)

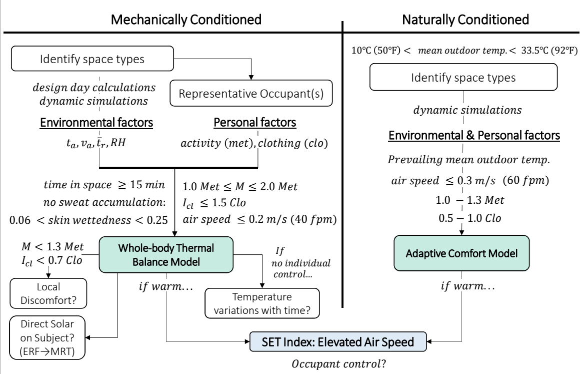
"We feel that enough physiological information on the effects on indoor temperature on health has been gathered to start putting this knowledge into practice. Therefore, the question rises: how can this knowledge be translated into the built environment?"

(Lichtenbelt et al. 2016)

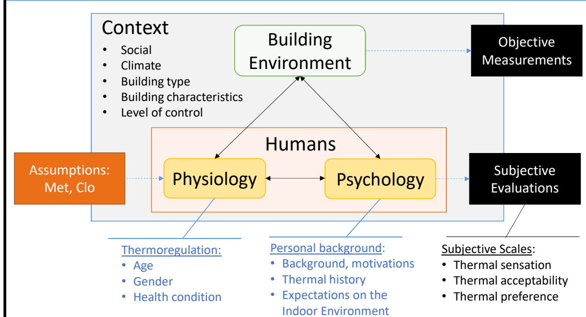
"Research in the UK and elsewhere has highlighted that older people are particularly vulnerable to negative health effects of overheating"

(Gupta et al. 2016)

2. Background - Thermal Comfort & ASHRAE Standard 55-2013



2. Background - Thermal Comfort & ASHRAE Standard 55-2013



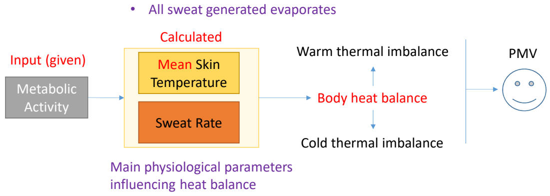
"Comfort is a construct that exists in our thinking & cannot be measured directly" (Cain 2002)

2. Background - Thermal Comfort & ASHRAE Standard 55-2013

Rational Model: PMV-PPD Thermal Comfort Model *(Fanger 1970)*

The thermal balance of the human body results in skin temperatures & sweat rates that should be kept within specified ranges, depending on metabolic activity & thermoregulation (physiology), to produce a neutral thermal sensation (sensory psychology) & subsequent conscious thermal satisfaction (cognitive psychology).

Main Assumptions
- Body not far from thermal neutrality
- Narrow range of environmental conditions
- All sweat generated evaporates



2. Background - Thermal Comfort & ASHRAE Standard 55-2013

Local Discomfort:

Tolerance/Thresholds = f(overall thermal sensation, personal control)

Temporal thresholds:
- ***Temperature variations with time:***
  - Deviation from neutral (drifts): amplitude
  - Fluctuations: frequency (minutes, hours, days)

Spatial thresholds:
- ***Local discomfort:***
  - Air drafts: ankle, neck
  - Vertical air temperature difference (stratification): standing, seated
  - Radiant thermal asymmetry: cold/warm wall, cold/warm ceiling
  - Floor surface temperature

2. Background - Thermal Comfort & ASHRAE Standard 55-2013

Research Directions (Relevant to Health Care):

- Adaptive Inner Mechanisms & Occupant Building Interactions
- Transient Activities
- Non-uniform & Non Steady-State Environments
- Drastic Thermal Transitions: Alliesthesia (Thermal Pleasure)
- Long-term Thermal Comfort Indices & Excursions
- Uncertainty Quantification: Confidence in Predictions
- Multi-node Models of Thermal Physiology & Comfort
- Thermal Comfort for Vulnerable Populations
- Comfort, productivity, & performance
- Interactions: odor, lighting, noise
- Personal Comfort Systems

(van Hoof 2008, Carlucci and Pagliano 2012, de Dear et al. 2013, Rupp et al. 2015)

3. Physiological Signals to be Monitored

Thermal Stress (heat loads acting on the body):

- *Net Heat **Load** on the Body from the Combined Contributions of Metabolic Heat Production and External Environmental Factors.*

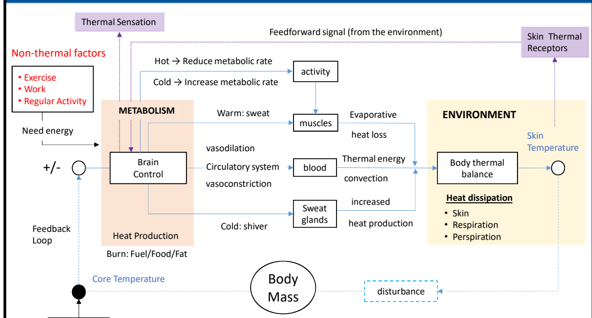
Thermal Strain (body's thermoregulatory response):

