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Saving energy when using air conditioners in offices—Behavioral pattern and design indications

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ABSTRACT

Air Conditioners (ACs) in office buildings consume so much energy that the Chinese government enacted a regulation to limit the temperature setting range. To evaluate its effectiveness and provide clues for new behavior change methods, the study surveyed 527 office workers' knowledge of the compulsory approach, temperature sensation and preferences. The latter is included to evaluate the reasonableness of the regulation. Their actual behaviors covered in this survey include factors influencing temperature setting, operating patterns in setting, and readjusting behaviors after setting. The aim is to find possible ways to encourage higher temperature setting and correct operation. The results show that although the regulation is reasonable (within the [26 °C to 28 °C] range), more than half of the users violate it with an average setting at 24.9 °C. The low awareness of the regulation (31.9%) can only account for part of the ineffectiveness: people with knowledge set higher, but still below 26 °C. The survey also found some non-comfort motivations that can be potentially used to encourage higher temperature setting: personal health, noontime napping, connecting with nature, and protecting the environment. On the contrary, office workers would set the temperature lower when they first entered the office. It should be noted that office workers strongly consider colleagues when setting the temperature, but generally do not consider electricity consumption. Some of their operating patterns should also be paid attention like setting a low initial temperature; and constantly shutting off and turning on the AC. The discussion includes applications of these findings in terms of enhancing user motivation and simplifying thermostat operation.

1. Introduction

1.1. Energy problem: ACs play a large part

With a higher standard on the thermal comfort, people are relying more on air conditioners (ACs) to gain comfort in modern life. In developing countries like China, ACs are covering increasing building areas. According to [1], the sale of air conditioners is currently increasing at a 20% annual rate in China. This leads to a rapid growth in energy consumption by ACs. For example, in Shanghai, one city of China with a hot summer and cold winter climate, central air conditioning consume almost 31.1% of the total energy consumption in large-scale public buildings [see in [1]]. The energy challenge also exists in developed countries where HVAC almost consumed half of the energy in buildings and 20% of the overall national energy consumption [2]. Both residential and commercial buildings contributed to this consumption [2], and among them, office buildings have a large share. In office settings, people are not as free as they are at home where they can change clothes easily or open windows when they want, thus increasing the possibility of air conditioner usage. Hwang et al. [3] showed that 57% of office workers chose to turn on air conditioners over other approaches to make themselves comfortable, as compared to only 16% in residential homes. Therefore, it is important to decrease the energy consumption of ACs in office buildings.

Although various ways including technological innovation can decrease energy consumption of ACs, changing user behavior is critical to energy saving. In fact, researchers have constantly found a "rebound effect" of energy efficient products [4,5]: people use the products more when they know the products are energy efficient. Studies in residential houses also showed that electricity consumption varied a lot with user behaviors [6–9]. The consumption sometimes can be as high as 4:1 in identical houses [10]. Therefore, this study aims to survey office workers' ACs using behavior, seeking chances to save energy via behavior change. Since in most Chinese cities, the electricity shortage usually happens in hot summers when ACs are pervasively used, the target behavior is limited to the summer season.

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1.2. Two possible behavioral changes to save energy

Due to the reliance on ACs to cool off in offices [3], behavior changes for energy saving had better focus on changing the process of operating instead of trying to reduce using. This leaves us two possible behavior changes: set at a relatively higher temperature, and adopt correct operating patterns.

1.2.1. Increase the temperature when setting air conditioners

Higher temperature setting is not easy to obtain because thermal comfort is usually the most important motivation to use ACs, and it can only be attained within a temperature range. The first way to overcome the comfort need is resorting to compulsory forces. The regulation on AC temperature control from the State Council of China is one of these restrictions [11]. According to the regulation, in public places including offices, temperatures should be set at no lower than 26 °C in the summer. Although the regulation has been disseminated via various media forms, the effectiveness of the regulation hasn't been evaluated. Previous studies on government restriction hasn't been successful as expected: Luyben [12] found that only 27% of the families responded to the president appeal on the thermostat setting, and those who knew the appeal did not behave differently from those who did not. The author concluded that room temperature might be more important than antecedent conditions like appeal or price. This is supported by another study where people did not follow the government suggestion of setting at 28 °C and use the ACs along with fans to cool off in the summer [3]. People simply did not want to adopt this measure at the sacrifice of their comfort. Judging from these evidences, the awareness of rules is only a necessary but not sufficient condition of behavior change. It must be reasonable in terms of comfort. Therefore, besides the investigation of office workers' knowledge of the regulation and actual setting, their temperature sensations and preferences were also addressed in the study to get a proper range of temperature settings.

