Benjamin McLellan *Editor*

Sustainable Future for Human Security

Society, Cities and Governance

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Preface

This volume, *Sustainable Future for Human Security: Society, Cities and Governance*, is the first of two in a series discussing a variety of critical issues for a sustainable and secure future for humanity. Sustainability is a systemic concern that can be examined from a variety of perspectives, at various levels of socio-environmental systems and sub-systems. Sustainable development is also a highly contextual concept, with no two societies or environments being exactly identical with regards to both endogenous factors and exogenous influences. It is therefore impossible to make a perfectly comprehensive examination of the topic of sustainability when considering its applications in (or interpretations from) the real world. However, a range of examples from a variety of fields of examination, such as that offered in these two volumes, should help to create an understanding of the broad landscape of sustainability.

This volume specifically presents on topics of governance, buildings and urban development, environmental science and disaster management.

Governance is a vitally important consideration in effectively achieving the goals of society – whether this is social justice and equitable distribution of benefits or achieving environmental goals such as the mitigation of climate change. Examples in this volume cover human rights, regional identity and the expansion of a renewable energy industry.

Cities are widely acknowledged as vital elements of social change and environmental impact mitigation for the future. Populations of most countries around the world are increasingly becoming more urbanized, as people seek out opportunity in the largest markets. The impact of urban form and the performance of individual buildings as well as their combined effect is vital for the comfort and well-being of the urban population, but also has a significant impact on environmental performance – particularly the need for energy usage and the mitigation of emissions. This volume covers various topics on the impact of vegetation, open spaces and technologies for construction and infrastructure.

Socio-environmental science, linking society's needs with environmental impacts and the improvement of both, is a common theme of many of the chapters in this volume. The use and development of well-being indicators and the examination of a variety of technologies for remediation and valorization of waste are presented.

The final section of this volume is particularly important to the concept of human security, focusing on disaster management. While it is considered that climate change may exacerbate certain extreme weather, and therefore present a greater hazard to human societies, the non-climate related disasters – earthquakes and volcanic eruptions for example – are also important. This volume presents a number of disaster types and their social impacts, as well as solutions for monitoring or mitigating risk.

The chapters presented in this volume were developed by authors who presented at the SUSTAIN 2015 conference, and have been reviewed by the conference committee. The editor would like to acknowledge the efforts of the authors, the editorial staff and the Sustain Society for the successful publication of this volume.

Kyoto, Japan Benjamin McLellan

Contents

Chapter 16
Thermo-adaptive-Psychological Thermal Comfort Index of PMVtapsem Development of a PMVtap Index Based on the SEM Approach

Sugini and Jaka Nugraha

Abstract The purpose of this research is to develop the PMVtapsem index model through the development of the PMVtap index of Sugini (2007) based on the method of SEM. Sugini's research in 2007 was performed by placing variables in a parallel position with multiple regression analysis; this PMVtapsem model relies on a different approach based on SEM analysis. SEM analysis forms the basis of the multilevel PMVtap model, which reflects the hierarchical structure and is therefore closer to the conceptual framework. The object of this study is an air-conditioned room with learning and office functions and inhabitants ranging from teenagers to adults with a level of activity not exceeding a metabolic level of 1.4 met. The building sample and room-zoning election are determined deliberately, and the respondents are selected randomly. The empirical data are collected by measurement and observation. Data related to attitude, physiological condition, and different psychological parameters are collected by the questioner. The PMV data are calculated with ASHRAE software. The results of this research are as follows: (1) there are five model variations of PMVtapsem that can be developed and (2) the PMVtapsem model can describe the hierarchical structure of the relational concepts between thermal comfort and variables in terms of the thermo-adaptive-psychological paradigm. However, this model is less applicable and precise than Sugini's 2007 PMVtap model.

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16.1 Introduction

16.1.1 Background

The current state of global warming is correlated with the amount of world energy consumption. The issue of energy security in the era of climate change is becoming acute (Anceschi 2012). Indonesia is the thirteenth largest energy-consuming country in the world (Resosudarmo et al. 2012). Of the total world energy consumption, 45.36% is used in buildings. Of this fraction, the largest area of energy consumption is that of air-conditioning (AC) (Wiggiton 2006). Therefore, this study is important and urgent.

