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Preliminary Model Framework to Study Natural Ventilation Performance through Passive Design (Case Study: Tapak Semaian Mantin, Seremban)

S.C.Chan
Division of Quantity Surveying, Faculty of Engineering, Science, Technology and Mathematics, INTI International University, Putra Nilai, Negeri Sembilan Darul Khusus, Malaysia
W.S.Yeaw
Division of Quantity Surveying, Faculty of Engineering, Science, Technology and Mathematics, INTI International University, Putra Nilai, Negeri Sembilan Darul Khusus, Malaysia
A.I.Che Ani
Department of Architecture, Faculty of Engineering and Built Environment, National University of Malaysia, UKM Bangi, Selangor Darul Ehsan, Malaysia

Abstract

Numerous studies have been conducted to explore the potential usage of natural ventilation in buildings. However, this issue has not yet been effectively resolved due to the inconsistency of air flow patterns and the extent of the parameters involved in the studies. This paper aims to identify the usefulness of the ventilation optimization model framework that intends to assess the natural ventilation performance within an office space through allocation of passive designs. An administration office of nursery unit known as Tapak Semaian Mantin located in the outskirt of Seremban District which consists of 17 respondents was selected in this study. Feedback in Likert scales set in questionnaires was collected, analyzed and evaluated throughout this study. The final findings of this study show that the findings generated through the framework are able to provide an alternative estimation approach to assist the designer and the building management professionals to justify the applicability of passive design to enhance the natural ventilation performance in office buildings in the future.

1. Introduction

Although a number of strategies have been developed to address the issues brought about by the energy crisis, significant developments still need to be achieved to cope with the situation effectively [1-3]. Therefore, creating a cost-effective energy usage efficiency model has become a priority issue for researchers since the energy crisis of the early 1970s [4-7]. Many analytical models have been developed to evaluate and design a sustainable work environment [8] to reduce energy usage rates without sacrificing the building users' thermal comfort levels [9-13].

Further effort is needed to review and establish a more efficient and effective operating model to address the related parameters that affect thermal comfort levels in buildings. These parameters should be explored further to identify their potential utilization and to integrate them in a more comprehensive manner to resolve the issue more effectively. Thus, an integrated model framework which is able to consider both human and non-human parameters is developed based on this scenario. Through a case study, this paper aims to justify the validity of the results provided by this model.

2. Materials and Methods

2.1. Current Development

The success of natural ventilation utilization in buildings depends on the complicated relationships among related key parameters. Therefore, researchers in this field have studied this issue extensively. A number of solutions were proposed to solve this issue from different perspectives [14]. However, each of the suggested solutions has its limitations based on the assumptions and the applied concepts. Chen (2009) [15] grouped the ventilation simulation models into seven major groups which can be further classified into two major categories, namely, physical modeling and computer modeling. The physical modeling approach uses full- or small-scale physical structures to test the air flow performance. Although these structures provide good results with high accuracy, they are limited in terms of application because they are seldom used in real-life projects. Furthermore, these models are quite costly and require a longer preparation time.

Currently, computational fluid dynamics (CFD) software is applied widely as a computer modeling method [16]. This software is user-friendly and can save operating time and costs. However, the operations involved in computer modeling are quite complex, and not every consultant or designer can understand the simulated output [17]. In addition, the accuracy of the findings is questionable because a number of assumptions should be made. At present, the application of computer modeling is still under study to further verify the validity of the model before it is applied in the construction industry.

2.2. Model Operational Procedure

Since the proposed model is requested to include multiple parameters to produce a more comprehensive simulation to justify the natural ventilation performance in office buildings through passive design, therefore this model needs to operate based on operational research which consists of two major analytical methods: (a) analytical hierarchy process (AHP) and (b) multiple regression analysis (MRA). These methods are used in the model to analyze and evaluate the data in a spreadsheet format.

2.2.1. AHP- Individual-Based

This file records all the primary data collected from the individual zone that was studied separately. Three interrelated worksheets are found in this file. All the primary data are recorded in the first sheet, which is then linked to the second sheet for the AHP analysis. The results of the analysis are then displayed in the third sheet as the summarized main outputs for the studied zone.

2.2.2. MRA-Integrated-Based

The output of the AHP file is used as the input for this file. As in File (1), three interrelated worksheets are included in this file. The first sheet is the major record sheet for the analyzed output from each AHP file. The transferred values are then averaged, and the composite mean value is obtained for each zone.

The values are then transferred to the second sheet to simulate and evaluate the trend of the paired parameters that are based on the categories through the application of the default regression analysis function in the spreadsheet. The analyzed correlation values are used as the coefficient values for the independent parameters (x) to iterate the final optimum weightage. Then, these final optimum weightages between the main parameters, which are related to the suitability level of the respective physical design areas, are further analyzed and grouped according to building zones. The results are exported to the third sheet, which is combined with the subjective evaluation preference from the users' or designers' requirements. This process is performed to produce the optimum areas or sizes for all the passive design elements. These areas or sizes can optimize the utility of natural ventilation.