Government regulation is an external reinforcement of setting high temperatures, but users do have internal reasons that can be enhanced to deviate from the most thermally comfortable setting. According to Fanger and Toftum [13], thermal comfort is determined by air temperature, air humidity, mean radiant temperature, relative air velocity, activity level and thermal resistance of clothing. However, Williamson and Riordan [14] found that about 25% of the heating or cooling events were due to non-comfort factors. One of the prominent factors is the energy cost. In fact, this is the underlying logic of some feedback-based interventions [15–17], which promote energy-saving settings by informing people of their consumptions. However, these interventions are designed for residential buildings where people pay their own electricity costs. In the office context, energy cost may not remain to be a good motivator because they do not pay for it [18]. Besides the energy cost, people's actual behaviors may be determined by factors like care for environment and other people. For instance, environmentalists do not feel comfortable in hot summer weather as other people, but they prefer to set the temperature high to avoid high CO_2 emission, whether it is at home or in offices. Apparently, the feedback device displaying the factor the users concerned most will be the most effective. Hence, this study surveyed the factors that affect people's AC settings to find the potential best-performed motivators in feedback devices. On the contrary, those factors urging lower temperature settings were also investigated for restriction purposes.

1.2.2. Adopt correct operating patterns of air conditioners

Temperature is not the only setting that can be controlled by office workers. A thermostat is usually also equipped with the functions of adjusting wind speed, humidity, etc. Programmable thermostats also have scheduling features that allow people to program the ACs to run or shut off at certain times. Judging from this, a good combination of these features can save a lot of energy. For instance, office workers have relatively fixed schedules, so it is very suitable to time the ACs in case they forget to shut them off. However, it has been found in residential houses that the use of the schedule features in programmable thermostats is limited [19]. In office settings, the usage of the programming function and other features still need investigation to find possible energy saving opportunities.

Setting a thermostat is not the end of thermal context control. Due to the delayed feedback from room temperature change and general misconceptions, people usually find their initial setting inappropriate and have to adjust again after some time [20]. In this process, inappropriate operation patterns may lead to energy waste. For instance, when operating air conditioners at home, a popular misconception is that the lower the setting, the faster the air conditioner will cool the room [21,22], so the corresponding behavior may be setting the thermostat at a low temperature and setting it back when it cools off. Readjusting patterns like this need to be explored to check whether office workers have the same problems.

To sum up, ACs consume lots of energy in office buildings, contributing much to summer electricity shortages in China. To change office workers' behavior in terms of setting higher temperature and adopt correct operating patterns, this study first evaluated a compulsory approach to save energy and then checked its reasonableness considering temperature sensation and preference. To find out internal factors that can be enhanced by feedback devices to promote voluntary behavior change, the questionnaire also included items focusing on non-comfort factors that may influence office workers' temperature settings. Current AC operating patterns were also addressed, including the functions used and the readjusting behaviors. Section 2 of this paper introduces the development of the questionnaire and the distributing process; this is followed by the results of knowledge about the compulsory regulation, temperature sensation, internal factors that influenced temperature setting, and operating patterns. Finally, the indications for designing energy saving thermostats are discussed based on the findings from the survey.

2. Method

Questionnaires were used to address the topics above. As adopted by Lin and Deng [23] and Frontczak et al. [24] in thermal environment studies, this method is well fit for exploring people's knowledge and behavioral patterns. However, the survey is different with current studies in sensation measurement [e.g. 25, 26], thus needing further remarks. The temperature sensation in this study is not the sensation when people are answering the questions (under certain contexts), but perception of temperatures in general. Although personal activity, clothes, sunlight, etc. also affect people's sensations, they cannot be isolated from temperature in practice. In daily life, people build a match between the sensations resulting from the mixed effects of all these factors and temperature information gathered from thermostat displays. The government regulation on temperature setting also only restricts the "temperature", considering all other factors as the typical contexts people are usually in (i.e. background context). Therefore, to evaluate the reasonableness of the regulation, general rather than specific temperature sensations should be rated based on personal experience.

2.1. Questionnaire development

First, in-depth interviews with six office workers on thermostat usage were conducted. Their responses were categorized based on our interested topics: the temperature settings, the factors influencing their settings, and possible knowledge of ACs related regulation. Second, integrating the interview results and the current literature, questionnaires with 33 items were developed and pre-tested by 8 professionals in measurement psychology to revise the ambiguous items and other statement inappropriateness. The final questionnaire consisted of four parts:

(1) *Knowledge of the government regulation:* single choice of either knowing the government regulation or not; if yes, write the lowest temperature for summer.
(2) *Temperature sensation and preference:* rate a certain temperature (19–31 °C) as cold, cool, slightly cool, neutral, slightly warm, warm, or hot; select the preferred ones from the seven feelings.
(3) *Behavioral pattern:* rate how a statements on thermostat function usage, temperature setting, and readjusting behaviors after setting the AC are consistent with one's own behavior on a 7-point Likert scale from 1 (very untrue of me, strongly disagree . . .), to 7 (very true of me, strongly agree. . .); answer their common setting by filling in the blank.
(4) *Respondent information:* respondent's gender and age information.

