Measurement of Climate and Thermal Comfort

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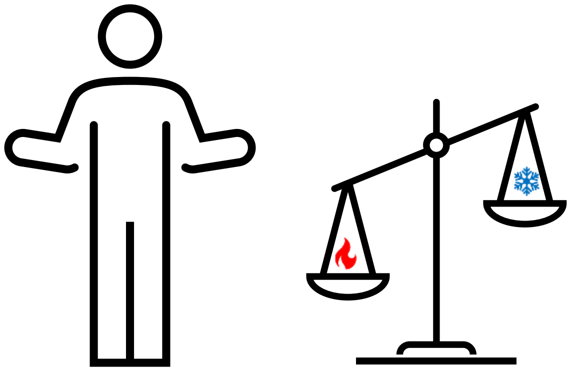

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1. Thermal comfort

“Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment & is assessed by subjective evaluation (ASHRAE 55)”

Thermal comfort parameters

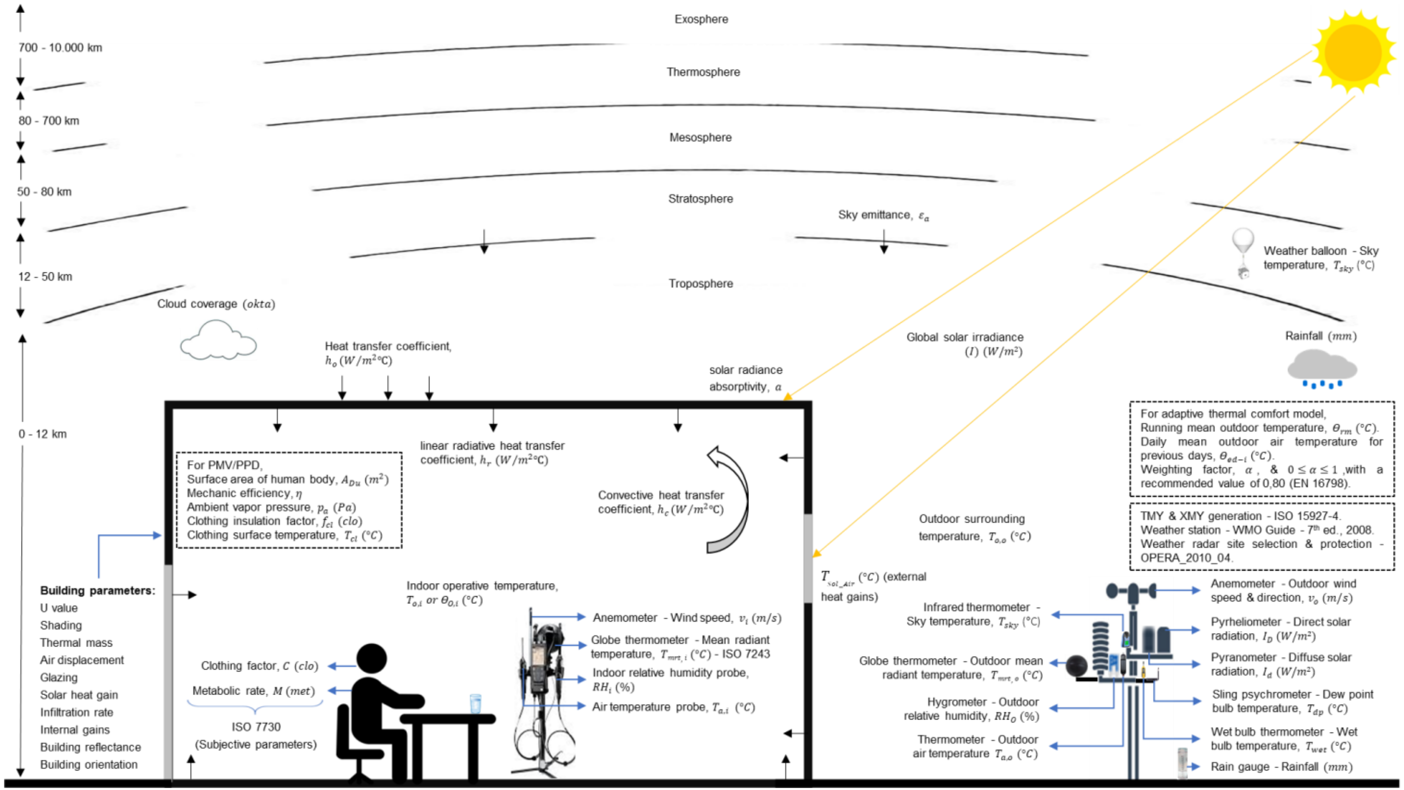


Fig. 1. Thermal comfort parameters

2. Climate Measurements

Climate Measurements

Why?

1. Increase in recent climate change due substantial attribution to human activity [1].
2. Regional climate variability, which requires detailed regional observations & measurements [2].

