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Long abstract**Modelling of ‘behavioural adjustments’ and its impact on energy consumption in offices**

M. Endravadan, F. Thellier and F. Monchoux

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Summary: In this study the concept of ‘adaptive behavioural regulation’ is extended to look at the effects of personal adjustments and regulator control changes provided in offices. It is evident from experience as described in the adaptive approach, that clothing can play an important role, although it does not contribute to energy savings directly; however, as clothing adjustment is possible, the heating set-point could be lowered and the cooling set-point could be raised, thus decreasing the energy consumption. To experimentally determine the effects of clothing or regulator temperature changes would be tedious and difficult. Hence, this paper proposes to study the coupling of occupant behaviour and the building through simulation.

A behavioural regulator (BR) model is created and implemented in the building simulation program (TRNSYS). The ‘BR model’ is based on clothing and/or the regulator set-point temperature adjustments made by the occupant. Thermal sensation is calculated by the Predicted Mean Vote equation.

Keywords: behavioural adaptation, clothing adjustments, set-point temperature
Category: Individually controlled environments

1 Introduction

In this study, the objective was to look at the adaptive behavioural actions [1] in order to design a behavioural regulator (BR). The three main principle forms of behaviour that will affect the heat balance between the body and the environment are the following actions that changes [2]:

- the metabolic heat production, changing activities becoming more/less vigorous,
- the rate of heat loss from the body surface, that is, changing clothing,
- the thermal environment, like changing the regulating temperature of a heating or cooling system, putting on a ventilator, etc.

A behavioural regulator (BR) model is created and implemented in the building simulation program (TRNSYS). Depending on his/her thermal sensation the occupant can *actively* participate to make both *personal* and *external* adjustments. One of the most important personal adjustments is removal or addition of clothing that has been cited in many field experiments [3]. It should be noted that another personal adjustment is change of posture; however, this will not be considered in this study. The external adjustments are the controls available in the office which the occupant can act on, that is, increase/decrease the set-point temperature of a heating or air-conditioning system. Again, controls like blinds/windows and doors will not be considered. Hence, the ‘BR model’ is based on clothing insulation (I_{cl}) and/or the regulator set-point temperature (T_{REG}) adjustments made by the occupant.

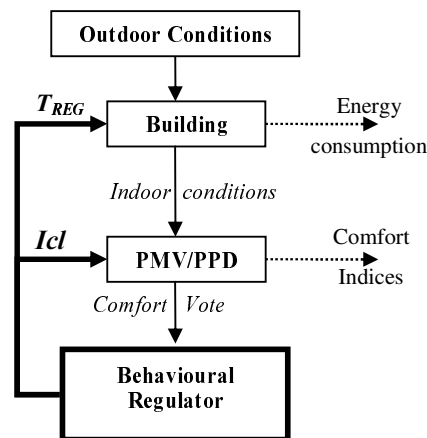
2 Behavioural Regulator System

Fig. 1. Information flow diagram for the simulation.

The meteorological conditions (outside) affects the energy balance of a given building, and the building’s indoor climate responds accordingly. The human occupants of the building maintain their own energy balance with indoor climatic conditions and the extent to which they are comfortable or uncomfortable is given by their thermal sensation, i.e. PMV/PPD [4]. As shown in Fig.1, the fact that the occupant can make behavioural adjustments allows the variables clothing and temperature regulation as inputs which are fed back into the system. The model works in several modes in order to simulate individual behavioural differences, for example, it can consider clothing adjustments or set-point temperature changes only, or the occupant

may change his clothing before acting on the temperature of the regulation/vice-versa or make both changes simultaneously. Each morning, the clothing insulation and the set-point temperature are reset to standard values, that is, in winter 1.0 clo and 19 °C.

3 Results

The preliminary simulations were conducted using an idealized heating/cooling system. An example is presented here. The amount of personal or external changes made by an individual is a function of metabolism. The simulation of a BR system is compared to a fixed regulator system. The type of BR simulated in Fig. 2 takes into account the clothing adjustment first then considers changing the regulator temperature. The comparison is made for a period of one month in the heating season. The mean clothing insulation for the fixed regulation is 1.0 clo, whereas in the BR mean insulation varies from 1.5 clo to 0.5 clo. The mean set-point temperatures and mean PPD against metabolism are plotted in Fig. 2. It should be noted that for most office-type activities (58 – 116 W m⁻²) the PPD is less than 10% for BR. This is not the case for a fixed regulator. The large variance in PPD for BR reflects the changes made in clothing and temperature set-point. One explanation of this high dispersion is due to resetting the clothing insulation and regulation temperature values each morning. More details on these will be discussed in the paper.

The graph of energy consumption (not included in this abstract) shows that less energy is

consumed with a BR system which works at a set-point of 19 °C compared to a fix regulator at 22 °C, for sedentary activity. However, this does not cause discomfort as occupants are able to change their comfort by putting more insulation. Although, the choice of increasing the regulator temperature is available; often the regulator is not touched during the winter.

Simulations will be done with a realistic heating system for winter and the impact of a using a ventilator in summer will also be analysed with the BR system. The results will be compared to a fixed regulator system which has a fixed set-point temperature and fixed clothing values for the seasons. The effect of behavioural actions on comfort and energy consumption will be analysed.

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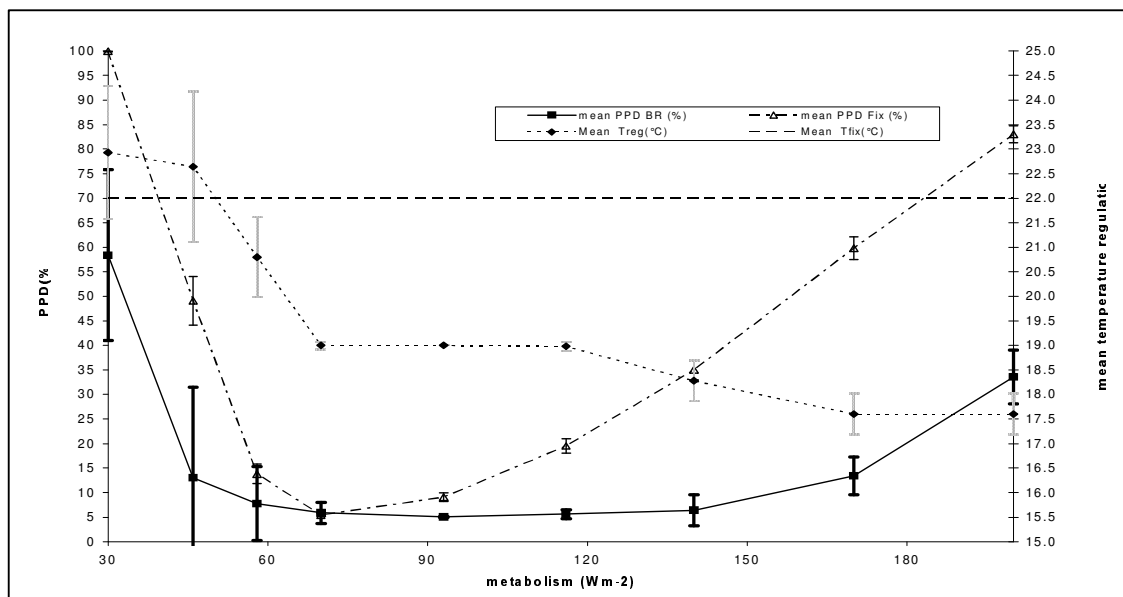


