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The relationship between thermal environments and clothing insulation for rural low-income residents in China in winter

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Abstract: China is developing rapidly, but there is an obvious imbalance in the development level between urban and rural areas. Differences in economics, living conditions and life style contribute to differences in indoor thermal environments, and may result in differences in the perceptions of thermal comfort between urban and rural areas. Clothing insulation as one of the most important parameters that affect thermal comfort is studied in this research. A field study is conducted in the rural areas of Lankao, China. A total of 384 valid samples were acquired. 54.97% researched houses suffered extreme cold indoor temperatures between 2℃ and 6℃. Clothing insulation value of researched population is significantly larger than in other research. Clothing insulation value of female is significantly larger than that of male. It was also found that clothing insulation value correlates positively with age, that clo grow with the increase of age significantly. 7-days running mean outdoor temperature was selected from four temperature indices to predict clothing insulation value. Clo value is negatively correlated with 7-days RM outdoor temperature. But, the slope is quite small in such an extreme cold condition. A case study was conducted to estimate influence of adaptive clothing insulation on heating energy consumption (from Nov. to Mar.). Results show that 863 heating hours are reduced by using adaptive clothing insulation model. The total Heating Degree Hours (HDH) is reduced from 6445 to 1367 by 78.8% which means the same percentage of heating energy conservation. Besides, this case study also concluded that "adaptive clothing insulation model" has higher influence on heating energy consumption in transition season.

1. Introduction

Clothing acts as a layer of insulation between the human body and the ambient environment, affecting the heat exchange between both ends. The resistance of this heat exchange is usually called clothing insulation which is expressed in a unit named "clo". Clothing insulation plays an important role in thermal comfort research. It is one of the six most important parameters that affect the thermal comfort calculation, and is an input of PMV and PPD calculations in many thermal comfort standards such as ASHRAE 55 and ISO 7730. In adaptive thermal comfort research, clothing adjustment is viewed as the most important and efficient adaptive behaviour [1, 2]. For near-sedentary activities with a metabolic rate of 1.2 met, the effect of changing clothing insulation on optimum operative temperature is approximately 6 ℃ per clo [1]. So, the selection of clothing insulation for thermal comfort calculation during design stage of HVAC system and building affect the energy consumption of the building greatly. Unfortunately, in most standards, only 0.5 clo and 1.0 clo are used, with 0.5 clo for the cooling season and 1.0 clo for the heating season. More accurate research should be conducted, and thus adaptive

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clothing insulation models should be proposed based on the situation of the research areas.

The relationship between clothing insulation and indoor/outdoor environment has long been a topic of previous researchers. Outdoor temperature is believed to be the most critical factors that affect people`s clothing insulation. However, different indices are used by researchers. Daily mean outdoor dry bulb temperature was used by Morgan and de Dear to develop a linear relationship with clothing insulation [3], while, outdoor air temperature measured at 6 o`clock a.m. was used by De Carli to predict the clothing insulation [4]. As well as the linear models used by these research, other types of model have also been developed to predict clothing insulation. For example, the cubic model used by Nicol et al [5], the logistic model used by Liu et al [6] and a multivariable model used by Schiavon et al [1].

Similar research have been conducted on different populations in different building types in urban areas, such as research on young children in kindergarten [7], students in university [8], workers in workshop [9], people in shopping mall [3] and elderly people in elderly care house [10, 11]. Clothing insulation and its influence on energy consumption in low income rural areas in China is seldom researched. The typical ensemble in winter, the change of clothing insulation with gender, age and indoor/outdoor environments and influence on energy consumption in winter are not clear. These problem are studied in this paper. This research is part of the thermal comfort research in this area. The aims of this research are:

1) To study the difference of clothing insulation between different genders and ages in winter.
2) To study the relationship between clothing insulation and indoor environment and outdoor environment in winter
3) To develop an adaptive prediction model for clothing insulation in winter.
4) To estimate the influence of clothing insulation on energy consumption in winter.

