Title:

Real-time Multi-Factor Thermal Comfort Assessment

Authors:

Georgia Tzitziou, Christos Tzouvaras, Asimina Dimara, Alexios Papaioannou, Stelios Krinidis, Konstantinos Arvanitis, Christos-Nikolaos Anagnostopoulos, Dimosthenis Ioannidis, and Dimitrios Tzovaras

Abstract:

The predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) are commonly used metrics for thermal comfort estimation, nevertheless estimating clothing insulation and the metabolic rate remains a challenge. The main objective is to mitigate the error in estimating personal factors by taking into account as many factors as possible, such as indoor and outdoor conditions. To address this issue, an algorithm that combines existing approaches to enhance precision is proposed. Experimental results demonstrate that thesuggested method is more accurate than other approaches. The proposed approach has significant implications for designing and evaluating heating, ventilation, and air conditioning systems, buildings, and indoor spaces.

Fact:

People's connection to their homes is intimately tied to the quality of their thermal comfort. Thermal comfort factors influence indoor temperature and they overall comfort from design to renovation[1].

Definition:

Thermal comfort is defined as satisfaction with one's thermal environment according to ISO standard 7730 [2]

Considerable facts:

- Indoor temperature tends to stay more constant than outdoor temperature and therefore closer to the average seasonal temperature, for reasons such as insulation of the building, heating and cooling systems, and solar radiation.
- As the PMV value is closer to 0 there is a better thermal sensation, and it is expected that in the summer season, it tends to go higher, whereas, in the winter season, it is lower.

Challenges:

- Input variables such as mean radiant temperature, average air speed, and relative humidity are easily measured through sensor installation
-no standard real-time methods to calculate metabolic rate and clothing insulation values for building occupants
-Big variation depending on factors like gender, age, cold and heat tolerance, and temperature [7]
-The complexity of human behavior, absence of established standards pose challenges for building occupant research [8]

Thermal Comfort Inference

Importance of thermal comfort estimation

1 direct impact on the health, productivity, and overall well-being of occupants

2 significant effect on energy efficiency and sustainability in buildings

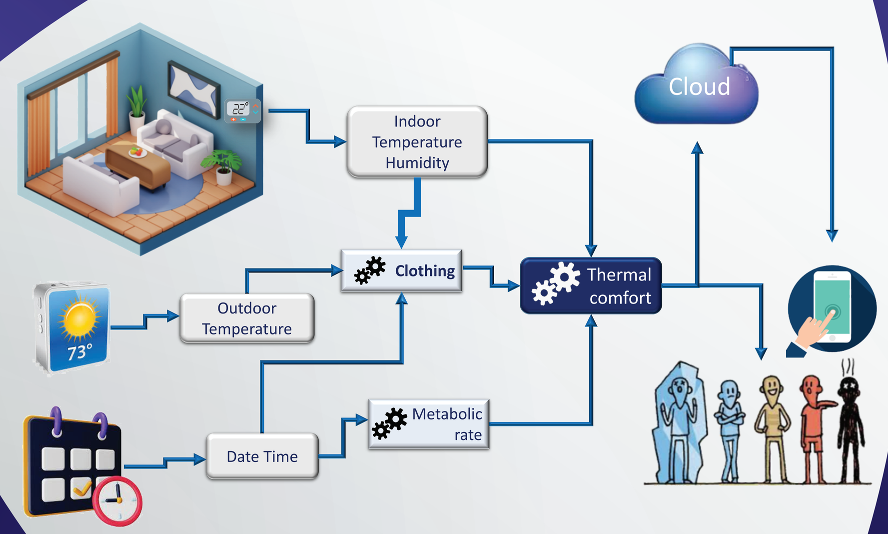
3 determination of the overall quality of life

FANGER'S PMV MODEL

Accounts for multiple factors affecting thermal comfort

Is widely accepted under the International ISO 7730 standard [2]

Reliably estimates human thermal comfort in diverse situations



Metabolic Rate

low-level activities are more feasible in a household setting(i.e.1.2 met), while more strenuous activities such as cleaning the house are not so frequent [10]

during the night, the activity may be set to sleep (i.e. 0.7 met)