Fig. 2. Mean PPD and Mean set-point temperature against metabolism

Modelling of 'behavioural adjustments' and its impact on energy consumption in offices

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Summary: *In this study the concept of 'adaptive behaviour' is extended to look at the effects of personal adjustments and regulator control changes provided in offices. It is evident from experience as described in the adaptive approach, that clothing can play an important role, although it does not contribute to energy savings directly; however, as clothing adjustment is possible, the heating set-point could be lowered and the cooling set-point could be raised, thus decreasing the energy consumption. To experimentally determine the effects of clothing or regulator temperature changes would be tedious and difficult. Hence, this paper proposes to study the coupling of occupant behaviour and the building through simulation for summer.*

A behavioural regulator (BR) model is created and implemented in the building simulation program (TRNSYS). The 'BR model' is based on clothing and/or the regulator set-point temperature adjustments made by the occupant. Thermal sensation is calculated by the Predicted Mean Vote equation.

Keywords: *behavioural adaptation, clothing adjustments, set-point temperature*

Category: *Individually controlled environments*

1 Introduction

Human 'behaviour' in office environments is often overlooked in terms of building design and installation of heating and cooling systems. However, the importance of this has been increasingly noted in many field experiments [1-2]. Such behavioural aspects or rather adaptive behaviour is of two particular categories: *personal* - actions which change the rate of heat loss from the body surface, that is, changing clothing; and *external* - actions which change the thermal environment, like changing the regulator temperature of a heating/cooling system or putting on a ventilator.

Amongst the personal behaviour, clothing adjustment [3] is indirectly quite significant in terms of energy consumption or savings. For example, in summer wearing clothing equivalent to 0.7 clo and cooling the air at a temperature of 24 °C is not the same as wearing 0.4 clo and having the regulation temperature at 26 °C. It should be noted that another personal adjustment is change of posture [2]; however, this will not be considered in this study.

Apart from acting on his/her own clothing, the occupant also interacts with other 'external' systems/controls available within the office structure, like, window blinds/shutters, lighting system, or adjusting the regulation temperature of the HVAC system. It would be interesting to look at the wide variety of external adjustments possible;

however, in this paper we focus only on the regulation temperature of the cooling system.

Behaviour in itself is a complicated issue, as it is composed of both conscious and unconscious actions. Due to habits certain actions of conscious nature can become unconscious actions of second order; here only conscious actions are considered. In this study, the objective was to look at the adaptive behavioural actions in order to design a *behavioural regulator* (BR) model. This model is created and implemented in the building simulation program (TRNSYS) [6]. Depending on his/her global thermal sensation the occupant can *actively* participate to make both *personal* and *external* adjustments. Hence, the 'BR model' is based on clothing and/or the regulator set-point temperature adjustments made by the occupant in summer.

2 Behavioural Regulator System

The meteorological conditions (outside) affects the energy balance of a given building and the building's indoor climate responds accordingly. The human occupants of the building maintain their own energy balance with the indoor climatic conditions and the extent to which they are comfortable or uncomfortable is given by their thermal sensation, i.e. PMV/PPD [4]. As shown in Fig.1, the fact that the occupant can make behavioural adjustments allows the variables clothing (Icl) and temperature regulation (Treg) as inputs which are fed back into the system.

The clothing/temperature regulation adjustment made depends on PMV, for example an adjustment of removing 0.1 clo or lowering Treg by 0.5 °C is possible if the PMV lies between 0.2 to 0.5 range; and so forth [5].

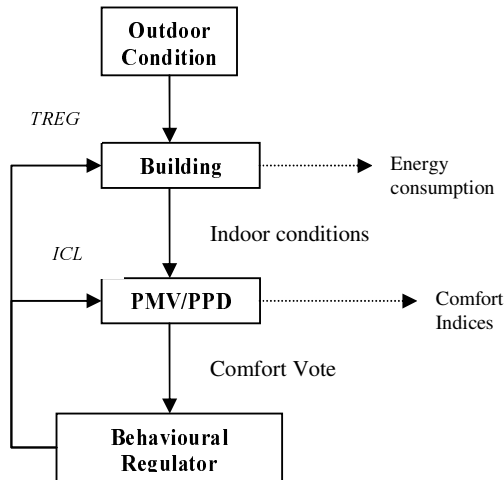


Fig. 1 Flow diagram of the behavioural regulator and other components of the modelling system.

The model works in several modes in order to simulate individual behavioural differences, for example, it can consider clothing adjustments or set-point temperature changes only, or the occupant may change his clothing before acting on the temperature of the regulation/vice-versa or make both changes simultaneously. Each morning, the clothing insulation and the set-point temperature are reset to standard values, that is, in winter 1.0 clo and 19 °C; and in summer 0.5 clo and 26 °C.

3 Results

Simulation Conditions: A single occupant office-type cell is created in TRNSYS [6] with a zone volume of 50 m³. The dimensions of the cell are 4.0 m x 5.0 m x 2.5 m. The window is on the East wall and has a fenestration area of 3.5 m². The walls are made up of bricks called ‘monomur’, that had a coefficient of thermal transmittance $U = 0.45 \text{ W m}^{-2} \text{ K}^{-1}$. The walls of the cell can be considered as those with a reasonable high thermal inertia. The ventilation in the zone is kept fixed at a rate of 0.5 vol/h and the local air velocity was 0.1 m s⁻¹. There were no internal gains and no changes in opening/closing the windows/blinds. A low-office activity of 70 W m⁻² and clothing insulation of 0.5 clo was selected.

The simulation results presented in this section are both for a building which is non climatized (naturally ventilated - NV) and climatized (that has a cooling system) in summer. The BR model shown works in the mode where clothing adjustments are

done before cooling regulation adjustments. The meteorological conditions used were from Agen (southwest of France). The trends in the outdoor air temperature (Tout), running mean outdoor temperature (Trm) and the total horizontal solar radiation (HSRad) can be seen in Fig. 2. Trm is the mean temperature that takes into account the temperatures of past days [2]. For the four hot days studied, the maximum outdoor temperature goes up to 35 °C.