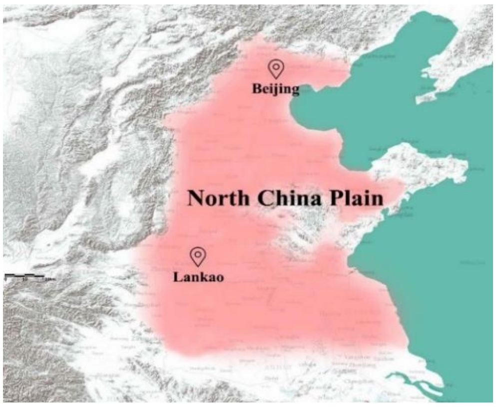

Figure 1. Location of Lankao on North China Plain.

Figure 2. Researched villages in Lankao.

Figure 3. Typical residential buildings in research area.

2. Method

2.1. Sample selection

A field study was conducted in rural regions of Lankao county. Lankao county is located in the "Cold Zone" on the North China Plain. The North China Plain is the most densely populated region in China, and the "Cold Zone" is one of the five "Building Climate Zones in China". The PCDI of rural population in Lankao is only about £1253 per year which is close to but a little smaller than the China average £1543 [12, 13].

Seven villages in Lankao were selected randomly for this field study. Almost all rural residential buildings in research villages are in free-running conditions. Participants were also selected randomly in villages. There is a total of 423 subjects (214 male and 209 female) interviewed in this field study.

2.2. Field measurement

In this study, a transverse field survey method was adopted. The study was conducted in workdays from 21th Dec. 2018 to 23th Feb. 2019, the typical winter season in this region. Visiting time was from 10:00 to 17:00 on every research day. Finally, 423 questionnaires were collected, from which 384 effective questionnaires were selected.

The complete investigation consists of two parts, a questionnaire and a simultaneous environment measurement. The questionnaire contains information on basic information of the participants, their thermal comfort and clothing garments. Indoor parameters were measured during the interview. Usually, the interview took place in the occupant's bedroom or living room. The participants were asked to stay in the room, either seated relaxed or standing relaxed, for at least 15 minutes. Instruments were set either in the centre of the room or in a suitable position close to subject, and were protected from solar radiation and heating devices. Two heights (0.6m and 1.1m) are optional for instruments according to the activity state of interviewed participant.

2.3. Clothing insulation estimate

Clothing garments were noted on the questionnaires according to subjects' description. Participants` ensemble were transformed to clothing insulation value, based on ISO 7730, ISO 9920 and Chinese Standard GBT 50785. Chair insulation was not considered here for 2 reasons. Firstly, most participants were not in a seated position. Secondly, people would not consider chair insulation when choosing garments in the morning.

2.4 Influence on energy consumption

To estimate influence of adaptive clothing insulation on heating energy consumption in winter, two parameters were used and compared. These are heating hours and Heating Degree Hours (HDH). HDH was defined as a measurement to quantify the demand for energy needed to heat a house. It is quite similar to the HDD. The difference is that, HDD uses daily outdoor temperature and base temperature, while HDH use hourly PMV and base PMV for calculation. The calculation is to subtract hourly PMV from Base PMV. If the value is less than or equals zero, that hour has 0 HDH. If the result is positive, the value represent the number of HDH of that hour. Then HDH of a period can be calculated by sum up HDH of each hour. The larger HDH is the more heating energy will be consumed to achieve indoor thermal comfort.

A typical house model was built and simulated in Designbuilder for a case study. Hourly mean PMV-PPD was then calculated based on simulation results. Heating hours and HDH with a base PMV of 0.85 (limit of 80% comfort zone) was calculated and compared.

However, this is a rough estimation of energy consumption. A dynamic simulation and more accurate energy reservation is under process.

3. Results and discussion

3.1. Outdoor climate and indoor environment

This field study was conducted from 21 December 2018 to 23 February 2019, the coldest three months in the research region. Daily outdoor air temperature and relative humidity curves of the period are shown in **Figure 4**. A basic description of outdoor environmental parameters are listed in **Table 1**.