2.2. Questionnaire distribution

The questionnaires were distributed in August and September of 2012 when people in most parts of China are using the AC for cooling. They were sent out in two ways. The first was sending them to office workers that were having part-time classes. In total, 200 questionnaires were sent out in this way to people in offices that could control their thermal environments themselves. The second way was inviting working friends and relatives to complete the questionnaire online. In this case, they sent the hyperlink to their colleagues. In total, 413 questionnaires were completed online after removing the respondents without controllable thermostats (78).

3. Results

The printed questionnaires had 16 invalid cases for missing data. After removing them, 174 questionnaires were left with a valid rate of 91.6%. Sixty of the online surveys were also removed for short competition time, and unreasonable answers that indicated careless responses for the remuneration. Therefore, 353 questionnaires were valid with a valid rate of 85.5%. In total, 527 questionnaires were collected for further analysis. The questionnaires covered 24 of the 32 provinces in China. The respondents had an average age of 30, and females consisted of 58.9% of the entire sample.

This section first presents results on how the government regulation is implemented, followed by the temperature sensation and preference aiming to check the regulation's reasonableness. Lastly, the influencing factors of AC setting and operating pattern are presented.

3.1. Knowledge about the temperature setting regulation

If the regulation was to be obeyed, it must be acknowledged first. However, as shown in Fig. 1, 56.5% of the respondents did not know the regulation, and 11.2% of the people who claimed to know the regulation had wrong answers for the lower limit of the allowed temperature. Overall, only 31.9% of the people knew that the

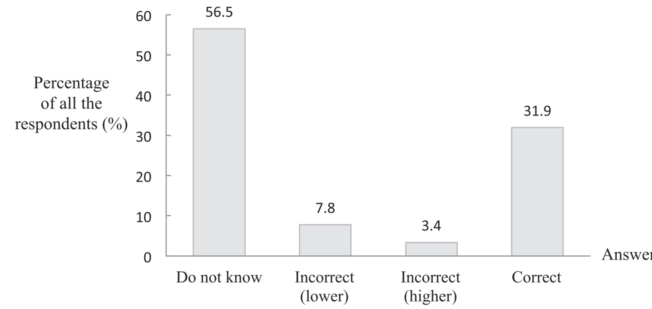

Fig. 1. Office workers' knowledge of the government regulation on temperature setting.

temperature should be set no lower than 26 °C in the summer. When coding that 39.1% as 1 and the remaining people as 0, a positive correlation was found between the knowledge of the regulation and actual settings: Spearman's $\rho = 0.16$, $p < 0.001$, indicating that people aware of the regulation had higher temperature settings of ACs (25.4 °C vs. 24.6 °C).

3.2. Temperature sensation and preference

The following Fig. 2 shows office worker's sensations of given temperatures. Since the temperature sensation scale only had seven discrete values and the sensation vote overlapped across many temperatures and respondents, the frequency of votes for a corresponding temperature was represented by the size of the circle in the graph. The size of the circles reflects the general pattern of sensation for the entire sample: ≤22 °C (cool, cold); 23 °C, 24 °C (neutral to slightly cool); 25 °C, 26 °C (neutral); 27 °C, 28 °C (neutral to slightly warm); ≥29 °C (warm, hot). The red dots in Fig. 2 represent the average sensation values for a corresponding temperature. The intersection point of the line with the *x*-axis was estimated to be 25.5 °C through linear interpolation.

Since people may prefer several sensations, sensation preference was displayed based on the percentage of preference votes of every sensation as Fig. 3. The sensation range [−1,1] was preferred by 90.4% of the respondents, which consisted of the majority of people. Moreover, smaller ranges greatly decreased temperature sensation preference and larger ranges could not add value in the preference, indicating that the proper temperature settings should

