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Affective Temperature Control in Food SMEs using Artificial Neural Network

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ABSTRACT

This paper highlights modeling affective temperature control in food small and medium-sized enterprises (SMEs). Modeling defined that workstation temperature set point could be controlled based on worker heart rate and workstation environment using Artificial Neural Network (ANN). The research objectives were: 1) to propose modeling affective temperature control in food SMEs based on heart rate and workstation environment; and 2) to develop an ANN model for predicting workstation temperature set point. Training and validation data were collected from six food SMEs in Yogyakarta Special Region, Indonesia. The data of temperature set points were verified using a simulated confined room. The inputs of the ANN model were worker heart rate, workstation temperature, relative humidity distribution and light intensity. The output was temperature set point. Research results concluded satisfactory performance of ANN. The model could be used to provide environmental ergonomics in food SMEs.

1.1 Introduction

Recently, the Indonesian Government has encouraged the program of Digital Economy (Anonym, 2016). The objective is to utilize appropriate information technology in the industry to compete in the ASEAN Economic Community. Application of digital economy is expanded to small and medium-sized enterprises (SMEs) to reduce the development gap. Food SMEs are fundamental to support food sovereignty in Indonesia. Most of the food SMEs are a human-based production system (Ushada *et al.*, 2015). The workstation environment is specifically controlled for producing value-added products, for instance boiling, steaming, frying, baking and assembly. However, the environment for workers is left uncontrolled.

Some previous works have evaluated the importance of workstation environment for industrial competitiveness. In the manufacturing industry, most

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workers have low satisfaction level in the workstation environment (Dianat, et al., 2016). The recommended noise and illumination heat levels were not confirmed in about half of the workstations surveyed (Dianat et. al., 2016). In the construction industry, a high-temperature environment causes the worker stress and thus decreases productivity (Li et al., 2016). In educational services, most of the student's thermal preferences were not in the comfort range related to the building environment (Zomorodian et al., 2016). In the packaging industry, there is a high need for automated workstation environmental monitoring (Oikonomou et al., 2016). Aliabadi et al. (2015) developed an intelligent technique for predicting the noise level in industrial embroidery workrooms. However, none of these studies focus on food SMEs.

A temperature-controlled model could be proposed as a technology innovation in information technology for food SMEs. Takahashi et al. (2002) have suggested the temperature parameter to control the environment within a simulated confined space. Xiong et al. (2015 and 2016) stated that temperature steps are possibly recognized as environmental factors that influence human thermal comfort and health. Ushada et al. (2015) suggested temperature monitoring before and after working to assess worker capacity. The temperature before and after working could be categorized as temperature steps in terms of the workstation of SMEs. Xiong et al. (2015) concluded that temperature step magnitude has an important impact on human subjective perception. Chen et al. (2016) developed a controller model that determines the optimal indoor temperature based on the feedback of occupants thermal sensation. However, none of these studies have evaluated the workstation temperature control in food SMEs.

This article highlights the modeling of affective temperature control in food SMEs. An affective design is highly required for environmental control. The term affective refers to the human psychological and emotional parameters of human satisfaction (Kwong et al., 2016). Worker heart rate is proposed as nonverbal affective parameters based on the Kansei Engineering approach (Ushada et al., 2015). Xiong et al. (2015 and 2016) indicated that temperature set points changes influence the human heart rate. The modeling defined that workstation temperature set point could be controlled based on worker heart rate. An Artificial Neural Network (ANN) model was developed for workstation temperature control. Some workstation-related research has utilized ANN. Takahashi et al. (2002) used ANN for local temperature control within a confined space. The environmental parameters were used as input for ANN to assess worker capacity (Ushada et al., 2015). Buratti et al. (2016) developed an algorithm using ANN to predict thermal comfort sensation. Kolus et al. (2016) developed an adaptive neuro fuzzy inference system to classify the work rate. Morimoto and Hashimoto (2009) combined ANN and genetic algorithm for the quality of products based on an environmental control system, called the speaking plant/fruit approach. None of these studies utilize worker heart rate to predict the temperature set point.

The research objectives are: 1) to propose modeling affective temperature control in food SMEs based on heart rate and workstation environment; and 2) to develop an ANN model for predicting workstation temperature set point. The research advantage is to support the implementation of an appropriate information technology in the Indonesian governmental program of digital economy. The ANN model could be used to provide environmental ergonomics for supporting competitiveness of food SMEs in the ASEAN Economic Community.