Table 1. Outdoor environmental parameters

	Parameters	Average	MAX	MIN	SD
Outdoor	Air Temperature (°C)	0.67	8.09	-7.34	3.02
	RH (%)	62.63	97.38	29.63	17.83

Distribution of indoor operative temperature measured in surveyed houses is shown in **Figure 5**. Indoor operative temperatures were divided into several bins with a step of 2 °C . The number and frequency of acquired indoor operative temperature drop-in each bin is counted. Indoor operative temperatures between 2.0 °C and 6.0 °C take up more than half, about 54.97%, of all the measured data.

Most families have to suffer extreme low indoor temperature. Building insulation and heating devices are not affordable due to the outdated construction techniques and low income of the local residents. None of researched houses were built with insulation layers, and only 19.2% of the houses were running their heating devices when the interviews took place (Shown in **Figure 6**). Actually, many families do have heating devices, but, none of them keep the heating devices running all day long. Most families only turn on heating devices when they experience extreme cold indoor conditions. The average running time of heating per day is about 2 hours according to local residents` subjective impression.

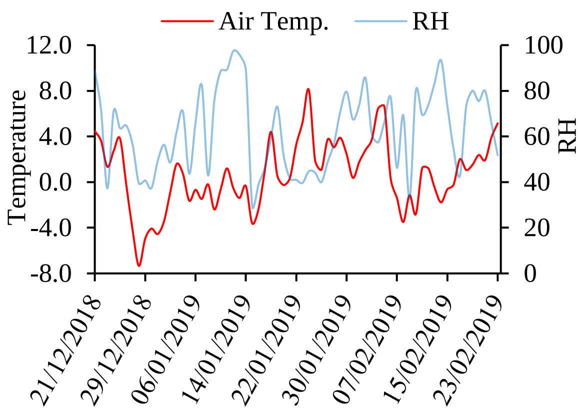

Figure 4. Daily outdoor air temperature and RH

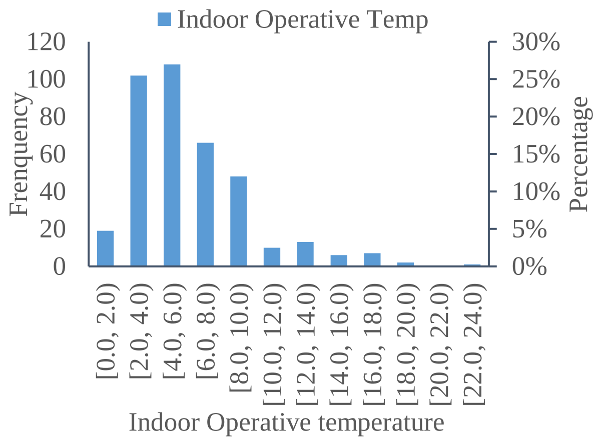

Figure 5. Distribution of indoor operative temperature

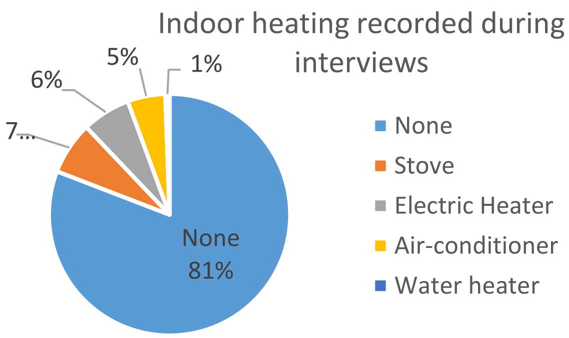

Figure 6. Percentage of heating device in running during interview

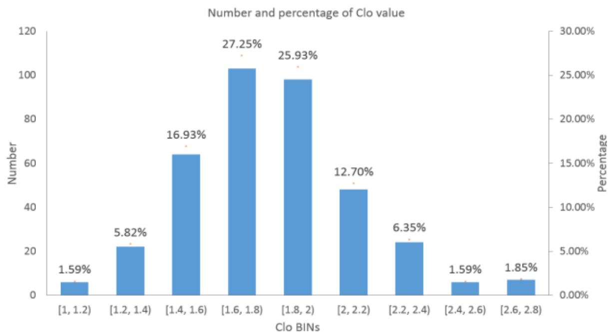

Figure 7. Distribution of clo value.

