PREDICTION OF INDOOR ENVIRONMENTAL PARAMETERS FOR NATURALLY VENTILATED BUILDING USING ARTIFICIAL NEURAL NETWORK: A REFLECTION OF OUTDOOR PARAMETERS

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Dedicated specially

To my beloved Father, Mother and Siblings

For their invaluable sacrifice,

Love and encouragement,

Thanks for everything…

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In the Name of Allah, the most Gracious, the most Compassionate, Praise be to Allah, Lord of the Universe

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ABSTRACT

This research investigates the environment condition within two types of buildings, naturally ventilated and air-conditioned to gain better understanding of the indoor environment condition of the selected buildings. The main purpose of this study is to develop predictive model to forecast indoor environmental parameters using Artificial Neural Network (ANN) technique. Field measurements were conducted at four traditional Malay houses in Peninsular Malaysia to acquire the actual indoor and outdoor data; and to provide data for network training during model development. Hourly time-series data of three indicators including: air temperature, relative humidity and air velocity were used to forecast the indoor environmental parameters. The performance of the developed model was evaluated using R squared (R^2) and Mean Square Error (MSE). Network testing was performed to validate the models developed. The accuracy of the model was measured using the Mean Absolute Percentage Error (MAPE). Results from the research show that twelve ANN models with the best structure were successfully developed to forecast indoor temperature, humidity and velocity. The MAPE values for the comparison between the actual and predicted for naturally ventilated building is less than 20 percent for indoor temperature and humidity which can be considered acceptable as suggested by many researchers. However, the MAPE value is more than 20 percent for indoor velocity. As for air-conditioned building, the MAPE values exceed 20 percent for all parameters. It was found that the developed models only applicable for naturally ventilated building. The models in general could predict indoor temperature and humidity pattern with modest accuracy. However, it is not applicable for air-conditioned building due to the different building characteristics.

Keywords: indoor environment, natural ventilation, prediction, Artificial Neural Network.

ABSTRAK

Kajian ini menyiasat keadaan persekitaran di dalam dua jenis bangunan, pengudaraan semula jadi dan penghawa dingin untuk mendapatkan pemahaman yang lebih baik bagi keadaan persekitaran dalaman bangunan yang telah dipilih. Tujuan utama kajian ini adalah untuk membangunkan model ramalan bagi meramal parameter persekitaran dalaman dengan menggunakan teknik Rangkaian Neural Buatan. Pengukuran lapangan telah dijalankan di empat buah rumah tradisional Melayu di Semenanjung Malaysia untuk mendapatkan data dalaman dan luaran sebenar; dan untuk menyediakan data untuk latihan rangkaian semasa proses pembangunan model. Data setiap jam bagi tiga petunjuk termasuk: suhu udara, kelembapan relatif dan halaju udara telah digunakan untuk meramal parameter persekitaran dalaman. Prestasi model yang dibangunkan dinilai menggunakan R kuasa dua (R^2) dan *Mean Square Error (MSE)*. Pengujian rangkaian telah dilaksanakan untuk menentukan keberkesanan model yang telah dibangunkan. Ketepatan model diukur dengan menggunakan *Mean Absolute Percentage Error (MAPE)*. Hasil kajian ini menunjukkan dua belas model ANN dengan struktur yang terbaik telah berjaya dibangunkan untuk meramal suhu, kelembapan dan halaju dalaman. Bagi perbandingan antara nilai sebenar dan ramalan suhu dan kelembapan dalaman untuk bangunan pengudaraan semula jadi nilai *MAPE* adalah kurang daripada 20 peratus. Kebanyakan penyelidik mencadangkan nilai *MAPE* kurang daripada 20 peratus adalah boleh diterima. Walau bagaimanapun, nilai *MAPE* bagi halaju dalaman adalah melebihi 20 peratus. Bagi bangunan berhawa dingin, nilai *MAPE* untuk semua parameter adalah melebihi 20 peratus. Hasil kajian menunjukkan bahawa model yang dibangunkan hanya boleh digunakan untuk bangunan pengudaraan semula jadi. Secara umum, model-model tersebut boleh meramalkan corak suhu dan kelembapan dalaman dengan ketepatan yang sederhana. Walau bagaimanapun, ia tidak boleh digunakan untuk bangunan berhawa dingin disebabkan oleh ciri-ciri bangunan yang berbeza.

Kata Kunci: persekitaran dalaman, pengudaraan semula jadi, ramalan, Rangkaian Neural Buatan.

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LIST OF SYMBOLS AND ABBREVIATIONS

AI	-	Artificial Intelligent
ANN	-	Artificial Neural Network
ASHRAE	-	American Society of Heating, Refrigerating and Air-Conditioning Engineers
IEQ	-	Indoor Environmental Quality
RH	-	Relative humidity
Temp	-	Temperature
MSE	-	Mean square error
MAPE	-	Mean Absolute Percentage Error

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CHAPTER 1

INTRODUCTION

1.1 Background of the Research

"Indoor" refers to the environments inside homes, schools, public buildings, and similar spaces to which the public has access (National Research Council, 1981). In recent years, the issue of indoor environmental condition in building has received great attention. Global warming and rapid development in building and construction industry added the increasing of environmental condition issue. The main reason was because of people typically spend most of their times in the indoor environment compared to the external environment which implies that the indoor environment has become more important to the public health.