- *The **Net Physiological** Load Resulting from Heat Stress (the body's **response**)*

3. Physiological Signals to be Monitored

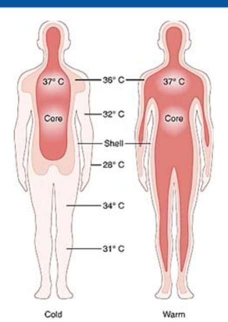
- ***Thermoregulation** is a process that allows your body to maintain its core internal temperature.*
- *All **thermoregulation** mechanisms are designed to return your body to homeostasis. This is a state of equilibrium. A healthy internal body temperature falls within a narrow window.*

3. Physiological Signals to be Monitored



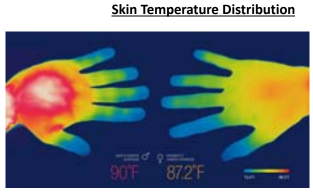
Homeostasis: 36.1℃ (97°F) $< core\ temperature <$ 37.8℃ (100°F)

3. Physiological Signals to be Monitored



(Wenger 1997)

Skin Temperature Distribution

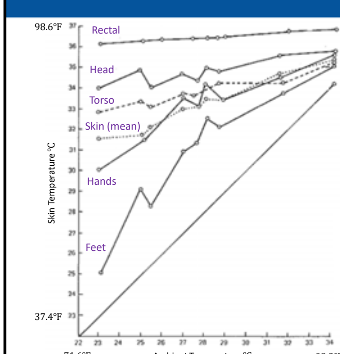


Man's hand　　Woman's hand

"Blood vessels in the body's extremities are the first to constrict when temperatures drop"

(National Geographic 2014)

3. Physiological Signals to be Monitored



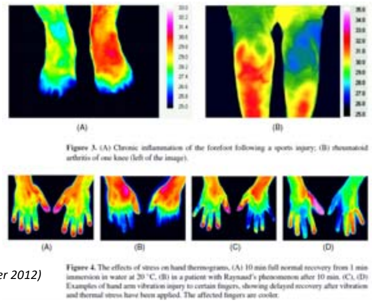
Skin Temperature Distribution

Measured Skin Temperatures on a Nude Person

(BW Olesen 1982, Thermal Comfort Technical Review, Bruel & Kjaer)

3. Physiological Signals to be Monitored

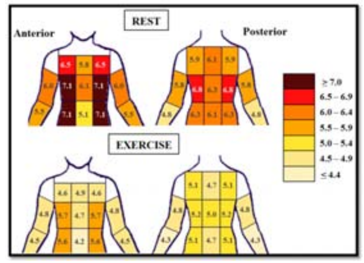
Patient Thermal Comfort: Impaired Thermoregulation



(King and Ammer 2012)

3. Physiological Signals to be Monitored

Regional distribution of thermal sensitivity to cold at rest and during mild exercise in males



"Thermal sensitivity corresponds to two opposite sensibilities, the sensitivity to warm and the sensitivity to cold. These feelings are detected by some specific points which are sensitive to hot and warm and that are scattered all over the skin with a lower density than those dedicated to mechanical stresses. Moreover, the sensitive points to cold are more numerous than those sensitive to hot."

(Ouzzahra et al. 2012)

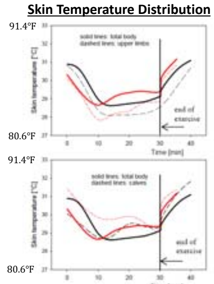
3. Physiological Signals to be Monitored

(Tanda 2015)

Two athletes: before, during, after exercise

Before | During | After

Skin Temperature Distribution

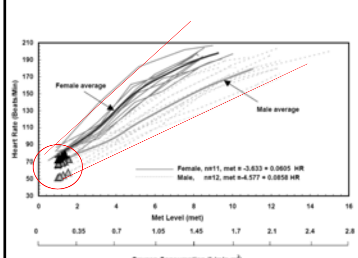


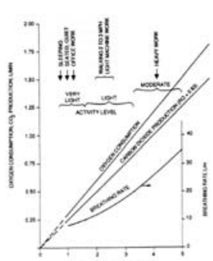
Different colors refer to different athletes