1.2 Material and Methods

1.2.2 *Modeling Affective Temperature Control*

Figure 1 indicates the modeling of affective temperature control for food SMEs. The modeling consists of three subsystems: subsystem 1: Management; subsystem 2: Software and subsystem 3: Hardware. Initially in subsystem 1, the manager is dissatisfied with the environmental condition in food SMEs. In subsystem 2, the database is accessed to generate the data of the environment and the worker. The data of the workstation environment are the distribution of RH, light intensity and temperature. The data of the worker affective state is heart rate. An ANN model is developed to predict the temperature set points based on the data of the workstation environment and the heart rate. In subsystem 3, the set point was transformed as a signal to a microcontroller. The microcontroller controls the hardware of the air conditioner, fan, natural ventilation, humidifier, lighting system and heart-rate sensor. The input formats of the air conditioner, humidifier and heart-rate sensor are digital continuous numbers. The input of the fan is classified as switch of scales 1, 2 and 3. The input of natural ventilation is the mechanical control of open and close. If the manager is satisfied with the worker's performance, the temperature set points are decided. If the manager is dissatisfied, the database generates the data to subsystem 2.

Fan was suggested as an important hardware to control the affective human parameters since it consumed less energy than an air conditioner (Liu et al., 2013). Air conditioner was suggested when the use of other controls could not create a satisfactory thermal environment in hot and cold weather (Liu et al., 2013).

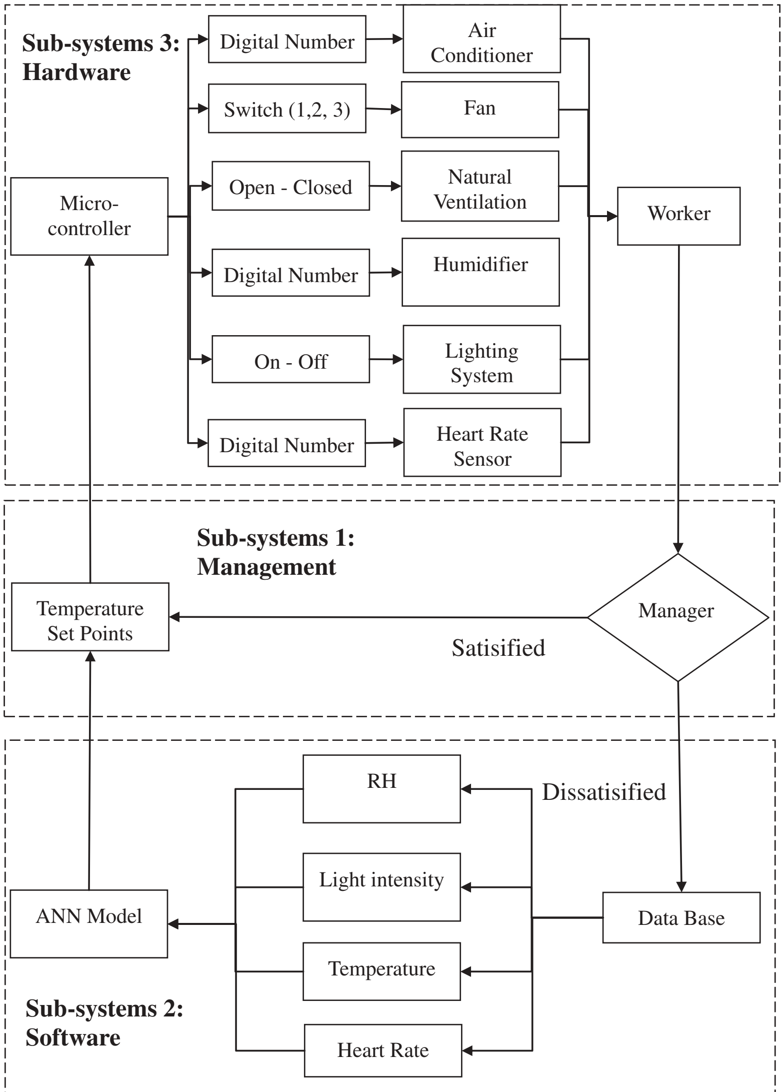

Figure 1. Modeling affective temperature control in food SMEs.

1.2.3 *Research methodology*

Figure 2 describes the methodology for predicting the affective temperature set points in food SMEs using ANN. The methodology consists of the following.