Non Climatized Condition: The trend in indoor air temperature (Tin) for a NV heavy weight building (HWB) is shown in Fig. 2 as well. The mean indoor and surface temperature during the four days is 26 °C ($\delta=1.9$). Fig. 3 shows the trends in PMV with fixed clothing and when clothing adjustments are carried out. On the third and fourth day, the PMV value during the hottest part of the day is above 1.0 for fixed clothing ensemble. This value is reduced by about 0.4 when the individual decides to make adjustments. This reduction is significant in improving comfort. The overall PPD is reduced from 14.5 % ($\delta=8.8$) to 7.9 % ($\delta=3.7$). The explanation of these PPD values is evident from the trends of clothing insulation (in clo units). During the three out of four days, it is seen that if given the possibility the individual prefers clothing insulation of 0.2 clo to 0.5 clo.

Furthermore, in NV buildings the air change rate per hour (ACH) and the local velocity which a person may experience play an important role on thermal sensation. For example, using a simple linear logic, to simulate other ventilation conditions – with ACH=1.0, $v=0.5 \text{ m s}^{-1}$ and ACH=2.0, $v=1.0 \text{ m s}^{-1}$; the results obtained for a hot summer day (Day 3 in reference to Figs 2 and 3) are shown in Fig. 4. An ACH=2.0 in the night allows the indoor temperature to drop around 23.7 °C; resulting in a PMV equal to -0.1. In the afternoon, around 15 h, when the Tout is maximum, warm outdoor air flows into the building increasing Tin. This is the only time when Tin (ACH=2.0) surpasses slightly the Tin (ACH=0.5 or 1.0) for few hours. With ACH=1.0 or 2.0, the PMV value is 0.4 lower than that with ACH=0.5.

It is important to consider Fig. 4 with Fig. 5 which shows the clothing adjustments for the same hot day in summer. For each air change rate, the mean Icl values are shown in Fig 5. It is evident and normal that at night when the local windspeeds increase, the individual covers himself with more bedding; and slightly more insulation during the day as well. For calm conditions ($v=0.1 \text{ m s}^{-1}$), apart from early morning hours; during most part of the day the clothing insulation is 0.2 clo.

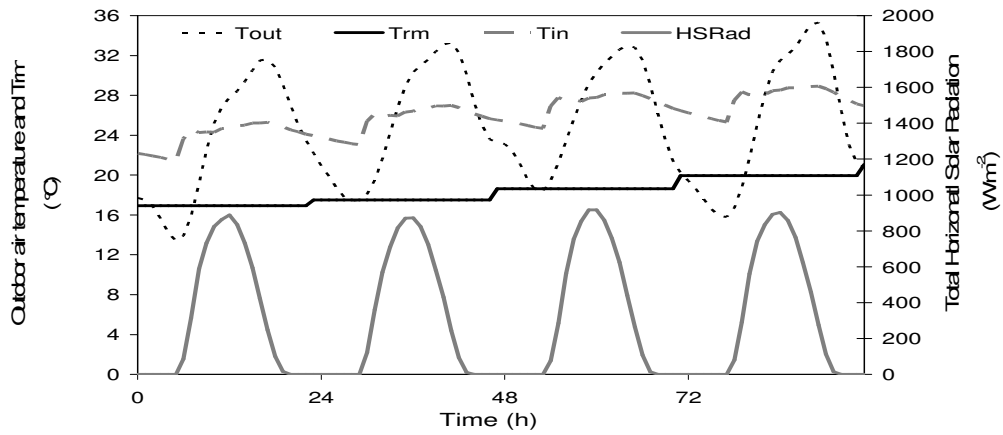


Fig. 2 The meteorological conditions of Agen.

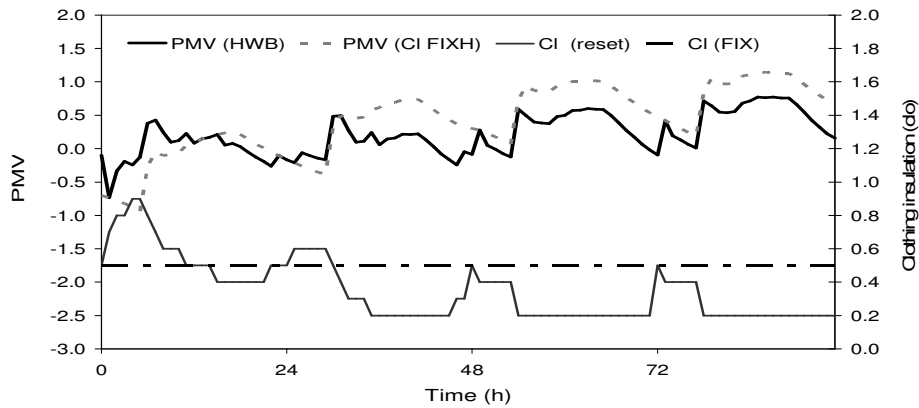


Fig. 3 Trends in PMV with fixed and adjusted clothing in the naturally ventilated heavy weight building.

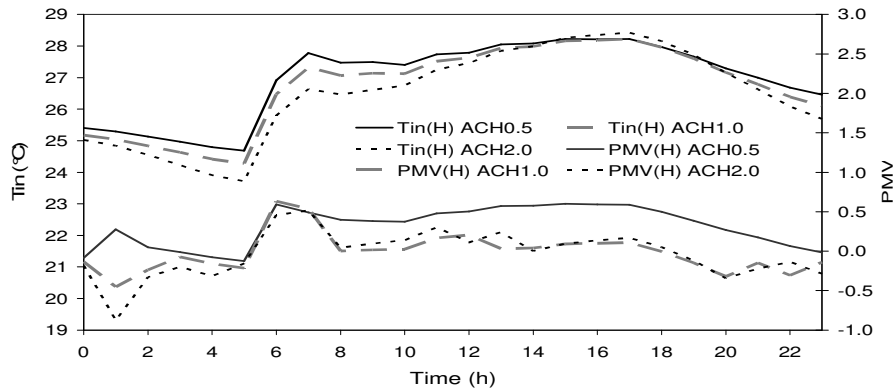


Fig. 4 The trends in indoor air temperature and PMV for a hot day in summer with different air exchange rates.

