

DEVELOPMENT OF HUMANIZED ADAPTIVE BASELINE INFORMATION TECHNOLOGY (HABIT) FOR ENVIRONMENTAL CONTROL SYSTEMS

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ABSTRACT

Many existing Building Management systems (BMS) used for building services system control were not designed to incorporate records of occupant view and did not integrated the real-time occupants' response in order to fine tune the building services system to the individual demands in a dynamic manner. This study based on a survey conducted for collecting occupant's feedbacks towards indoor thermal environments, proposed a Bayesian approach in operation of building services systems of air-conditioned buildings in a humid and subtropical climate in Hong Kong. It enables an adaptive interface relationship between occupants' complaints of indoor thermal environment and the set point of environmental control system. With the technology developed in this study, the design condition in existing BMS systems would be updated automatically with occupant's feedbacks. Compared with traditional 'complaint and readjust-the-set-point' process, the energy saving of air-conditioning system in a hot and humid climate was demonstrated. This algorithm could be useful in optimization of the acceptance of an indoor thermal environment serving a group of occupants with a single set point, as determined by physical measurements and subjective surveys.

KEYWORDS

Humanized Adaptive Baseline Information Technology (HABIT) Building, Occupants' view, Building Management System (BMS)

INTRODUCTION

Thermal comfort is defined in terms of the perception of satisfaction that a subject experiences in a given thermal environment (ASHRAE 1992, 1995; Fanger 1972). The sensation of thermal comfort is found to be dependent on six environmental and physical factors: air temperature, radiant temperature, air speed, air humidity, and metabolic rate as well as clothing level of the subject (ASHRAE 1992, 1995). Temperature ranges, as a dominant environmental parameter for the thermal comfort sensation, under certain humidity and air speeds were also specified in design guides for minimizing thermally unsatisfactory response by building occupants (Mui and Wong 2006). Some survey studies shown that these design criteria were adopted in specifying the temperature set point for air-conditioning systems in Hong Kong and a single set point of either 23°C for high grade buildings, 24°C for average buildings, or 25°C for public buildings was commonly adopted (Mui 2006). It was estimated the energy impact of 1°C air temperature in 22°C to 25.5°C for some air-conditioned office buildings in Hong Kong was about 3% to 4% (Lam and Hui 1996).

The energy crisis in 1973 triggered the increased use of automated energy management systems. The building intelligence, implemented in a building management system (BMS), had become a salient feature of air-conditioned buildings since 1980s. The systems were designed to serve building occupants at a desired comfortable, safe and sustainable indoor environment with a set of

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'pre-determined' environmental control parameters, e.g. air temperature, relative humidity, carbon dioxide (CO₂) concentration. However, the system has yet not integrated the real-time occupants' response in order to fine tune the building services system to the individual demands in a dynamic manner.

With a survey of occupant's views on the temperature set-point of a large in-use air-conditioned office in subtropical climate, a control algorithm using Bayesian was used to develop an adaptive interface relationship between occupants' complaints of indoor environment and fine-tune mechanism for the set points of the environmental control parameters (Mui and Chan 2003; Mui and Wong 2006; Wong et al. 2006, 2007). This algorithm intends to optimise the acceptance of indoor environment as determined by design guidelines and subjective responses from a number of building occupants. In particular, the Bayesian algorithm would be applicable for combining various kinds of information pertaining to event occurrence and has been applied in predicting outdoor environmental parameters (Wong et al. 2007). In this study, the set-point of the indoor air temperature of a centralized air-conditioned system serving a number of occupants, which have been selected at the minimum predicted percentage dissatisfied of occupants, is 'updated' by an 'observed' likelihood derived from the occupant's feedback, which represents implicitly the desired environmental condition. It also enables an effective feedback to the occupant complaints by indicating the corresponding system response and probably the 'benchmark' of the occupant request in terms of the desired temperature set-point.

DEVELOPMENT OF HABIT

Complaints on the environmental discomfort have been reported in many air-conditioned spaces (Mui and Wong 2006). The environmental parameter set point of the building services system would be reset, according to the complaints, with expert opinion and the reset 'set point' is deemed to be satisfactory until another complaint is reported. This complaint-and-re-adjustment process would be implemented with a control algorithm incorporated into the building management systems through computer networks, which adopts the occupant's views as a primary control parameter in adapting the environmental condition, known as the Humanized Adaptive Baseline Information Technology (HABIT), as shown in Figure 1. This technology argues the occupant's view could be adopted as an essential control parameter for an indoor environment and the use of this data could lead to an effective control of building services system. Through a computer workstation, an occupant could feedback for the perceiving environment and could contribute to maintaining the suitable indoor environmental condition.