The standards of room thermal comfort have been established based on the thermal index. The international thermal standard ISO 7730 is based on the predicted mean vote (PMV) thermal index, and the American ASHRAE standard is based on the SET and DISCOMFORT indexes. The Indonesia Standard SNI is based on the thermal ET. The question is how exactly indexes can be used as a basis for determining the convenient thermal range standard in a room. Among them, the PMV is an index, used as an international standard, that contains a total of six physiological-physical aspects (Sugini 2002a). However, the problem is that PMV has significant bias when it is implemented in the field (Humphreys et al. 1995; Humphreys and Nicol 2002; Brager and de Dear 1998). It has caused the prediction of the required thermal comfortable range to be excessive, resulting in wasted energy in nine official buildings in Jakarta (Karyono 1995).

Sugini (2007) proposed an index model of thermal comfort that is expected to eliminate the bias, namely, PMVtap. This model is based on the thermo-adaptive-psychological paradigm. It is the latest paradigm subsequent to the physical-physiological paradigm, which is used as a basis for the PMV model. Sugini's PMVtap model employs a regression model in linear variables that weights thermo-adaptive-psychological factors of thermal comfort equally. In one of his recommendations, Sugini proposed an alternative approach that couples a structural variable using the SEM method. This approach is expected to align with the conceptual framework of the PMVtap thermal thermo-adaptive-psychological model.

The PMVtapsem index model of development is important because it provides an additional alternative index that ensures a comfortable standard in accordance with psychological differences and corrects the model of Fanger that suffers from overestimates in tropical countries. The PMVtapsem model is expected to provide more precise thermal comfort standards in air-conditioned spaces to reduce energy waste. Ultimately, attention to energy consumption can improve energy security.

16.1.2 State of the Art of the Domain of the Thermal Comfort Paradigm and Resulting Research

Based on the taxonomic study of thermal comfort and research mapping (developed from Sugini 2002b), the study of thermal comfort with the thermo-adaptive-psychological approach is still limited. However, this approach is believed to be capable of eliminating bias in research into the thermo-adaptive-physiological approach. Thus, research addressing thermal comfort based on the thermo-adaptive-psychological paradigm is necessary and important. The concept of thermal comfort has developed based on a shift of the thermal comfort paradigm. It has moved from a thermo-physiological paradigm to a thermo-adaptive-physiological paradigm and then to a thermo-adaptive-psychological paradigm.

Based on Fanger's work, the basic concept of the occurrence of thermal comfort is the maintenance of heat balance. In the process of body metabolism, sideline products such as body heat occur. This body heat is constantly transferred to the environment. At equilibrium, the rate of production of body heat and the speed at which body heat waste enters the environment are balanced. In such a condition, one experiences a heat balance. The amount of heat waste is coupled to parameters such as radiation, conduction, garments, and evaporation.

The thermo-adaptive-psychological paradigm states that thermal comfort is determined not only by the proportion of body heat but also by a process in which psychological thermal comfort determines the achievement of convenient thermal comfort (Auliciems 1989)

Sugini (2004) proposed a conceptual framework for thermal comfort termed thermal thermo-adaptive-psychological comfort. This concept states that psychological differences between individuals determine thermal comfort. The framework was then revised in his dissertation in 2007.

16.1.3 Research on the Thermal Index Model

At the end of 1923, Houghten, Yaglou, and his colleagues pioneered studies that led to a search for a thermal index. Three physical parameters, namely, air temperature, humidity, and air velocity, are combined in the effective temperature (ET) equation. Based on reports by Koenigsberger and Mayhew (1973), Markus (1980), Fanger (1982), and Sugini (2007), Sugini in 2012 then identified a number of thermal indexes that have been developed, namely, equivalent warmth (EW) (Bedford, English),operative temperature (OT) (Winslow Herington and Gagge, USA), the equatorial comfort index (ECI) (Webb, 1960, Singapore), and resultant temperature (RT) (Missenard French); predicted four-hour sweat rate (P4HSR) (Naval Authority 1947 British), heat stress index (HIS) (USA), graphics bioclimatic (V. Olgyay, Australia), and index of thermal stress (ITS) (Givoni); and predicted percentage of dissatisfied (PPD) (Fanger 1982), PMV (Fanger 1982), and PMVtap (Sugini 2007).