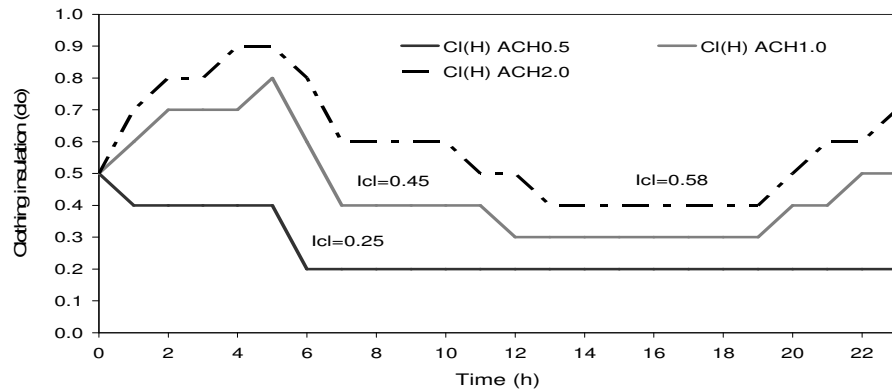


Fig. 5 The trends in clothing insulation for a hot day in summer with different air exchange rates.

Climatised Condition: The cooling system was regulated with a controller that had a dead band of ± 0.5 °C. The regulation system was based on the indoor air temperature. A cooling power of 0.36 kW was supplied when needed. The regulation temperature was then determined with either a fixed regulator or a behavioural regulator (BR). For summer conditions the personal adjustment can be made with two fixed insulation values, that is, a small adjustment of ± 0.1 (adjustment of sleeves,...) or addition or removal of a light summer jacket/shirt of 0.2 clo.

For fixed regulation, the temperature was taken from the range of cooling temperatures recommended by ISO 7730 [7]. Hence, the temperatures were 24.5 °C for fixed regulation and 26 °C for a BR (usually used in France). It should be noted that for the BR, the Treg and clothing insulation started with 26 °C and 0.5 clo each morning. The variation in temperature regulation (Treg), indoor air temperature (Tin), cooling power (CP) signal, clothing insulation (Icl) and PMV for fixed regulation are shown in Fig. 6. The mean Tin and Tsurface are 24.2 and 24.3 °C. A PPD of 6.5 % ($\delta=3.5$) is obtained.

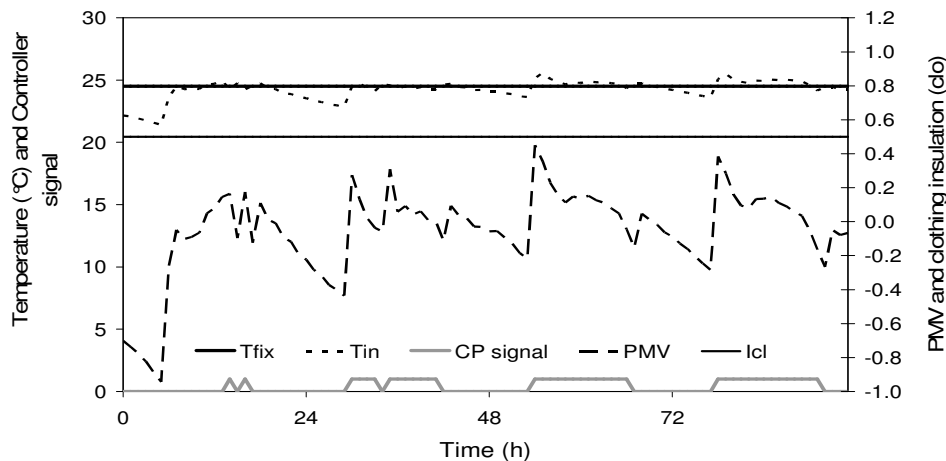


Fig. 6 The variables for a fixed regulation system.

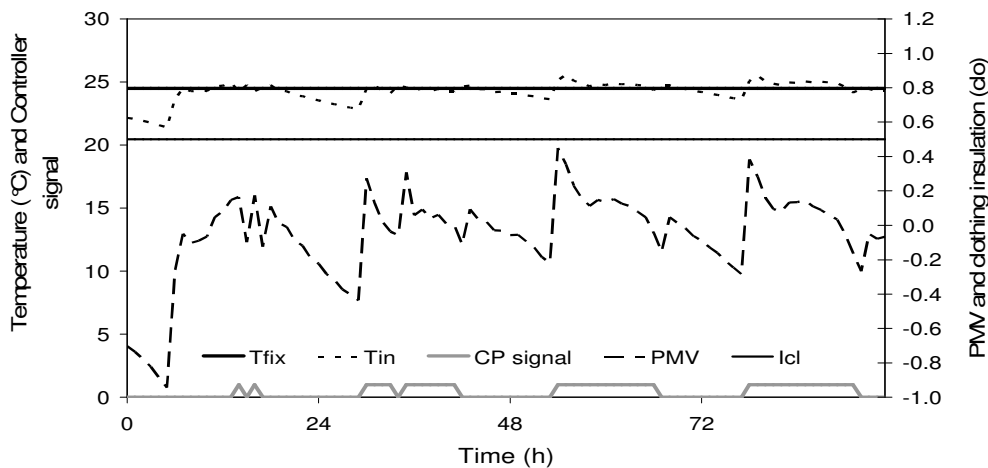


Fig. 7 The variables for a behavioural regulation system.

In comparison, for a behavioural regulation the mean Tin and Tsurface are about 25 °C (see Fig. 7). The regulation temperature remains at 26 °C and does not change, although the option to change it is available. The PMV levels tend to be comfortable during most part of the day, however, it fluctuates slightly more than those observed in Figures 3 and 6.

In all these graphs, the morning peak in PMV is due to the increase in indoor air and wall temperatures in response to solar radiation. With behavioural regulation the PPD obtained is 6.0 % ($\delta=1.8$); and it should be noted that the standard deviation is lower than that observed in NV or for fixed regulation. In terms of energy consumption, its not surprising that

BR consumes 8.6 kWh compared to 14.4 kWh that by a fixed regulator.

4 Discussions

Modelling the occupant's clothing behavioural effect is not straight forward because the computer models of building energy consumption do not normally allow for the occupant's clothing insulation value to be changed from time step to time step in response to simulated thermal conditions. However, Newsham [3] had used FENESTRA (a computer based model) which modelled clothing adjustments at every 5 mins, which may tend to be unrealistic.

In naturally ventilated buildings, the most common option available to an occupant is to add/remove clothing in order to be comfortable. The mean insulation obtained for the four days was 0.35 compared to 0.41 with BR. A clothing counter was implemented to count the number of times the individual makes clothing adjustments. With NV condition, 19 changes were recorded compared to 32 changes made in case of a BR. With increase in windspeed the number of times the person acts on his/her clothing increases.