3.2. Clothing basic

A basic description on clothing insulation value and number of garments of the total sample are shown in **Table 2**. The average, maximum and minimum clothing insulation of the samples are 1.81 clo, 2.78 clo and 1.01 clo, respectively. The standard deviation is 0.30.

The distribution of clothing insulation value is shown in **Figure 7** by Bin method with a step of 0.2 clo. People with clothing insulation value of 1.6 clo to 2.0 clo make up 53.18% of the sample.

Table 2. Basic description on clo value and number of garments

	Average	**MAX**	**MIN**	**SD**
Clo Value	1.81	2.78	1.01	0.30

These results for clothing insulation values are significantly higher than many other previous research [1, 11, 14, 15]. This can be explained by the following reasons: First, both outdoor temperature and indoor temperatures (air temperature and operative temperature) are extremely low. Second, for the low income of rural families, heating devices are unaffordable, and even those who could afford them only use them sparingly, due to the cost of the fuel. Thus, increasing clothing is the main method of increasing thermal comfort for rural residents in cold winters. Other research conducted in regions with similar outdoor weather and indoor operative temperature [10, 16] gave similar levels of clothing insulation values.

3.3. Clothing insulation of different sex

The discrepancies of clothing insulation on sex are listed in **Table 3**. The average clothing insulation value of female is 1.84 clo, larger than male`s 1.78 clo. To test whether females ‘clothing insulation value is significantly larger than that of male, a one-tailed T test was conducted with a significant level of $\alpha = 0.05$. The P-value of the one-tail t-test result is 0.026, much smaller than 0.05, implying that the clothing insulation value of the female is significantly larger than that of the male. From the above results, females tend to be more sensitive to the cold environment than males and prefer to wear thicker clothing than males to keep thermal comfort in the research region during winter.

Table 3. Clothing insulation differences on sex.

		Average	Max	Min	SD
Clothing insulation	Male	1.78	2.46	1.01	0.286
	Female	1.84	2.78	1.07	0.315

3.4. Clothing insulation of different ages

In this section, the relationship between clothing insulation value with the age were discussed. The BIN method is again used. “mean clo” for each age group were calculated. The Pearson`s correlation coefficient equals 0.778, means a strong linear relationship between “mean clo” and age. Linear function was developed with a $R^2 = 0.6064$ and P-value < 0.01 (**Figure 8**). This means clo and number of garments show trends of growth with the increase of age. The results agree with previous research that elderly people tend to have lower activity levels and metabolic rates, and prefer to increase clothing insulation level to acquire thermal comfort.

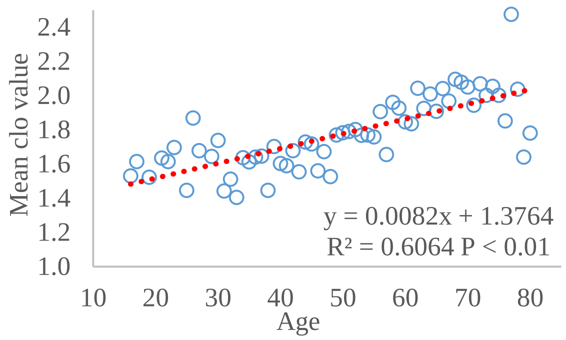

Figure 8. Regression mean clo on age.

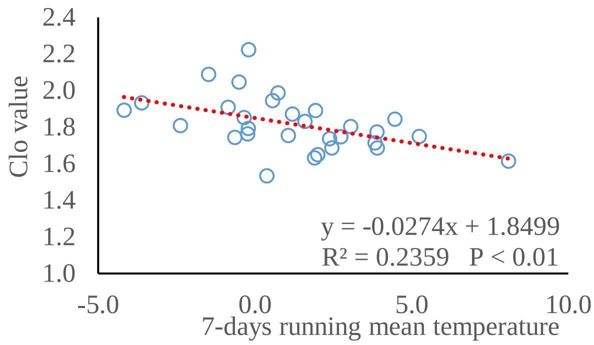

Figure 9. Regression clo on 7-days running mean outdoor temperature

3.5. Clothing insulation and Environment

This part explores the relationship between Clothing insulation with indoor and outdoor environment. As temperature is always the most important factor affecting people's choice of clothing, four temperature indices used most extensively in thermal comfort research were selected to discover their relationship with clothing insulation value. They are: indoor air temperature, indoor operative temperature, outdoor air temperature and the 7-days running mean temperature. For the interior linear relationship between them, only one most correlated index will be selected.

