Adaptive thermal comfort-based HVAC control in real open plan office buildings

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Introduction

Heating, ventilation and air-conditioning system plays a key role in shaping the building performances. The effective and efficient HVAC operations not only achieve energy savings but also create a more comfortable environment for occupant indoors. Moreover, compared to private office environment, open-plan office environment has become a trend in most of office buildings since it not only creates opportunities for employers to communicate with one another and improve productivity but also reduce construction cost. However, open-plan office building is also faced with problems like much too interruption and unsatisfactory shared indoor temperature and humidity. Since HVAC system aims to create comfortable thermal environment and improve energy performances of the building, it is of great importance to develop new paradigm of HVAC system framework so that everyone could work under their preferred thermal environment while the system could also achieve better energy performances.

Therefore, this project aims to study individual thermal comfort/sensation profile with subset of RP 884 database, which collected a total of 22000 sets of data from the real office environments across the world. Then, the thermal comfort profile will applied to design an adaptive HVAC controller with reinforcement learning.

Description of the subset of RP884 dataset

Size of the dataset: 5776 instances

Data collection methods:

▪The data was collected from real open plan offices by various sensor measurements and user survey feedback across the world.

Selected climate zones and locations:

Location	Climate Zone
Grand Rapids	humid midlatitude
Ottawa Canada	humid midlatitude
Brisbane Australia	humid subtropcial
Sydney Australia	humid subtropcial
San Francisco Bay Area	mediterranean
san Ramon	mediterranean
Antioch	mediterranean
Auburn	mediterranean
Jakarta Indonesia	wet equatorial
Singapore wet equatorial	wet equatorial

Methodology

- **Preprocessing**
  - Feature selection
    - Algorithm: random forest-based feature ranking

Variable's Code Name	Description of Variable and Units
Class: ash	ASHRAE Thermal Sensation Scale [-3, +3]
met	average metabolic rate of subject [met]
insul	clothing plus upholstery insulation [clo]
taav	average of three heights' air temperature [°C]
rh	relative humidity [%]
dayav_ta	outdoor average of min/max air temp on day of survey [°C]
dayav_rh	outdoor average min/max relative humidity on day of survey [%]

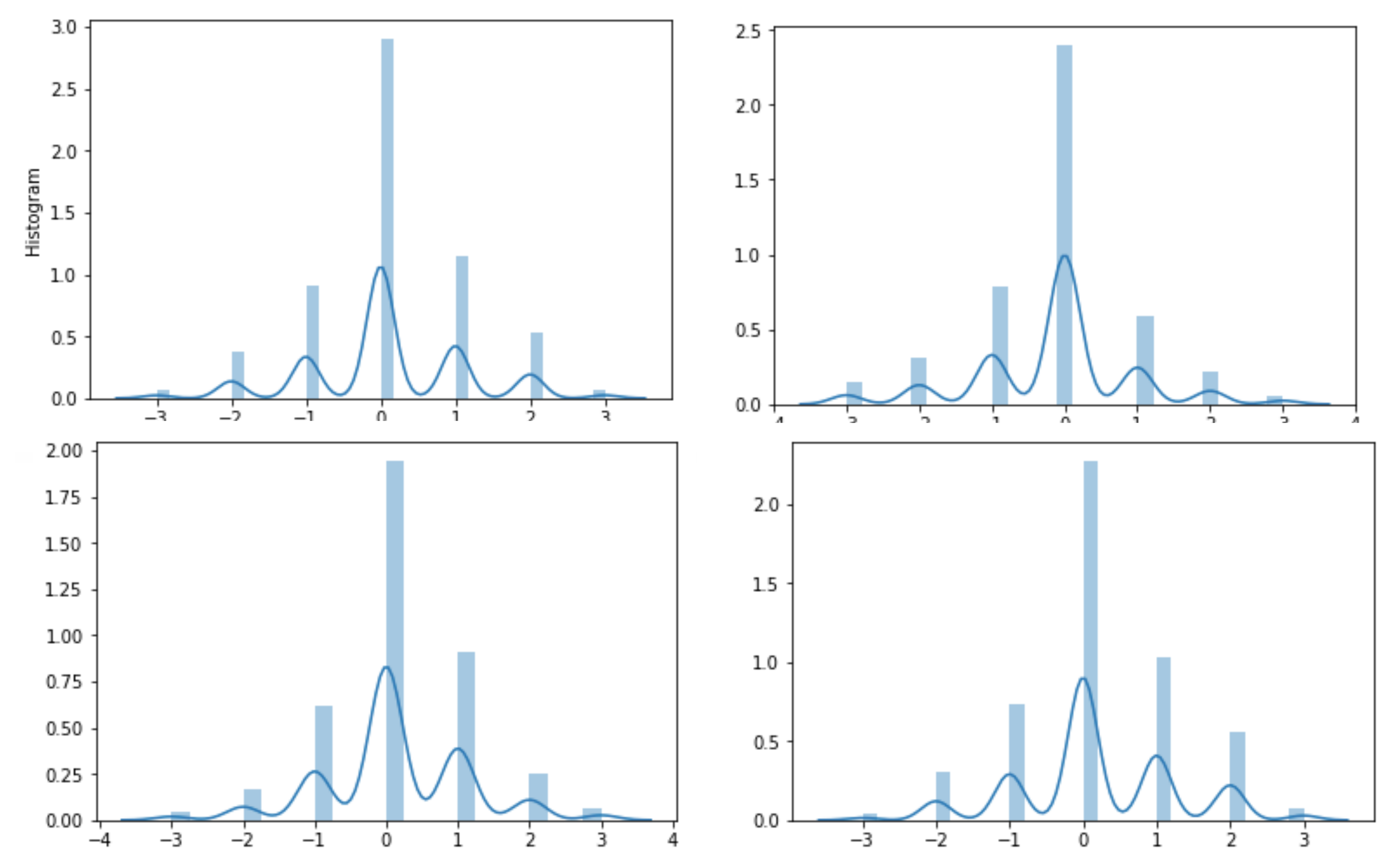
- **Analysis of differences between individual thermal comfort**
  - Algorithm: GMM clustering with optimal K
- **Development of individual thermal sensation prediction model**
  - Algorithm1: Kernel-based Support Vector Machine
  - Algorithm2: Random Forest
  - Algorithm3: Hidden Markov Model
    - Viterbi's algorithm
      - Transition matrix:

$$\begin{array}{llll} & \text{uncomfortably cool} & \text{comfortable} & \text{uncomfortably warm} \\ \text{uncomfortably cool} & p & 1-p & 0 \\ \text{comfortable} & p & 1-2p & p \\ \text{uncomfortably warm} & 0 & 1-p & p \end{array}$$

- **Development of HVAC controller with the prediction from individual thermal sensation profile**
  - Algorithm: Value-iteration
  - State space:
    - thermal sensation [-3,+3] with the inputs of clothing insulation, indoor air temperature and relative humidity, outdoor air temperature and relative humidity and metaboic rates
  - Actions:
    - 0.5 C warmer, 0.5 C cooler and no change
  - Rewards:
    - thermal sensation = -3 or 3, r=-5.
    - thermal sensation = -2 or 2, r=-2.
    - thermal sensatinon = -1 or 1, r=-1.
    - thermal sensation = 0, r=5

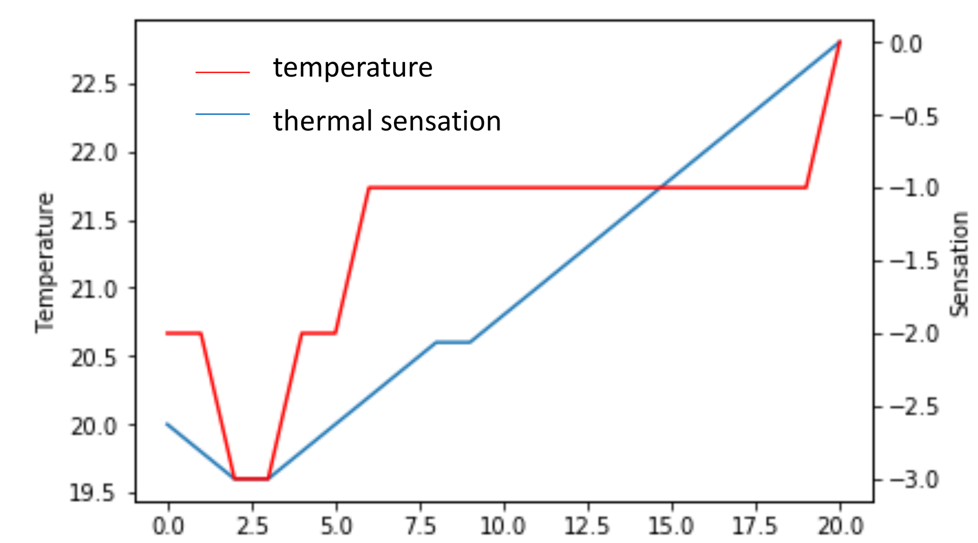
Results

ranking	feature	score
1	clothing insulation	0.237908
2	indoor air temperature	0.236746
3	indoor relative humidity	0.234287
4	outdoor air temperature	0.111386
5	metabolic rate	0.101274
6	outdoor relative humidity	0.078398



sensation distributions with 4 clusters

Algorithm	Accuracy of sensations
SVM	34%
Random forest	45.2%
HMM	54%



RL controller based on thermal sensation prediction

Conclusion and Future Work

- Even if different people have different sensations under similar conditions, the differences is limited.
- The random forest model has the highest accuracy of predicting individual thermal sensations.
- The prediction model can be applied to HVAC control with reinforcement learning so as to adapt the individual thermal comfort.