Nowadays, people are demanding on their quality of life. In order to sustain the quality of life, healthy, safe and comfortable indoor environments are needed. A quality indoor environment is one which promotes comfort, health, and well-being of the building occupancy. Building exist to protect people from the elements and to otherwise support human activity. However, unless buildings are managed well, indoor environmental conditions have the potential to make people sick, cause them discomfort, or otherwise inhibit their ability to perform.

A building is a system that is linked to its surrounding environment and is subject to a range of interactions between the external conditions and the indoor comfort condition (Naseer, 2013). To create a comfortable indoor climate, architects and engineers should have to take decisions from the beginning of the design process (Malinda Anthony, 2002).

A good building design will contribute to a good quality of living space. Hanafi (1999) stated that traditional building design deliver good indoor comfort and suitable with local climate. It is often regarded as a good natural ventilated dwelling in hot humid climate due to its design strategies and material selection (Mohd Hafizal et al., 2012). It can be described as raised on timber stilts with floor and wall gaps to allow maximum cross ventilation (Mohd Hafizal et al., 2012) and made of materials which were easily available from the tropical forests such as timber, bamboo, rattan and leaves (Wafi and Ismail, 2008). However, the local building materials and the coherent design principles of the traditional forms are being abandoned under the influence of modernism.

According to Hanafi (1999), the traditional concept of the building had been displaced with modern design which incorporates architectural styles and materials that ignore the local climatic conditions as well as the cultural, social and economic interactions. It has been modified to adapt with new materials for their durability such as concrete and bricks for walls; metal, concrete and clay tiles for roofing in several types, colours and styles. In fact most of imported building technologies are not thermally suitable under Malaysian climate (Wafi and Ismail, 2008). Consequently, such buildings will end up with poor indoor climate, which affects comfort, health and efficiency. The problem is found in dwellings as well as workplaces or public buildings, such as schools and hospitals.

The location of Malaysia which is under tropical climate region is naturally hot and a humid climate. According to Rajapaksha et al. (2003), local climate greatly affects the indoor thermal environment in buildings. Buildings are overheated during the day due to solar heat gain through the building envelope and solar penetration through windows. Ahmed (2003) stated that comfortable outdoor spaces have a significant bearing on the comfort perception of the indoor ambience. Therefore, the demand for comfort conditions in buildings is significantly increased as a result of exposure to uncomfortable outdoors. In the context of Malaysia,

overheated outdoor environment of the city has contributed to a growing preference for a lower comfort temperature indoors. Considering this situation, a large number of the buildings are served by air-conditioning units and other mechanical ventilation systems that are designed to maintain a thermally comfortable indoor environment (Wafi and Ismail, 2008; Khalil and Husin, 2009). This in turn has put an immense pressure on the energy demand in the cities. This situation contributes to the excessively high amount of energy consumption for cooling as well as its running cost. Besides that, it also will have a negative impact on the environment.

Climate is a principal physical environment factor in the design of buildings and settlement for the indoor environment comfort condition. According to Manibhai (2013), the climate of a region plays a great role in determining the design and construction of a building because the indoor environment is strongly influenced by the impacts of outdoor environment. Conducive spatial and indoor environments are major aspects in the successful performance in a building. Both human beings and buildings interact with heat, light, sound, air, and other climatic and geophysical elements that surround them and they contribute to the formation of comfort condition. Besides that, the external factors directly influence the indoor climate in many buildings. Hence, outdoor overall planning requires to be considered in order to identify factors that encourage the formation of an acceptable indoor fresh air flow into the building. Therefore, in order to design a structure responding to environment all factors that effect on the external environment as well as aspects of internal environment should be considered (Lavafpour and Surat, 2011).

The creation of comfortable, healthy and safe environments with the most efficient of energy consumption is fundamental to the successful operation of a building. These requirements are of greater importance as concern grows over both the qualities of indoor climate and the global impact of energy use. Considering both the severe global environmental situation brought by high energy consumption and the environmental quality needs from building occupants, the concept that to achieve better environmental quality, higher performance and more sustainable building by exploring climatic conditions and environmental strategies in the conventional vernacular building form has been put forward and got wider recognition (Olgyay and Olgyay, 1963; Givoni, 1998; SHI and Edward, 2014). The concept has been known as climatic design, a method for reducing overall energy cost of a building

(Lin and Deng, 2008; Shakoor, 2011). Climatic design creates comfortable, energy efficient and environmentally wise buildings. Besides that, it can be learned and stimulated by observation and prediction.

Classical process-based modelling approaches can provide good estimations of indoor environment, but they usually are too general to be applied directly without a lengthy data calibration process. They often require approximations of various processes, and these approximations may overlook some important factors affecting the processes within the environment. According to Palani et al., (2008) a process based model requires a lot of input data and model parameters that are often unknown, while data driven techniques provide an effective alternative to conventional process-based modelling. Moreover, this models developed by data-driven techniques are expected to be computationally very fast and require fewer input parameters than process-based models.

Data-driven modelling techniques have gained popularity in the last several years. The scientific and engineering communities have acquired already extensive experience in the development and usage of data-driven techniques. One of the most popular data-driven approaches is Artificial Neural Network (ANN). ANN is as simplified mathematical models of brain-like systems (Hassan and Li, 2010).