Spearman`s rank correlation coefficient was used to estimate the correlation level of relationship. The Bin method was not used here. The use of bin method will artificially reduce variance and increases the correlation coefficient of determination. This will introduce a loss of information in this case.

Table 4 shows the correlation value (Spearman`s rank correlation coefficient) and significant level. Results of four temperature parameters are similar. All of them have a negative relationship with clothing insulation value. Results show that those two outdoor temperature parameters have closer correlations with clothing insulation value. In addition, the significance level of outdoor parameters are better than that for indoor parameters. The 7-days running mean temperature tend to be the best index to represent the affection of temperature on Clo value than other three indices. Linear regression of Clo against 7-days running mean temperature is shown in **Figure 9**. This function is view as adaptive clothing insulation model, and will be used to predict clothing insulation value in following research.

Table 4. Spearman`s correlation coefficient.

		Indoor		Outdoor	
		Air Temp	Operative Temp	Air Temp	7-days running mean Temp
Clo	Correlation Coefficient	- 0.118	- 0.122	- 0.210	-0.232
	Significance	0.021	0.017	0.000	0.000

Thermal experience (past outdoor temperatures) significantly influences the in clothing insulation value [1, 17]. This can be easily explained by phenomenon in daily life in research area. First, the choice of cloth in the morning is based on not only the forecast temperature of today but more on the thermal experience and weather of past few days. Second, the ensemble for today tend to inherit the ensemble for yesterday. In addition, in this region, people do not usually change clothes. Those low income local residents don`t have much clothes to change. Also, the inconvenience of washing clothes also decreases the possibility of changing.

4. A case study

It is very important to take clothing adjustment into consideration for future design of HVAC system for rural low-income houses. This can be explained from two aspects. Firstly, for rural low-income residents, if they can achieve same level of thermal comfort by adjusting clothing, they would not turn on heating system. Secondly, by adjusting clothing, rural low-income residents can achieve same level of thermal comfort in lower indoor temperature. That means both heating hours and heating setpoint temperature of HVAC system can be reduced. This will surely lower heating energy consumption without reducing occupants` thermal comfort.

In this part, a case study was presented to analysis how clothing adjustment influences occupants` thermal comfort and building`s heating energy consumption. A typical rural low-income house was modelled and simulated in the 3 typical winter months (December, January and February) plus 2 transition months (November and March) adjacent to typical winter months. The “adaptive clothing insulation model” developed above was used to predict clothing adjustment of rural residents in experiment group. A constant 1.0 clo was used in control group for comparison. PMV-PPD index were used to represent thermal comfort. Heating hours and HDH (defined in section 2.4) were used to estimate reduction of heating energy consumption.

This is a rough estimation of heating energy conservation. The relationship between HDH and energy is not clear yet. However, a more accurate research with a dynamic simulation is under process, which will calculate the exact amount of energy saved by using “adaptive clothing insulation model”.

4.1 Heating hours

Hourly PMV can be calculated from simulated results. If calculated PMV are beyond the 80% (and 90%) comfort zone limits, the hour is considered as uncomfortable hour. Then, total comfortable hours and uncomfortable hours in each month and the whole period can be summed up. As shown in **Table 7**, if the constant value 1.0 clo is used, only 2 hours out of 3623 hours falls in the 90% comfort zone. However, comfort hours increase to 500 hours when “adaptive clothing insulation model” is used. That means heating hours can be reduced by 498 hours. If the 80% acceptable range is used, number of comfort hours increase from 44 to 907, by changing constant value 1.0 clo to “adaptive clothing insulation model”, which means a reduction of 863 heating hours. Heating hours is reduced by 23.8% for 80% comfort zone and 13.7% for 90% comfort zone, by using “adaptive clothing insulation model”.