The question which arises is: why are there more changes in BR than in NV; as one would expect the indoor environment with a conditioned system more stable than that which changes constantly. One of the reasons for the higher number of changes in the conditioned building is due to the controller on/off signals. As during these signals there is a change in thermal sensation and hence this causes the change in clothing insulation value (see Fig. 7). Furthermore in both cases, the occupant can change his/her clothing up to a minimum clothing level. This means that being comfortable by clothing changes only is limited in extreme situations. Hence, the advantage of a BR would be that it allows individuals a second chance in acting and improving their own comfort.

If a global cooling system exists where high cooling temperatures like 25.5 or 26.0 °C are employed, the PPD of 7.9 % (or 7.3 % with ACH=1.0) in NV is reduced to 6.0 %!! This means that the indoor air temperatures are reduced by 2 or 3 °C; in which case slightly more insulation is adapted in the conditioned building. The naturally ventilated heavy weight building shows that by taking advantage of clothing modifications, the PPD levels could be maintained below 10 %; hence, the building may not necessarily require cooling.

A lower cooling temperature as seen in case of fixed regulation with fixed clothing was simulated to show the energy costs. The fixed regulator consumes 6 kWh more than BR. This brings us

back to the importance of clothing behaviour and the indirect role it can play in saving energy. Hence, if the occupants adapt to the same clothing behavioural attitude as in NV, the amount of cooling energy consumption can be reduced.

Thermal inertia of buildings also acts as an important parameter that changes the behaviour of building occupants. It is known that light buildings tend to react quickly to the outdoor meteorological conditions. This aspect has been analysed, however the results are not presented here. Apart from these, simulations conducted for the cold season show that with a lower heating temperature and clothing behavioural adjustments, reasonable comfort levels are achieved [5].

5 Conclusions

If one of our global aims is to construct more low energy buildings, then it is necessary and important to consider the clothing behaviour of individuals in enclosed environments. Furthermore, the degree of freedom allowed in terms of dress code needs to be more flexible. This aspect could be interesting for many tropical and developing countries where cooling buildings is becoming more and more frequent. Of course, an energy conscious attitude needs to replace the fast-growing consumption nature we have developed.

References

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Modelling of 'behavioural adjustments' and its impact on energy consumption in offices

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ROOMVENT Conference, Sept 6, 2004.



Objectives

- To look at occupant-controlled **COOLING** in buildings.
 - To propose a 'model' as a tool for coupling occupant behaviour and building through simulation.
- Approach presented is **GLOBAL**.
- Today's presentation:
 - Human behaviour in offices**
 - The behavioural regulator system**
 - Results: Naturally ventilated building and Regulated Building for summer conditions**
 - Energy Consumption**
 - Conclusions**



Human behaviours in office space



Personal

CLOTHING (Icl)