3. Physiological Signals to be Monitored

Sensing State / Condition	Measured Variable Physiological Bio-signal(s)	Model	Factors	References
Thermal sensation	• Skin temperature: local, mean	Questionnaires Statistical regression	BMI Age Gender	(Yao et al. 2007, Zhang et al. 2010, Choi et al. 2012a, Sim et al 2016, Choi et al. 2017)
Thermal sensation	• Heart rate (HR)	Questionnaires Statistical regression	MET Gender BMI	(Choi et al. 2012b)
Thermal comfort (Metabolic rate)	• Heart rate (HR) • Oxygen uptake ($\dot{V}O_2$) • Carbon Dioxide (CO_2)	Metabolic rate correlation	RQ	(ASHRAE 2013)
Thermal comfort (Metabolic rate)	• Heart rate (HR) • Heart rate variability (HRV) • Basal metabolic rate (M_0)	MET correlation (Lab. protocol) MET correlation (Field calibrated)		(ISO 8996 2004) (Revel et al. 2015)
Activity (exercise)	• Heart rate (HR) • Heart Rate Variability (HRV) • Oxygen uptake ($\dot{V}O_2$)	Regression models	Exercise level, Dehydration Age, Fitness Level, Altitude	(Strath et al.2000, Achten and Jeukendrup 2003)

3. Physiological Signals to be Monitored



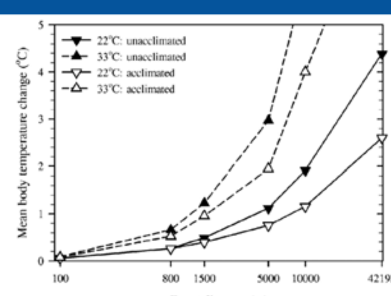


(Zhang et al. 2002) → ? *(ASHRAE 62.1-2016)*

Children? Elder?

3. Physiological Signals to be Monitored

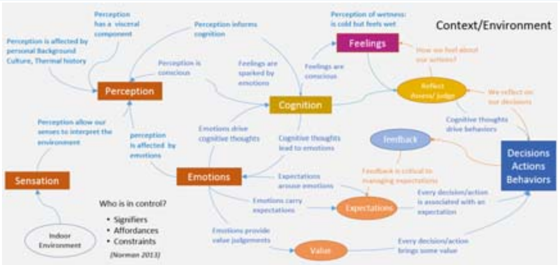
(Taylor and Cotter, 2006)



Physiological Adaptation

- Comparison of Physiologically adapted Vs. un-adapted athletes during a marathon

3. Psychological Signals to be Monitored



Emotions & Feelings
Drive our Decisions & Actions…

Questions:

- Measure Emotions & Feelings?
- Leading to Thermal Satisfaction?

3. Psychological Signals to be Monitored

"Psychological drivers might help explain inter-individual differences where different individuals experiences the same thermal environment differently according to their specific cognitive or emotional state. They might also foster our general understanding of thermal comfort, such as that in certain settings comfort might be experiences differently by the majority of people because of certain psychological state they are in (e.g. being very focused on a task as opposed to being at leisure)."

(Shipworth et al. 2016)

"Participants who were feeling positive about themselves after having received manipulated feedback about their carbon footprint judged the temperature in a climate-controlled room to be higher than those who did not have a positive feeling induced. Hence, depending on how we feel, we might judge the same thermal conditions rather differently."

(Taufik et al. 2015)

3. Psychological Signals to be Monitored

Perceived & Exercised Control:

- *Perceiving control over aspects of the local thermal environment can increase satisfaction with a wider range of temperatures.*
  (Paciuk 1990, Brager et al. 1998)
- *Allowing occupants to create a micro-climate is associated with greater worker productivity and significant energy savings.*
  (Zhang et al. 2015)
- *"The objective of current comfort standard is to ensure that only a minority of occupants are dissatisfied. However, in the context of dwelling for people with dementia it is important that thermal environments achieve much higher comfort levels since occupants may not request help or express adequate response in case of discomfort."*
  (Kinnane et al. 2016)

3. Psychological Signals to be Monitored

Perceived & Exercised Control:

"Autonomy for people with dementia to "take initiative and make choices for their lives and care" is a key issue for Lawton (2010), and for Calkin (2001), who describes "Personal Control" as a central component to person-centred therapeutic design. In contrast, highly controlled environments, with an emphasis on health and safety, have be shown to have a negative impact of the quality of life of older people (Torrington, 2007). In this regard Innes (2011) refers to research (Chalfont, 2007)(Chalfont and Rodiek, 2005) which proposes "..a move away from design intended for control, surveillance or to diminish behavioural difficulties to considering how environments can encourage curiosity and engagement in everyday activities." (Innes et al., 2011)p.548). With this approach in mind the provision of greater individual control over the thermal environment for people with dementia may not only allow them adapt their thermal environment to their specific needs, but also provide a level of control that reinforces autonomy, personal control and engagement with everyday activities."