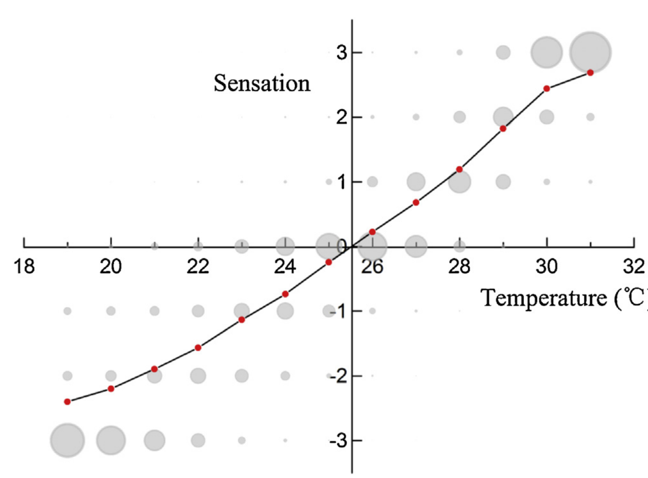

Fig. 2. Temperature sensation distribution and average value of office workers. The size of the circle represents the frequency of being chosen by respondents for a certain temperature. The line graph displays the average sensation value for corresponding temperatures. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

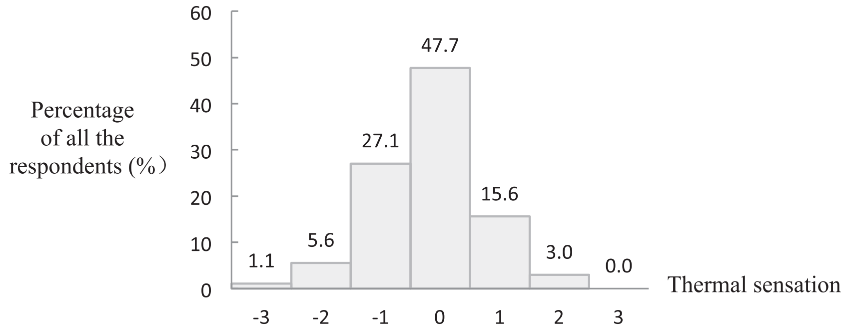

Fig. 3. Preferred temperature sensation.

be perceived within this range. When integrating Figs. 2 and 3, it is clear that the preferred temperature range is [23 °C to 28 °C], where [26 °C to 28 °C] is the preferred energy saving range.

3.3. Actual temperature setting and factors in adjusting

Fig. 4 shows the proportion of different temperature settings. They ranged from 15 °C to 28 °C with an average value of 24.9 °C (SD = 2.2 °C). More than half (50.2%) of the settings were below 26 °C, and 36% of the settings were 26 °C, which was the most common setting and also the lower limit in government AC temperature setting regulation. Fig. 4 also shows people's preferred temperatures transformed from their preferred sensations. The peak of preferred temperature was consistent with that of the actual setting (25 °C and 26 °C), but it distributed within a wider range with smaller deviations (0.053 preferred vs. 0.098 actual).

The difference between temperature preference and actual setting might be due to other factors. The following Fig. 5 shows the nine factors explored in the survey. The gray bars on the right represent the scores of the factors that had significant influence on temperature setting, while the gray ones on the left were factors that people did not consider when operating ACs.

Respondents considered other people in their offices the most when setting temperatures ($t_{1/2}(526) = 29.6$, $p < 0.001$), followed by personal health ($t_{1/2}(526) = 20.9$, $p < 0.001$). They would also set the temperature higher when having a noontime nap, considering the environmental protection and connection with nature. Comparatively, they report setting lower temperatures when they just entered the office from the outside ($t_{1/2}(526) = 4.4$, $p < 0.001$). However, they would not set it lower to cool their computer, water and other similar things ($t_{1/2}(526) = -13.1$, $p < 0.001$) or simply to resist sleepiness ($t_{1/2}(526) = -17.2$, < 0.001). It should be noted that electricity was not considered as very important in determining AC settings (see the white bar in Fig. 5). Considering all of the factors as nine levels of a variable and the scores as the dependent variable values, an ANOVA was conducted to compare the order of the factors. The final order based on average influence was "Other people, Health > Enter the office from outside, Noontime nap, Environmental protection, Connection with nature, Electricity >Sleepiness, and Cool computer, etc."

3.4. Operating patterns

The operating patterns include the functions used for setting and the readjusting behaviors after the initial setting.

3.4.1. Functions used

To analyze how office workers operated the air conditioners, functions of a common thermostat were analyzed. Fig. 6 shows that people had little motivation to adjust humidity ($t_{1/2}(526) = -19.3$, $p < .001$). Programming features like "Time" ($t_{1/2}(526) = -15.8$, $p < .001$) and "Sleep" ($t_{1/2}(526) = -19.3$, $p < .001$) were also not used frequently. As expected, temperatures were used very often ($t_{1/2}(526) = 24.6$, $p < .001$). The function "fan" was used frequently to adjust the wind speed while cooling the office. Considering all the function as five levels of a variable and the scores as the dependent variable values, an ANOVA was conducted to compare the frequency order of the functions. The final order based on the operation frequency was temperature > fan> humidity, time, and sleep.