How?

General guidelines:

- Avoid heat sources like chimneys, heaters, exhaust vents, etc.
- At least 30 m away from any asphalt or concrete roadway.
- Avoid installations near structures that receive a lot of sun.
- Ideally, the sensor suite should be 1.5 m above the ground.
- Avoid tree canopies or buildings that create shadows. [3,4]

Fig. 2. Accelerating impacts of climate change [5].

Davis Vantage Pro2 Plus

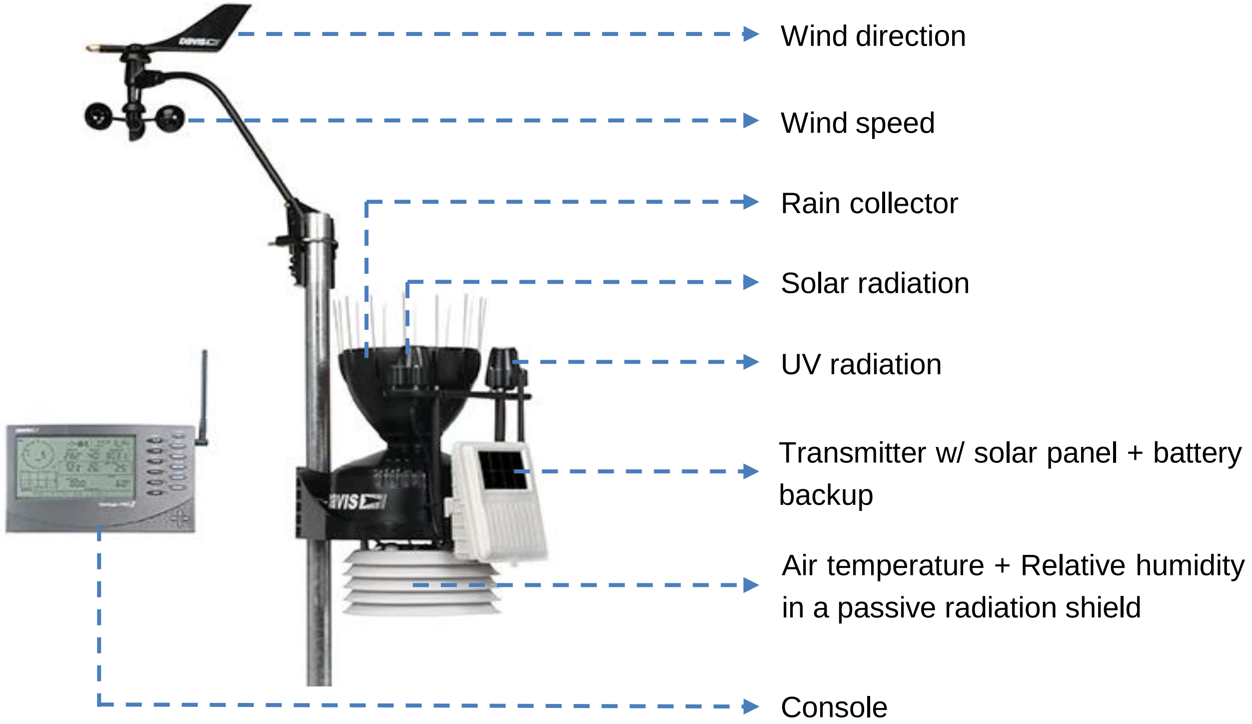


Fig. 3. Davis Vantage Pro2 Plus weather station [6].