(Kinnane et al. 2016)

3. Psychological Signals to be Monitored

Dementia & Design for Assisted Living:

- People experience dementia in very different ways, common symptoms include high levels of anxiety and stress, and increased sensitivity to the social and built environment.
  (Marshall 1998)
  *… **Context-aware device**: adjust hearing volume depending on the type of noise (sound masking)*
- Problem behaviors may be exacerbated by inappropriate environments.
  (van Hoof 2010)
- People with dementia are typically older, and therefore may also have to deal with age related impairments, such as mobility, visual, and hearing difficulties.
  (Marshall 2009)

3. Psychological Signals to be Monitored

Exploring Physiological, Behavioral, and Psychological Reactions to Thermal Stimuli:

"…results show that the restriction to keep the window closed is counterbalanced by an increased amount of physiological reactions, such as an increased level of skin temperature…"

(Schweiker, M., Brasche, S., Bischof, W., Hawighorst, M., & Wagner, A. 2013)

3. Psychological Signals to be Monitored

Quantifying Mental Stress:

Measured Variable Body Signals	Model	Factors	References
Physiological: • Heart rate (ECG) • Electrical activity of muscles (EMG) • Electrical conductance of the skin (skin conductance) • Respiration	Questionnaires Correlations	Driving conditions Experimental	(Healey et al. 2004)
Physiological: • Electrical conductance of the skin (skin conductance) Behavioral: • Body movements (accelerometer)	Questionnaires Correlations	Experimental Phone usage Alertness Sleep quality	(Sano and Picard 2013)
Physiological: • Skin temperature • Electrical conductance of the skin (skin conductance) • Pulse wave frequency (BPM)	Experimental correlation & validation	Wearable stress monitoring patch	(Yoon et al. 2016)

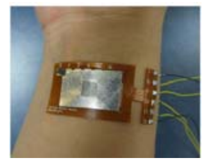
Traditional in Medical field: Psychological questionnaires
Physiological measures: saliva samples (cortisol), blood pressure

3. Psychological Signals to be Monitored

Monitoring Mental Stress:

A Flexible and wearable Human Stress Monitoring Patch:

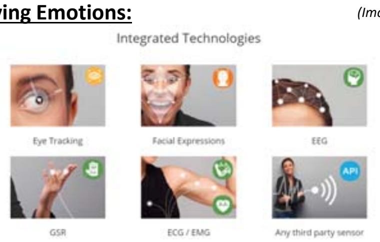
(Yoon, S., Sim, J. K., & Cho, Y.-H. 2016)



3. Psychological Signals to be Monitored

Quantifying Emotions:

(Imotions 2017)

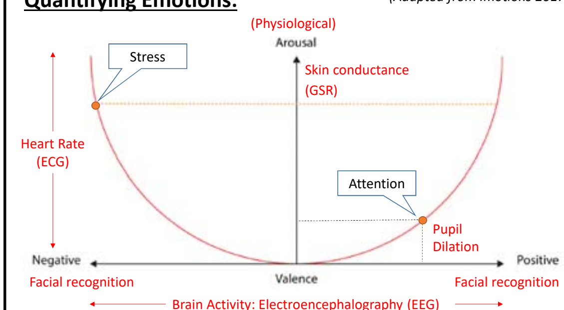


Whenever sweat glands are triggered and become more active, they secrete moisture through pores towards the skin surface. By changing the balance of positive and negative ions in the secreted fluid, electrical current flows more readily, resulting in measurable changes in skin conductance (increased skin conductance = decreased skin resistance).
This change in skin conductance is generally termed ***Galvanic Skin Response (GSR)***.

3. Psychological Signals to be Monitored

Quantifying Emotions:

(Adapted from Imotions 2017)



4. Sensing & Monitoring Technologies

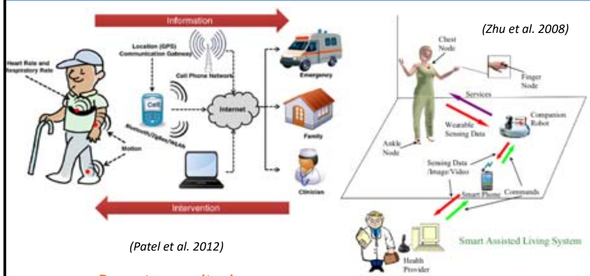
Goal: Condition/State	Thermal Comfort · Activity · Mental stress · Anxiety · Arousal · Fatigue…
Scope/Context	Personal: Single/Multimodal · Ambient/Fixed · Hybrid
Bio-signals	Skin temperature · Heart rate · Oxygen uptake · Carbon dioxide · Skin conductance…
Location	External · Wearable · Implantable · Ingestible
Functionality	Unsupervised · Supervised · Semi-supervised
	Passive · Active · Smart (context aware)
	Real-time · Off-line
Advanced	Pervasiveness · Remote monitoring · Data processing & analysis