ANN often offers a superior alternative to traditional physical-based models, and excels at understanding the behaviour of patterns or relationships in data. It is also a powerful non-linear estimator which is recommended when the functional form between input and output is unknown or it is not well understood but believed to be nonlinear (Salazar et al., 2007). This is especially the case in providing comfortable indoor environment where the factors influencing indoor comfort condition are highly interactive. These considerations justify the use of ANN modeling approach. Moreover, as an artificial intelligent (AI) information-processing tool, the ANN system has been proven to be a powerful approach to solving complex nonlinear mappings with higher accuracy than regression methods.

There are available numerous software tools to design and manage the ANN. However, only a few of them were used in papers more often than the others. Among of them, MATLAB was successfully used in several works including Strik et al., (2005); Sofuoglu (2008); Al-Shamisi et al., (2011) and Sapon et al., (2011). Therefore, the MATLAB Neural Network Toolbox was used in this study because it

is flexible and easy to apply. The list of available software mentioned is presented in Table 1.1.

Table 1.1: List of Artificial Neural Network Tools (Source: Krenek et al., 2014)

Tool name	Environment	License
NeuroShell 2	SA	Commercial
Weka	SA	GNU GPL
Neural Network Toolbox	MATLAB	Commercial
NeuroXL	MS Excel	Commercial

The use of artificial neural networks (ANN) is a new promising approach to simulate engineering problems (Sharma et al., 2000; Ramli, 2011). It has been shown to be a powerful and versatile tool, particularly in dealing with prediction and classification problems. Besides that, ANN has been utilized in various building applications such as prediction of heating load, ventilation rate and indoor temperature. Therefore, primary interest of this study is to analyze environmental parameters within both naturally ventilated and air-conditioned buildings and to construct predictive models by using the ANN technique.

1.2 Problem Statement

Malaysia as warm and humid tropical climate is known by its characteristics of high temperatures, high relative humidity and very low wind speeds. Under these weather conditions, these for sure make the environment conditions uncomfortable in building. In view of this, it is important to study the indoor environment especially thermal environment. Therefore, it is important to conduct this study to get all the parameters needed in developing the indoor environment prediction model and to propose indoor environment prediction with improvement of indoor environment statistical model.

There are many prediction models that have been developed to forecast environment condition within building. However, there has been no research purposely done on the forecast of indoor environmental parameters model based on

ANN. In this study, with the aid of ANN which is one of data driven modeling techniques, indoor environmental parameters prediction model will be developed and the advantages of using ANN for forecasting will be identified.

1.3 Aims and Objectives of the Research

The aim of this research is to develop prediction model using Artificial Neural Networks (ANN) technique to predict indoor environmental parameters in natural ventilated building in Malaysia. To achieve this aim, the following objectives have been identified and carried out:

i. To investigate real data sets pattern for environmental parameters both indoor and outdoor at a specific locations in Peninsular Malaysia.
ii. To determine the level of indoor environmental condition at the selected buildings and compare the results with recommended standards and previous research.
iii. To develop models using ANN to predict indoor environmental parameters in four traditional Malay houses in Peninsular Malaysia.
iv. To simulate and validate the accuracy of the prediction model.

1.4 Scopes and Limitations of the Research

The scope of research falls into two broad sections, that is, environmental parameters measure including air temperature, relative humidity and air velocity at both natural ventilated and air-conditioned buildings through selected case study; and forecasting models of indoor environmental parameters.

For the first section, a comprehensive literature review on the issues of the indoor environment was conducted. Through this review, a better understanding on the theoretical aspect of the study can be achieved. Three locations were identified

as suitable case study area which is located at Johor, Negeri Sembilan and Kedah. In order to develop the prediction model, data for all parameters considered for the study area need to be identified and it will be collected using anemometer.

In developing forecasting models of indoor environmental parameters, a literature review on theory and application of artificial neural networks serves as a prelude to develop the ANN models. The prediction model will be developed by using MATLAB Neural Network Toolbox software.

Both field measurement and application of MATLAB software are used in a complementing manner in the investigations of indoor environment condition as part of the methodology employed in this research, and thus bears the limitations of the toolbox used.

1.5 Significance of the Research

This study is beneficial because it can provide baseline information and advancement of knowledge and design appropriate within tropical climate for best indoor environmental condition for the future building design. Moreover, data such as temperature distribution and wind speed can be used as a guideline by relevant government bodies, houses developers and agencies to come up with more energy conserving building design. Through this study also, it is expected lesson can be drawn from the climatic design of traditional house for the future building design in the modern context.

From a comprehensive research finding output, a Neural Network Model developed. The developed application hopefully will be a potential application to forecast environment condition within building at any given time and also can be used to supplement measurements, or to predict impacts when measurements cannot be made. Besides that, with the aid of the prediction model also helps the engineers to formulate strategies and mitigation measured for minimizing the energy consumption within building.

REFERENCES

Abd Rashid, M.S., and Dawa, M.N. (2005). The Symbolism of Tunjuk Langit (Finials) in the Malay Vernacular Architecture. *International Seminar Malay Architecture As Lingua Franca,* National Museum, Jakarta: Universitas Trisakti.

