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NEW HEAT PUMP SYSTEM FOR LONG-TERM CARE CENTER IN CENTRAL TAIWAN TO IMPROVE THERMAL COMFORT OF PUBLIC SPACE

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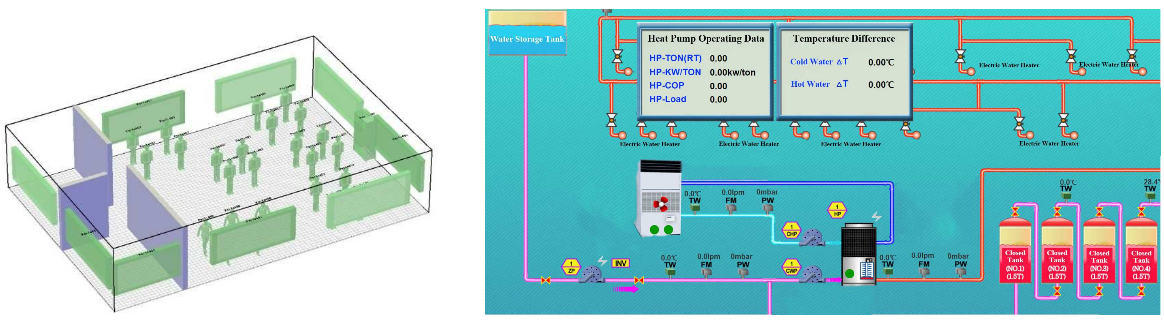
Abstract. *Population aging becomes more serious in Taiwan in response to health care problem. Thermal comfort of indoor space is affected by high temperature and high humidity in summer and continental cold air group in winter. New developed heat pump system supplies cold source and heat source for air conditioning system in summer and winter respectively to construct indoor comfortable air conditioning and ventilation. All numerical parameters are tested and verified by measured values, and then, improvement efficiency of indoor space before and after installing this new system is investigated by Computational Fluid Dynamics (CFD). Analytical results reveal that indoor temperature maintenance remains 23.6-29.2°C and 18.0-24.5°C, thermal comfort of Predict Mean Vote (PMV) interval remains −0.6 to 0.9 and −1.2 to −0.6 in summer and winter respectively. Waste heat recovery of this new system provides hot water for sixty living units. Electric water heater power consumption saves 67.35% within 95% confidence interval.*
Keywords: Thermal comfort, Heat pump system, The aged, Long-term care, Computational Fluid Dynamics (CFD)

1. **Introduction.** Aging population of Taiwan accounts for 14% of the total population which becomes an aging society. Aging speed is much faster than that of Europe and the United States [1]. Health care problem in response to aging population is an important topic of Taiwan. Long-term caring and medical institutions will take charge of aging population [2]. According to “10 years Long-Term Caring Project” and “The second project of service plan of friendly caring for aging population” of Taiwan, ideas of service plan of long-term institutions and friendly caring of aging population are proposed by Taiwan government. Therefore, how to create a comfortable indoor environment and low energy consumption of energy based on aging users’ needs are main issues of Taiwan. This environment provides active aging space and is great concerned care quality of elders [3]. Especially, Taiwan is located in subtropical area with high temperature and humidity in summer and affected by continental cold air group in winter, which influences indoor thermal comfort of long-term caring institutions. The purpose of this study is that the new developed heat pump system is applied to supplying cold source and hot source for air conditioning in summer and winter respectively based on the users’ needs of elders to construct a comfortable indoor space with suitable air conditioning and ventilation. A senior citizens’ home of long-term caring institution is selected as a sample to test and verify

the comfortable benefits and energy-saving efficiency of this proposed system in central Taiwan. Old electric boiler system is replaced by this new heat pump system to improve indoor temperature and humidity and promote care quality of long-term caring institution. In this study, all numerical parameters of Computational Fluid Dynamics, CFD are investigated by real test to simulate the real improvement efficiency in four seasons. Therefore, temperature variation and PMV before and after improvement are compared with each other to make sure the improvement efficiency of this proposed system.