4. Sensing & Monitoring Technologies

Type of bio-signal	Type of sensor	Notes
Skin temperature	• Thermistor • Infrared imaging • iButton (data logger)	A measure of the body's ability to dissipate heat
Heart rate (HR) & Heart Rate Variability (HRV)	• PPG (Photoplethysmography)	Frequency of the cardiac cycle in beats per minute (BPM), i.e. pulse rate
Heart: electrical activity	• Electrocardiogram (ECG) Skin/Chest electrodes	Continuous waveform showing the contraction & relaxation phases of the cardiac cycles
Perspiration (sweating) or skin conductance	• Galvanic skin response (GSR)	Electrical conductance of the skin associated with activity of sweat glands
Respiration rate	• Piezoelectric / piezoresistive sensor	Number of movements indicative of inspiration & expiration
Oxygen level in blood	• Pulse oximeter	Peripheral oxygen saturation
Muscles: electrical activity	• Electromyogram (EMG) skin electrodes	Electrical activity of the muscles
Body movements (inertial)	• Accelerometer, gyroscope	Acceleration forces in 3D space
Electroencephalogram (EEG)	• Scalp-placed electrodes	Electrical spontaneous brain activity

4. Sensing & Monitoring Technologies

(Zhu et al. 2008)



(Patel et al. 2012)

Remote monitoring

Applications Undergoing Assessment in Health Care

4. Sensing & Monitoring Technologies

Ambient Sensing

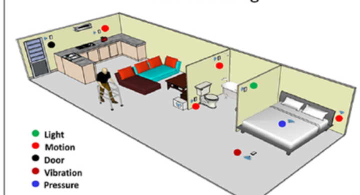


Figure 5 Ambient sensors can unobtrusively monitor individuals in the home environment. Ambient sensors can monitor activity patterns, sleep quality, bathroom visits etc. and provide alerts to caregivers when abnormal patterns are observed. Such sensors are expected to make the home of the future smarter and safer for patients living with chronic conditions.

Building blocks:
1. Sensing & data collection
2. Communication
3. Data analysis

Enabling technologies:
- Microelectronics (MEMS)
- Flexible materials
- E-textiles, garments
- Integrate multiple sensors
- Wireless
- Cloud-based
- Low-power
- Integrated GPS
- Data mining, AI

Smart Home research projects

(Patel et al. 2012)

4. Sensing & Monitoring Technologies

Detecting & Measuring Occupancy:

T. Labeodan et al. / Energy and Buildings 93 (2015) 303–314

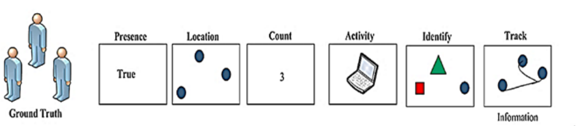


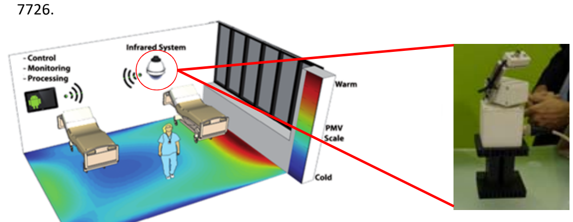
Fig. 1. Spatial–temporal properties of occupancy measurement.

- Identify people in a room & adjust the thermal environment for those people…
- How long does a person stay in a particular type of environment?
- Where exactly is that person in the room?

Comfort Eye Technology

Revel, G. M., Arnesano, M., & Pietroni, F. (2015)
www.univpm.it

The Comfort Eye is a low-cost, IR based comfort sensor for the monitoring of thermal comfort in multiple position of the space according to ISO7730 and ISO 7726.



Better comfort monitoring with the possibility to measure maps of radiant temperatures which affect strongly thermal comfort, especially in case of strong warming of building envelope

Comfort Eye Technology

Revel, G. M., Arnesano, M., & Pietroni, F. (2015)
www.univpm.it

The new version of the Comfort Eye is under development and optimization

Completely re-designed for:
- Easier installation
- Higher modularity
- Short and long period monitoring
- Cloud data storage
- Higher data accessibility

The new IR scanning system provides higher IR resolution and communicates wirelessly with devices. It can be mounted on tripod for short-term monitoring, on the ceiling for long-term or permanent monitoring

Communication module is interchangeable supporting different standards (WiFi, BLE, Zigbee, LoRa)

In addition to thermal comfort, Indoor Air Quality can be monitored with embedded sensor for CO2 and TVOC measurement.

Integration with wearable devices for real time metabolic rate measurement.