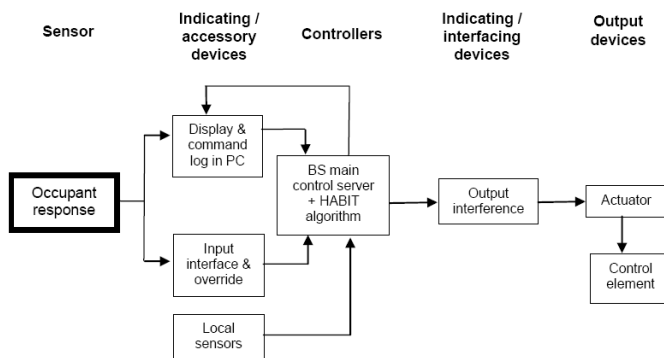


Figure 1. Flow control diagram for the HABIT building

The air temperature set-point in a large air-conditioned office is used as an example of environmental control parameter for discussion. For the identification of temperature set-point, international design guidelines and codes of practice are used as references to determine an expected temperature setting $T_{a,0}$ of the system, by the expected values of an acceptable thermal comfort temperature from a number of occupants in the space. Suppose the temperature expected by an individual occupant T_a relates to the predicted percentage dissatisfaction (PPD) of thermal comfort overall, then $T_{a,0}$ would be set at the minimum PPD (ASHRAE 1992; Wong et al. 2006, 2007).

$$T_{a,0} = \langle \tilde{T}_a \rangle = \left\langle \int_{T_1}^{T_2} f(T_a) dT_a \right\rangle \quad \dots (1)$$

where, T_1 (°C) and T_2 (°C) are arbitrary constant temperatures for the control algorithm.

Complaints related to the thermal environment at a temperature T would be recorded in an air-conditioned space (Mui and Wong 2006). A complaint made by an occupant at certain level of satisfaction ξ would be classified as 'Hot' ($T = T^+$) or 'Cold' ($T = T^-$); a step function describing the percentage of dissatisfied occupants at a range of temperature is assumed,

$$\xi(T) = \begin{cases} 1-\lambda & ; \left\{ \begin{array}{l} T < T^+; T > T^- \\ T \geq T^+; T \leq T^- \end{array} \right. \end{cases} \quad \dots(2)$$

where, λ is an arbitrary selected parameter indicating the probability of acceptance for a temperature set point. For an occupant making a complaint, $\lambda < 0.5$ with a minimum value of 0.05 (i.e. minimum PPD) is used.

Assuming the complaint is a sign of, to some extent, dissatisfaction among the occupants in the space, the distribution of the temperature expected by every occupant i would be expressed by,

$$\tilde{T}_{a,i} = \xi(T) \quad ; \quad T_1 \leq T \leq T_2 \quad \dots(3)$$

Given i at certain T in the temperature domain (T_1, T_2), a Bayesian approach is adopted in evaluating the suitable set point of temperature T^* for an air-conditioned space serving a number of occupants (Franco et al. 2004; Lee 2004; Sucar et al. 1997),

$$T^* = \left\langle p(\tilde{T}_{a,0} | \tilde{T}_{a,i}) \right\rangle = \left\langle \frac{p(\tilde{T}_{a,i} | \tilde{T}_{a,0}) p(\tilde{T}_{a,0})}{\sum p(\tilde{T}_{a,i} | \tilde{T}_{a,0}) p(\tilde{T}_{a,0})} \right\rangle \quad ; \quad i = 1, \dots, \infty \quad \dots(4)$$

where, $p(\)$ is the probability density function of a variable; $\langle \tilde{T} \rangle$ is the expected value of the distribution of temperature set points expected by the occupants.

MODULE OPERATION

Figure 2 shows a schematic block diagram for the HABIT module. For the implementation of the control module in HABIT building, occupants will first activate the socket (client side) to request the connection with the socket server. The socket server will listen to the socket (client side) and establish the connection. Once connected, the socket server will receive the occupants' responses and microclimate information from the occupants' workstations. An acknowledgement will be sent to the

socket (client side) from the socket server. At the same time, occupants' responses and microclimate information will then be passed to the microclimate database. The microclimate settings will be modified based on the occupants' response using the HABIT algorithm. Updated settings will be sent to the BS main control server for adjusting air-conditioning system and other microclimate control device. The setting information will also be reported back to the socket (client side). If no further requests from the occupants, the connection will be terminated.

The temperature set point of an air-conditioning system for a space would be adjusted so that the thermal comfort condition would satisfy most of the occupants. In this study, the survey indoor environments would be used as references to determine an expected temperature set point of the system for a pre-occupied space. The minimum PPD is determined by the expected values of an acceptable thermal comfort temperature from the occupants in the space, with the temperature expected by an individual occupant.