In 2007, Sugini developed a thermal index model (termed the PMVtap thermal thermo-adaptive-psychological index) based on a conceptual framework of thermal thermo-adaptive-psychological comfort. This work was published as *The Index of PMVtap Reformulation of Thermal Comfort Index Base Model on Thermoform able sandwich concept-Adaptive-Psychological Paradigm* (Sugini 2012).

Sugini's PMVtap model is based on multiple regressions by weighting psychological difference variables equally.

The form of model is as follows:

$$\text{PMVtap} = \text{PMV} + \hat{\text{Y}}\text{vorpmv} \quad (16.1)$$

The PMVtap index is formed by a parameter comprising the PMV (in terms of air temperature, radiant temperature, air humidity, and air velocity) and the parameters that determine the $\hat{\text{Y}}$vorpmv. The $\hat{\text{Y}}$vorpmv is determined by the parameters of the variables related to psychological differences between the individual occupants.

The general model (a model that can be treated in the population within the scope of its limitations) of the general $\hat{\text{Y}}$vorpmv is as follows:

$\hat{\textbf{Y}}$**vorpmv general** = 0.712 **d1** + 0.803**d2** + 0.238 **xls6** + 0.044 **dxls13**–0.892 **dxk8–**0.233**dxk2**

Thus, the general model of the PMVtap is as follows:

PMVtap general = **PMV**+ 0.712 **d1** + 0.803**d2** + 0.238**xls6** + 0.044 **dxls13**–0.892 **dxk8**–0.233**dxk2**

This formula shows that the $\hat{\text{Y}}$vorpmv is defined in terms of the thermal comfort of the occupant to the room (d1 and d2), the type of room ventilation (dxk8), the duration in the air-conditioned room (xls13), the economic status as characterized by personal income (xls6), and the quality of the room distress determined by the occupant's assessment of furniture density or objects (dxk2).

Sugini's PMVtap model addresses the bias inherent in the PMV model in real rooms through the $\hat{\text{Y}}$vorpmv score; it thus achieves its purpose to identify a model of thermal thermo-adaptive index comfort through the development of PMV by managing bias. Bias management can be performed by searching for the bias association by variation of the parameter variables' individual psychological differences. The multiple linear regression analysis method is used to order the parameters in position in a row. It is important to complete the thermal index model of the thermo-adaptive PMVtap model by incorporating a psychological approach through further analysis. Her recommendations have mentioned the need to develop the model by incorporating the SEM approach. For this reason, the research proposed in this proposal is important and interesting in terms of scientific development in the field of thermal comfort. This development is expected to benefit the development of practical knowledge of the thermal convenient range.

16.1.4 Research Problem

The research problem is the development of the PMVtapsem variation index model and its comparison with the PMVtap model (Sugini 2007).

16.1.5 Specific Objectives

The specific aim of this research is to develop model variations of the PMVtapsem thermal thermo-adaptive-psychological index comfort with the SEM approach.

The PMVtap model is based on empirical studies in the scope of a building population with office room functions and classroom/study locations with level 1.4 metabolisms. This model is restricted to office rooms and classroom/study locations to limit population variations that would complicate the comparison between older models and the current results.

16.2 Design and Research Method

16.2.1 Population and Sample

The research population involves learning and office rooms containing occupants ranging from youths to adults, with a metabolic level no higher than 1.4. The selection of building samples, rooms, and room zoning was determined deliberately based on the objective of the respondents' characteristics. At the level of individual occupants in the building, the respondents were chosen randomly. The number of samples was 910. According to the respondents' characteristics, six SEM models were derived.