Health Care & Elder Care

Revel, G. M., Arnesano, M., & Pietroni, F. (2015)
www.univpm.it

Integration with healthcare and elder care services through **heart rate** monitoring devices

$PMV = f(t_a, RH, v_a, t_r, \mathbf{M}, I_{cl})$

HR_0 = HR at rest

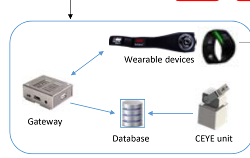
RM = increase in the heart rate per unit of metabolic rate

M_0 = metabolic rate at rest

Continuous measurement

$$HR = HR_0 + RM(M - M_0)$$

Inputs



1. HR
2. BR
3. Acceleration
4. Activity
5. Posture

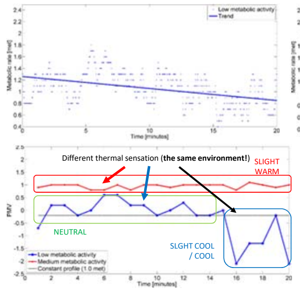
To improve the measurement accuracy with a new equation, the minimum set of parameters to be used is 3

Pietroni, F., Casaccia S., Revel GM., Scalise L. (2016)

Health Care & Elder Care

Revel, G. M., Arnesano, M., & Pietroni, F. (2015)
www.univpm.it

Integration with healthcare and elder care services through **heart rate** monitoring devices



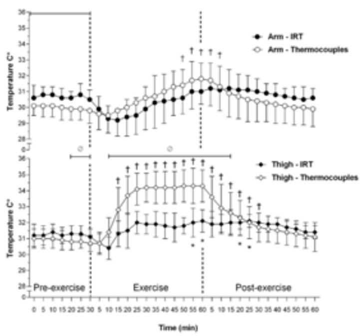
Example of real time measurement of the metabolic rate & application to thermal comfort monitoring

5. Issues & Requirements

1. **Sensor Placement & Contact Force**
   - Specific location
   - Spatial Distribution
   - Placement/Positioning
2. **Accuracy**
   - Range of applicability
   - Affected by movement
   - Affected by sweating
3. **Number of sensors**
   - Single
   - Multimodal
4. **Persistence**
5. **Ergonomics**
   - Unobtrusive/ Noninvasive
   - Wireless
6. **Sepsis**
7. **Secondary effects**
   - Skin irritability
   - EM radiation emission
   - Heat generation
8. **Reliability**
   - Battery/Power
   - Communication
   - Logging/Sampling Interval

5. Issues & Requirements

Accuracy:



(de Andrade Fernandes et al. 2014)

Conclusions

- Make Health Care Environments Acceptable for more People > 80%
- Lack of Quantitative Thermal Comfort Data from Health Care
- Recognize Occupancy Diversity in Health Care
- Physiological Sensing: Opportunity to Acquire Data → Comfort
- Help Understand Individual Comfort Needs ↔ Indoor Environments
- Need Quality-Controlled Physiological Signals/Data
- Transform Signals into Thermal Comfort Requirements & Models
- Challenges: Psychology & Health Condition
- Next: Test & Use Sensing Technologies in Field & Lab
- Goal: Improved Designs & Responsive Indoor Climate Technologies

Bibliography

Achten, J., & Jeukendrup, A. E. 2003. Heart Rate Monitoring. Sports Medicine, 33(7), 517–538. https://doi.org/10.2165/00007256-200333070-00004

ASHRAE. 2013a. ANSI/ASHRAE Standard 55-2013, Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating, Refrigerating and Air-conditioning Eng., Inc.

ASHRAE. 2013b. ASHRAE Handbook of Fundamentals, Chapter 9: Thermal Comfort, American Society of Heating, Refrigerating and Air-conditioning Eng., Inc.

ASHRAE. 2016. ANSI/ASHRAE Standard 62.1-2016. Ventilation for Acceptable Indoor Air Quality. Atlanta: American Society of Heating, Refrigerating and Air-conditioning Eng., Inc.

Brager, G. S., & de Dear, R. J. (1998). Thermal adaptation in the built environment: a literature review. Energy and Buildings, 27(1), 83–96. https://doi.org/10.1016/S0378-7788(97)00053-4

Cain W. 2002. The construct of comfort: a framework for research. Proceedings: Indoor Air 2002. Monterrey, California, June 30-July 5, 12-20.

Carlucci, S., & Pagliano, L. 2012. A review of indices for the long-term evaluation of the general thermal comfort conditions in buildings. Energy and Buildings, 53, 194–205. https://doi.org/10.1016/j.enbuild.2012.06.015

Choi, J.-H., & Loftness, V. 2012a. Investigation of human body skin temperatures as a bio-signal to indicate overall thermal sensations. Building and Environment, 58, 258–269. https://doi.org/10.1016/j.buildenv.2012.07.003

Choi, J.-H., Loftness, V., & Lee, D.-W. 2012b. Investigation of the possibility of the use of heart rate as a human factor for thermal sensation models. Building and Environment, 50, 165–175. https://doi.org/10.1016/j.buildenv.2011.10.009

Choi, J.-H., & Yeom, D. 2017. Study of data-driven thermal sensation prediction model as a function of local body skin temperatures in a built environment. Building and Environment, 121, 130–147. https://doi.org/10.1016/j.buildenv.2017.05.004

De Dear, R. J., Akimoto, T., Arens, E. A., Brager, G., Candido, C., Cheong, K. W. D., … Zhu, Y. 2013. Progress in thermal comfort research over the last twenty years. Indoor Air, 23(6), 442–461. https://doi.org/10.1111/ina.12046

Fanger, P.O. 1970. Thermal Comfort: Analysis and Applications in Environmental Engineering, pp. 244. Copenhagen: Danish Technical Press.