Abdul Aziz, U.H.H. (2012). A Study of Regional Development in Malaysia Based on state level data. International Islamic University Malaysia: Bachelor's Degree Thesis.

Abdul Rahman, A.M. (1995). Housing design in relation to environmental comfort. Build.

Abdullah, A.H. (2007). A Study on Thermal Environmental Performance in Atria in the Tropics with Special Reference to Malaysia. Heriot-Watt University: Ph.D Thesis.

Abdulmalik, A. and Young, A. (1993). Thermal comfort study as an aid to determine energy savings in buildings in Malaysia, Pro. Energex 93, Vol.II, Seoul.

Abu Bakar, S. K. (2013). An Evaluation of Passive Cooling Strategies on Indoor Thermal Performance of an Office Space. University Tun Hussein Onn Malaysia: Master's Degree Thesis.

Afzali, M., Afzali, A., and Zahedi, G. (2011). Ambient air temperature forecasting using artificial neural network approach. *International Conference on Environmental and Computer Science*, *vol.19,* pp. 176-179.

Ahmed, K.S. (2003). Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments. Energy Build. 35: 103 – 110.

Al Shamisi, M.H., Assi, A.H., and Hejase, H.A.N. (2011). Using MATLAB to Develop Artificial Neural Network Models for Predicting Global Solar Radiation in Al Ain City – UAE, Engineering Education and Research Using MATLAB, Dr. Ali Assi (Ed.), ISBN:978-953-307-656-0, InTech, Available from: http://www.intechopen.com/books/engineering-education-and-research using-matlab/using-matlab-to-developartificial-neural-network-models-for-predicting-global-solar-radiation-in-al

Aminuddin, A.M.R. and Rao, S.P. (2008). Sustainable air-conditioning for the tropical buildings, Journal of Design and Built Environment, 4(1), 55 – 62.

Anantwar, S.G. and Shelke, R.R. (2012). Simplified approach of ANN: Strengths and Weakness. *International Journal of Engineering and Innovative Technology (IJEIT), vol.1, no.4,* pp. 73 – 77.

Aprita, Y.D. (2004). Optimize the Percentage of Opening Area due to Thermal Comfort in Hot Humid Residential (Using Eco House as Model Simulation). *SENVAR5 - The 5th International Seminar on Sustainable Environmental Architecture* (pp. 1–10).

Ariffin, S.I. (2001). Order in Traditional Malay House Form. Oxford Brookes University, U.K.

ASHRAE Standard 55-1992. 1992. *Thermal Environmental Conditions for Human Occupancy*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

Bailey, D. and Thompson, D. (1990). "How to develop neural network applications", *AI Expert, 5(6),* pp. 38-47.

Bajpai, S., Jain, K., and Jain, N. (2011). Artificial Neural Networks. *International Journal of Soft Computing and Engineering (IJSCE), vol.1, issue – NCAI,* pp. 27-31.

Bajracharya,. B., Kumarasurya, A., and Demirbilek, F.N. (2003). Vernacular Architecture in Queensland, Australia: Current Planning Issues and Opportunities.

Beale, M.H., Hagan, M.T., and Demuth, H.B. (2010). *Neural Network Toolbox™ 7: User's Guide*. The MathWorks, Inc., Natick, MA.

Bluyssen, P. (2009). The Indoor Environment Handbook: How to Make Buildings Healthy and Comfortable. London: Earthscan.

Boussabaine, A.H. (1996). "The use of artificial neural networks in construction management: a review", *Construction Management and Economics, vol.14, no.5*, pp. 427-436.

Çakir C. (2006). Assessing thermal comfort conditions; A case study on the metu faculty of Architecture Building. (Masters dissertation, Ahmadu Bello University, 2006). Retrieved from data base.

Charles, K.E. (2003). *Fanger's Thermal Comfort and Draught Models*. Ottawa, Canada.

Chen, V.F. (1998). *The Encyclopedia of Malaysia, Volume 5, Architecture*. Archipelago Press, Kuala Lumpur.

Cheng, J., Li, Q.S., and Xiau, R.C. (2008). A new artificial neural network – based response surface method for structural reliability analysis. *Probabilistic Engineering Mechanics, vol.23, no.1*, pp. 51-63.

CIBSE Guide Volume A, Design Data 1986, Watford.

Cybenko, G. (1989). Approximation by superpositions of a sigmoidal function. *Mathematical Control Signals Systems 2*, pp. 303-314.

Dadan, N., Tee, B.T., and Gan, C.K., and Leman, A.M. (2006). Carbon dioxide concentrations analysis inside lecture rooms. *International Conference on Energy and Environment (ICEE).*

De Groot, C., and Wurtz, D. (1991). Analysis of univariate time series with connectionist nets: a case study of two classical examples. *Neurocomputing 3*, pp. 179-192.

Deppisch, J., Bauer, H. –U., and Geisel, T. (1991). Hierarchical training of neural networks and prediction of chaotic time series. *Physics Letters 158*, pp. 57-62.

Donald, L.H. and James, F.H. (1997). "*Data, statistics and decision models with excel*", John Wiley & Sons Inc., New York.

Duch, W., and Jankovski, N. (1999). Survey of neural transfer functions. *Neural Computing Surveys, vol.2*, pp. 163 – 212.

Fanger, P.O. (1970). *Thermal Comfort*. Danish Technical Press, Coopenhagen.