1.2.2.1 *Data Acquisition*

Table 1 indicates the profile of the parameters in data acquisition. Six food SMEs of different food products were used as the case studies. Food SMEs were crackers, nuggets, fish chips, bakpia, tempe and herbal instant

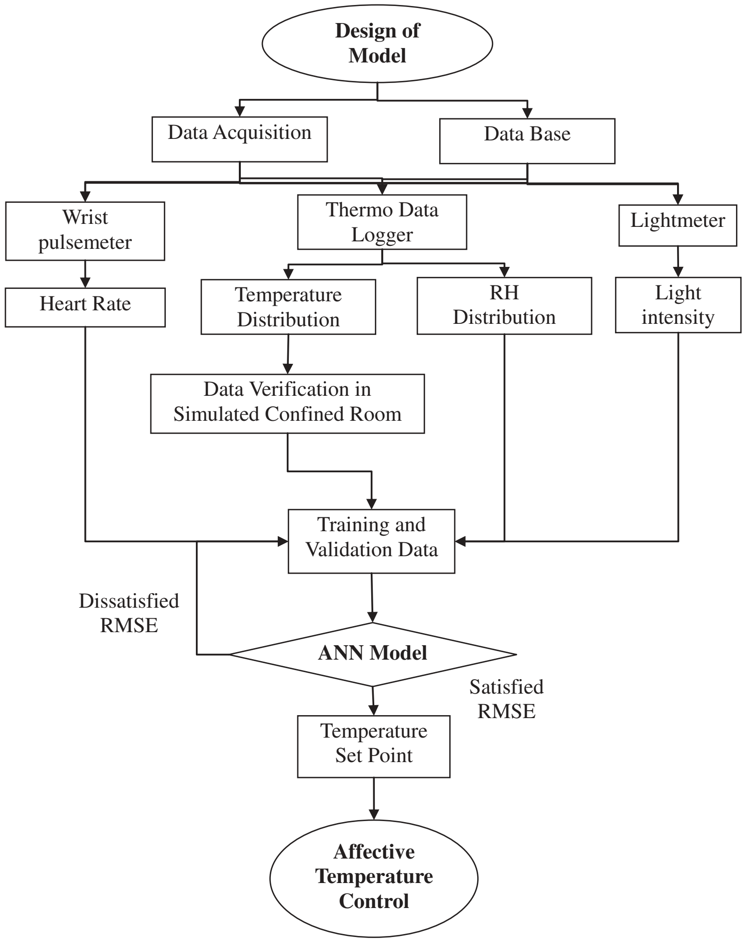

Figure 2. Methodology for predicting affective temperature set points.

Table 1. Profile of data.

No	Parameters	Average and standard deviation
1.	Heart rate	88.9 ± 10.5
2.	Workstation temperature	33.4 ± 2.9
3.	Workstation relative humidity	65.3 ± 12.0
4.	Relative humidity set points	76.4 ± 6.8
5.	Light intensity	1603.7 ± 3801.5
6.	Temperature set points	29.3 ± 1.8

beverages. The data from four food SMEs were acquired from our database during 2013–2015 as crackers, fish chips, bakpia and tempe, whereas the others were acquired in 2016.

The temperature set point was measured before working time, Li et al. (2016) concluded that the working time of 14:00–15:00 was identified as the most hazardous for workers throughout the day and the time from 07:00 to 09:00 was identified as the least hazardous time. This is in agreement with the workstation of food SMEs, which stated on average before working from 06.00 to 08.00 and after working from 15.00 to 16.00. This confirms that the temperature before working is the least hazardous; therefore, it is recommended as the temperature set point. Besides, this confirms that temperature after working is suitable as one of the inputs for the ANN model.