Bibliography

Fernandes, A. de A., Amorim, P. R. dos S., Brito, C. J., de Moura, A. G., Moreira, D. G., Costa, C. M. A., … Marins, J. C. B. (2014). Measuring skin temperature before, during and after exercise: a comparison of thermocouples and infrared thermography. Physiological Measurement, 35(2), 189–203. https://doi.org/10.1088/0967-3334/35/2/189

Filingeri, D., Fournet, D., Hodder, S., & Havenith, G. (2014). Body mapping of cutaneous wetness perception across the human torso during thermo-neutral and warm environmental exposures. Journal of Applied Physiology, 117(8), 887–897. https://doi.org/10.1152/japplphysiol.00535.2014

Gupta R., Barnfield L., Gregg M. 2016. Assessing overheating risk and preparedness in care facilities in the UK. Proceedings of 9th Windsor Conference: Making Comfort Relevant Cumberland Lodge, Windsor, UK, 7-10 April 2016. Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Healey, J. A., & Picard, R. W. (2005). Detecting Stress During Real-World Driving Tasks Using Physiological Sensors. IEEE Transactions on Intelligent Transportation Systems, 6(2), 156–166. https://doi.org/10.1109/TITS.2005.848368

Imotions. 2017. iMotions: Human Behavior Research Software, Simplified.. Retrieved June 19, 2017, from https://imotions.com/?gclid=CNXn4JiWy9QCFQyifgodM7YP1A

ISO 8996. 2004. Ergonomics of the thermal environment — Determination of metabolic rate. Retrieved June 19, 2017, from https://www.iso.org/obp/ui/#iso:std:iso:8996:ed-2:v1:en

Kinnane O., Grey T., and Dyer M. 2016. Thermal environments and comfort in dementia friendly dwellings. Proceedings of 9th Windsor Conference: Making Comfort Relevant Cumberland Lodge, Windsor, UK, 7-10 April 2016. Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Labeodan, T., Zeiler, W., Boxem, G., & Zhao, Y. (2015). Occupancy measurement in commercial office buildings for demand-driven control applications?A survey and detection system evaluation. Energy and Buildings, 93, 303–314. https://doi.org/10.1016/j.enbuild.2015.02.028

Lichtenbelt W., Hanssen M., Pallubinsky H., Kingma B., Shellen L. 2016. Healthy excursions outside the comfort zone. Proceedings of 9th Windsor Conference: Making Comfort Relevant Cumberland Lodge, Windsor, UK, 7-10 April 2016. Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Marshall M. 1998. Therapeutic buildings for people with dementia. In: Judd S., Phippen, P., and Marshall M. (eds.) Design for dementia. London: Journal of Dementia Care.

Bibliography

Marshall M. 2009. The needs of people with dementia and their carers and the potential role of design and technology. Dementia, Design and Technology, vol. 24. IOS press books.

Mora R., Meteyer M. 2017. Designing Acceptable Thermal Comfort in Healthcare Settings: Practical Challenges and Research Needs. Article in preparation.

National Geographic. 2014. Degrees of Separation. National Geographic Magazine. May 2014.

NBC 4 New York. 2015. New York City Cracks Down on Retailers That Leave Doors Open When Air Conditioning Is On, Internet website: http://www.nbcnewyork.com/news/local/Air-Conditioning-Waste-Retail-New-York-Manhattan-Business-Consumer-Affairs-Investigation-318189311.html last accessed: June 15, 2017.

Olesen, B. W. (1982). Thermal Comfort. Technical Review - Bruel & Kjaer, 2(2), 47. Retrieved from http://www.bksv.co.uk/doc/TechnicalReview1982-2.pdf

Ouzzahra Y., Redortier B., and Havenith G. 2012. Regional distribution of thermal sensitivity to cold at rest and during mild exercise in males. Journal of Thermal Biology, 37(7).

M. Paciuk, “The Role of Personal Control of the Environment in Thermal Comfort and Satisfaction at the Workplace,” Doctoral Dissertation, University of Wisconsin, Milwaukee, 1989.

Parsons, K. C. 2002. Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance.

Patel, S., Park, H., Bonato, P., Chan, L., Rodgers, M., Bonato, P., … McSorley, K. (2012). A review of wearable sensors and systems with application in rehabilitation. Journal of NeuroEngineering and Rehabilitation, 9(1), 21. https://doi.org/10.1186/1743-0003-9-21

Pietroni F., Casaccia S., Revel G., Scalise L. 2016. Methodologies for continuous activity classification of user through wearable devices: Feasibility and preliminary investigation. SAS 2016. Sensors Applications Symposium, Proceedings, art.no. 7479867, pp. 326-331.

