The Effect of Roof Angles on Indoor Air Temperatures in Terrace Houses in Malaysia

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Abstract

The main aim of energy efficiency in building design is to create buildings that utilise minimum amount of energy while meeting the comfort standards as high as or higher than those provided by conventional buildings. To achieve these standards, it is necessary to study the local environment in order to assess its positive and negative features (impact on the building). The results will provide a basic understanding of heat transfer and human thermal comfort requirements. It also provides foundation for which an energy efficient design of buildings can be established.

The design of residential buildings has a significant impact on everyday lives of people. It includes the types and forms of buildings that are commonly occupied by people. In Malaysia, the 'terrace house' constitutes the majority of the residential building stock on which this study is based. The study considers the effects of the different roof angles on reducing solar gain and indoor temperatures through eight directions within 24 hours.

To analyse and explain that effect, five different angles of roof were chosen for the simulations. In general, all the angles were chosen due to their architectural design characteristics. These angles start from 0 degree as a horizontal flat roof to 60 degrees, i.e. increment of every 15 degrees. The research is seen as providing a tool in evaluating the dynamic indoor air temperature and the effect of roof angles. The evaluation is derived from a series of computer simulations using commercially available software called BLAST.

Keywords: *roof design, thermal comfort, orientation, indoor air*

Introduction

The lack of thermal comfort in terrace houses is mainly due to the poor thermal properties of the building constructions, such as materials, design parameters and ventilation. Various studies (Abdul Rahman, 1997; Abdulmalik, A and Young, 1993; Azni, Z. A, 2000) have been carried out with regard to roofs, especially the materials, but not many on the effect of the roof angles. Hence, the study of roof angles which are exposed to the solar radiation more than 10 hours every day and their orientations is very important. The orientation, as an example, becomes an important factor to determine roof angles and the effect of solar radiation on buildings. Thus, the study of roof angles on indoor comfort in hot regions has aroused scientific interest in many countries for several reasons, including the facts that the roof is:

a) a major source of heat gain in the building,
b) subjected to longer exposure to solar radiation than walls, and
c) constructed from many different materials and forms.

Studies on Indoor Air Temperature in Malaysia

Thermal comfort has become major concern when it relates to energy efficiency and occupants comfort. Some of the factors that influence the condition are roof designs and the use of passive features into the building. The consideration of these factors is crucial when designing a building. According to Prasasto, (2004), thermal comfort is based on the condition within the occupants' zones, i.e. area within the building where occupants move. Thus, the location of activities and circulation determine this. For countries in tropical region, such Malaysia or Indonesia, the penetration period of sun rays in a day onto building is considerably long. Daytime is about 12 hours +/- 30 minutes. This daytime length, combined with 60% - 90% cloud coverage, will determine the solar exposure values.

Fanger (1982) had set the international standard for thermal comfort studies by quantifying specific parameters and putting them into a unified thermal comfort equation. He suggested that thermal comfort might be determined by using the Predicted Mean Vote (PMV). This equation predicts the mean thermal comfort of people under any circumstances. Based on his finding the thermal comfort zone for Malaysia is 24.5-26.5 deg. C. In a study conducted by Noor Aziah, (1994), it was found that the traditional buildings, such as the Malay house, enjoy a mean indoor air temperature 2.5 deg. C lower than the contemporary terrace houses. Ahmad & Woods' (1995) study on terrace houses found more negative result. They have identified that the problem of maintaining a comfortable thermal environment in the terrace houses is due to owners' action to close the internal air well of the houses. Other studies done on comfort zone obtained almost the same results for the comfort zone in Malaysia, i.e. between 24% - 29% respectively (Malik & Young (1993); Rahman (1997); Davis, (1998); and Azni (2000).

Influence of Roof Design on Indoor Thermal Conditions

The roof is the building component most exposed to the climate elements .The impact of solar radiation on clear days in summer, the loss of heat by long wave radiation during the night and winter, the rain and snow, all have effects on the roof more than any other part of the building components. In the hot regions and seasons, the roof has tremendous effects on the indoor climate. In fact, the roof serves as a potential route of heat gain which is mostly dependent on its angles and materials. Under warm ambient conditions, the roof also affects the indoor temperature and, to some extent, it has to depend on certain details. In hot countries, it is generally believed that the roof is the main heating element of the house. This is so in most cases because the roof is incorrectly designed (Givoni, 1976). The inference has greater effect on indoor climate.