The samples in the empirical stage included as many as seven buildings spread across North Yogyakarta (Sleman), Middle Yogyakarta (Municipality), South Yogyakarta (Bantul), and West Yogyakarta (Kulon Progo). In the second part, new data were collected from additional samples from as many as 417 respondents.

16.2.2 Data Collection and Analysis

In the development of the empirical model in the field, the data were collected in multiple ways. Opinion, the perception of the thermal and other room qualities that were appropriate, and data related to psychological variations were recorded through a survey. The objective data of thermal and other qualities that were possibly related were collected by instrument measurement or by observation.

To observe the relationship between variables, it is often the case that each variable cannot be measured directly through observation. Variables such as these are called latent variables; they are observed through an indicator. Multiple regression analysis is a statistical method analysis to construct a model or patterns of relationships between independent variables and the interplay between variables. Analysis factors are used to formulate a relationship between the latent and indicator variables. SEM is a combination of regression and factor analysis. SEM is a type of statistical modeling approach used to explain the relationship between variables. Relations between the variables in SEM are produced through a series of similarity regression analyses. The interplay of the dependent variables of the regression equation became independent variables of another regression equation (Hair et al. 1998). SEM is a useful statistics tool for researchers in all fields of social knowledge and can be used to test a theory (Bentler 1980).

Different SEM software implementation types exist, including linear structural relationships (LISREL), AMOS, and EQS. LISREL is the most common program used for SEM and is often referenced in various scientific journals in various disciplines (Austin and Calderon 1996). Gefen et al. (2000) determined that in three Information System journals examined from 1994 to 1997, LISREL was used more often than EQS and AMOS.

The analysis of SEM includes three stages: model conceptualization, flowchart formulation, and model specification (Gozali 2005). Model conceptualization is associated with developing a hypothesis (based on the theory) as the basis in linking latent variables with other latent variables and other indicator variables. The path diagram construction simplifies visualization of the hypothesis advanced during model conceptualization. The model specification is the stage of determining the number and characteristics of parameters being estimated.

16.3 Results and Discussion

16.3.1 Sample Description

The sample empirical data indicated that the average of air temperature was 28.4 °C, the wind speed (air velocity) was 0.06 m/s, the relative humidity was 51%, and the radiation was approximately 29.84 °C. The condition of physiological variables of thermal comfort of the occupants of the level of clothing was 0.74 with a 1 met level of metabolism.

Based on the measurements and observation, the occupants' opinions on thermal and other variables related to thermal comfort to the room based on the PMV index can be recorded. Data analysis was performed using ASHRAE software. It was determined that the average of thermal comfort according to the PMV index was 1.4, while based on the voting respondents (VORs), the thermal comfort was −0.19.

Data analysis included the *paired samples test* to indicate significant differences. For that reason, model management included different VOR values with the PMV (VOR-PMV). The range difference based on a difference in the average of two indexes was 1.6287, in which the PMV-predicted room quality was higher than the occupants' perception. Thus, the PMV overestimates this parameter. This finding is consistent with those of Sugini (2007) and certain other reports.

16.3.2 Analysis of PMVtapsem Model Development

According to the aim of the research, the analysis is performed again with SEM in two stages: mathematical simulation and empirical stages. The analysis of the mathematical simulation and empirical stage was performed using multiple simulation conditions to produce the path diagram scheme shown in Fig. 16.1.

When the model was tested based on the application aspect in predicting, it predicted the possibility of relational patterns between the factors of "vorpmv," "past," "social," and "present" (i.e., the (e) model). This model produced an RMSEA score of 0.087. The factor of "social" indirectly influenced the score of "vorpmv." It influenced the score of "vorpmv" through the factors of "past" and "present."