**metabolism, posture*



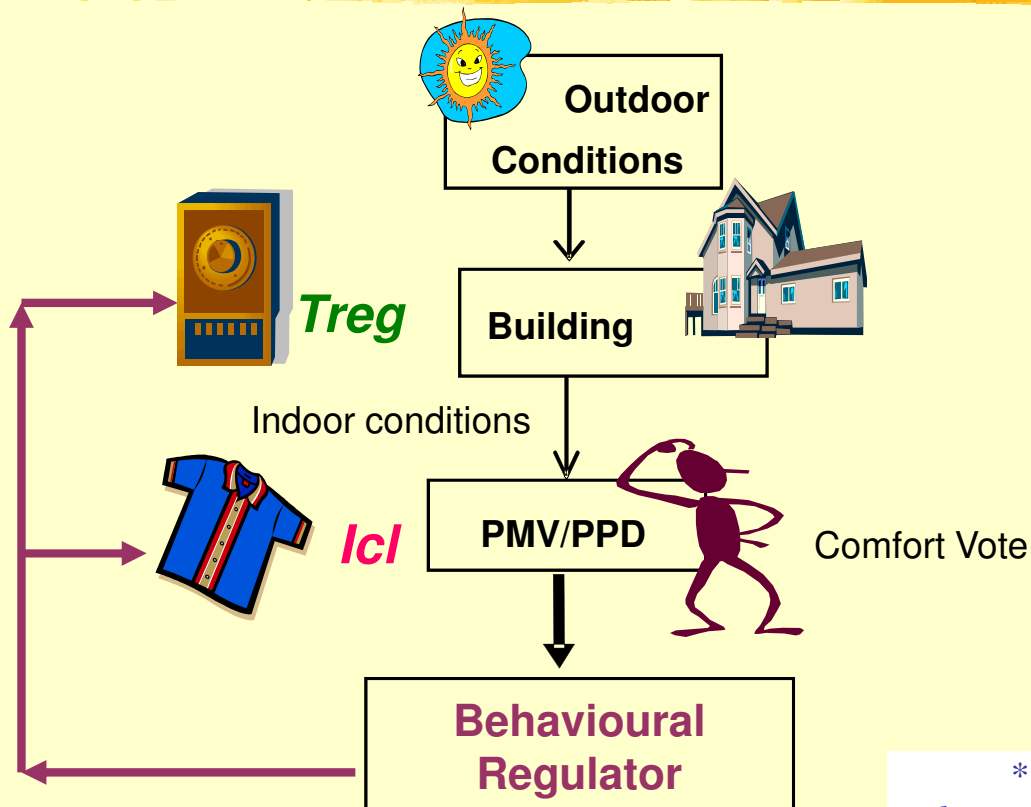
External

**TEMPERATURE
REGULATION (Treg)**

**solar blinds, lights*



Flow diagram





Ajustements in Behavioural Regulator

PMV

CLOTHING

TEMP. REGULATION

NEUTRAL: $+0.2 \leftrightarrow -0.2$

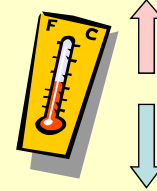
No change

No change

SMALL: $\pm 0.2 - \pm 0.5$



0.1 clo

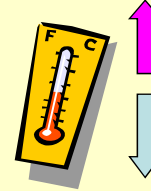


0.5 °C

LARGE: ± 0.5 and above



0.2 clo

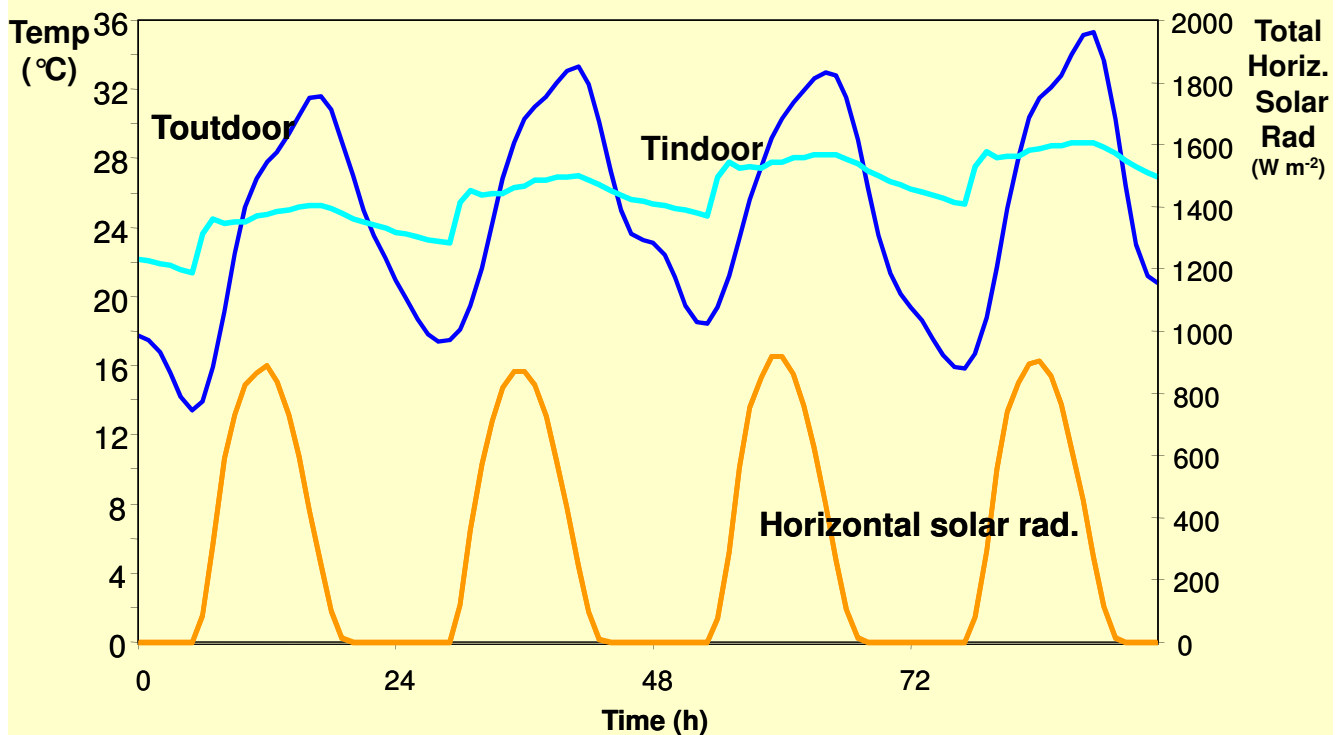


1.5 °C

Endavadan et Al. 5



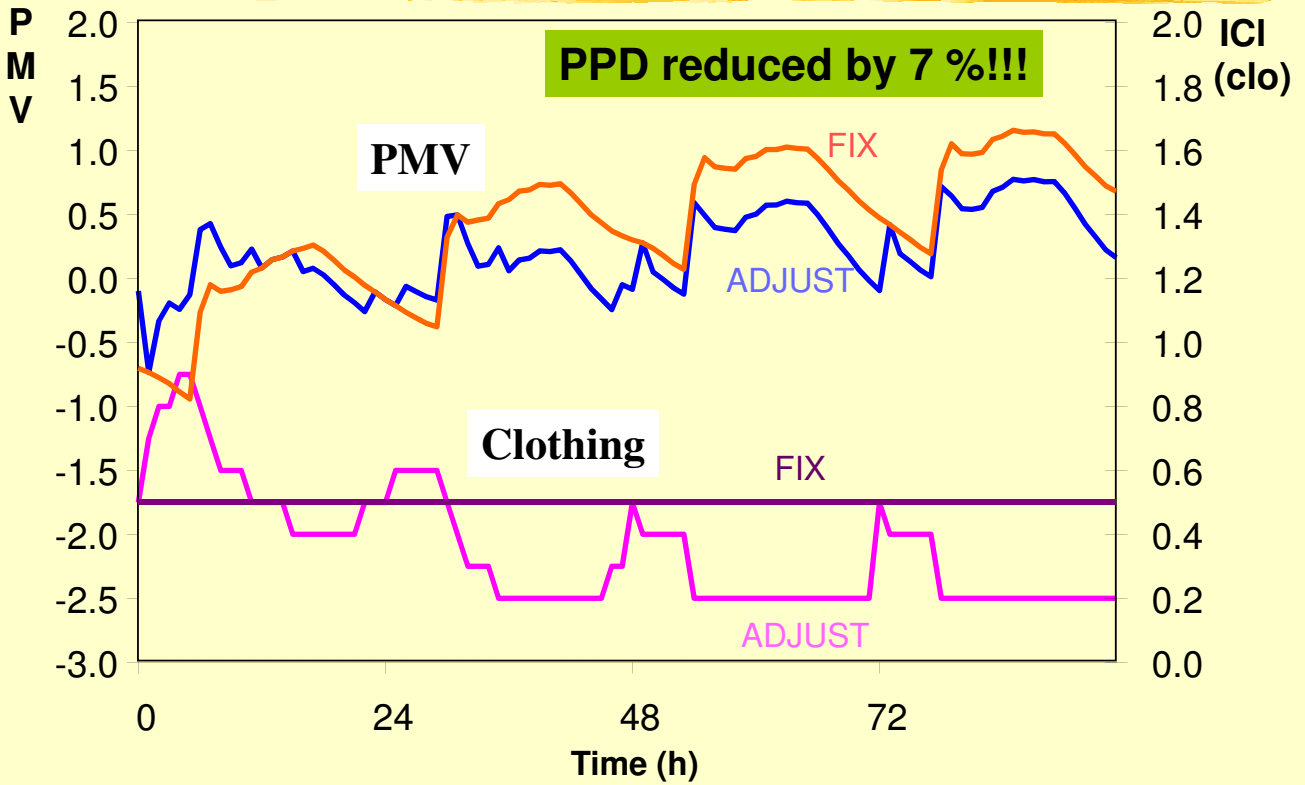
RESULTS: Meteorological conditions for Agen