2. **Problem Statement and Literature Review.** Thermal comfort shows satisfaction level of the surrounding temperature, is a subjective judgment. In order to make hot and cold feeling of human body to reach a comfortable level, heat transfer relationship of human body and the outside environment should attain balanced state [4]. Currently, national standards of many countries mainly refer to ISO 7730 [5] based on environmental parameters, including air temperature, average radiation temperature, wind velocity and humidity to combine as Predict Mean Vote (PMV). PMV, average value of hot and cold feeling of human being, is applied to evaluating temperature perception of human body in an environment. Range of PMV is between 3 to -3, and represents the temperature perception from hot to cold respectively. If PMV value is less than -1 or greater than 1, it represents unsatisfied. Otherwise, PMV between -1 to 1 reveals that this environment is satisfied [6]. The purpose of this study is to investigate thermal comfort range of public space for elderly users. Variation of thermal comfort of seniors depends on latitude change based on the research achievement of Chindapol et al. [7] such as: thermal comfort range of Indonesia, Singapore, Malaysia and Thailand is 29.2-29.9°C, 28.2-28.8°C, 27-32.6°C and 25.6-31.5°C respectively. Thermal comfort for seniors, more than sixty years old in Taiwan is 25.2°C for neutral temperature in summer and 23.2°C for neutral temperature in winter; the range of thermal comfort for summer and winter is 23.2-27.1°C and 20.5-25.9°C respectively [8]. Neutral temperature in winter is 16.63°C and range of thermal comfort is 18.32-22.08°C for elders in Shanghai [9]. Seniors' tolerance temperature for Chinese is 31-32°C and 3-4°C for summer and winter respectively [10]. Otherwise, neutral temperature in summer is 26.5°C and range of thermal comfort in summer is 25.5-30.9°C for elders in Chongqing [11]. In this study, the range of thermal comfort and PMV in summer and winter, based on the seniors living in Taiwan, are applied to evaluating the thermal comfort in public indoor space before and after installing this new system.

3. **Methodology.** To evaluate the comfortable benefits and energy-saving efficiency of this proposed system, public indoor space of a senior citizens' home of long-term caring institution is selected as a sample. The analysis range of this public space is 13.7 M $*$ 9.2 M $*$ 3.2 M, shown in Figure 1(a) to construct analytical model. The proposed heat pump system, shown in Figure 1(b), is to combine the air conditioning and hot water. Waste



(a) Analytic model (b) The proposed heat pump system

FIGURE 1. Sample space and proposed heat pump system

heat of air conditioning retrieves for hot water system to supply for hot water demand of sixty seniors.

3.1. **Computational Fluid Dynamics, CFD.** In this study, Computational Fluid Dynamics, CFD is applied to simulating the comfortable benefits and energy-saving efficiency of this proposed system. Airflow state, calculated from CFD, should be verified by measured values in real test space to make sure the real situation of CFD. Figure 2 is the research flow chart of this study. Firstly, governing equation of turbulent flow field is simplified based on model hypothesis with boundary and initial conditions. Calculation results of this study, calculated by governing equation, can be visualized.