1.2.2.2 *Data Verification in a Simulated Confined Room*

Indoor simulated environment is important to verify data for ANN (Wang et al., 2015). The data of temperature set point is verified using an empty simulated confined room. An empty workstation was used in Laboratory of Production System, Department of Agro-industrial Technology, Universitas Gadjah Mada. The objective of the workstation simulation is to verify the

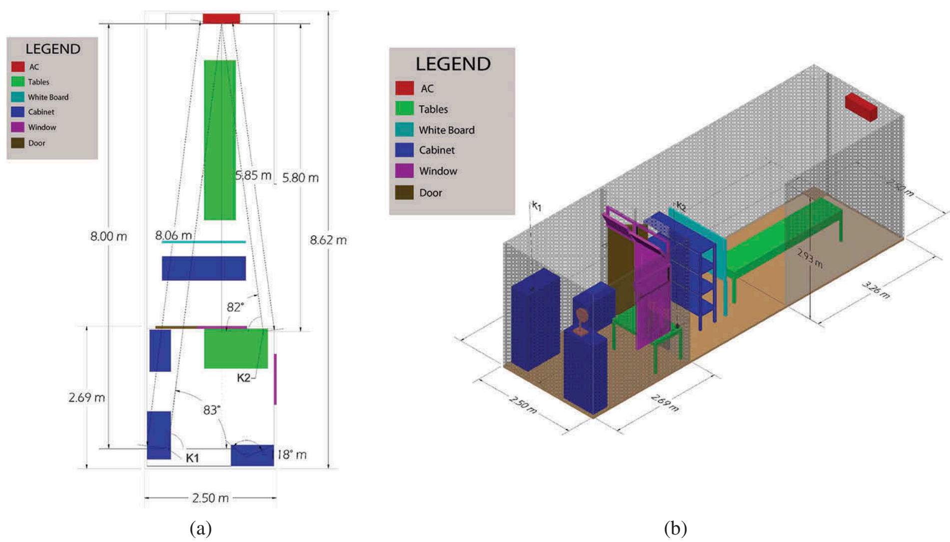

Figure 3. Workstation layout of simulated confined room: (a) upper view; (b) front view.

Table 2. Design of experiment for the verification of temperature set points.

Experiment	Lighting	Fan 1	Fan 2	Air conditioner	Ventilation	T_{mode0} (^{0}C): K1	T_{mode0} (^{0}C): K2
1	×	×	×	×	×	29.1	29.7
2	√	√	×	×	×	30.2	29.8
3	√	√	×	×	√	29	28.6
4	√	√	×	√	√	29	28.5
5	√	√	√	×	√	28.2	27.9
6	√	√	√	√	√	28.8	28.5
7	√	√	×	√	√	29.6	29.1
8	√	√	×	√	√	29.1	28.7
9	√	√	×	√	√	30.2	29.6
10	√	√	×	√	√	29.4	29.0
11	√	√	×	√	√	29.0	28.6
Average Value of Mode						29.3 ± 0.5	29.0 ± 0.5

√ = Applied
× = Not applied

data of temperature set points from food SMEs. The simulation was pursued in 11 days. Figures 3a and 3b indicate the layout of workstation. K1 and K2 are the locations of the temperature data logger.

Table 2 indicates the various experimental designs based on hardware lighting, fan 1, fan 2, air conditioner and ventilation. The temperature of the simulated confined room is set as the temperature set point since there is no human and production process inside. The mode value of the temperature set points is measured in two different positions of K1 and K2 (Figs. 3a and 3b). The simulated confined room verified that the data (29.0 ± 0.5 to 29.3 ± 0.5) are similar to the collected data from food SMEs in Table 1 (29.3 ± 1.8).

1.2.2.1 *Worker and Environment*

Table 3 indicates the low coefficient of determination (R^2) value between the heart rate and the environmental parameters of T_0, RH_0, RH_1, L_1 and T_1. The

Table 3. R^2 value between HR and environment.

No	Relationship	R^2 value
1.	HR and T_0	0.00
2.	HR and RH_0	0.03
3.	HR and RH_1	0.03
4.	HR and L_1	0.00
5.	HR and T_1	0.06