Revel, G. M., Arnesano, M., & Pietroni, F. 2015. Integration of Real-Time Metabolic Rate Measurement in a Low-Cost Tool for the Thermal Comfort Monitoring in AAL Environments (pp. 101–110). Springer International Publishing. https://doi.org/10.1007/978-3-319-18374-9_10

Ring, E. F. J., & Ammer, K. 2012. Infrared thermal imaging in medicine. Physiological Measurement, 33(3), R33–R46. https://doi.org/10.1088/0967-3334/33/3/R33

Bibliography

Rupp, R. F., Vásquez, N. G., & Lamberts, R. 2015. A review of human thermal comfort in the built environment. Energy and Buildings, 105, 178–205. https://doi.org/10.1016/j.enbuild.2015.07.047

Sano, A., & Picard, R. W. (2013). Stress Recognition Using Wearable Sensors and Mobile Phones. In 2013 Humaine Association Conference on Affective Computing and Intelligent Interaction (pp. 671–676). IEEE. https://doi.org/10.1109/ACII.2013.117

Schweiker, M., Brasche, S., Bischof, W., Hawighorst, M., & Wagner, A. (2013). Explaining the individual processes leading to adaptive comfort: Exploring physiological, behavioural and psychological reactions to thermal stimuli. Journal of Building Physics, 36(4), 438–463. https://doi.org/10.1177/1744259112473945

Shipworth D., Huebner G., Shweiker M., Kingma B. 2016. Diversity in Thermal Sensation: drivers of variance and methodological artefacts. Proceedings of 9th Windsor Conference: Making Comfort Relevant Cumberland Lodge, Windsor, UK, 7-10 April 2016. Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Sim, S., Koh, M., Joo, K., Noh, S., Park, S., Kim, Y., & Park, K. (2016). Estimation of Thermal Sensation Based on Wrist Skin Temperatures. Sensors, 16(4), 420. https://doi.org/10.3390/s16040420

Strath, S. J., Swartz, A. M., Bassett, D. R., O’Brien, W. L., King, G. A., & Ainsworth, B. E. (2000). Evaluation of heart rate as a method for assessing moderate intensity physical activity. Medicine and Science in Sports and Exercise, 32(9 Suppl), S465-70. https://doi.org/10.1097/00005768-200009001-00005

Tanda, G. 2015. The use of infrared thermography to detect the skin temperature response to physical activity. Journal of Physics: Conference Series, 655(1), 12062. https://doi.org/10.1088/1742-6596/655/1/012062

Taufik F., Bolderdijk JW., Steg L. 2015. Acting green elicits a literal warm glow. Nature Climate Change 5, 37–40 (2015) doi:10.1038/nclimate2449

Taylor N., and Cotter J. 2006. Heat adaptation: Guidelines for the optimisation of human performance International Journal of SportMed. 7(1):33-57 · January 2006

Van Hoof, J. 2008. Forty years of Fanger’s model of thermal comfort: comfort for all?. Indoor Air, 18: 182–201. doi:10.1111/j.1600-0668.2007.00516.x

Van Hoof, J., Kort, H.S.M., Hensen, J.L.M., Duijnstee, M.S.H., and Rutten, P.G.S. 2010. Thermal comfort and integrated design of homes for people with dementia. Building and Environment 45: 358-370.

Wenger B. 1997. Human adaptation in hot environments. US Army Research Institute of Environm. Medicine Natick, Mass. 01760-5007

Bibliography

Yoon, S., Sim, J. K., & Cho, Y.-H. (2016). A Flexible and Wearable Human Stress Monitoring Patch. Scientific Reports, 6, 23468. https://doi.org/10.1038/srep23468

Zhang, H., Arens, E., & Arens, C. 2002. Using a driving game to increase the realism of laboratory studies of automobile passenger thermal comfort. SAE Technical Paper Series. Retrieved from http://escholarship.org/uc/item/4bq4n92h

Zhang, H., Arens, E., & Zhai, Y. (2015). A review of the corrective power of personal comfort systems in non-neutral ambient environments. Building and Environment, 91, 15–41. https://doi.org/10.1016/j.buildenv.2015.03.013

Chun Zhu, Wei Sun, & Weihua Sheng. (2008). Wearable sensors based human intention recognition in smart assisted living systems. In 2008 International Conference on Information and Automation (pp. 954–959). IEEE. https://doi.org/10.1109/ICINFA.2008.4608137

QUESTIONS?

Rodrigo Mora, PhD., P.Eng.
Rodrigo_mora@bcit.ca

Mike Meteyer, PE
mmeteyer@erdman.com

Marco Arnesano, PhD.
m.arnesano@univpm.it