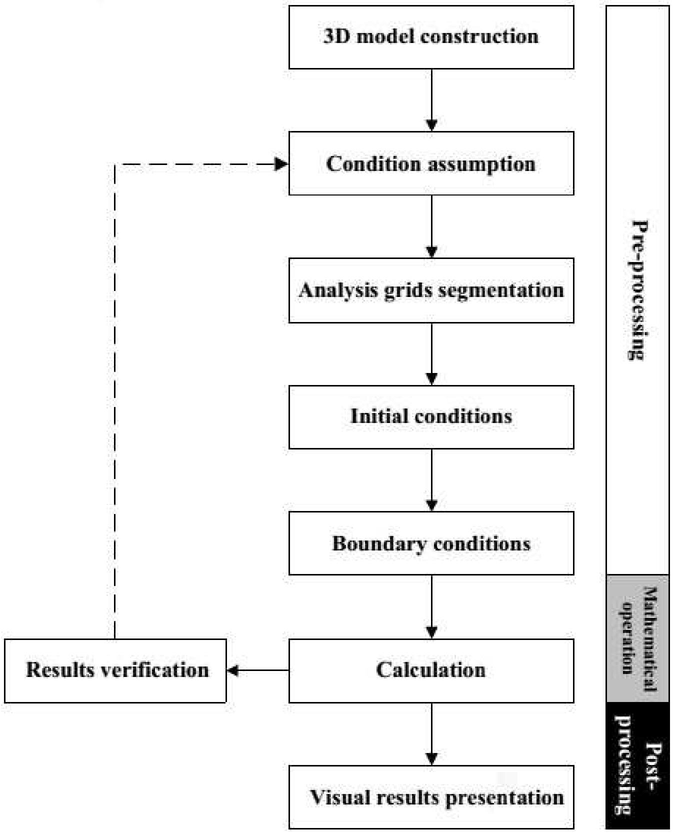


FIGURE 2. Research flow chart of this study

The Stander k-ε model equation, proposed by Launder and Spalding in 1974 [12], is used as theoretical analysis of turbulence model in this study. The advantages of this model are wide application range, reasonable accuracy and fast operation speed. Scale of large eddy current ℓ and turbulent kinetic energy k are related to kinetic energy dissipation rates ε in turbulent flow field. The equation is shown as follows:

$$\ell = \frac{k^{\frac{3}{2}}}{\varepsilon} \tag{1}$$

where ℓ: large eddy current scale; k: turbulent kinetic energy; ε: kinetic energy dissipation rates.

Turbulence viscosity coefficient is the function of turbulent kinetic energy and kinetic energy dissipation rates, revealed in Equation (2).

$$V_T = C_\mu \frac{k^2}{\varepsilon} \tag{2}$$

where V_T: turbulence viscosity coefficient; C_μ: mode constant; k: turbulent kinetic energy; ε: kinetic energy dissipation rates.

The greater turbulent kinetic energy or smaller kinetic energy dissipation rate is, then, the greater turbulent viscosity coefficient. k-ε models also include governing equation of turbulent kinetic energy and kinetic energy dissipation rate, shown as follows:

$$\frac{DK}{Dt} = \frac{\partial}{\partial x_j}\left[\frac{V_T}{c_k} \cdot \frac{\partial k}{\partial x_i}\right] + \left[\frac{\partial \overline{U}_i}{\partial x_j} \cdot \frac{\partial \overline{U}_j}{\partial x_i}\right] \cdot \frac{\partial \overline{U}_i}{\partial x_j} - \varepsilon \tag{3}$$

where $\overline{U}_i$: flow time average; x_i: direction of velocity; $c_k = 1.0$; k: turbulent kinetic energy.

$$\frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_i}\left[\frac{V_T}{c_\varepsilon} \cdot \frac{\partial \varepsilon}{\partial x_i}\right] + c_{1\varepsilon}\frac{\varepsilon}{k}V_T\left[\frac{\partial \overline{U}_i}{\partial x_j} \cdot \frac{\partial \overline{U}_j}{\partial x_i}\right] \cdot \frac{\partial \overline{U}_i}{\partial x_j} - c_{2\varepsilon}\frac{\varepsilon^2}{k} \tag{4}$$