Davis Vantage Pro 2 Plus Configuration

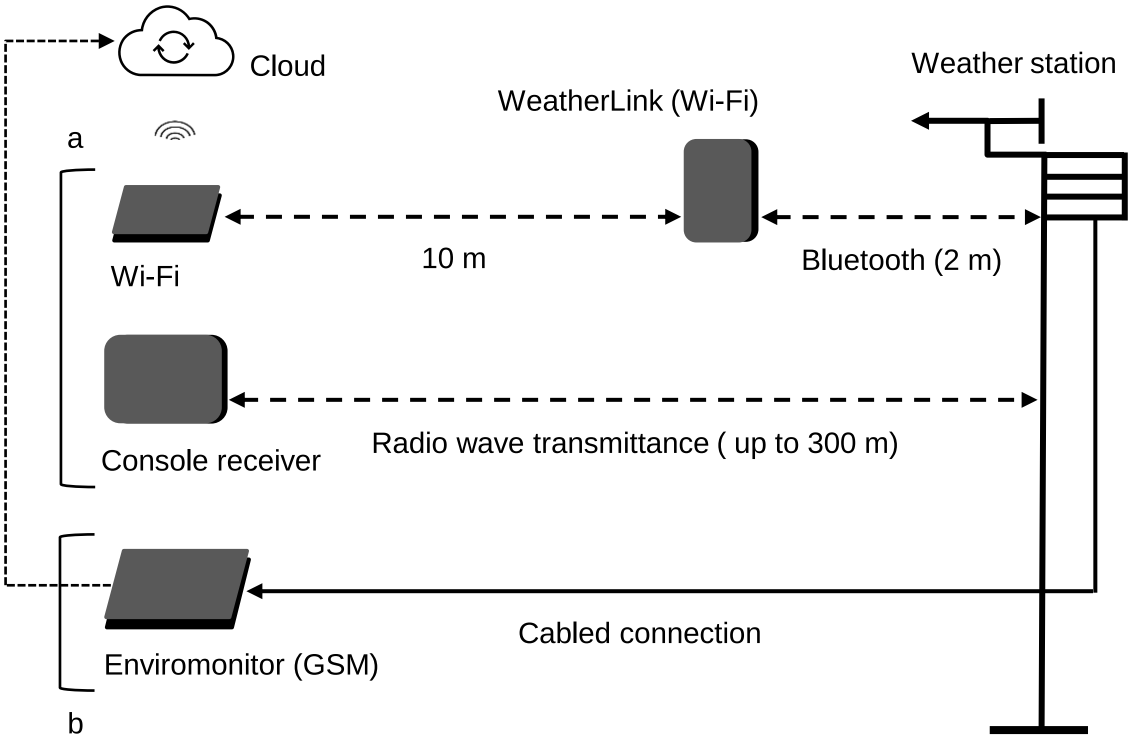


Fig. 4. Davis Vantage Pro2 Plus configuration.

Data to cloud platform transfer via:

a. Wi-Fi - WeatherLink

b. GSM - Enviromonitor

Installed on the same mounting pole as the sensor suite.

Data logging duration at 15 mins intervals:

- AC supply - 26 days
- battery - 13 days

WeatherLink Live Platform

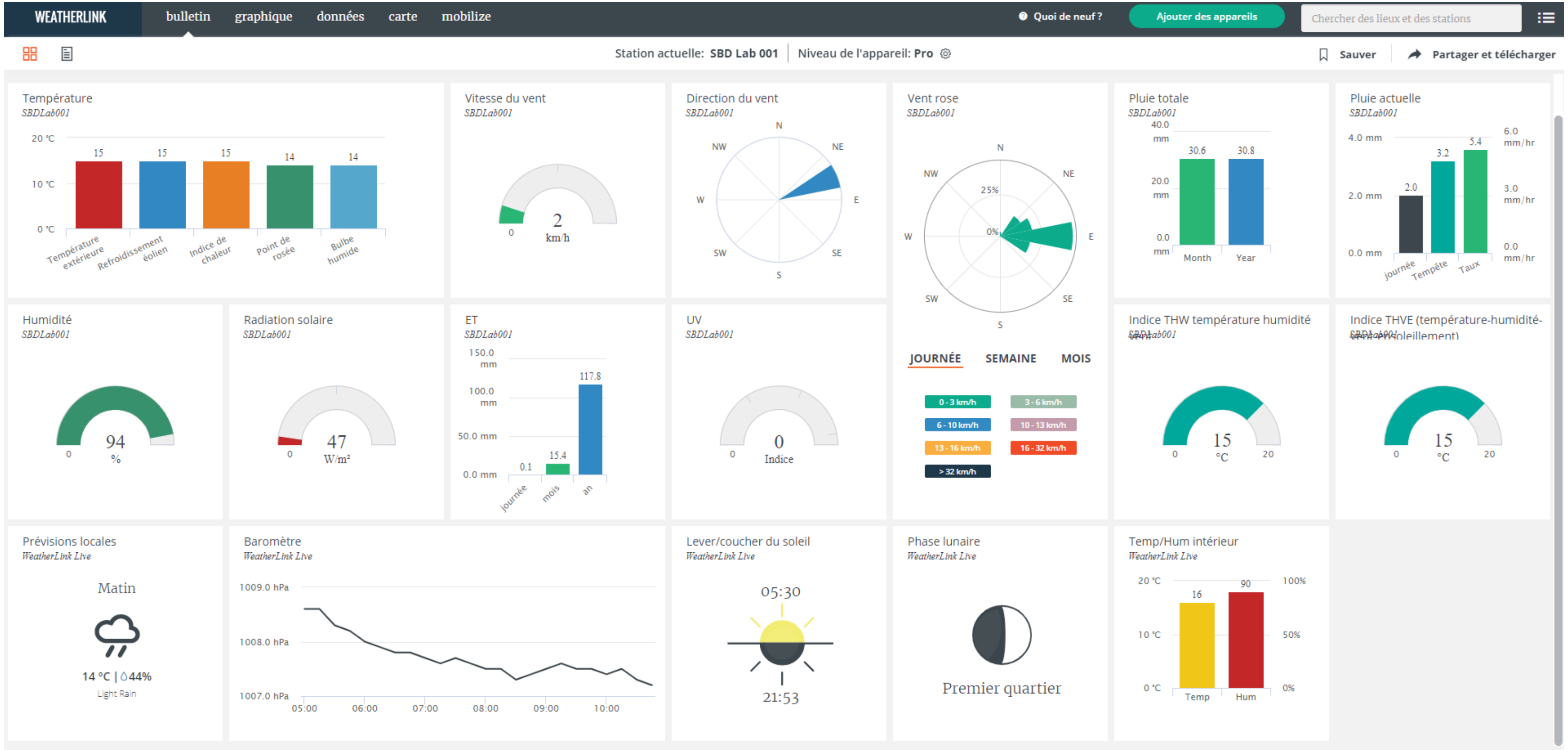


Fig. 5. Davis Vantage Pro2 Plus WeatherLink live cloud platform.

Urban Heat Island Effect

- **Urban heat island effect** occurs when cities replace the natural land cover with buildings, pavement, etc., that absorbs & retains heat.
- **Effects:** increases the energy costs, air pollution levels, & heat-related illness & mortality [7].

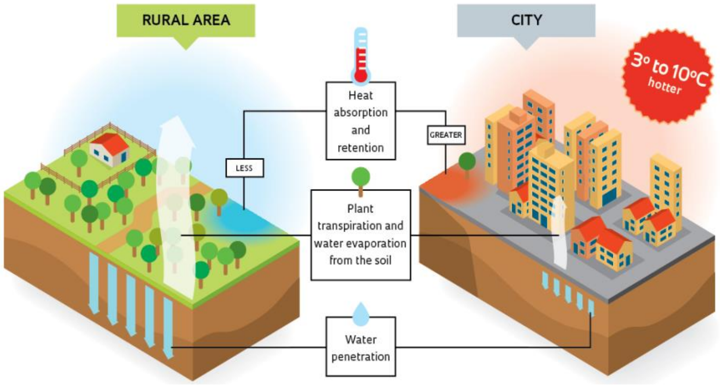


Fig. 6. Urban heat island effect [8].

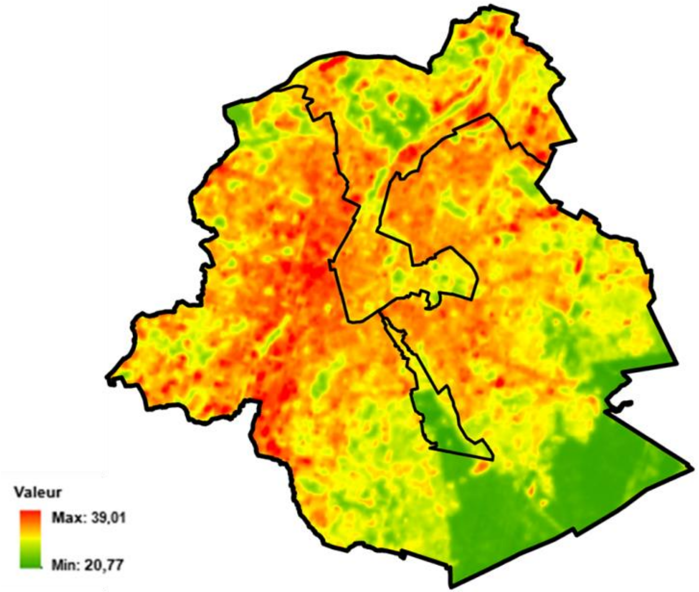


Fig. 7. Thermal map for Brussels, Belgium, during the heatwave on 02.08.18, using Landsat 8 data - Arrar, H (Project Ilots).

3. Thermal Comfort Measurements

Thermal Comfort Measurements

Why?

1. Influences the occupants' health & productivity [9].
2. The effects of thermal comfort on building energy efficiency is becoming increasingly relevant.
3. Buildings account for about 40% of the global energy consumption & contribute over 30% of the CO_2 emissions [10].

Thermal Comfort Models:

PMV/PPD model: Built on experiments involving the exposure of subjects to steady-state conditions in climatic chambers.

Limits based on operative temperature for air-conditioned buildings. [11]

Adaptive model: Built on field studies considering that access to environmental controls can influence the occupants' thermal expectations & preferences.

Limits based on an upper & a lower limit derived from running mean outdoor temperature using standards like **EN 16798**. [12]

How?

For environmental parameters: ASHRAE 55

1. Device Criteria:

- Must meet the requirements as given in ASHRAE 705 or ASHRAE 1136 or ISO 7726.

2. Measurement Positions:

- Measurements shall be made in occupied zones.
- In the center of the room or zone.
- Height above the floor varies between sedentary & standing activities & the parameter measured.

3. Measurement periods:

- The measuring period varies wrt the parameter.