3.4.2. Temperature adjusting after initial setting

The choice of a temperature is not always the end to setting the AC. People may readjust the settings after some time based on their changing sensations. Fig. 7 shows the possible readjusting pattern. The first setting may fall into three categories: too high, within the desired range, or too low. People would set the temperature lower when their initial temperature setting was too high ($t_{1/2}(526) = 13.9$, $p < .001$). If their initial setting fell into the desired range, then some of them chose to do nothing while others preferred to turn off the air conditioners when they were not hot anymore ($t_{1/2}(526) = 5.8$, $p < .001$). The two behavioral patterns had negative correlations with each other ($r = -0.21$, $p < 0.001$). When the initial setting was too low, people would turn off the air conditioners ($t_{1/2}(526) = 12.1$, $p < .001$) or adjust the temperature higher when they felt cold ($t_{1/2}(526) = 9.8$, $p < .001$). Although the two choices were also negatively correlated with each other, the correlation was not statistically significant ($r = -0.04$, $p = 0.42$), indicating that the same people may choose both settings at different times.

It is worth noting that Fig. 7 is only a simplified illustration of the adjusting patterns. Besides the simplification of the relationship between room temperature and cooling time (linear), people may begin their second adjustment before the room temperature reached their previous settings. It is also possible that the adjusting pattern is the mix of the five basic patterns due to overcompensation in the process of adjusting.

4. Discussions

The survey shows that although the compulsory regulation is reasonable (within the [26 °C to 28 °C] range), it is not effective, with more than half of the users setting temperatures lower than 26 °C. Low awareness rate (31.9%) can only account for part of the ineffectiveness since although people know the regulation had higher setting; their average setting did not meet the criterion. Behavior changes due to internal reasons may happen in several situations. Individual decisions in setting the AC are heavily influenced by other people, like one's colleagues. In decreasing order, people may set the temperature higher for personal health, a noontime nap, connecting with nature, and environmental protection. On the contrary, they would set the temperature lower when

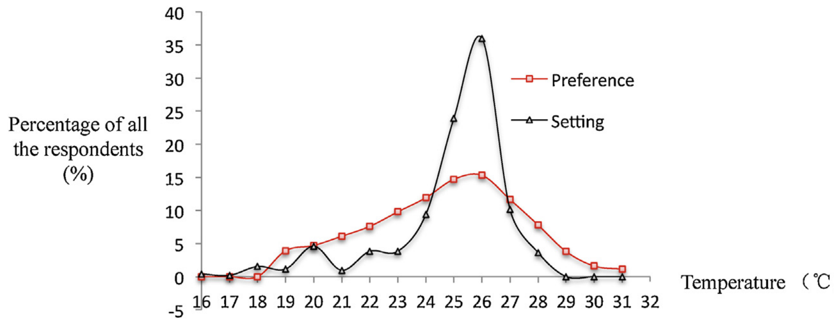

Fig. 4. Temperature setting and preference of office workers.

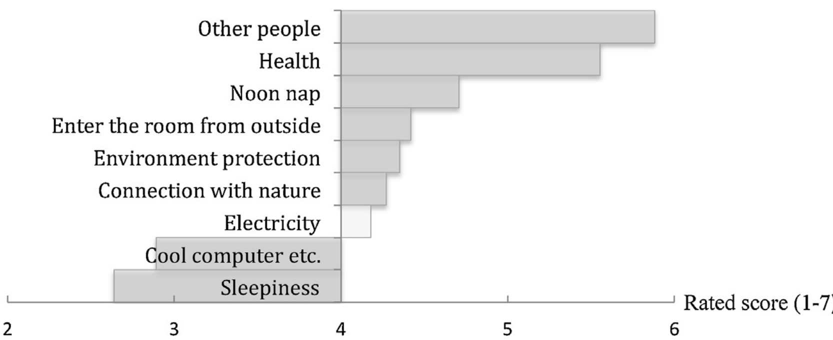

Fig. 5. Factors that affect temperature setting. The bars represent average influence of the factors on temperature setting voted on a 7-point scale. All of the scores, except for the white bar representing electricity consumption, were significantly different from the neutral value "4".