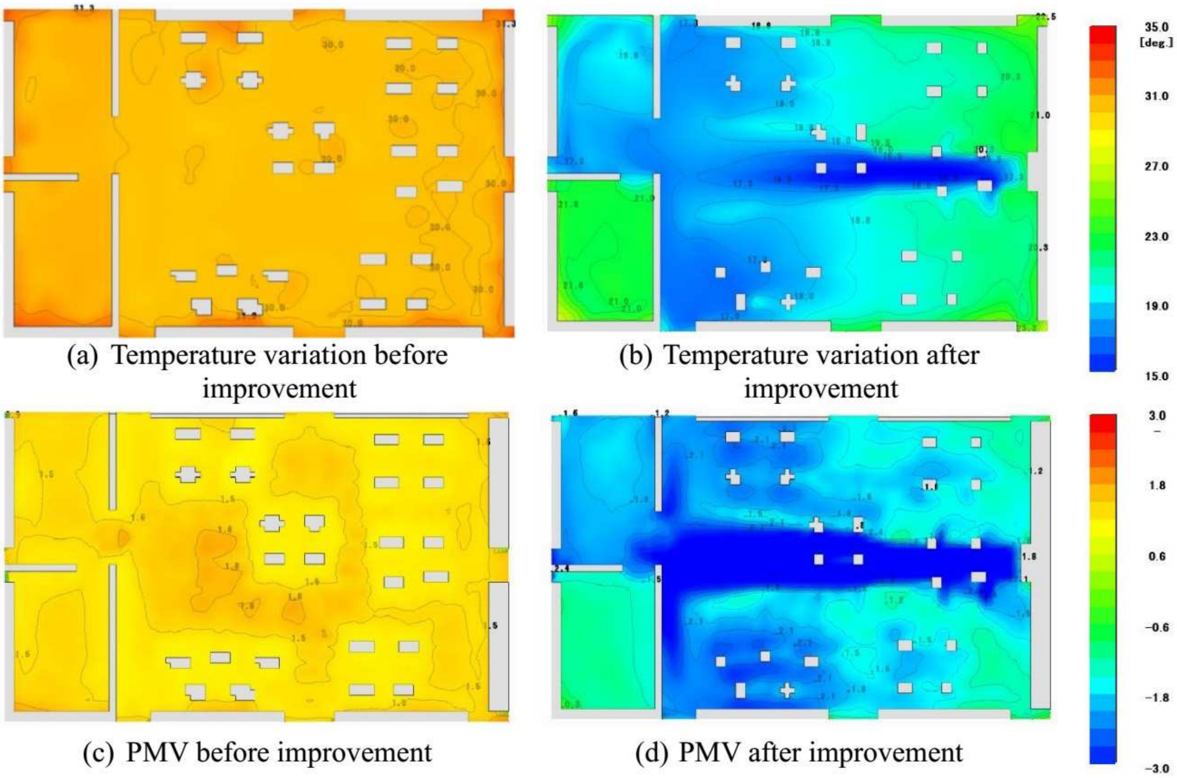
where $c_{1\varepsilon} = 1.44$; $c_{2\varepsilon} = 1.92$; $c_k = 1.0$.

3.2. **Simulation parameters of CFD.** WindPerfect DX 2016 software for CFD simulation is used in this study. Range of indoor public space for investigating the comfortable benefits and energy-saving efficiency of this proposed system is 13.7 M $*$ 9.2 M $*$ 3.2 M. Space of mesh for CFD simulation is set as 0.1 M $*$ 0.1 M $*$ 0.1 M. The settings of outside air temperature and starting temperature are based on the seasonal climate, recorded from the micro weather station. Target temperature depends on the setting temperature of this proposed system. Daily heat load refers to Typical Meteorological Years- TMY3 [13]. Assuming daily heat load of spring and fall is 500 W/m^2, summer and winter is 700 W/m^2 and 300 W/m^2 [13] respectively. Body calorie in accordance with Design and Technique Directions for Energy Saving of Building on Hotel and Restaurant [14] is set as 60 W/person. Lighting load and equipment load are 10 W/m^2 and 15 W/m^2 respectively. Thermal conductivity of wall and roof are 2.15 W/m^2$*$°K and 1.0 W/m^2$*$°K according to the real test data. Air conditioning conditions of this proposed system are connected with hot water system to provide cold source for summer and hot water for winter. Outlet temperature is 13°C, 25°C and the amount of air is 120 CMM for summer and winter respectively. Processing mode of turbulence adapts standard k-ε mode. Number of iterations is 100 times. Convergence coefficient is 1E-005. Section height sets as 1.5 M.