For personal parameters: ISO 7730

1. Clothing & Metabolic activity:

- Estimated from ISO 7730 through surveys & observation.

Testo 400 - IAQ and Thermal Comfort

- Testo 400 - Universal IAQ instrument:
    a. **PMV/PPD & turbulence - ISO 7730 and ASHRAE 55**.
    b. HVAC grid measurement - ISO 12599 and ASHRAE 111.
- CO_2 probe with temperature and humidity sensor.
- Turbulence probe - Hot wired anemometer - **ISO 7730 and ASHRAE 55.**
- Globe thermometer - **ISO 7243, ISO 7726, DIN 27726 and DIN 33403**.

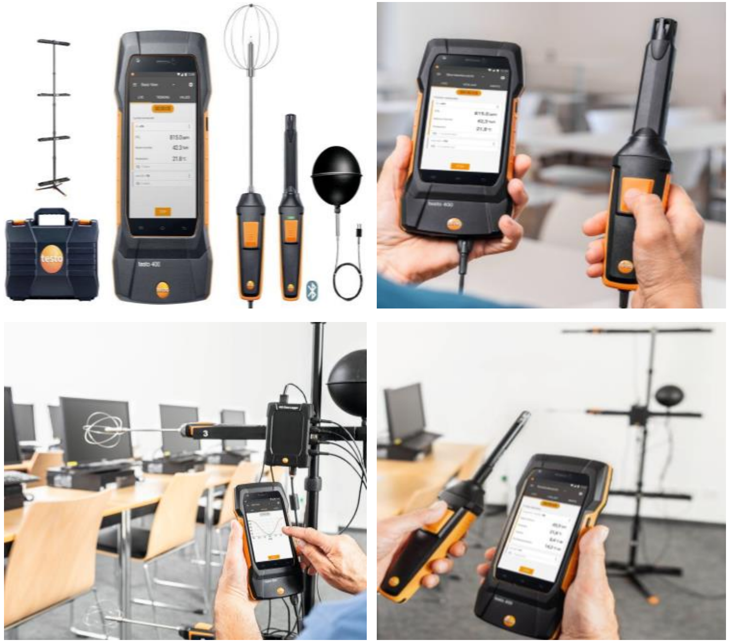


Fig. 8. Testo 400 IAQ & Comfort [4], [5].

Testo 400 - Specifications

Table 1 . Testo 400 IAQ & comfort sensor specifications.

	CO_2 probe			Turbulence probe Air velocity	Globe thermometer Mean radiant temperature
	Air temperature	Relative humidity	Ambient CO_2 levels		
Range	0 to 50 °C	5 to 95 %RH	0 to 10000 ppm	0 to 5 m/s	0 to 120 °C
Accuracy	± 0.5 °C	± 3 %RH (10 to 35 %RH) ± 2 %RH (35 to 65 %RH) ± 3 %RH (65 to 90 %RH) ± 5 %RH (Remaining Range)	± (50 ppm + 3 % mv) (0 to 5000 ppm) ± (100 ppm + 5 % mv) (5001 to 10000 ppm)	± (0.03 m/s + 4 % mv)	Class 1 (According to standard EN 60584-2, accuracy of Class 1 refers to -40 to +1000 °C - Type K)
Resolution	0.1 °C	0.1 %RH	1 ppm	0.01 m/s	

Field Measurements - Senior House Kain, Tournai

Study location: Senior house Kain, Tournai, Belgium

Coordinates: 50° 38’ 12.69” N, 3° 22’ 50.44” E

Building: Passive house certified built in 2017.

Duration: April 2022 to October 2022.

Heating/Cooling: Reversible air to water heat pump (Gas).

Measurement zone: Bedroom

Equipment used: Testo 400

Fig. 9. Frontal view - Senior house Kain, Tournai, Belgium.