The PMVtapsem index model can be formulated as follows:

$$\text{PMVtapsem} = \text{PMV} - 0.02\,(\text{thermal lifestyle}) - 0.1(\text{temporary room condition})$$

where:

$$\text{Thermal lifestyle} = -0.7(x7) - 0.6(x8) - 0.13(X10) + 0.23(x11) - 0.17(\text{social})$$

$$\text{Temporary room condition} = 0.66(x29) + 0.71(x30) + 0.32(x31) + 0.11(x32) + 0.37(x33) + 0.3(x34)\ 0.19(x36) - 0.13(\text{social})$$

$$\text{Social} = 0.46(x1) + 0.98(x2) + 0.55(x3) - 0.03(x4) - 0.1(x5)$$

By incorporating the past thermal experience of the occupant, it can be concluded that the thermal comfort is determined by physiological-physical aspects and psychological differences that are defined by activities related to the thermal and temporary room condition. These physical and physiological variables are measured with the PMV index parameter, and the psychological difference is characterized by the two psychological variables of thermal lifestyle and temporary room conditions. Hierarchically, they are determined by social conditions.

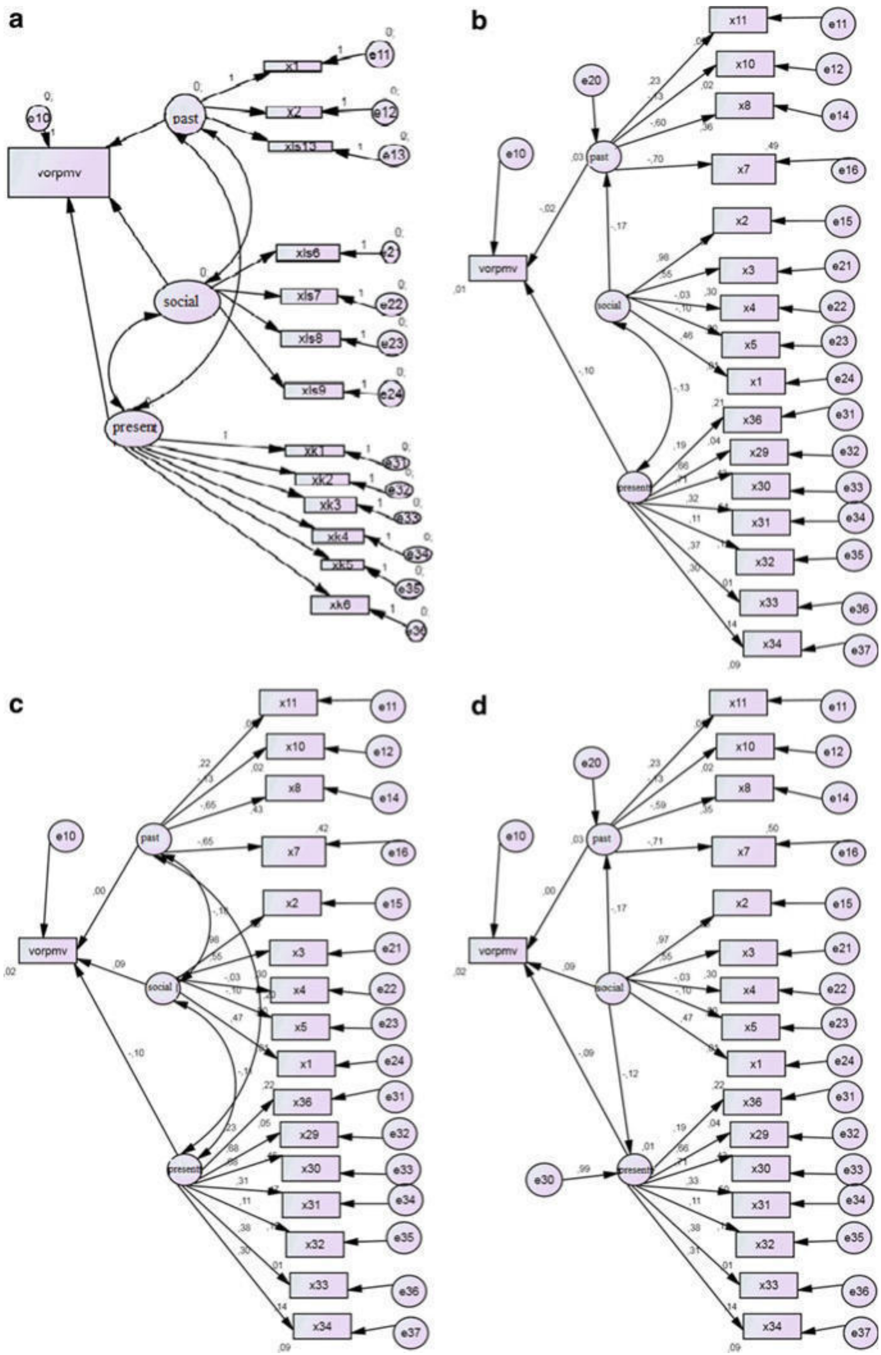

Fig. 16.1 PMVtapsem model-based path diagram analysis of SEM. (**a**) *Model a*: better with mathematical approach. (**b**) *Model b*: alternative 1 with empirical approach. (**c**) *Model c*: alternative 2 with empirical approach. (**d**) *Model d*: better empirical approach. (**e**) *Model e*: the best model

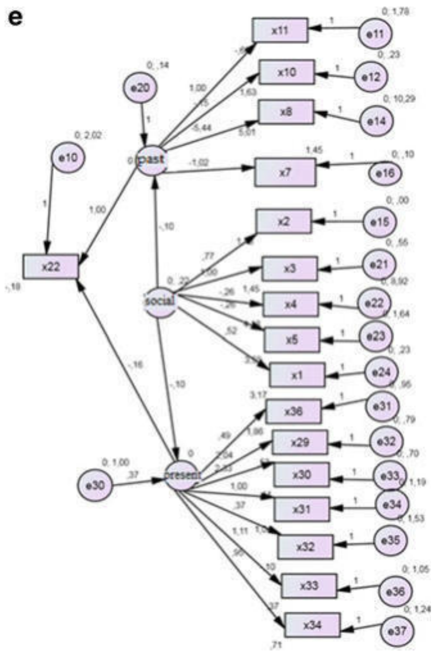

Fig. 16.1 (continued)

16.3.3 Comparison of PMVtap Model (Sugini 2007) and PMVtapsem

Taking the PMVtapsem thermal index model as the previously existing control, the thermal comfort paradigm based on the consistent thermo-adaptive-psychological paradigm can be continuously tested conceptually and practically. The findings support the accuracy of the thermo-thermal-adaptive-psychological comfort paradigm proposed by Sugini in 2007.