4. **Results and Discussions.** The analysis results of indoor thermal environment are shown in Figures 3-5 for spring-fall, summer and winter, including indoor temperature variation and PMV value before and after installing this proposed system.

4.1. **Amends conditions of indoor thermal environment in spring and fall.** Figure 3(a) shows that indoor temperature remains around 29.4-31.4°C, higher than outdoor air temperature 24.0°C. Figure 3(c) displays that thermal comfort value of PMV reaches 1.5-1.9, classified in warmer region. Actually, indoor temperature is affected by heat load of daily radiation and indoor heat sources; indoor heat is hard to discharge by natural ventilation. Figures 3(b) and 3(d) are analysis results of new system operation, indoor temperature reduces to 16.6-22.1°C, PMV down to -2.1 to -0.3.

4.2. **Amends conditions of indoor thermal environment in summer and winter.** Before installing this new system, Figures 4(a) and 4(c) reveal that the indoor temperature attains above 40.0°C, affected by high outdoor air temperature, high radiation and indoor heat sources, even, PMV reaches 3.0, extremely uncomfortable in summer. PMV is higher than tolerance range. In winter, indoor temperature is around 17.2-19.1°C and PMV attains -2.1 to -1.8, shown in Figures 5(a) and 5(c). It is in clod side and thermal comfort is bad. It will cause adverse reactions of seniors in summer and winter. When this proposed system operated in summer, temperature variation of indoor temperature reduces to 23.6-29.2°C, shown in Figure 4(b) and PMV of most public space is around -0.6 to 0.9, Figure 4(d). Quality of indoor heat environment and thermal comfort is good. Figures 5(b) and 5(d), indoor temperature variation and PMV in winter, show



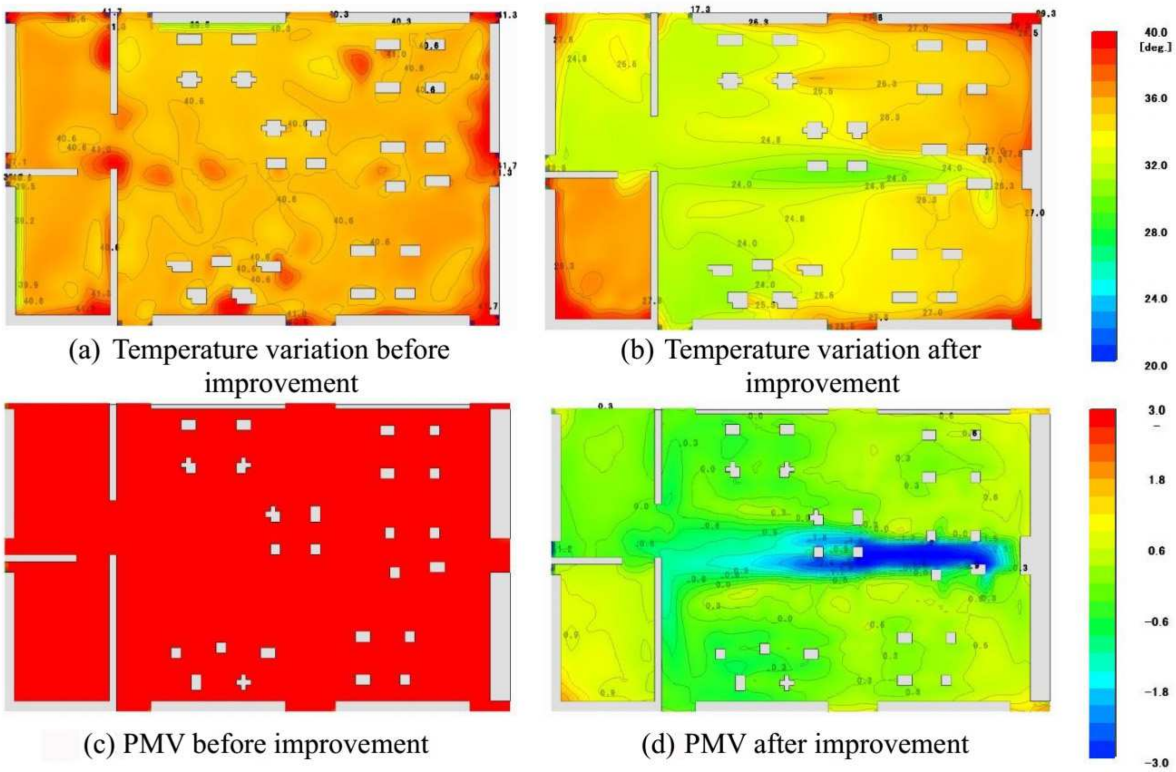
(a) Temperature variation before improvement