Table 5. Comfort hours

	Calculated with “adaptive clo value prediction model”	calculated with fixed clo value 1.0	Total hours
90% acceptable comfort hours	500	2	3623
80% acceptable comfort hours	907	44	3623

Figure 10 shows the distribution of 80% acceptable comfort hours in each simulated months. Comfort hours in November and March (transition seasons) increase a lot, while remain almost unchanged in December, January and February (typical winter months). That means “adaptive clothing insulation model” can help to reduce heating hours of HVAC system and heating energy consumption in transition seasons significantly. 69.8% and 50.7% heating hours are reduced in November and March respectively.

4.2 Heating Degree Hours

However, heating hour is not able to show all influences clothing adjustment might bring to energy consumption. Heating setpoint also influences energy consumption. Heating setpoint temperature by using “adaptive clothing insulation model” is surely lower than that by using constant value 1.0 clo. Difference in heating setpoint temperature can be mapped to PMV difference. By adjusting clothing, residents can achieve better PMV than using constant clothing insulation, in same indoor environment. In other words, PMV deviate less from comfort zone by using “adaptive clothing insulation model”. When PMV deviate from comfort zone, heating is required, energy is consumed. The more PMV deviate from comfort zone, the more energy will be consumed. HDH is based on PMV deviation and is used to quantify the energy needed for heating. The more PMV deviating from comfort zone, the larger HDH is, the more heating energy is consumed.

HDH of adaptive clothing insulation model and constant 1.0 clo in each month and whole period was calculated and plotted in **Figure 11**. In November and March, HDH are reduced by 90.8% and 90.7% respectively. The percentage are higher than that in December (74.5%), January (73.7%) and February (77.6%). This result proves that adaptive clothing insulation model has more obvious influence in heating energy consumption in transition season. Total HDH is reduced from 6445 to 1367 by 78.8% which means the same percentage of heating energy conservation.

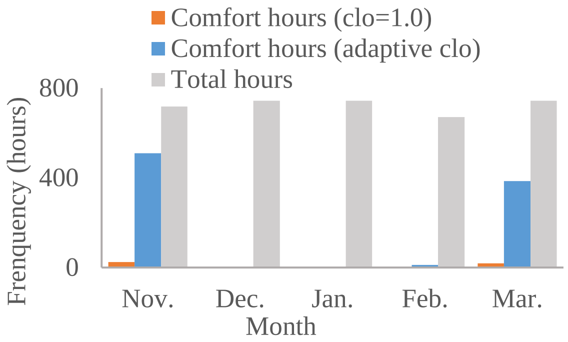

Figure 10. Distribution of 80% acceptable comfortable hours of each month.

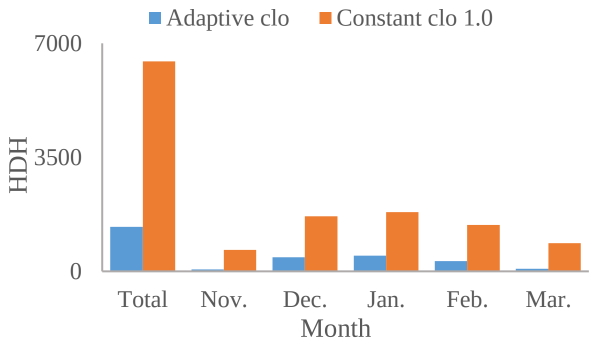

Figure 11. *WT* with different clo value in each month

5. Conclusion

This paper research on clothing insulation and influence of clothing adjustment on heating energy consumption in rural low-income houses in China. Results are based on 382 valid field study questionnaires collected from seven villages in Lankao in winter.

54.97% recorded indoor operative temperature during interview ranges from 2℃ to 6℃. Most families have heating devices, including traditional stove, electric heater, air-conditioner and so on. But only 19% of them are running their heating devices when interview took place.

Mean clothing insulation value of researched population is 1.81 clo, significantly larger than that in other previous research, that people have to wear more to maintain their thermal comfort in extremely cold living conditions. Female has a mean clothing insulation of 1.84 clo which is 0.06 clo larger than that of male in research area. It is significantly according to the one-tailed T test. It was also found that clothing insulation value is positively correlate with age, that clothing insulation grow with the increase of age significantly.