Gallo, C. (1994). Bioclimatic architecture. *Renewable Energy 5 (5–8),* pp. 1021 – 1027.

Givoni, B. (1998). *Climate considerations in building and urban design*. New York: John Wiley & Sons.

Givoni, B. (1976). *Man, Climate and Architecture*. 2nd Edition. Applied Science Publishers:

Gulam Hassan, M.A., and Gholam Hassan, A.A. (2003). Development Planning and Regional Imbalances in Malaysia. FEA Working Paper 2003 – 5, Faculty of Economics and Administration, Universiti of Malaya, Kuala Lumpur. Available: http://fep.um.edu.my/images/fep/doc/2003%20Pdf/FEA-WP-2003-005.pdf

Gupta, N. (2013). Artificial Neural Network. *International Conference on Recent Trends in Applied Sciences with Engineering Applications, Network and Complex Systems, vol.3, no.1,* pp. 24-28.

Hanafi, Z. (1999). *Rekabentuk Bangunan Dalam Iklim Panas dan Lembap di Malaysia*, Kuala Lumpur : Dewan Bahasa dan Pustaka.

Harun, S. (1999). Forecasting and Simulation of Net Inflows for Reservoir Operation and Management. University Teknologi Malaysia: Ph.D Thesis.

Hassan, A.S. (2001). Towards Sustainable Housing Construction in Southeast Asia. *Journal of Agenda 21 for Sustainable Construction in Developing Countries,* First Discussion Document. Rotterdam, Netherland. In-House Publishing, pp. 17.

Hassan, A.S., and Ramli, M. (2010). Natural Ventilation of Indoor Air Temperature: A Case Study of the Traditional Malay House in Penang. *American J. of Engineering and Applied Sciences, 3(3),* pp. 521 – 528.

Hassan, R., and Li, M. (2010). Urban Air Pollution Forecasting Using Artificial Intelligence-Based Tools, Air Pollution, Vanda Villanyi (Ed.), ISBN: 978-953-307-143-5, InTech, Available from: http://www.intechopen.com/books/air-pollution/urban-air-pollution-forecasting-using-artificial-intelligencebased-tools

Haykin, S. (1999). *Neural Networks: A Comprehensive Foundation*. Prentice Hall.

Helena, C. (1998). Bioclimatism in vernacular architecture. *Renewable and Sustainable Energy Reviews*, 2(1-2), pp. 67 – 87.

Hellsing, V.U.L. (2009). *Indoor Air Quality in junior high schools in Reykjavik*. University Of Iceland: Master's Degree Thesis.

Hidayat, W. (2011). Application of Malay traditional architecture elements as regional identity towards sustainable city. *Proceedings of the 12th International Conference on Sustainable Environment and Architecture (SENVAR)*. Malang: Brawijaya University, Indonesia.

Hornik, K., Stinchcombe, M., and White, H. (1989). Multilayer feedforward networks are universal approximators. *Neural Networks 2*, pp. 359-366.

Hush, D., and Horne, B.G. (1993). Progress in supervised neural networks. *IEEE Signal Process Magazine, vol.10, no.1*, pp. 8-39.

Ibrahim, S.H. (2004). Thermal Comfort in Modern Low-Income Housing in Malaysia. University of Leads, UK: Ph.D. Thesis.

Ibrahim, S.H., Baharun, A., Abdul Mannan, M.D., Abang Adenan, D.A. (2013). Importance of thermal comfort for library building in Kuching, Sarawak. *International Journal of Energy and Environment (IJEE),* Vol. 4, Issue 6, pp. 1003 – 1012.

Ibrahimy, M.I., Ahsan, M.R., and Khalifa, O.O. (2013). Design and Optimization of Levenberg-Marquardt based Neural Network Classifier for EMG Signals to Identify Hand Motions. *Measurement Science Review, 13(3)*, pp. 142-151.

Irie, B., and Miyake, S. (1988). Capabilities of three-layered perceptrons. *In Proceedings of the IEEE International Conference on Neural Networks, I*, pp. 641-648.

Ismail, Z., and Ahmad, A.S. (2006). Modularity Concept on Traditional Malay House (TMH) in Malaysia. *Proceeding of International Conference on Construction Industry (ICCI), Padang, Indonesia*, pp. 698 – 709.

ISO 7730. 1994. *Moderate Thermal Environments – Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort.* 2nd Edition. International Organisation for Standardization, Geneva, Switzerland.

Jain, A.K., Mao, J., and Mohiuddin, K.M. (1996). Artificial Neural Networks: A Tutorial. *IEEE Computer Special Issue on Neural Computing, vol.29, no.3*, pp. 31-44.

Ju, S.R., Omar, S., Ko, Y. E. (2012). Modernization of the Vernacular Malay House In Kampong Bharu, Kuala Lumpur. *Journal of Asian Architecture and Building Engineering (JAABE), 11(2)*, pp. 95-102.

Kaastra, I., and Boyd, M. (1996). Designing a neural network for forecasting financial and economic time series. *Neurocomputing, 10(3)*, pp. 215-236.

Khalil, N. and Husin, H.N. (2009). Post Occupancy Evaluation towards Indoor Environment Improvement in Malaysia's Office Buildings. *Journal of Sustainable Development, vol.2, no.1*, pp. 186-191.