Most of the heat that builds up in the interior comes through the roof. Depending on its types and angles, the external surface of the roof is often subjected to the largest temperature fluctuations in which they can be evaluated on two types of roof, i.e. flat roof and pitch roof. Most residential buildings in the world are either of a single or 2-storey type. Nevertheless, heat gain and indoor climate condition are frequently controlled by the selection of right materials and roof angles, besides other considerations such as fire pre-caution, life span of building and other matters (Markus & Morris, 1980).

Research Aim and Objectives

The main aim of the research is to determine the variation effect of roof angles on the hourly dynamic indoor air temperature in spaces in conventional terrace house buildings in Malaysia.

The objectives of the study are:

a) to study the effect of roof angles on indoor temperature.

b) to study the relationship between roof angle direction and day hours of sun path position
c) to study the effect of roof angles on indoor climate in Malaysian terrace houses.

Research Methodology

The research is based on simulation programs using BLAST software. All data was taken from the Malaysian Meteorological Department for 30-year records of yearly weather data. Indoor spaces of the houses were used as exact location for computation.

For the case study of this research, typical Malaysian terrace houses have been taken as the model for the computer simulation.

In terms of selection of Simulation Programs for analysis, several commonly used thermal simulation programmes were assessed, such as BESA, BUNYIP, DOE-2 and BLAST. BLAST (Building Loads Analysis and System Thermodynamics) simulation tool has been selected for this research. BLAST is a family of programs for predicting heating and cooling energy consumption in buildings and analyzing energy costs (BLAST Support Office, 1993). Supporting computer programmes have been developed to facilitate weather file generation, automated simulation process, extraction of key results and data analysis on microcomputers. The effectiveness of BLAST is then supported by HBLC. HBLC (Heat Balance Loads Calculator) is an easy-to-use graphical user interface for the BLAST engine (BLAST Support Office, 1995). Together BLAST and HBLC form a comprehensive thermal software package (Evans, 1987). BLAST is an acceptable simulation tools (ASHRAE, 1989) as well as has been proven by Nor Zaini (2006).

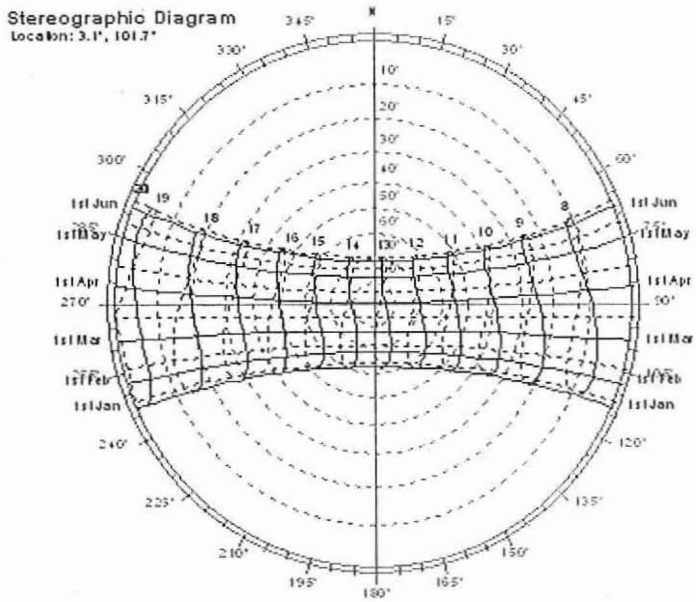
Thermal Comfort

Dynamic indoor air temperature analysis may be used to assess a given environment. This analysis is important in determining energy management strategy in buildings, especially when it refers to human users. The human body temperature regulation determines the physiological thermal comfort of the occupant of a room, as the human body exchanges heat with the environment. Heat is exchanged by radiation, convection, and evaporation. The heat is primarily produced by metabolism, which results from digestion. The body temperature control system tries to maintain this temperature in the varying thermal environments.

Man has always striven to create a thermally comfortable environment. This is reflected in building traditions around the world, from ancient history to the present day. Today, creating a thermally comfortable environment is still one of the most important parameters to be considered when designing buildings. Thermal comfort has been defined as the condition of mind that expresses satisfaction with the thermal environment. The reference to mind emphasizes that comfort is a psychological phenomenon too (Fanger, 1973).