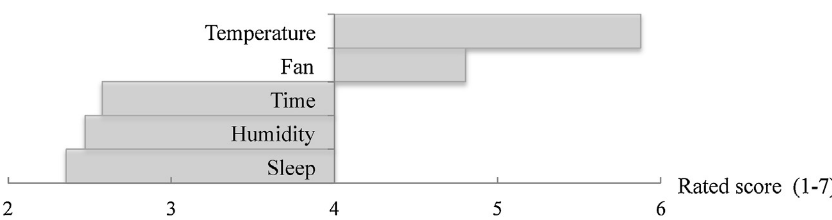

Fig. 6. Frequency of the used functions. All the functions were significantly different from four on the 7-point scale from scarce use to frequent use.

they first enter the office. It should be noted that office workers generally do not consider electricity consumption when setting the AC. They also have some behavioral patterns that need to be improved in order to save energy, such as: setting a low initial temperature, and constantly shutting off and turning on the AC afterwards. This section first discusses the temperature range for energy saving found in the survey. Closely followed were the evaluation of the compulsory regulation and an extension of evaluating

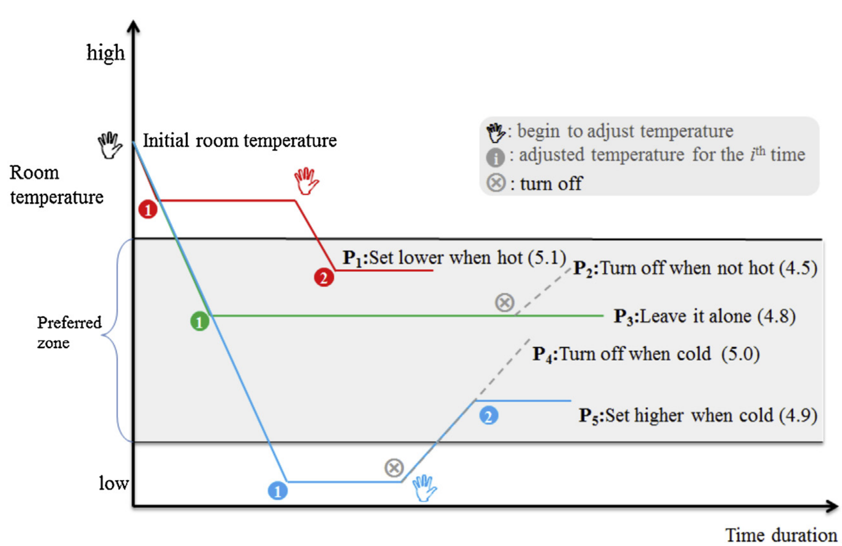

Fig. 7. Basic temperature adjusting pattern in offices. The dashed line represents temperature change after turning off the air conditioner.

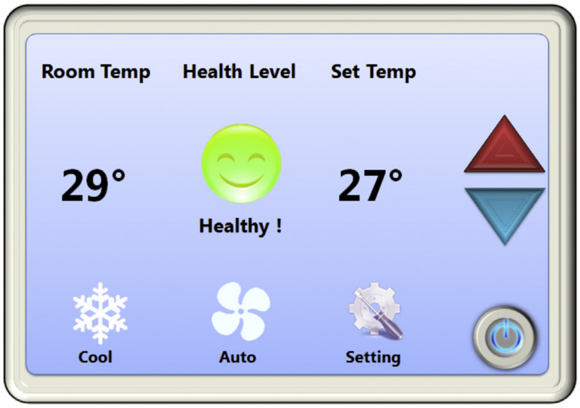

Fig. 8. Interface design based on motivation to care for health. The health level and the expression vary simultaneously with temperature setting.

previous energy feedback devices. Finally, new design clues for thermostat were discussed based on current findings and previous works.

4.1. There is room for saving

Studies aim at energy saving in buildings usually have to deal with the conflict between energy saving and comfort. The common practice in the current literature is to minimize energy consumption while keeping the comfort within a range defined by Fanger's PMV index [27]. It is assumed that people's comfort can be assured when they feel neutral (PMV = 0). However, field studies have reliably found evidences [25,28,29] indicating that the requirement of PMV = 0 does not necessarily match inhabitants' thermal comfort, and most of the time, people do not have very rigid requirements for the thermal environment [30]. In this study, the average temperature setting is 24.9 °C, which has a "slightly cool" sensation. Atthajariyakul and Lertsatittanakorn [31] found that for each centigrade increase in AC setting, 6% of the energy in Thailand could be saved. It can be inferred that much energy could also be saved in China if this average temperature setting was increased from 24.9 °C to 27 °C. In fact, considering that most people have a "neutral" or a "slightly warm" sensation at this temperature, this increase is not an excessive demand, especially when effective measures were taken to promote energy saving.