(b) Temperature variation after improvement

(c) PMV before improvement

(d) PMV after improvement

Figure 3. The comparison of spring-fall before and after installing this proposed system



(a) Temperature variation before improvement

(b) Temperature variation after improvement

(c) PMV before improvement

(d) PMV after improvement

Figure 4. The comparison of summer before and after installing this proposed system

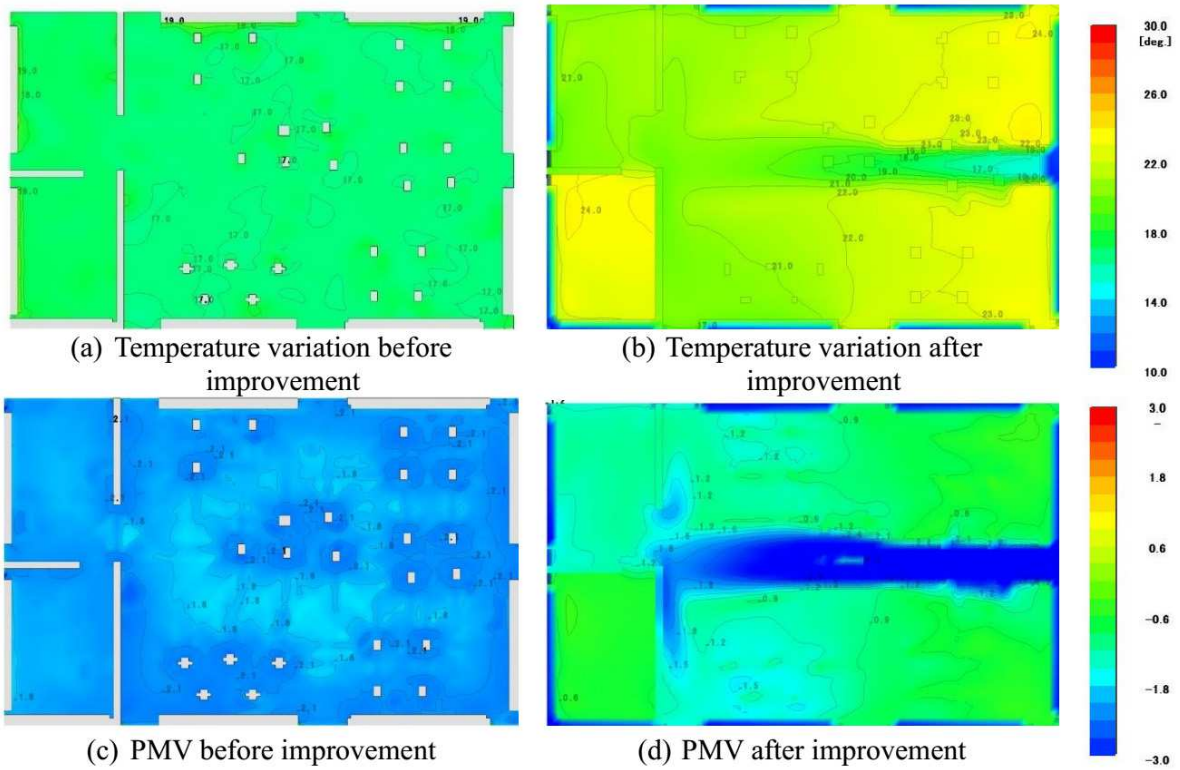


FIGURE 5. The comparison of winter before and after installing this proposed system

that indoor temperature and PMV are around 18.0-24.5°C and −1.2 to −0.6 respectively. Indoor heat environment has been improved by this new system.