Clothing insulation

CONTRIBUTING FACTORS

- INDOOR TEMPERATURE: non-linear regression relationship between clothing insulation and indoor temperatures based on feedback observation
- INFLUENCE OF SEASON: During colder seasons, individuals require more insulation to keep warm, while during warmer seasons, individuals require less insulation to avoid overheating
- OUTDOOR TEMPERATURE: method was tested in real-life environments and has proven to be accurate enough
- INDIVIDUAL'S ACTIVITY LEVEL
- AIR SPEED

PMV Index

Based on ASHRAE Standard 55:

PMV ESTIMATION FACTORS

Room Environmental Conditions

Ta: Room Temperature (°C)

RH: Room Humidity(%)

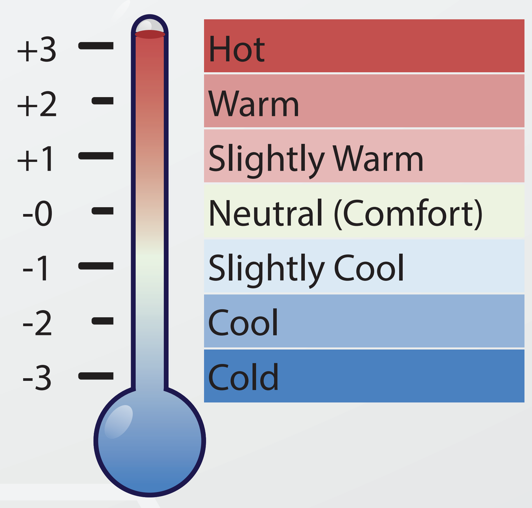
Personal Factors

M: Metabolic Rate (met)

Icl: Clothing Insulation (clo)

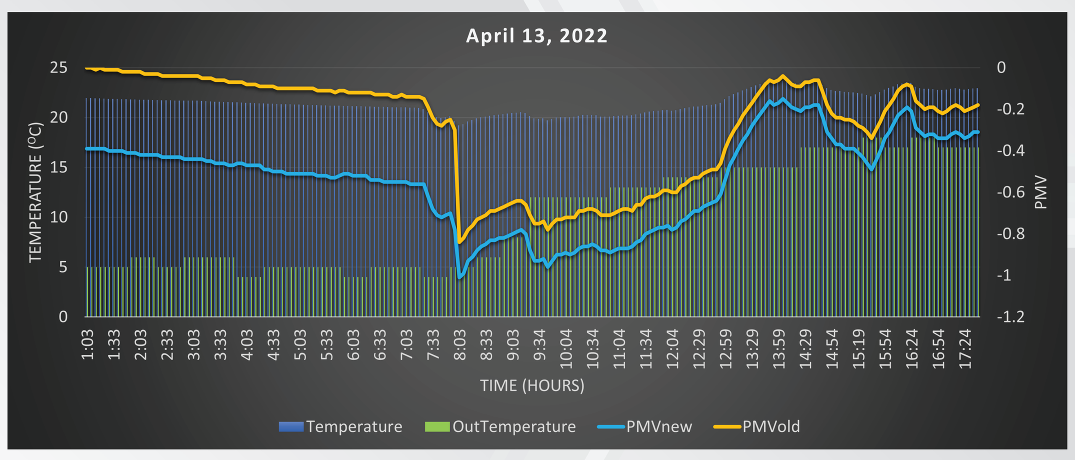
PMV=f(Ta, RH, Icl, M)