4.2. Evaluating existing energy saving measures and indications for new measures

The government regulation intends to compulsorily increase office workers' temperature setting. The temperature preference survey shows that the proper energy saving range for most people falls within the range [26 °C to 28 °C], which confirmed that the governmental regulation of setting temperatures no lower than 26 °C is reasonable. A field study conducted in a humid subtropical area of China also supported the regulation and even suggested higher settings [32]. However, it failed to accomplish this goal for two reasons. First, 68.1% of the people did not have accurate knowledge of the regulation, which is a large proportion. This suggests the limited scope in publication phase. Second, no incentives or penalties were explicitly stated in the regulation, making the regulation not effective as intended.

Although a natural deduction is to advocate the regulation and enact penalty for not obeying. However, better approaches existed. As shows by frameworks rooted in psychology [20,33,34], people should have the motivation (want to do), and ability (be able to do) related with a behavior before actually performing the behavior. Within this framework, the government regulation in fact added the "motivation to comply with law" to the ACs setting behavior. However, as shown by the survey, people already have some inherent motivations to set high temperatures (e.g. care for one's health, see Fig. 8). So long as these inherent motivations can be enhanced to promote higher setting, there is no need to create new motivations at high cost.

In residential houses, various approaches have been taken to motivate people to save energy: cost feedback [35], economic reward [36], commitment [16], etc. [see the review 37]. Among them, feedback of energy cost (or consumption) is a way to enhance existing motivations, and has been proved to be a very effective method [35]. The underlying assumption of these feedback devices is that people care about the electricity consumption. In office settings, however, Karjalainen et al. [18] and Hwang et al. [3] have found that people have little motivation to save in offices. Surveying about the specific behavior of setting high temperature (different with the general aim of energy saving, will be discussed in Section 4.3.1), the study found that even the need for connection with nature was a stronger motivator to set higher temperature that energy consumption. Therefore, it is very likely that feedback based on energy consumption will not be as effective as they are in residential houses.

Ability is a concept relative to the difficulty of a task. In line with this principle, thermostat should be designed so that people can save energy in simple ways. Although the fixed schedule of office workers makes it possible to save energy with programming features on the thermostat (time and sleep), the features were not used much, similar to previous findings in residential houses [38]. One prominent cause may be the usability problems [39,40] that made the programming feature difficult to use. The complicated operation makes people incapable of saving energy. To sum up, thermostat should be designed so that they can enhance users' motivation to set high, and simple enough for users to understand and operate correctly. The following section discusses potential methods suggested from the current findings based on the two principles.

4.3. Potential energy saving measures

4.3.1. Enhance existing motivations: Focus on specific behavior, not general aim

One may think that enhancing existing motivations is the same with enhancing energy saving motivations. However, they are different: the former targets at setting high temperature, which is a specific behavior; while the latter targets at a general aim of researchers. More specifically, "setting at a high temperature" may be motivated by care for one's own health and friends. But to the user, it has nothing to do with energy saving. The idea of obtaining target behavior via alternative motivations unrelated with the real aim is important, especially to people that are not interested in energy saving.

This study identified several motivations that were connected with higher temperature setting: personal health, environment protection, want to have a noon nap, etc. Among them, health was mostly concerned by office workers due to the prevalence of sick building syndrome (SBS) in air conditioned houses [41]. People in air conditioned contexts are more likely to get headaches, dry throat, etc. [42] or heat shock when they go outdoors due to reduced adaptation ability [41]. Usually the larger the temperature difference with that of the outdoors, the more serious these problems are. Therefore, it is natural that office workers would set a higher temperature to avoid SBS in summer. Corresponding to this, a thermostat capable of telling users the health level of their setting may be effective (e.g. Fig. 9).

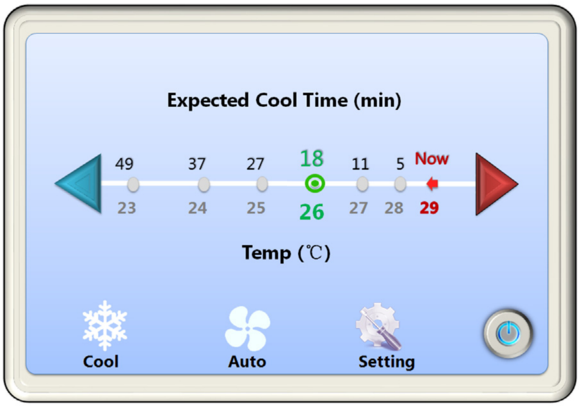

Fig. 9. Interface design with "train route map" mental model. This new mental model stimulate correct operating pattern compared with "valve" mental model. It also simplifies operations by direct tapping on desired temperatures.