2.3. Case Study: Main Office Building in Tapak Semaian Mantin

This feasibility study was carried out in Tapak Semaian Mantin (TSM), which is also known as the Mantin Nursery Site. TSM is under the management of the Ministry of Forestry in the state of Negeri Sembilan. This site is used as the nursery center which supplies and maintains the plants within the region, and is located on the outskirts of the nearby town of Mantin. The site is located along the main road that links Mantin and the city of Seremban. The two-storey office building was built in the nursery area, which acts as the main administration and control office for the nursery. The building is surrounded by a green field and is located about 200 m away from the main road. The nursery is located within a valley area, and most of the surrounding areas at the main office are occupied by green fields with plants. Thirty percent of the area is allotted for parking. Figure 1 shows the building façade and its surroundings, while Figure 2 shows the interior condition of the building.

Figure-1. Tapak Semaian Mantin (TSM) office building and its surroundings

Figure-2. Interior Condition of TSM

Seventeen respondents were involved in the research. They were given a detailed briefing before participating in the questionnaire section. At the same time, the researcher carried out fieldwork by measuring and recording the passive design elements and the sizes within the building.

Figure-3. Respondents from TSM answering questionnaires

The ground floor area of the building is same as that of the first floor (378 m2). Not all of the building zones are occupied by the respondents. Therefore, only the currently occupied building zones are included in this study. To ease the data collection and analysis, the office area of the building as further divided into coded study zones, as shown in Figure 4. The locations and sizes of the zones are shown in Table 1.

Figure-4. Study zones in the building

Zone 3	Zone 4	Zone 5
Zone 2	Zone 1	Zone 6
Zone 9	Zone 8	Zone 7

Table-1. Locations and areas of study zone

Zone	Location	Area (in m^2)
1	Ground Floor	44.53
3	Ground Floor	39.42
6	First Floor	44.53
7	First Floor	67.5
9	Ground and First Floor	20

With reference to the Figure 4 shown above and through the site observation record, as Zones 2, 4, 5, and 8 are not currently used, these zones are omitted in the operation.

This preliminary ventilation assessment model aims to identify the effectiveness of natural ventilation usage within the building area through the passive design elements (PDE). According to S.C. Chan et al (2011) [18-19], five categories of passive design area (PDA) are normally identified in buildings, namely, air well (AW), façade design (FD), vertical openings (VO), corridor and shading (CS), and wall and partitions (WP). All these elements were successfully identified in the study zones within TSM, and the sizes of the elements in their respective study zones are listed in Table 2 below.

Table-2. Sizes of elements compared to floor area

Passive Design	Area (in m^2) in Zone				
	1	3	6	7	9
AW	12	0	9	9	9
FD	15	9	0	17.1	9
VO	6	4	24.3	1.8	3.6
CS	12	7.3	27	3	6
WP	21.9	21.9	30	21	21

The outputs from Tables 1 and 2, the other related data within the building (such as the installed air conditioning units), and the parameters outside the building (such as availability of green area which was observed and measured during the site visit) were further analyzed and integrated in the subsequent operational procedure in the model.

3. Results and Discussion

3.1. Analysis of the Result: AHP-Individual-Based

The AHP method in this particular section of the preliminary model framework produces the weightages between the main parameters (MP). The MP used in the model includes thermal comfort (TC), operational cost (OC), green area ratio (GA), and air velocity (AV). The weightages for the MP were compared, analyzed, and evaluated based on the five study zones occupied by the respondents. The results from each study zone were further averaged to obtain the main reference weightage to be used in the case study. Table 3 shows the weightage output of the MP that were justified by the respondents and the respective average values.

Table-3. Weight age between Main Parameters based on Study Zones

MP	Zone 1	Zone 3	Zone 6	Zone 7	Zone 9	Average
TC	0.506	0.105	0.635	0.075	0.524	0.284
OC	0.223	0.105	0.24	0.675	0.18	0.273
GA	0.185	0.215	0.091	0.225	0.217	0.208
AV	0.086	0.575	0.034	0.025	0.079	0.235

As shown in Table 3, all the compared MP obtained a weightage which ranges from 0.2 to 0.3. The respondents appear to have given a fair evaluation of all the MP in the aspect of influencing the performance of natural ventilation in the building. All the parameters listed and involved in this model are considered equally important. However, in terms of determining the importance of the passive design elements (PDE) to play their roles to optimize the natural ventilation in TSM, the summary of the weightages obtained based on study zone are shown in Table 4 as follows:

Table-4. Weight age between Passive Design Elements (PDE) based on Study Zones

PDE	Study Zone					Average Value
	1	3	6	7	9	
AW	0.437	0.243	0.552	0.249	0.488	0.346
FD	0.249	0.243	0.254	0.056	0.257	0.204
VO	0.177	0.243	0.116	0.507	0.159	0.264
CS	0.093	0.027	0.053	0.094	0.065	0.085
WP	0.043	0.243	0.025	0.094	0.03	0.1

3.2. Analysis of the Result: MRA-Integrated-Based

As highlighted in Section 3.1, the output from the AHP-Individual-based Work File is used as the input data for the MRA-Integrated-based Work File. This step is performed to generate the final optimized index for PDA in the building being studied through the correlation function set in the spreadsheet. The summarized analysis and the results obtained in this file are illustrated as follows:

Table-5. Constant, Coefficient and Integrated Value after Iteration Process

No	Relative Constant and Coefficient Values in Iteration Process								Final Value
	MP	Constant	1st	2nd	3rd	4th	5th	6th	
1	AV	1.56	0	0	0	0	0	0	1.56
2	GA	1.502	-45.471	216.754	-245.366	113.522	0	0	2.028
3	TC	1.027	0	0	0	0	0.547	0	1.574
4	OC	1.712	-1.891	0	0	0	2.021	0	1.712

The output of the respective iterative process for each Main Parameters in terms of final, constant and coefficient values are shown in Table 5. These values are generated after using the correlation function preset in the spreadsheet. The process of iteration will only be terminated after the highest value of R^2 is obtained, which is the closet to 1.

3.3. Result Discussion

After four different sets of final values exist based on the MP identified for the study zones in TSM, and in order to ensure that these values are utilized effectively, thus they are further integrated into one composited value which is relocated based on the AHP weightage of MP, as highlighted in Table 3 under Section 3.1 based on each final value obtained in Table 5 under Section 3.2. The final integrated value is further relocated based on the weightage of PDE that is indicated in Table 4 under Section 3.1 to justify the final optimized area for each PDE. Finally, hypothesis testing based on the Z-values or t-distribution was conducted to justify the validity of the integrated values generated in this model. The analysis output for each section in the final stage is further explained in Table 6 and 7 as follows:

Table-6. Final Integrated Value based on Weight age between Main Parameters

Main Parameter	Weight age	PPDA	Final Integrated Value
TC	0.284	1.574	0.446897
OC	0.273	1.712	0.467682
GA	0.208	2.028	0.42171
AV	0.235	1.56	0.366627
Total	1		1.703

Table-7. Integrated value allocation for PD based on AHP Weight age

PD	Weight age	Integrated Value Allocation	Ranking
AW	0.346	0.589238	1
FD	0.204	0.347412	3
VO	0.264	0.449592	2
CS	0.085	0.144755	5
WP	0.1	0.1703	4
Total		1.703	

3.4. Hypothesis Testing

Hypothesis testing by using Z-values or t-distribution was used in evaluating the validity of the integrated values for the building compared with the current layout design. The confidence level is set at 95% with a rejection zone of 5% under a two-tail test condition. Table 8 shows both proportional passive design areas for current and proposed integrated values, and the outcomes of hypothesis test.

Table-8. Summarized Hypothesis Results based on the Parameters

Parameter	Mean	Integrated Value	Z-value	Indicator
PDA	1.559924	1.701297	1.541279	Accept H_0
AW	0.210985	0.589238	5.073379	Reject H_0
FD	0.253699	0.347412	1.261009	Accept H_0
VO	0.197716	0.449592	2.782411	Reject H_0
CS	0.281089	0.144755	1.472374	Accept H_0
WP	0.616435	0.1703	3.620294	Reject H_0

3.5. Findings

Based on the hypothesis testing results generated by t-distribution as highlighted in Table 18, significant effort is needed to increase the areas of AW and VO while further reducing WP. No significant changes in the FD and CS should be made as both Z-values are well accepted within the range of ± 1.963. Generally, the current ratio of PD compared with the floor area is still acceptable, according to the preliminary model estimation. The reallocation of spaces between these PDE should be emphasized in future studies. However, based on site observation, the buildings provide allocation for sufficient PPDA for VO, but most are closed and sealed because of fertilizer odor from the surrounding areas. This case further results in a smaller VO ratio in the overall assessment.

4. Conclusions

Generally, this preliminary model is considered fulfilled the target of the research to generate a more comprehensive estimation scenario to justify the effectiveness of natural ventilation in office space through passive design after considering both internal and external factors. However, more attention are much needed in order to generate this model in a more user-friendly version which including simulation, animation and simpler operation procedure.

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