From the prediction ability of thermal comfort range, the best model of PMVtap as elaborated above has a lower predictable ability than that of Sugini's 2007 model. The correlation score between the predictive score and score X22 is equal to 0.120333, which is still far lower than Sugini's PMVtap model from 2007, which has a correlated score of 0.598519.

It can be concluded that SEM analysis can illustrate the relational pattern to the clear factor; for arranging indexes, however, another method should be used for regression analysis.

Conceptually, based on the model described in the previous sections, the variables that determine thermal comfort can be delineated. Those variables are as follows:

1. Physiological physical variables, namely, (a) room micro climate, (i) air temperature, (ii) average radiant temperature, (iii) air humidity, and (iv) wind speed, and (b) physiological, (i) activities and (ii) clothes.
2. Psychological variables of differences as follows:
   (a) Past thermal experience corresponding to thermal lifestyle. The past thermal experience is determined by the following: (i) daily ventilation types at office/work room/class, (ii) daily time duration in the AC room, (iii) freedom to control daily room ventilation, (iv) thermal comfort experience, (v) room thermal comfort image that will be occupied, and (vi) social status
   (b) The degree of occupation as characterized by perception: (i) degree of crowding, (ii) object density, (iii) lighting, (iv) degree of openness, (v) room noise quality, and (vi) room facilities

Additional components are (vii) the types of room ventilation and (viii) social conditions.

3. Social condition. Thermal experience or thermal lifestyle and comfortable temporary room perception were determined by social status, which is dependent on the following: (i) level of education, (ii) type of work, (iii) personal income, (iv) family income, and (v) number of people in the family

A comparison between the PMVtap model of Sugini (2007) and the PMVtapsem model is shown in Fig. 16.2.