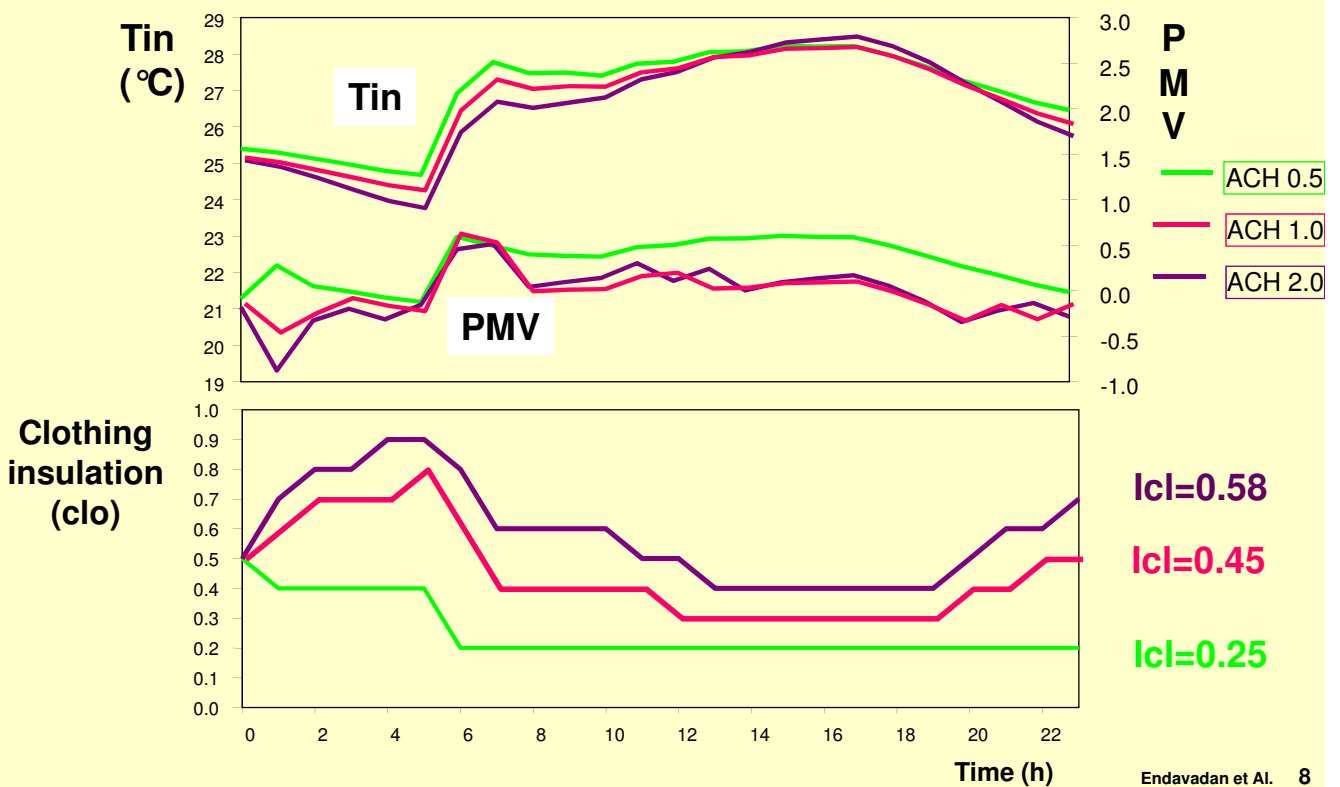
Endavadan et Al. 6



Naturally ventilated Heavy Building

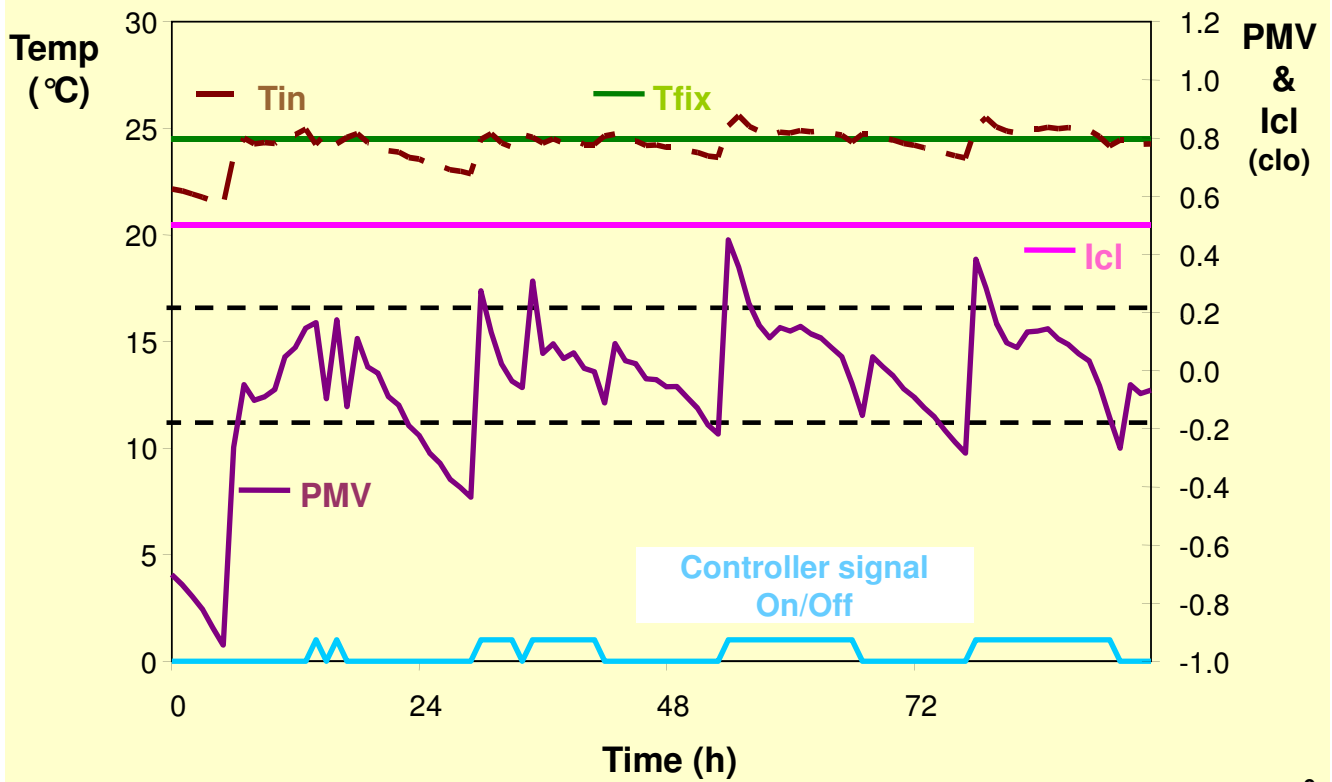


Different rates of air change

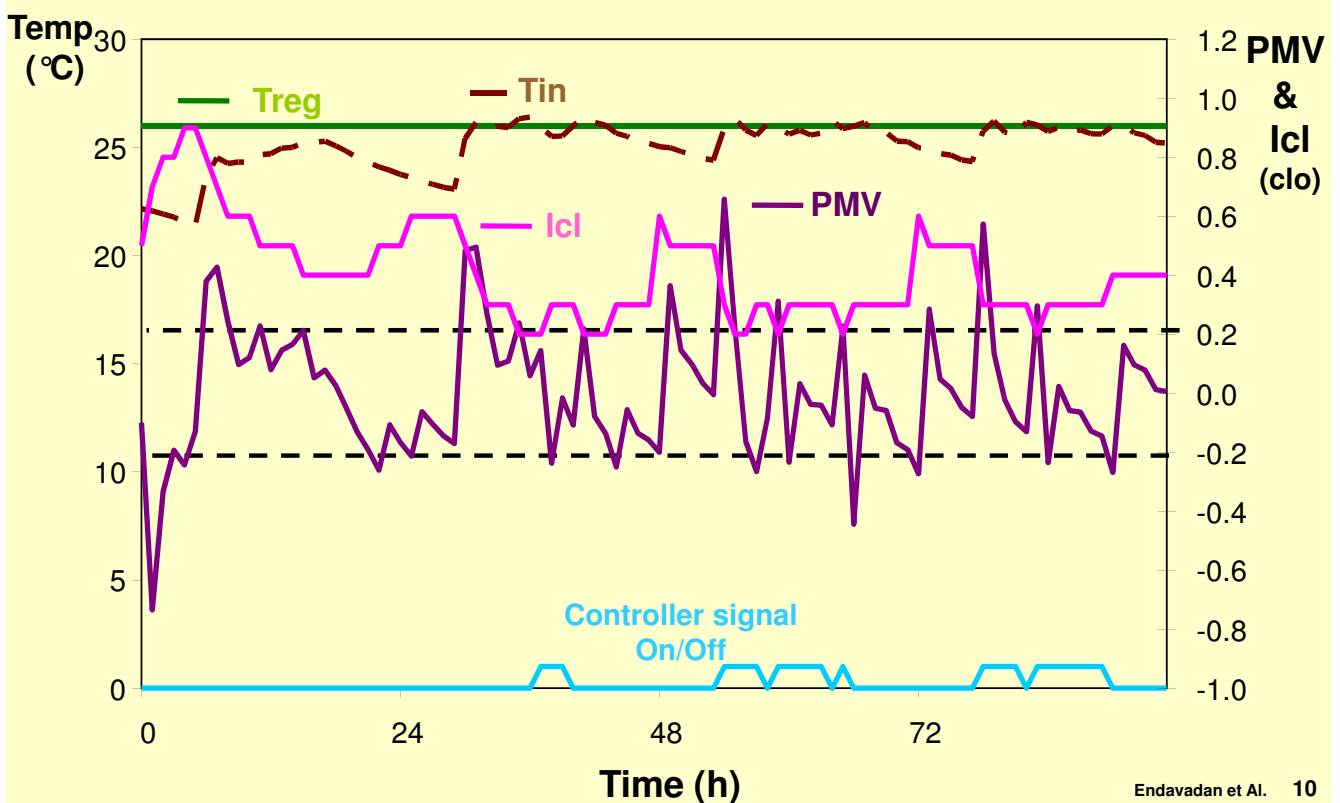




FIXED REGULATION

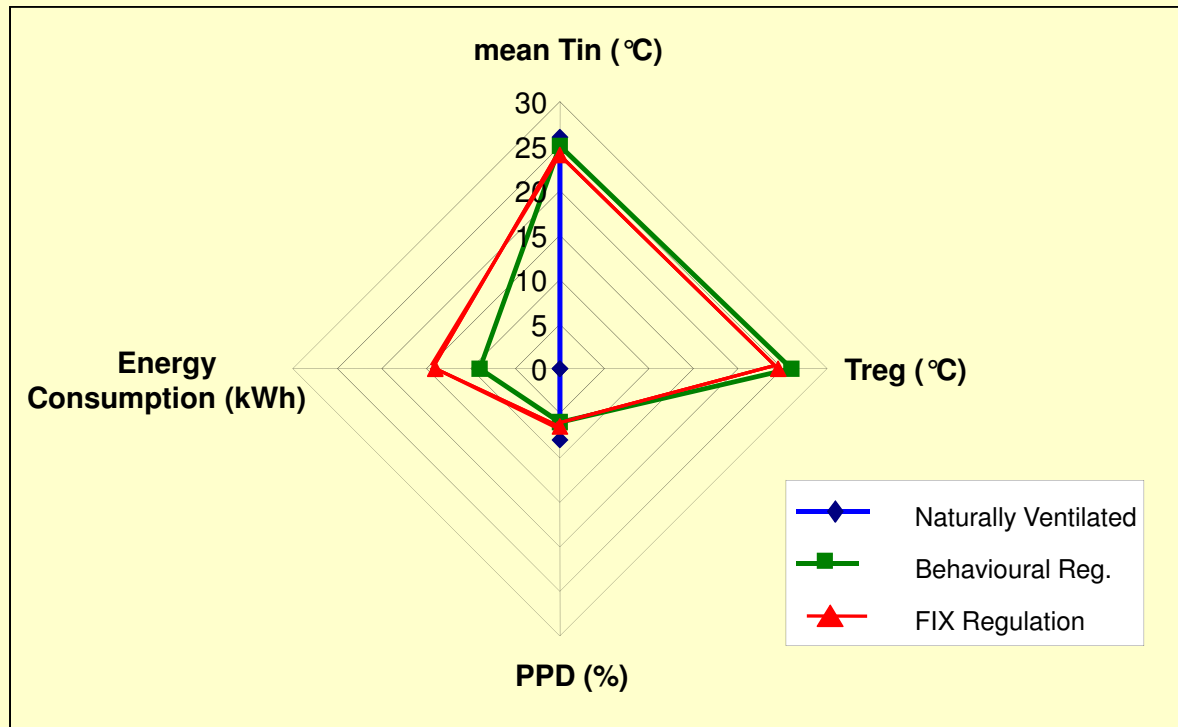


BEHAVIOURAL REGULATION





Comfort ---> Energy Consumption

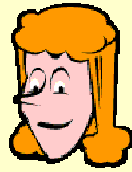
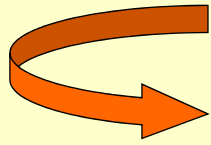


Conclusions

- * **Individual responsibility and motivation** to establish *'an intelligent clothing attitude'* to minimise energy consumption!!!!!!
→ Approach presented: GLOBAL – PMV used as a first estimation.
- **Future perspective:** develop a **local behavioural regulator** based on local thermal sensations.
- ** **Future aspect:** By developing an understanding of **'human behaviour'** in offices, the global HVAC systems could be replaced by individual conditioning/ ventilating systems.



**We need more
people like
these**



rather than these