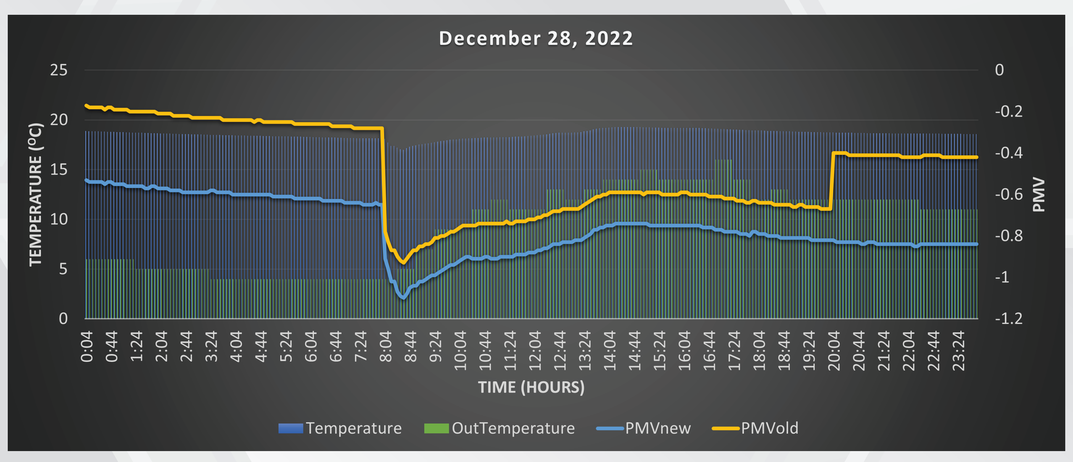
PPD=g(PMV)



Results:

Spring: the outdoor temperatures fall below average spring temperatures (e.g., average bellow 12 oC). As a result, the line of the PMV value calculated with the new equation is lower than the other, meaning that the resident is feeling colder.
Summer: outdoor temperatures are very close to indoor ones. So, here the fact that the PMV values calculated with the new equation are closer to 0, means that there is a better thermal sensation compared to the old one, as expected.
Fall: the line based on the old equation takes values higher than 0, which is in contrast to previous acknowledgments.
Winter: outdoor temperature values are far below the indoor ones and this leads to the conclusion that the line base on the new equation is more accurate.





Conclusions

In this paper:
- a novel approach for calculating thermal comfort was presented that combines algorithms to enhance the precision of existing approaches,
- the proposed methodology was tested in real-time environments and has proven to be accurate enough.

Conclusions based on graphs:
- when the outdoor and indoor temperatures are close, the new PMV values are more comparable to the optimum thermal sensation.
- the old method may produce a significant error in the thermal comfort calculation when the outdoor temperature is extremely higher or lower than the average seasonal outdoor temperature and consequently the indoor temperatures.

References

1. Sansaniwal, Sunil Kumar, Jyotirmay Mathur, and Sanjay Mathur. "Review of practices for human thermal comfort in buildings: present and future perspectives." International Journal of Ambient Energy 43.1 (2022): 2097-2123.
2. ISO, ISO7730. "7730: Ergonomics of the thermal environment Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria." Management 3.605 (2005): e615.
3. OpenAI. "Thermal Comfort Models." OpenAI, openai.com/thermal-comfort-models/. 2023.
4. Lourenço Niza, Iasmin, and Evandro Eduardo Broday. "Development of Thermal Comfort Models over the past years: a systematic literature Review." International Journal of Ambient Energy 43.1 (2022): 8830-8846.
5. ANSI and ASHRAE, Thermal Environmental Conditions for Human Occupancy. Atlanta, 2020.
6. Tartarini, Federico, and Stefano Schiavon. "Pythermalcomfort: A Python Package for Thermal Comfort Research." SoftwareX, vol. 12, Elsevier BV, July 2020, p. 100578. Crossref, doi:10.1016/j.softx.2020.100578.
7. Dimara, Asimina, et al. "A dynamic convergence algorithm for thermal comfort modelling." Computer Vision Systems: 12th International Conference, ICVS 2019, Thessaloniki, Greece, September 23–25, 2019, Proceedings 12. Springer International Publishing, 2019.
8. Harputlugil, Timuçin, and Pieter de Wilde. "The interaction between humans and buildings for energy efficiency: A critical review." Energy Research & Social Science 71 (2021): 101828.
9. Dimara, Asimina, et al. "NRG4-U: a novel home energy management system for a unique loadprofile." Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 44.1 (2022): 353-378.
10. Dimara, Asimina, et al. "Optimal comfort conditions in residential houses." 2020 5th International Conference on Smart and Sustainable Technologies (SpliTech). IEEE, 2020.