Khuntia, S. (2014). Modelling of Geotechnical Problems using Soft Computing. National Institute of Technology, Rourkela: Master's Thesis.

Kipli, K., Muhammad, M.S., Wan Masra, S.M., Zamhari, N., Lias, K., and Awang Mat, D.A. (2012). Performance of Levenberg-Marquardt Backpropagation for Full Reference Hybrid Image Quality Metrics. *Proceedings of the International MultiConference of Engineers and Computer Scientists (IMECS), vol.1*.

Klerfors, D. (1998). Artificial neural networks. St. Louis University, St. Louis, Mo.

Krenek, J., Kuca, K., Krejcar, O., Maresova, P., Sobeslav, V., and Blazek, P. (2014). Artificial Neural Network Tools for Computerised Data Modeling and Processing. *International Symposium on Computational Intelligence and Informatics (CINTI)*, pp. 255 – 260.

Krenker, A., Bešter, J., and Kos, A. (2011). Introduction to the Artificial Neural Networks, Artificial Neural Networks - Methodological Advances and Biomedical Applications, Prof. Kenji Suzuki (Ed.), ISBN: 978-953-307-243-2.

Krisprantono (2005). The Interaction of Vernacular Paradigm and Architectural Discourse in Developing Malay Architecture. *Proceedings of International Seminar Malay Architecture as Lingua Franca, Jakarta, Indonesia*. pp.162-168.

Kshirsagar, A.P. and Rathod, M.N. (2012). Artificial Neural Network. *Proceedings of the International Journal of Computer Applications (IJCA)*, pp. 12-16.

Kumar, A., and Singh, G. (2012). Artificial neural networks and its working. *International Journal of Data & Network Security, 1(2)*, pp.37-40.

Kutsurelis, J.E. (1998). *Forecasting financial markets using neural networks: An analysis of methods and accuracy*. Naval Postgraduate School: Master's Thesis.

Lakawa, A.R. (2011). Malay Vernacular in Indonesia and Malaysia: The Relationship between Language and Architecture. *Second International Journal of Arts and Sciences, Conference for Academic Disciplines at Harvard University*.

Lapedes, A., and Farber, R. (1987). Nonlinear signal processing using neural networks: prediction and system modelling. Technical Report LA-UR-87-2662, Los Alamos National Laboratory, Los Alamos, NM.

Lavafpour, Y. and Surat, M. (2011). Towards new approaches for converting principles of vernacular architecture into energy efficient buildings in hot and dry climates. *Journal of Building Performance, vol.2, issue 1*, pp. 33-45.

Li, M., Mehrotra, K., Mohan, C., and Ranka, S. (1990). Sunspots numbers forecasting using neural networks. *In Proceedings of the 5th IEEE International Symposium on Intelligent Control*, pp. 524-529.

Lin, Z. and Deng, S. (2008). A study on the thermal comfort in sleeping environments in the subtropics-Developing a thermal comfort model for sleeping environments. *Building and Environment*, 43(23): 70-81.

Loke, M.H., and Dahlin, T. (1997). A combined gauss-newton and quasi-newton inversion method for the interpretation of apparent resistivity pseudosections *In 3rd Meeting of the Environmental and Engineering Geophysics Society – European Sections*. London.

Madić, M. J., & Radovanović, M. R. (2011). Optimal selection of ANN training and architectural parameters using Taguchi method: a case study. *FME Transactions, 39(2),* pp. 79-86.

Malaysian Standard MS1525. (2007). *Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings*. Department of Standards, Malaysia.

Malinda Anthony, C.K.S. (2002). Indoor Climate of Multi-Storey Hospital Buildings in Hot Humid Regions: An attempt to achieve comfortable indoor climate through passive climatic design in Ampara, Sri Lanka. *Architecture, Energy & Environment,* pp. 1-21.

Manibhai, P.J. (2013). Thermal Comfort Techniques for Urban Poor's Housing. *International Journal of Research in Modern Engineering and Emerging Technology (IJRMEET), vol.1, no.4,* pp. 38 – 54.

Mao Zhi. (2002). Forecasting Total Factor Productivity Growth in the Construction Industry using Neural Network Modelling. National University of Singapore: Ph.D Thesis.

Markus, T.A. and Morris, E.N. (1980). *Buildings, Climate and Energy*. Pitman, London.

McMullan, R. (1998). *Environmental Science in Building*, McMillan Press Ltd., London.

Mehidi, S.H., Chakrabarty, N., and Mohiudin, H.M. (2014). An Application of Artificial Neural Network (ANN) process to Assess Risk in Cement Industries in Bangladesh. *Industrial Engineering & Management, vol.3, no.4,* pp. 1-6.

Mehrotra, K., Mohan, C.K. and Ranka, S. (1997). *Elements of Artificial Neural Network*, MIT Press, Cambridge, Mass.

Ministry of Energy, Telecommunications, and Post. 1989. *Guidelines for Energy Efficiency in Non-Residential Buildings*. Kuala Lumpur.