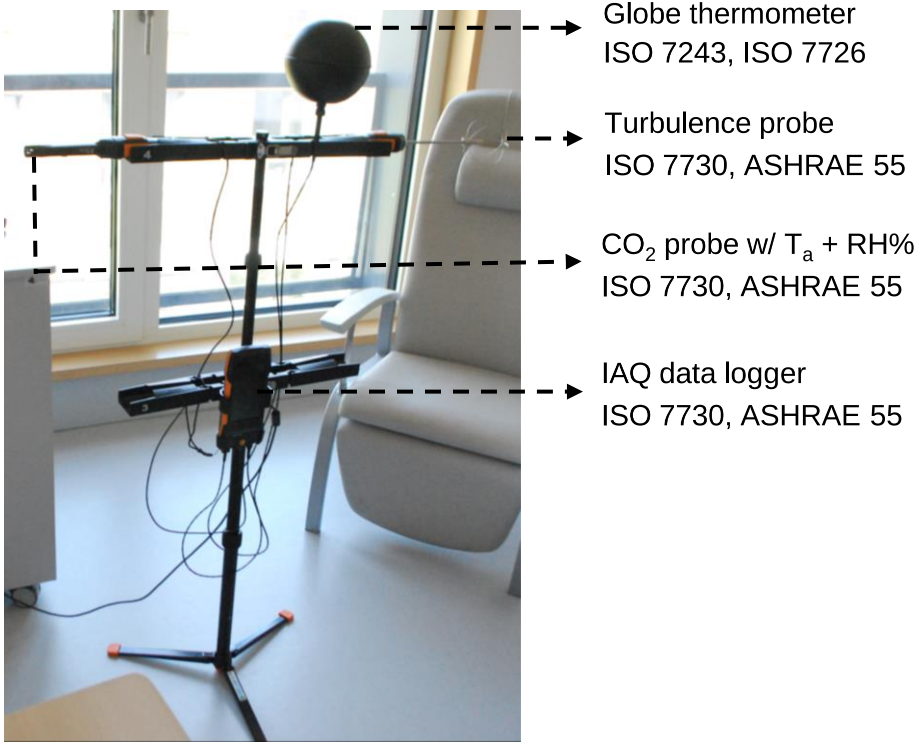


Fig. 10. Field measurements - Senior house Kain.

Indoor temperature distribution - Liege - 2020

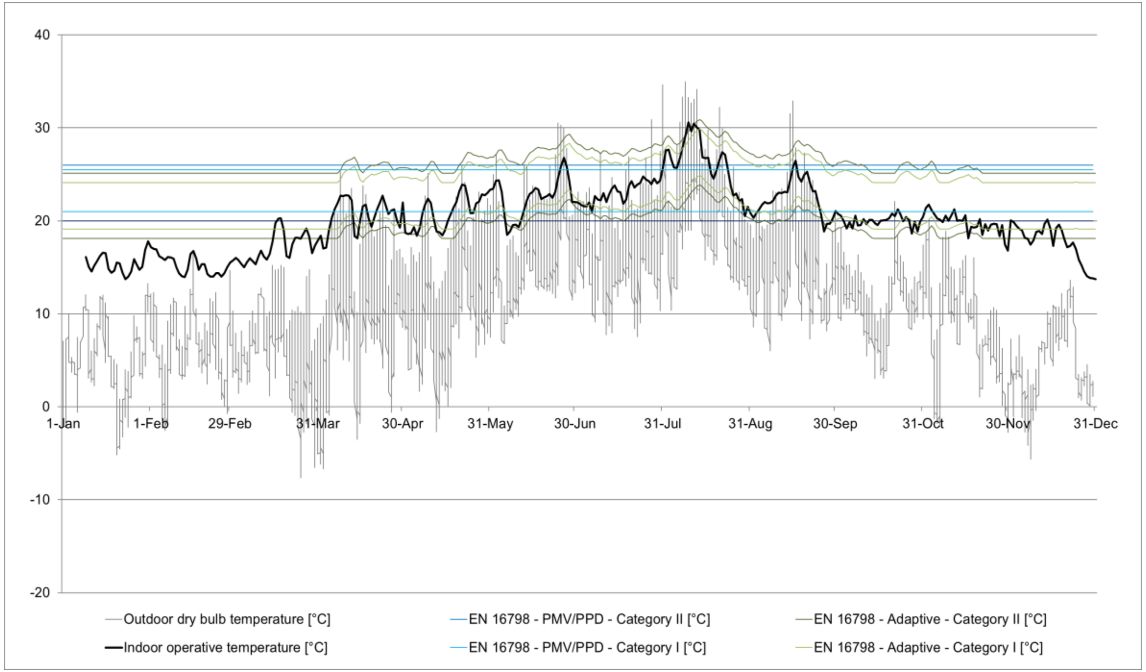


Fig. 11. Annual outdoor air temperature - MAR-ERA5 [15], Climatology Lab [16], ULiege, & observed indoor ambient temperature from Outremeuse, Liege - 2020.

Apartment: Outremeuse, Liege, Belgium

Coordinates: 50° 38' 23.57" N, 5° 35' 2.87" E

Building: Concrete w/ no insulation built in 1960s.

Heating: Gas fired heating system.

Cooling: Free running building with windows.

