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# Influence of weather and indoor climate on clothing of occupants in naturally ventilated school buildings

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ABSTRACT

Adaptive thermal comfort standards hold the potential for energy savings and greenhouse gas emission reductions in naturally ventilated buildings. The potential for energy savings relies on the fact that applying adaptive standards, indoor comfort temperature is shifted up on warmer days and shifted down in colder ones. In order to determine the correct comfort temperature inside, two variables need to be known in advance: The clothing insulation level and the metabolic activity of the inhabitants. Using an adult population, it was observed that the clothing insulation level can be calculated based on recent thermal memory and weather prediction. The field study was carried out with 732 individuals for one year. All individuals performed the same task. In these circumstances, the clothing insulation level revealed to be a key issue. The clothing insulation level of the population was determined by the *clo-checklist* method and showed significant variation along the time period, with standard deviation representing about 23% of the mean clo (1 clo = 0.155 $m^2$ K $W^{-1}$). Results showed that the clothing insulation level worn inside has the most significant relationship to the previous day's average outside temperature ($T_{day.x-1}$: $R^2$ = 88%) followed by the maximum outside temperature during that day ($\max T_{day.x}$: $R^2$ = 71%).



## 1. Introduction

Clothing can be defined as a mobile environment, making it possible for a person to adapt to almost any environment, not only inside buildings and vehicles but also outside. From an energy point of view, clothing provides a cheap and clean method of controlling the microclimate [1]. The importance of this is emphasised by the fact that the single largest impact exerted by an office building on its outdoor environment, throughout its entire life cycle, results from the energy used creating a comfortable indoor climate [2]

In the thermal comfort theory, clothing was described as a single layer of thermal insulation uniformly interposed between the human subject's body surface and the immediate thermal environment [3].

Complementary to this physical approach, clothing can also be analysed from another different perspective according to the subsets of social criteria that each piece of garment and the whole ensemble have to fulfil. The subsets of social criteria that are present upon clothing selection are: Personality; Social status; Cult; Mood; Religion; Marital status; Corporate dress code and Organisational. In a workplace environment context, additional ergonomic criteria may be important for the worker's safety and health. Clothing can provide protection against various kinds of physical, chemical and biological hazards. However, for most people, like for the whole population in this study, ergonomic criteria do not apply to garment selection.

Another aspect that plays an important role upon clothing selection is fashion. This aspect is somewhat difficult to define concisely. To some, fashion is an art form, to others is just a business industry. In this context, fashion is defined as a method to emphasise and conceal some particular characteristics of the individual physiognomy. Fashion is an aspect present on clothing selection, not quantifiable in decision weight and transversal to all subsets of social criteria.

Each day, most persons have to make multicriteria decisions about a clothing ensemble. This process combines the available climatic information (indoor and outdoor), relative Indoor/Outdoor exposure and the subsets of social criteria that the ensemble has to fulfil. The relative weighting of the relevant criteria, combined with

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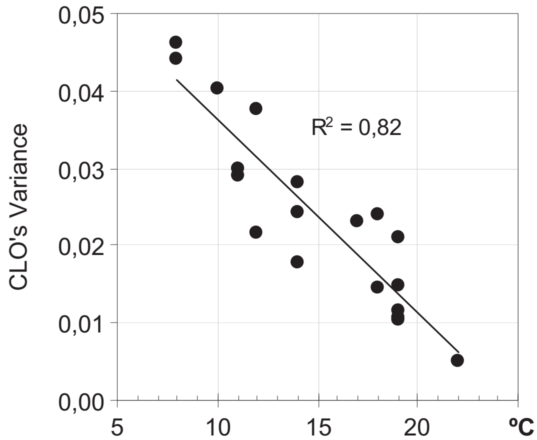


**Fig. 1.** Clothing insulation level's variance ($\sigma^2$) for each field essay and the average outside temperature registered during that same day.

the accuracy of the climatic information results in an ensemble output considered adequate among the available options. Independently of the criteria that aroused during the selection process, the chosen ensemble can be expressed in terms of thermal insulation in adequate units (*clo* or $m^2\,°C\,W^{-1}$).

The *clo* and *met* units were proposed [4] as a measure of clothing insulation and metabolic activity level, respectively. Both units have been extensively used to address the insulation of clothing systems and were adopted internationally [5,6].