Mohd Hafizal, M.I., Hiroshi, Y.and Goto, T. (2012). Comparative Study of Indoor Environment in Residential Buildings in Hot Humid Climate of Malaysia. *International Journal of Civil, Architectural, Structural and Construction Engineering, 6(11).*

MS 1525. 2001. Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings. *Department of Standards Malaysia.*

Naseer, M.A. (2013). Energy Efficient Building Design: Revisiting Traditional Architecture. *The Asian Conference on Sustainability, Energy & the Environment,* pp. 470-482.

Nasir, A.H., and Wan Teh, W.H. (1996). *The traditional Malay House*. 1st Edn., Fajar Bakti Press. ISBN: 9-676-53341-6, pp: 91.

National Research Council (1980). *Estimating population and income for small places*. Washington, D.C.:National Academy Press.

National Research Council. (1981). *Indoor Pollutants*. Washington: National Academy Press.

Nicol, F. (1995). *Standards for thermal comfort: indoor air temperature standards for the 21st century (1st ed.).* London New York: Chapman & Hall.

Nigrin, A. (1993). *Neural Networks for Pattern Recognition*. Cambridge, MA: The MIT Press, pp. 11.

Noriega, L. (2005). *Multilayer perceptron tutorial*. School of Computing. University.

Olgyay, V., and Olgyay, A. (1963). *Design with climate: bioclimatic approach to architectural regionalism*. Princeton, NJ: Princeton University Press.

Oliver, P. (2006). *Built to Meet Needs: Cultural Issues in Vernacular Architecture*. Oxford: Architectural Press, Burlington.

Ortiz-Rodríguez, J. M., Martínez-Blanco, M. R., and Vega-Carrillo, H. R. (2011). Evolutionary Artificial Neural Networks in Neutron Spectrometry, Artificial Neural Networks - Application, Dr. Chi Leung Patrick Hui (Ed.), ISBN: 978-953-307-188-6, InTech, Available from:

Ostafe, D. (2005). Neural Network Hidden Layer Number Determination Using Pattern Recognition Techniques. *2nd Romanian-Hungarian Joint Symposium on Applied Computational Intelligence (SACI)*.

Paevere, P., Brown, S., Leaman, A., Haerwagen, J., and Luther, M. (2008). Indoor environment, productivity and sustainable commercial buildings. Your building, profitting from sustainability.

Palani, S., Liong, S.Y., and Tkalich, P. (2008). An ANN application for water quality forecasting. *Marine Pollution Bulletin 56*, pp. 1586 – 1597.

Panchal, G., Ganatra, A., Kosta, Y.P., and Panchal, D. (2011). Behaviour Analysis of Multilayer Perceptrons with Multiple Hidden Neurons and Hidden Layers. *International Journal of Computer Theory and Engineering, vol.3, no.2*, pp. 332-337.

Parker, L.E. (2010). Notes on Multilayer, Feedforward Neural Networks. Available from: http://web.eecs.utk.edu/~parker/Courses/CS425-528 fall10/Handouts/Neural-net-notes.pdf

Rajapaksha, L.H., Nagai, M., and Okumiya, M. (2003). A Ventilated Courtyard as a Passive Cooling Strategy in the Warm Humid Tropics, *Renewable Energy* 28: 1755 – 1778.

Ramakishan, S. (2008). Development of inferential measurement for air density using neural network. Universiti Malaysia Pahang: Ph.D Thesis.

Ramli, M.Z. (2011). Development of Accident Prediction Model by Using Artificial Neural Network (ANN). Universiti Tun Hussein Onn Malaysia: Master's Degree Thesis.

Ramli, N.H., Kassim, N., Mohd Taib, M.Z., and Masri, M. (2012). Re-Adaptation of Malay Vernacular Architecture Thermal Comfort elements: Towards Sustainable Design in Malaysia. (A Literature Review). *International Conference on Innovation and Technology For Sustainable Built Environment (ICITSBE 2012).*

Rumelhart, D., Widrow, B. and Lehr, A. (1994). "The basic ideas in neural networks", *Communication of the ACM*, 37(3), 87-91.

Rumelhart, D.E., Hinton, G.E., and William, R.J. (1986). Learning representation by backpropagation errors. *Nature, vol.3, no.6188,* pp. 533-536.

Sabarinah, SA. 2002. A Review on Interior Comfort Conditions in Malaysia. *ANZAScA Conference 2002*. The University of Queensland, Brisbane, Australia.

Salazar, R., Lopez, I., and Rojano, A. (2007). A neural network model to predict temperature and relative humidity in a greenhouse. *International Symposium on High Technology for Greenhouse System Management*, pp. 539 – 546.

Sapon, M.A., Ismail, K., and Zainudin, S. (2011). Prediction of Diabetes by using Artificial Neural Network. *International Conference on Circuits, System and Simulation*, vol.7, pp. 299 – 303.

Shah, R. (1988). *The Terengganu Timber Malay house*. Kuala Lumpur: Badan Warisan Malaysia.

Shakoor, A. (2011). Analysis of the Role of Natural Environment in the Compatibility of Human Settlements with it "Emphasizing Application of Climate in Esfahan Rural Architecture, Iran". Australian *Journal of Basic and Applied Sciences,* 5(12): 1524-1526.

Sharma, S.C., Lingas, P., Liu, G.X., and Xu, F. (2000). Estimation of AADT on Low Volume Roads: The Factor Approach Versus Neural Networks. *Transportation Research Board 79th Annual Meeting.* Washington D.C.