Measurement zone: Bedroom

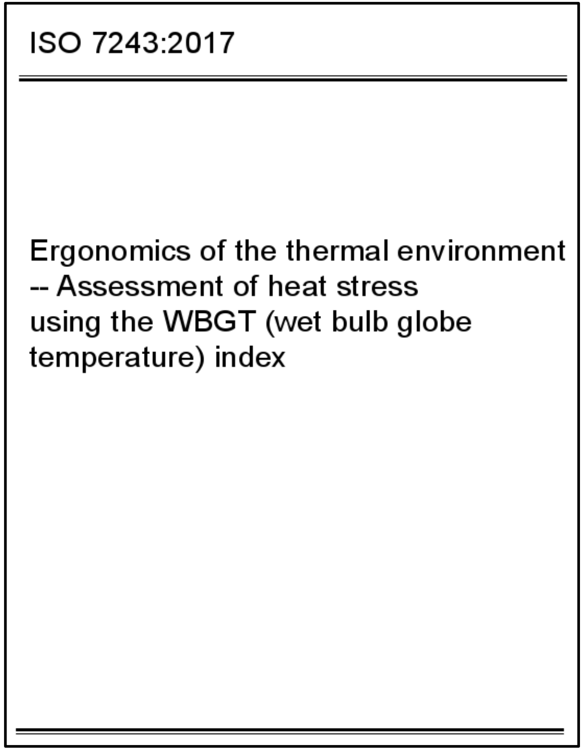
Equipment used: Wöhler CDL 210

Fig. 12. Wöhler CDL 210 data logger [17].

4. Cost-effective Thermal Comfort Monitoring Device

ISO 7243:2017 - Ergonomics of the Thermal Environment

- The globe characteristics:
  a. diameter: **150 mm**
  b. mean emission coefficient: **0.95, matte black globe**
  c. thickness: **as thin as possible, 0.4 mm**
  d. measuring range: **20 to 120 °C**
  e. accuracy of measurement:
     - for 20 to 50 °C: **± 0.5 °C.**
     - for 50 to 120 °C: **± 1 °C.**
- For globe temperature, material type will affect the time constant but not the steady-state globe temperature.
- Materials with **high thermal conductivity**, such as **copper**, will provide a lower time constant.


ISO 7243:2017

Ergonomics of the thermal environment -- Assessment of heat stress using the WBGT (wet bulb globe temperature) index

Fig. 13. ISO 7243:2017 [18].

Design and Construction

Materials required:

a. 150 mm hollow copper ball.

b. Temperature probe - DS18B20 Digital temperature sensor.

c. Plastic cable gland.

d. Data logger - emonTH.

Depending on the design:

a. Brass fitting - 2 nos.

b. Bolt that would thread into the existing brass fitting.

c. Locking nuts and bolts.

d. Plastic white tube to fit the length of the bolt.

e. Mounting bracket.

More information: www.weather-above.com/blackball%20sensor.html

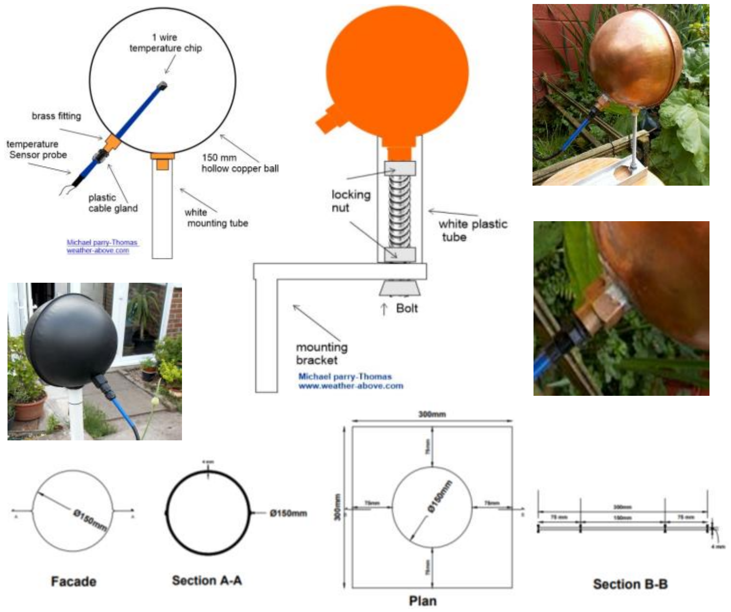


Fig. 14. Black globe sensor design [19].

emonTH Data Logger

a. Onboard **Si7021** temperature & humidity sensor:

- Range: humidity: 0 to 80 %RH, temperature: -40 to 125 °C.
- Accuracy: humidity: ± 3 %RH, temperature: ± 0.4 °C.

b. External **DS18B20** temperature sensor - for globe thermometer:

- Range: -55 to +125 °C and accuracy: ± 0.5 °C.

c. Data memory: Not available.

d. Software: Transmitted via wireless RF. emoncms for logging, processing, & graphing.

e. Microcontroller: Arduino compatible ATmega328p.

f. Expansion options: www.github.com/openenergymonitor/emonth

g. Battery life: With two AA batteries - 4 years.