Regarding the PMVtapsem model, the result of this research describes variable relationships that determine hierarchical thermal comfort in accordance with the theoretical concept. This concept complements the study of the PMVtap model presented by Sugini in 2007 that models variable relationships to varying degrees.

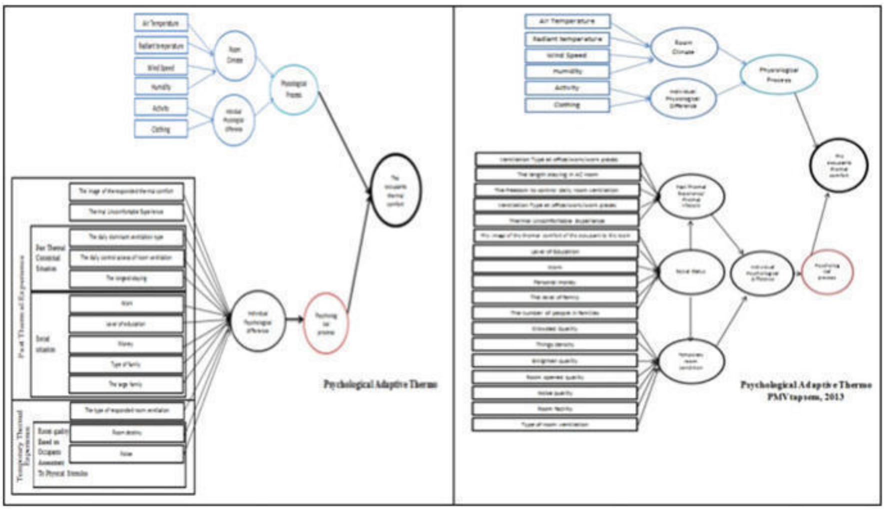

Fig. 16.2 Comparison of PMVtap model by Sugini (2007) and PMVtapsem

Based on the implementation aspect, the PMVtap model can explain the hierarchical structure of the variable relationship based on the concept, but for the sake of the application of standard determination and the prediction of thermal comfort distance, the thermal index of Sugini's PMVtap 2007 is easier to implement.

16.4 Conclusions

Based on the descriptive and comparative analysis, it could be concluded that PMVtapsem model can describe the relationship of variables that determine hierarchical thermal comfort in accordance with the theoretical concept. This study successfully developed five variations of PMVtapsem models, of which the best model is number five. The PMVtapsem index is a function of the PMV, thermal lifestyle, and temporary room condition. PMVtapsem = f{PMV, thermal lifestyle, and temporary room condition}. Thermal lifestyle: Thermal = f{type of daily workplace ventilation, length staying in AC room, the freedom to control daily room ventilation, thermal discomfort, the image of the thermal comfort of the occupant to the room, and social conditions}. Temporary room condition = f {occupants' perception of crowdedness, occupants' perception of object density, occupants' perception of room lighting, occupants' perception of degree of openness, occupants' perception of room noise quality, occupants' perception of room facility, and social conditions}. Social conditions = f{level of education, work, personal income, total family income, and number of people in the family}.

The room thermal comfort is determined by both the physiological-physical variables and the past thermal experience or thermal lifestyle and temporary room conditions. The thermal lifestyle is determined by the daily type of ventilation in the office/work room/class, the daily duration in the air-conditioned room, the freedom to control daily room ventilation, the thermal discomfort, the room thermal comfort shadow that will be occupied, and the social status. The temporary room conditions are determined by the degree of crowding, object density, room brightness, degree of openness in the room, room noise quality, facility, types of room ventilation, and social status. Social status is determined by levels of education, occupation, personal income, total family income, and the number of people in the family.

Based on a comparison with the model of Sugini 2007, it is concluded that the PMVtapsem model can better describe hierarchical structure of variable relation, but for the application of standard determination and the prediction of thermal comfort range, the thermal index of Sugini's PMVtap from 2007 is better and easier to use because it is simpler and more precise. Significant differences exist between the thermal comfort quantified by the PMV thermal index and the user response in the field. This condition is consistent with Sugini (2007) and certain other reports.

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