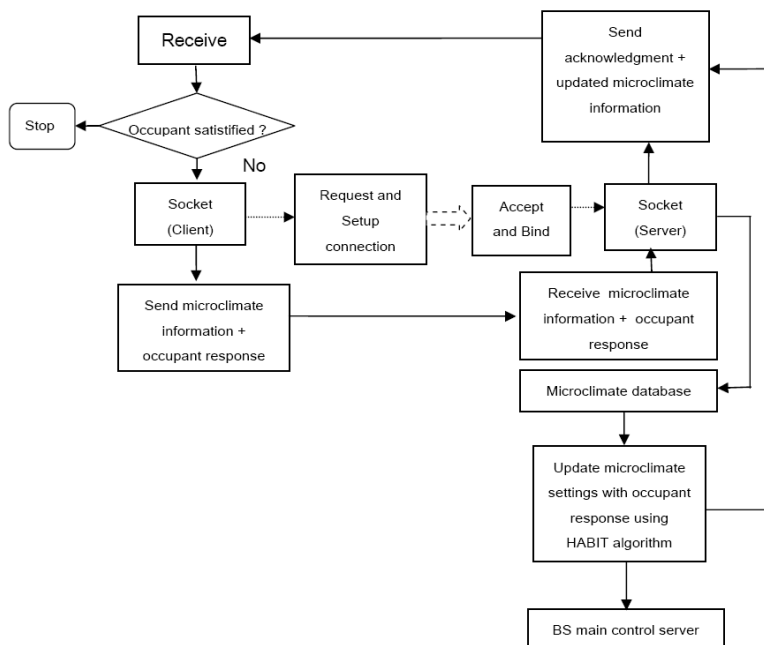


Figure 2. HABIT operation

APPLICATION EXAMPLE

The proposed HABIT was used in determining the air temperature set-point in a large air-conditioned office. Table 1 shows the survey results of thermal comfort parameters in some indoor office environment of subtropical climate (Chow 1996; Mui and Chan 2003; Mui and Wong 2006).

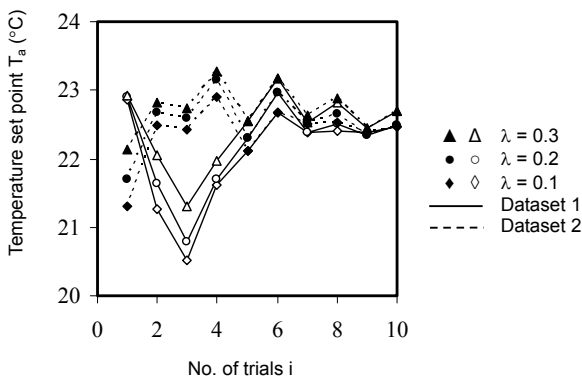
Table 1. Typical indoor office environment in subtropical climate

Typical design values	air movement	Occupant activities	thermal resistance of an occupant's clothing	mean radiant temperature	relative humidity
Range	0.2 to 0.4 ms ⁻¹	1 to 1.4 Wm ⁻²	0.124 to 0.186 m ² °CW ⁻¹	±1.5°C from the ambient temperature	50 to 70%

Survey results of occupant's response at certain temperature point in some air-conditioned offices were referred (Mui and Wong 2006). In this study, two sets of ten complaints shown in Table 2 on thermal discomfort at temperatures from a survey were selected as an illustrative example of the input parameters for the HABIT algorithm. A Monte-Carlo sampling technique was used to generation the complaint dataset from the surveyed frequency distribution of 'complaint' temperature (Millard 2002; Wong et al. 2007). With the prior temperature profile predicted by the PPD/PMV model by Fanger (1972), the output of the expected 'temperature set points' of HABIT according to the occupants' complaints are shown in Figure 3. The results showed that these temperature set points would approach the expected temperature range as surveyed.

Table 2. Example complaints about indoor air temperature

Record no. i	1	2	3	4	5	6	7	8	9	10
Dataset 1										
Complaint Temperature	Hot	Hot	Hot	Cold	Cold	Cold	Hot	Cold	Hot	Cold
	28	23.6	22.8	21	21.3	22.1	23	21.4	24	22
Dataset 2										
Complaint Temperature	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold
	23.6	21	28	21.3	22.8	22.1	24	21.4	23	22

**Figure 3.** Simulated temperature set points at occupants' requests using HABIT algorithm

Compared with traditional 'complaint and readjust-the-set-point' process, the proposed HABIT would be useful in fast tuning the temperature set point of a post-occupied air-conditioned space and in determining an efficient operation of an office air-conditioning system in a hot and humid climate without the penalty of thermal comfort. Hence, the proposed Bayesian approach would be a useful tool in determining and fine tuning the suitable temperature set point of the central air-conditioning system for a post-occupied air-conditioned space according to the occupants' complaints.

CONCLUSIONS

The HABIT technology integrates the collective real-time feedback control from end-user(s), with a balance of the imposed design conditions of the system in determining the suitable set point for a system serving a number of occupants. Apart from solving the negative response from the occupant, the performance of the building services system can be monitored systematically; and the proposed technology enables an effective feedback to the occupant complains by indicating the corresponding system response and can benchmark the occupant request in terms of the desired set point. This technology can be used for the formation of the updated design condition in the existing BMS system without any deterioration of the indoor environment. The expected cost would be low for programming the existing system but the alternation to the existing building systems / daily operations is not necessary.

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