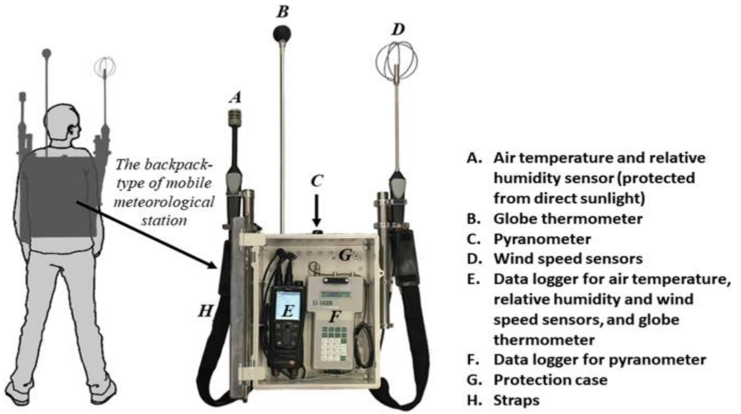


Fig. 15. A mobile weather station - a model for future development [20].

Fig. 16. emonTH data logger [21].

MaRTy Biometeorological Weather Station

Developed by Prof. Ariane Middel, ASU.

1. **Gill 2D WindSonic**:
   - Range: wind speed: 0 to 60 m/s, accuracy: ± 2% @ 12 m/s.
2. **GPS16X Garmin GPS:** accuracy: less than 3 meters.
3. **Hukseflux 4-component Net Radiometers:**
   - Range: shortwave radiation (SW): 0 to 2 kW/m².
     longwave radiation (LW): 0 to 1 kW/m².
   - Accuracy: shortwave & longwave radiations: ± 10%.
4. **HC2S3 Rotronic HygroClip2 T/RH Probe:**
   - Range: humidity: 0 to 100 %RH, temperature: -50 to 100 °C.
   - Accuracy: humidity: ± 0.8 %RH, temperature: ± 0.1 °C.
5. **Omega type T Thermocouple:**
   - Range: -250 to 350°C; accuracy: ± 0.5 °C.
6. **CR3000 Micrologger:** data acquisition unit.

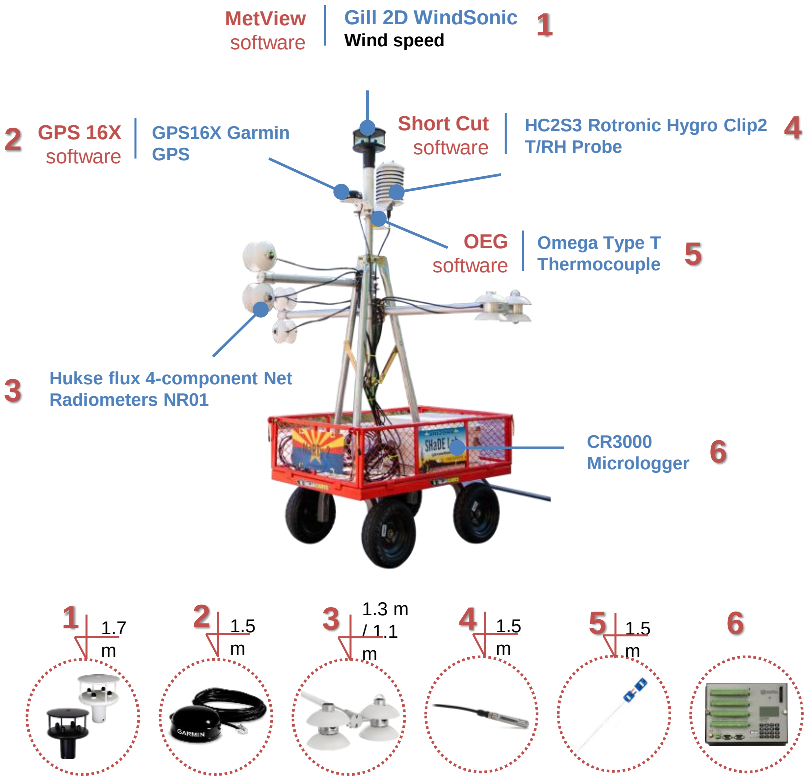


Fig. 17. MaRTy biometeorological weather station - ASU [22].

Discussions & Conclusions

1. Measuring weather helps to identify which regions are most likely to be affected by extreme weather.
2. Considering urban heat island effect, the measurements will help to map out the most vulnerable areas within a city and create contingency plans to withstand future catastrophic events.
3. The failure of existing buildings to achieve thermal comfort during the summer months indicates the importance of the implementation of sustainable cooling solutions.
4. The higher limits of adaptive models according to EN 16798 indicate the need to develop the standard further, keeping in mind the current climate change impacts.
5. Development of a cost-effective thermal comfort monitoring system will facilitate a multizonal thermal comfort analysis involving different occupied zones in the building.
6. The multizonal data can be then used calculate time-integrated building overheating indicators.
7. Existing autonomous weather stations like MaRTy, provides a great foundation for future autonomous and mobile thermal comfort system developments.

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We look forward to your feedback!!!

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