5. **Conclusions.** Analysis results of this study confirm that this proposed system achieves the objective of improving indoor thermal comfort. Some of conclusions can be summarized as follows.

1) This new heat pump retrieves waste heat to start up hot water system, and then, it provides cold source and hot source for air conditioning and heater in four seasons. Equipment efficiency of this system meets the requirements for improving indoor thermal comfort. Indoor temperature remains around 23.6-29.2°C and 18.0-24.5°C for summer and winter respectively. PMV is between −0.6 to 0.9 and −1.2 to −0.6 for summer and winter respectively.
2) Test results of this system with waste heat recovery show that this system provides hot water for sixty living units; electric water heater power consumption saves 67.35% within 95% confidence interval. System energy efficiency is quite good.

Analysis results of this study demonstrate that this proposed system provides high improvement efficiency of equipment efficiency of indoor thermal comfort for each season with good energy-saving effectiveness. Analysis of investment benefit should be verified in the future study to develop economic equipment.

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REFERENCES

[1] National Development Council (Taiwan), *Taiwan Population Projection Report (2016-2061)*, 2016.
[2] Ministry of Health and Welfare (Taiwan), *Aged Society White Paper*, 2015.
[3] Ministry of Health and Welfare (Taiwan), *Friendly Care for the Elderly Service Program*, 2013.

[4] ASHRAE, Thermal comfort, *ASHRAE Handbook Fundamental*, 1997.
[5] ISO, *ISO7730 2005: Presents Methods for Predicting the General Thermal Sensation and Degree of Discomfort*, 2005.
[6] ISO, *ISO7730 1995: Moderate Thermal Environments. Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort*, 1995.
[7] S. Chindapol, J. Blair, P. Osmond and D. Prasad, Elderly thermal comfort in tropical climates: Identifying the knowledge gap, *The International Journal of Aging and Society*, vol.6, no.1, pp.33-44, 2016.
[8] R. L. Hwang and C. P. Chen, Field study on behaviors and adaptation of elderly people and their thermal comfort requirements in residential environments, *Indoor Air*, vol.20, no.3, pp.235-245, 2010.
[9] X. Yao, Investigation and analysis of indoor thermal environment in welfare centers for the aged in Shanghai, *Journal Heating Ventilating and Air-Conditioning*, vol.41, no.12, pp.66-70, 2011.
[10] L. Zhou, X. D. Chen, P. Lin, Y. L. Chen, Y. H. Lee, A. L. Wu, Y. B. Cheng and Y. L. Jin, Grope for the critical temperature in the older, *Modern Preventive Medicine*, vol.34, no.4, pp.718-720, 2007.
[11] H. Zhang, *Thermal Comfort of Elderly People during Summer in Residential Buildings*, Master Thesis, Faculty of Urban Construction and Environmental Engineering, Chongqing University, 2013.
[12] B. E. Launder and D. B. Spalding, The numerical computation of turbulent flow, *Computer Methods in Applied Mechanics and Engineering*, vol.3, no.2, pp.269-289, 1974.
[13] M. C. Ho, K. T. Huang and J. C. Wang, The development and research on hourly typical meteorological years (TMY3) for building energy simulation analysis of Taiwan, *Research Project Report*, Architecture and Building Research Institute (ABRI), Ministry of the Interior, Taiwan, 2013.
[14] Construction and Planning Agency, Ministry of the Interior, Taiwan, *Design and Technique Directions for Energy Saving of Building on Hotel and Restaurant*, 2011.