The *met* unit [4] is the amount of metabolism of an average man resting in a sitting position, under conditions of thermal comfort. One met is equivalent to 58.15 $W/m^2$ or 50 $kcal/m^2h$. The *clo* unit [4] is the clothing insulation that maintains a man, resting in a sitting position, comfortable in a normally ventilated room (0.1 m/s air velocity) at the air temperature of 21 °C and relative humidity less than 50%. It was assumed [4] that 24% of the metabolic heat loss was done by evaporation from the skin. The remaining 44.2 $W/m^2$ would be lost thru the clothing by convection, conduction and radiation. It is generally accepted that the mean skin temperature of a person is within the 33–34 °C interval [7], provided that the person is in physiological conditions of comfort, and that sweating or shivering do not occur. Assuming a mean skin temperature of 33 °C, the total insulation of the clothing plus the ambient air layer is given by $I_t = (33-21)/44.19 = 0.2715\ m^2\,°C\,W^{-1}$ [1].

It was assumed that the insulation provided by the air, surrounding the person at this condition is $I_a = 0.1206\ m^2\,°C\,W^{-1}$. The insulation of the clothing can be obtained by a simple arithmetic subtraction and is $I_{cl} = I_t - I_a = 0.151\ m^2 \circ C\,W^{-1}$.

Thus, 1 *clo* unit equals 0.151 $m^2 \circ C\,W^{-1}$. In terms of garment, this value corresponds to underwear with short sleeves and legs, shirt, trousers, jacket, socks and shoes [5].

The most accurate way to determine a clothing insulation ensemble is by carrying out evaluations in the laboratory and/or climatic chamber. These environments allow the assessment on any combination of clothing ensemble, work level, wind and temperature [8]. Among the most accurate methods to determine clothing insulation are (1) measurements on heated mannequins [9,10] and measurements on active subjects [11,12]. However, in a field study like this one, none of these presents a valid option.

In this field study conditions each person was free to choose and change its clothing insulation level adjusting it to surrounding environment. Clothing ensembles were determined using a questionnaire with a checklist of the individual garments (*clo*-checklist method). Insulation values were determined using tables of the individual garments [6]. Overall accuracies for $I_{cl}$ in order of ±25%, are typical for this method, if the tables are used carefully [13]. Explanations for this discrepancy point out the differences in fabric weave, materials, fabric weight and variations in the ensemble which, in turn, modify the amount of sub-clothing air layer, available to thermally insulate the subject [14]. Another possible source of bias would be the way in which adjectives like "light, medium or heavy" are interpreted by the subjects. It was observed that clothing insulation's variance is smaller in warmer days, as presented in Fig. 1. Clothing uniformity increases with the daily average exterior temperature, even in the absence of any dress code. This would be expected once in warmer days there is a reductions in the number of individual pieces of garment. Field observations showed that with warmer temperatures, there is a clothing ensemble which is a winner among this population: jeans and t-shirt (Fig. 2).

## 2. Methods

The study was conducted in Leiria, Portugal (latitude 40°N) located at 18 km linear distance from the Atlantic Ocean. Field tests occurred during one year, between November 2010 and November 2011 according to the calendar presented in Table 2. All tests were performed inside classrooms of an academic campus.

The studied population was constituted by engineering students, with a gender distribution of 87.8% males and 12.2% females as showed in Table 1. However, this unbalanced male/female student distribution does not affect the results. Fanger [7] showed that man and women seem to prefer almost the same thermal environments. Women's skin temperature and evaporative loss are slightly lower than those of man, and this balances the somewhat lower metabolism of women. Also in field studies performed with primary school children, Humphreys [15,16], observed that there was no appreciable difference between the responses of the boys and the girls. The population in this study is fairly uniform in what concerns age (93% of the population was comprised in the 18–26 year's interval). A total of 732 valid enquiries were gathered in seven classrooms of two buildings (six classrooms in building A and one classroom in building B).

Both buildings A and B are naturally ventilated. Some authors refer to these buildings as free-running [17] once they don't have mechanical cooling in summertime even though they are provided with a heating system (aluminium radiators connected to a central boiler for both buildings). The regulation of the heating radiators is done individually. In every classroom, occupants have access to windows, shades and door.

The main physical based indicators recorded during the experiments were the effective temperature and the Predicte Mean Vote

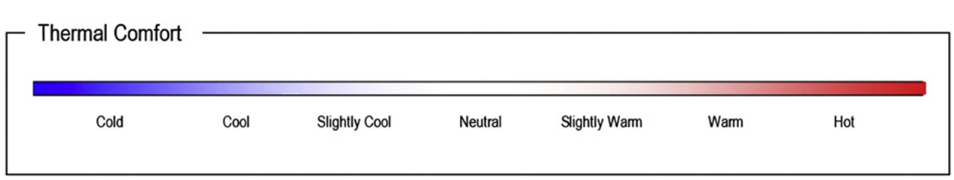


**Fig. 2.** Scale of thermal comfort.