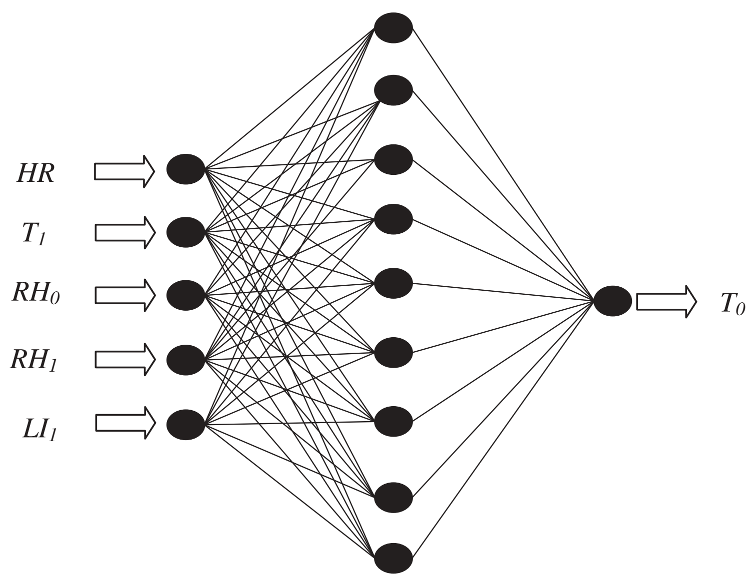

Figure 4. Artificial neural network model for affective temperature control.
Notes
HR = Heart rate of worker
T_1 = Temperature of workstation
RH_0 = Relative humidity set points
RH_1 = Relative humidity of workstation
LI_1 = Light intensity of workstation
T_0 = Temperature set points

R^2 value concluded that ANN is required to model the nonlinear relationship between the heart rate and the workstation environment in food SMEs.

1.2.2 *Artificial Neural Network*

An ANN model is developed to predict the temperature set points (Fig.4). The inputs of the ANN model are worker heart rate, workstation temperature, relative humidity distribution and light intensity. The output is the temperature set point. ANN uses the feed-forward architecture and the supervised back-propagation learning. The ANN software was developed using Macro-based Microsoft Visual Basic Application for Microsoft Excel (Okayama, 2002).

1.3 Results and Discussions

1.3.1 *Training and Validation Data*

Table 4 indicates the characteristic of data from different food SMEs. Regulation of Ministry of Energy and Mineral Resources (RMEMR) No.13 Year of 2012 has declared according to National Standard of Indonesia (SNI) for the transit room or lobby the temperature should be between 27 and 30^{0}C (Anonym, 2012). The transit room or lobby is the most approximate condition for the workstation of SMEs. National Standard of Indonesia (SNI) No. 16-7063-2004 has defined the threshold value in the workplace environment. SNI recommends the temperature range of 25–30^{0}C for the various workloads (Anonym, 2003). From these regulations of RMEMR and SNI, the value of 30^{0}C could be recommended as the affective temperature in the workplace. As a comparison, Zomorodian et al. (2016) stated in one of their reviews finding that range of 26.60–30.70 ^{0}C can be categorized as the higher limit of the affective temperature in educational buildings. Therefore, this confirmed 30^{0}C as the similar limit for the affective temperature between the workstation of SMEs and educational buildings (Table 4.)

Table 4. Mode value of training and validation data.

Parameters	Bakpia	Fish chips	Tempe	Cracker	Nugget	Herbal beverage
HR (pulse per minute)	98	96	77	98	98	98
T_0 (^{0}C)	27.6	30.3	30.2	27.7	30.3	29.1
T_1 (^{0}C)	33.1	31.1	34.2	35.7	30.1	30.1
RH_0 (%)	79.1	76	59	77	86.2	73.3
RH_1 (%)	60.5	61.2	57	51.5	78	71.3
L_1 (Lux)	65.5	1448.9	370	16.1	1457	20

Table 5. Specification of ANN training data.

No	Parameters	Minimum value	Maximum value
Input			
1.	*HR*	66	123
2.	T_1	27	46
3.	RH_0	59	92
4.	RH_1	30	91
5.	L_1	13	20000
Output			
1.	T_0	24	33

Table 6. Specification of ANN validation data.

No	Parameters	Minimum value	Maximum value
Input			
1.	*HR*	75	112
2.	T_1	28	46
3.	RH_0	59	92
4.	RH_1	30	91
5.	L_1	13	20000
Output			
1.	T_0	27	33

Figure 5. Learning iteration of the ANN model.

1.3.2 *Specification for ANN output*

The data were recapitulated into 356 data sets. The 315 data sets were used in training ANN model, whereas the remaining were used in validation data. Table 5 indicates the input and output ranges of the ANN training data and table 6, the validation data. The ANN model was trained and validated using these data.

1.3.3 *Artificial Neural Network*

Training process achieved the convergence approximately 30000 iterations. Learning coefficient of 0.1 and momentum of 0.9 were determined (Fig. 5).

Table 7. Sensitivity analysis of the ANN model.