Fig. 9 shows an interactive thermostat where the feedback can respond to users' setting. Depending on the temperature setting, the displayed health level can be a smiley face labeled as healthy or sad face labeled as unhealthy. More levels can be divided as needed. The thermostat was expected to be more effective than current feedback devices for two reasons: First, it gives instant feedback of the current setting on the thermostat, while traditional feedback devices give delayed feedback on an isolated device; second, the motivation to attain health is stronger than energy saving in offices.

Other motivators similar to health can also be used to design persuasive thermostats as Fig. 9. Their effects in raising temperature setting need to be evaluated in future works.

4.4. Simplify correct thermostat operations

The simplification of thermostat should be based on the behavioral patterns. For instance, the functions used more (setting temperature) should stand out beyond other functions (e.g. humility). Since previous works [40,43] have already contributed much in improving usability of scheduling features in thermostats, this section will not discuss it. Instead, it emphasizes a more prevalent behavior pattern that was also found in residential houses [21]: In Fig. 7, users having P_4 and P_5 set temperatures lower than their preferred zone, and readjust it later (shut off or set higher). Respondents' answer to the factors influenced their setting also confirmed this pattern: they would "set the temperature lower than usual when first entering the office from outside." In explaining residential thermostat setting behavior, [21] classified this pattern as a result of "valve theory" people hold toward thermostats: the lower the setting, the faster it cools off. This is true in modern varied-frequency ACs, however, in mainstream fixed-frequency ACs, the cooling speed is constant. Besides the incorrect mental model, energy waste and discomfort also comes from an inaccurate perception of cooling time. In a typical scenario, people set low to get a "higher" cooling speed, and planned to set it back to the preferred zone in a while. However, some of them forget to set it back until they feel cold (see the time duration below the preferred zone of P_4 and P_5 in Fig. 7). Therefore, an interface design can help people get rid of the "naive theory" [21] and facilitate their perception of cooling time are expected to increase their control ability.

Fig. 10 shows an example of thermostat adopting the "subway route map" as mental model. Thermostat learns from its past working log and give expected cooling time for potential settings (destinations). Setting a temperature is like selecting a destination before the travel. Since the needed time to arrive at each site is independent of user' destination, the "valve" mental model no longer existed. The timetable can also inform the users in advance the time needed to get desired setting, which reduced uncertainty in using ACs. Besides this, the new interface allow people to tap on the desired temperature in one step rather than press "temp down" button for several times. This simplification also increased users' ability.

The above two examples separately shows how the current findings can promote energy saving by stimulate motivation and increase users' abilities. In fact, the features can be integrated into one product to make it more effective. However, this study is not a direct investigation on behavior changing methods for energy saving, but an exploration on characteristics of current behaviors so that corresponding measures can be taken in the future. The design examples given above aimed to give clues, not solutions. Therefore, their actual effectiveness needs further evaluation works.

The energy issue is not a problem specific to China. For instance, HVAC systems consume 50% of the building energy and 20% of the total energy consumed in the USA [2]. The findings in this study could offer indications for related research topics in other countries as well. However, considering that different climate zones may have different comfort zones, even within China, the potential applications of the findings also need further experimental works.

5. Conclusions

Based on results from this study, people do not have extreme feelings within the temperature range of [23 °C to 28 °C], with 25.5 °C as the neutral temperature. The possible range for energy saving is [26 °C to 28 °C]. Since the average temperature setting found in this survey is 24.9 °C, there is room to improve. The energy saving range also indicates the reasonableness of the government regulation on temperature control (≥26 °C). However, the regulation is generally not effective, as evidenced by half of the respondents' violations. Limited awareness (31.9%) can only account for part of the ineffectiveness: a correlation analysis shows that people's knowledge of the regulation is positively correlated with higher temperature setting, but the "high" setting is still below 26 °C (25.4 °C).

Besides the external motivation to obey the law, the study found some internal factors that can be enhanced to encourage higher temperature setting. Most people would set the temperature higher for personal health (e.g. avoid SBS). Other factors like noontime naps, connection with nature, and environmental protection also influenced people to set higher temperatures, but had lower influencing power. These factors could be used as feedback contents in interactive thermostats that are responsive to users' settings. Colleagues can strongly affect people's decisions when setting the AC, but the direction can be lower or higher settings. It should be noted that office workers generally do not consider electricity consumption when setting air conditioners, so the persuasion measures in literature based on energy consumption or money saved were expected to be ineffective in offices.

In terms of behavioral patterns, the office workers used the "temperature" and "fan" functions a lot, but did not use the thermostat frequently for adjusting humidity or scheduling the AC. The study also found that many people liked to set the initial temperature low and would continuously shut off and turn back on the AC due to incorrect mental model and inaccurate perception of cooling time. It is strongly suggested to increase uses' correct operation of thermostats by adopting new mental models, offering additional information on cooling time and simplifying the operation.

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