Orientation and Solar Geometry and the Sun Path Diagram

The orientation of roofs is considered as a main factor in the design variables. Buildings should be planned in such a way that benefits are obtained from shaded indoor and outdoor protected living areas when the weather is hot and dry. The roof overhangs on the north, for example, should allow the sun to shine into the house when its warmth is required in winter and provide shade from high-angle sunlight in summer. This is an interesting point as compared to another situation in which the incident radiation on the east side in the morning and the west side in the evening is still high, but not as high as that on the north side during the middle of the day. Whilst, the south side does not receive direct penetration (Raychaudhuri, et. al.,1965).



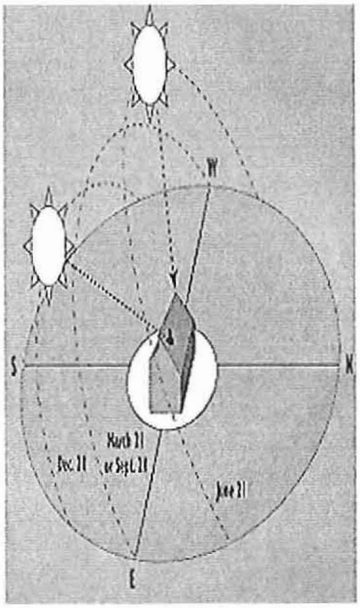


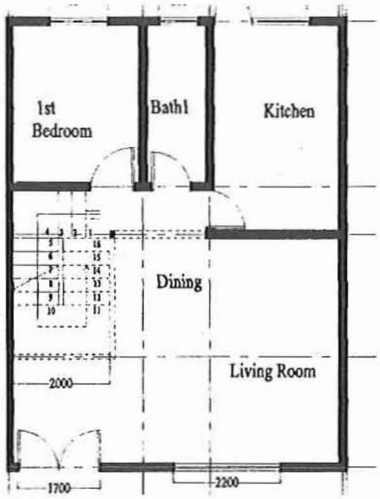
Figure 1

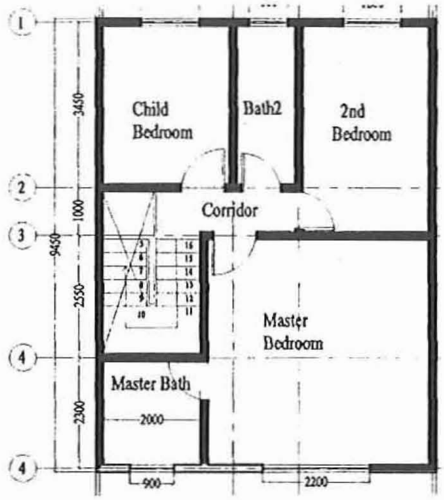
Right: Explanatory orientation diagram used in the evaluations (Olgyay, 1973)
Left : Sun path diagram for latitude 30′ 7″ (*Meteorological Station, 2000)*

Some basic climatic data is required for this study to determine the sun path. The data would help to get the sun position and optimize the built form, orientation, and exposure of elements such as windows, roof and walls for maximum or minimum solar gain. Sun path diagrams used in conjunction with solar irradiance data tables that will provide the information needed to determine internal environmental temperature and the likely thermal comfort of the occupants (Koenigsberger, *et al*, 1973) as in Figure 1.

Building Model - The Typical Malaysian Terrace House

The common prototype design that has been chosen in this study is the terrace house. About 40 layouts of terrace houses constructed in Malaysia were obtained from architectural firms in Kuala Lumpur. From the plans all necessary data was extracted and that included layouts, space types and sizes. Typical example of the said terrace house is shown in figure 2. The house is a two-storey building where each floor is divided into 4 or 5 spaces. The average size of Malaysian family living in a terrace house is 5 persons. The house consists of the ground floor, with spaces for living/dining area, kitchen, bedroom, bathroom and staircase and the first floor, with spaces for master bedroom (bathroom en suite), bedroom, child bedroom, bathroom and staircase (Mohamed, 2004) Figure 2