No	Hidden neuron	Iteration	RMSE training	RMSE validation
1.	5	10000	0.106	0.117
2.	8	10000	0.094	0.106
3.	10	10000	0.094	0.104
4.	12	10000	0.095	0.113
5.	10	20000	0.089	0.096
6.	12	20000	0.097	0.096
7.	8	30000	0.100	0.104
8.	10	30000	0.101	0.096
9.	12	30000	0.081*)	0.086*)
10.	12	40000	0.094	0.103
11.	14	10000	0.091	0.099
12.	14	20000	0.096	0.095

*) Minimum RMSE

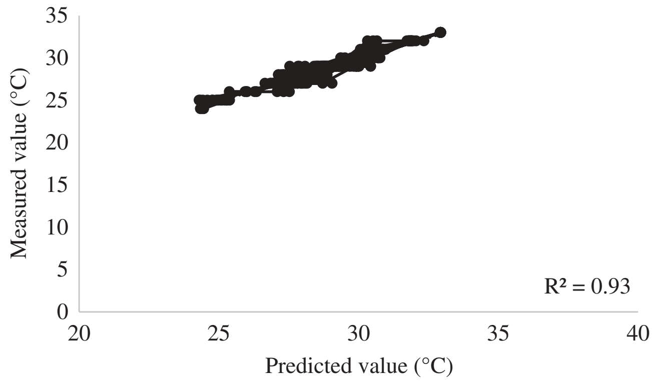

Figure 6. R^2 value of the training data between the measured and predicted temperature set points.

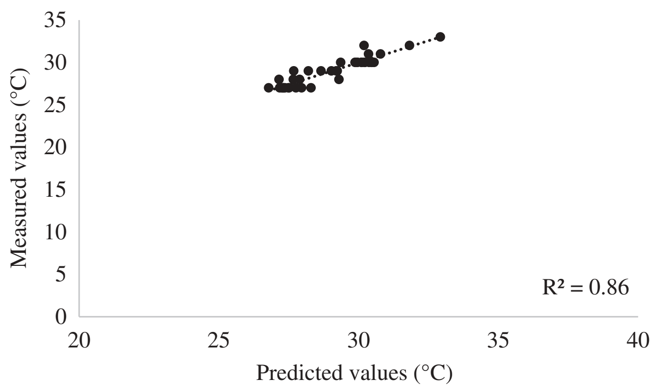

Figure 7. R^2 value of the validation data between the measured and predicted temperature set points.

The root mean square errors (RMSEs) of the training and validation data were 0.081 and 0.086, respectively.

Table 7 describes the sensitivity analysis of the ANN model. It is based on output error by trial and error basis. Based on the minimum RMSE of training and validation, 12 neurons in the hidden layer were selected. The architecture of ANN consisted of five neurons in the input layer, 12 neurons in the hidden layer and one neuron in the output layer (5-12-1).

Figures 6 and 7 indicate the comparison for the R^2 value between the predicted and measured temperature set points. The R^2 value for the training and validation data were 0.93 and 0.86, respectively. The ANN model tested successfully predicted temperature set points using the back-propagation supervised learning method.

1.3.4 *Research limitations and advantages*

This research measured the temperature set point before the working condition due to similarity to the outdoor temperature. The temperature set point of 29.1 ± 1.8 ^{0}C did not provide the maximum worker affectivity regarding thermal comfort of the worker as discussed in Xiong et al. (2015). However, this limitation could be traded off by the minimum cost of air conditioner utilization. Cost efficiency is important for food SMEs in Indonesia, where most of them are not capital intensive. Besides, cost efficiency is associated with energy saving. Wang et al. (2013) calculated that the average ambient temperature of 24.18^{0}C could save energy of 0.01679 MWh daily. Therefore, temperature set points of 29.1 ± 1.8 ^{0}C could save more energy in food SMEs, if it is implemented using an air conditioner.

1.6 Conclusions

This research proposed modeling the affective temperature control for food SMEs based on heart rate and workstation environment. The modeling consists of three subsystems: Management, Software and Hardware. The modeling of subsystem software was developed using ANN. The inputs of ANN were worker heart rate, workstation temperature, relative humidity distribution and light intensity. The output was temperature set point. An ANN model was developed successfully to predict the temperature set points using the back-propagation supervised learning method. The research results indicated the satisfactory performance of ANN with minimum error. The ANN model indicated the closeness of the R^2 value between training and validation data. It can be concluded that workstation temperature set points could be controlled using worker heart rate and workstation environment. The model could be used to provide environmental ergonomics in food SMEs.

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