The 7-day running mean outdoor temperature was selected from four temperature indices to predict clothing insulation value adaptively. Thermal experience seems to have obvious effect on clothing insulation value. Clothing insulation value is negatively correlated with 7-day running mean outdoor temperature. However, the slope is quite small in such an extreme cold condition.

A case study estimating clothing adjustment`s influence on heating energy consumption was conducted. By using adaptive clothing insulation model, heating time is reduced by 863 hours from November to March. Total HDH is reduced from 6445 to 1367 by 78.8% which means the same percentage of heating energy conservation. This case study also concluded that "adaptive clothing insulation model" has higher influence on heating energy consumption in transition season.

A further research on dynamic simulation of exact amount of heating energy consumption using adaptive clothing insulation model is under process.

References

1. Schiavon, S. and K.H. Lee, *Dynamic predictive clothing insulation models based on outdoor air and indoor operative temperatures.* Building and Environment, 2013. **59**: p. 250-260.
2. Newsham, G.R., *Clothing as a thermal comfort moderator and the effect on energy consumption.* Energy and Buildings, 1997. **26**(3): p. 283-291.

IOP Conf. Series: Earth and Environmental Science **329** (2019) 012023 doi:10.1088/1755-1315/329/1/012023

3. Morgan, C. and R. de Dear, *Weather, clothing and thermal adaptation to indoor climate.* Climate Research, 2003. **24**(3): p. 267-284.
4. De Carli, M., et al., *People's clothing behaviour according to external weather and indoor environment.* Building and Environment, 2007. **42**(12): p. 3965-3973.
5. Nicol, J.F., et al., *Climatic variations in comfortable temperatures: the Pakistan projects.* Energy and buildings, 1999. **30**(3): p. 261-279.
6. Liu, W., et al., *Indoor clothing insulation and thermal history: a clothing model based on logistic function and running mean outdoor temperature.* Building and Environment, 2018. **135**: p. 142-152.
7. Nam, I., et al., *A study on the thermal comfort and clothing insulation characteristics of preschool children in Korea.* Building and Environment, 2015. **92**: p. 724-733.
8. Cao, B., et al., *Field study of human thermal comfort and thermal adaptability during the summer and winter in Beijing.* Energy and Buildings, 2011. **43**(5): p. 1051-1056.
9. Yang, R. and W. Su, *Thermal insulation of clothing ensembles for Chinese textile workers in the cotton textile workshop.* Case studies in thermal engineering, 2016. **7**: p. 8-13.
10. Jiao, Y., et al., *Thermal comfort and adaptation of the elderly in free-running environments in Shanghai, China.* Building and Environment, 2017. **118**: p. 259-272.
11. Jiao, Y., et al., *The relationship between thermal environments and clothing insulation for elderly individuals in Shanghai, China.* Journal of thermal biology, 2017. **70**: p. 28-36.
12. *Henan Province Bureau of Statistics*. Available from: http://www.ha.stats.gov.cn/sitesources/hntj/page_pc/tjfw/tjgb/szgxgb/article20997a83e9a943bfb63c345c5c176c0d.html.
13. *National Bureau of Statistics*. 2018; Available from: http://www.stats.gov.cn/tjsj/zxfb/201801/t20180118_1574931.html.
14. Huang, L., et al., *Field survey of indoor thermal comfort in rural housing of northern China in heating season.* Journal of Southeast University (English Edition), 2010. **26**(2): p. 169-172.
15. Liu, H., et al., *Seasonal variation of thermal sensations in residential buildings in the Hot Summer and Cold Winter zone of China.* Energy and Buildings, 2017. **140**: p. 9-18.
16. Cheng, B., et al., *Characteristics of thermal comfort conditions in cold rural areas of china: A case study of stone dwellings in a tibetan village.* Buildings, 2018. **8**(4): p. 49.
17. de Carvalho, P.M., M.G. da Silva, and J.E. Ramos, *Influence of weather and indoor climate on clothing of occupants in naturally ventilated school buildings.* Building and environment, 2013. **59**: p. 38-46.