SHI, Y. and Edward, NG. (2014). The Climate Design in Chinese Vernacular Courtyard House Settlement – A wind Environmental Simulation. *International PLEA Conference,* pp. 1 – 8.

Sim, S. (2010). Redefining the Vernacular in the Hybrid Architecture of Malaysia. Victoria University of Wellington: Master's Degree Thesis.

Singh, M.K., Mahapatra, S., and Atreya, S.K. (2009). Bioclimatism and vernacular architecture of north-east India. *Building and Environment, 44*, pp. 878 – 888.

Singh, M.K., Mahapatra, S., and Atreya, S.K. (2010). Thermal performance study and evaluation of comfort temperatures in vernacular buildings of North-East India. *Building and Environment, 45*, pp. 320 – 329.

Singh, Y. and Chauhan, A.S. (2009). Neural networks in Data Mining. *Journal of Theoretical and Applied Information Technology, vol.5, no.6*, pp. 37-42.

Sofuoglu, S.C. (2008). Application of artificial neural networks to predict prevalence of building-related symptoms in office buildings. *Building and Environment, vol.43*, pp. 1121-1126.

Sprithall, R.C. (1993). *Basic Statistical Analysis (4th Edition),* Massachusetts, Allyn and Bacon.

Strik, D., Domnanovich, A.M., Zani, L., Braun, R., and Holubar, P. (2005). Prediction of trace compounds in biogas from anaerobic digestion using the MATLAB Neural Network Toolbox. *Environmental Modeling & Software, vol.20,* pp. 803 – 810.

Sundarraja, M.C., and Radhakrishnan, S. (2009). *Understanding Vernacular Architecture as a Tool for Sustainable Built Environment*. India: 10th National Conference on Technological Trends (NCTT09).

Swanson, D.A., Tayman, J., and Bryan, T.M. (2011). MAPE-R: A rescaled measure of accuracy for cross-sectional subnational population forecasts. *Journal Population Research, vol.28,* pp. 225-243.

Swikipedia. (2013). Category: Passsive Solar Design – Air movement. Retrieved from: http://www.sustainable-buildings.org/wiki/index.php/Air_Movement

Tahir, M.M., Che-Ani, A.I., Abdullah, N.A.G., Tawil, N.M., Surat, M., and Ramly, A. (2010). The Concept of Raised Floor Innovation for Terrace Housing in Tropical Climate. *Journal of Surveying, Construction & Property, Vol.1, Issue 1*, pp. 47 – 64.

Teh, W.H.W. (1994). *Rumah Melayu Tradisi*. Kuala Lumpur: Penerbit Fajar Bakti Sdn. Bhd.

The American Heritage Medical Dictionary. (2013). The Free Dictionary. Retrieved January 14, 2013, from Medical Dictionary: http://www.thefreedictionary.com/relative+humidity

Tinker, J.A., Ibrahim, S.H., and Ghisi, E. (2004). An Evaluation of Thermal Comfort in Typical Modern Low-Income Housing in Malaysia.

Wafi, S. and Ismail, M.R. (2008). The Relationship Between Thermal Performance, Thermal Comfort and Occupants. A Study of Thermal Indoor Environment in Selected Students Accommodation in Universiti Sains Malaysia (USM), Penang. 2nd *International Conference on Built Environment in Developing Countries (ICBEDC)*, pp. 675 – 690.

Waterson, Roxana. (2009). *The Living House, An Anthropogy Of Architecture in South-East Asia.* Singapore: Tuttle Publishing.

Wolkoff, P., and Kjaergaard, S.K., (2007). The dichotomy of relative humidity on indoor airquality. *Environ. Int*., 33: 850-857. DOI: 10.1016/J.envint.2007.04.004

Xie, H., Ma, F., and Bai, Q. (2009). Prediction of indoor air quality using artificial neural networks. *Fifth International Conference on Natural Computation (ICNC'09), vol.2*, pp. 414-418.

Yuan, L.J. (1987). *The Malay House: Rediscovering Malaysia's Indigenous Shelter System, Penang*. Institute Masyarakat, Malaysia.

Zain Ahmed, A. (2000). "Daylighting and shading for thermal comfort in Malaysian buildings", Ph.D thesis, Universiti Technologi MARA and Universiti Kebangsaan Malaysia, Malaysia.

Zainun, N.Y. (2011). Computerized Model to Forecast Low-Cost Housing Demand in Urban Area in Malaysia Using Artificial Neural Networks (ANN). University of Loughborough: Ph.D Thesis.

Zakaria, R. (2007). Sustainable Housing for Residential-Industrial Neighbourhoods in Malaysia – A study on the elements of Indoor Environmental Quality Improvements. Queensland University of Technology: Ph.D Thesis.

Zeng, L. (1999). Prediction and classification with neural network models. *Sociological Methods and Research, vol.27, no.4*, pp. 499 – 524.

Zhang, G., Patuwo, B.E., and Hu, M.Y. (1998). Forecasting with artificial neural networks: The state of the art. *International Journal of Forecasting, 14(1)*, pp. 35-62.

Zhang, X. (1994). Time series analysis and prediction by neural networks. *Optimization Methods and Software, vol.4*, pp. 151-170.

Zurada, J.M. (1992). *Introduction to Artificial Neural Systems*. Boston: PWS Publishing Company.