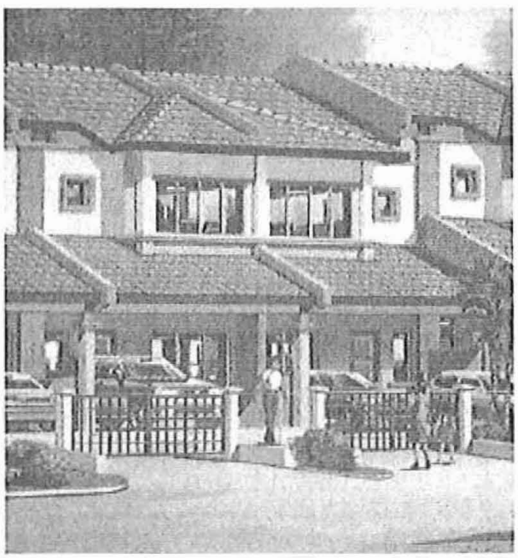


Figure 2
Plan of the terrace house for simulation studies First Floor

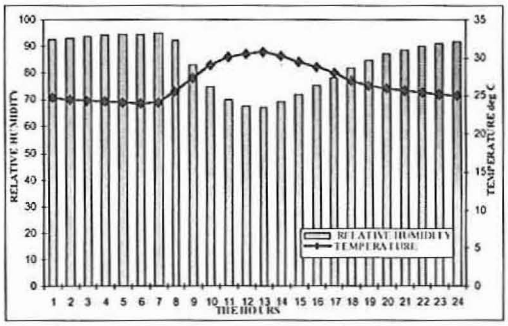
Kuala Lumpur Climate

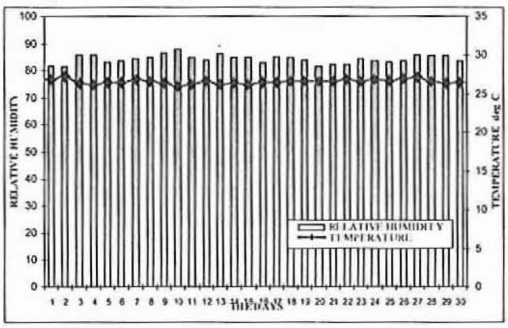
The climate in Malaysia can generally be described as tolerable in terms of thermal requirement. Since Malaysia is a small country and about sixty percent surrounded by sea its climate is almost the same for every part of the country. In this study, Kuala Lumpur was taken as the site for analysis and the climatic parameters were analyzed over a thirty year weather data in order to find the typical 'Design Day'. This data is vital for the calculation. The first conclusion is that the climate of Malaysia can be described as one with high humidity. The hourly relative humidity value ranges from 67% as the minimum up to 96% as a maximum value while the average value is around 80% .The daily variation is very small, about 5% between the days in the same year or in different years. For the outdoor air temperature value it ranges from the minimum of 24 degree C within the nighttime to the maximum of 33 degree C within the daytime. The average is 27 degree C.

There is no dominant direction for the wind but the wind speed average value is about 1.00 m/sec. The main factor for heat exchange is the solar radiation. The variation of the parameter depends on the sun path and the time (hourly, daily and monthly). Generally, the variation of temperature and humidity each year for 30-year period is considerably very low, but there is significant variation in solar radiation within a year for the same period. All the climate parameters have a high hourly variation within a day. Refer to Table 1 and Figure 3 (Malaysian Government, 2003).

Table 1:
Records of monthly mean of temperature, humidity and wind speed for the last 29 years (Malaysian Government – 30-year weather data records)

		Number of the years	JAN.	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
TEMP.	MEAN	30 years	26.9	27.2	27.5	27.6	27.7	27.8	27.3	27.3	27.1	27	26.6	26.6	**27.23**
	MEAN OF MAX.	30 years	32.5	33.3	33.5	33.5	33.3	33.1	32.6	32.7	32.5	32.5	32.1	31.9	**32.79**
	MEAN OF MIN.	30 years	23.1	23.4	23.8	24.2	24.3	24.1	23.7	23.7	23.6	23.7	23.6	23.3	**23.71**
Relative Humidity (RH)		30 years	78.4	78.2	79.3	81.5	80.6	78.9	78.9	78.9	80.6	81.6	83.6	81.9	**80.20**
The Mean of Wind Speed(m/s)		30 years	1.02	1.10	1.06	1.00	1.00	1.07	1.17	1.15	1.03	1.16	0.97	0.90	**1.05**

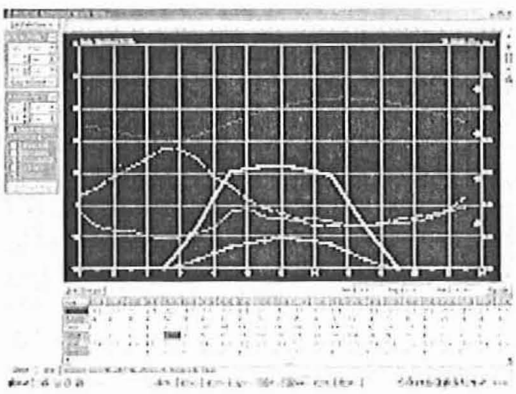




Tabulated Daily Solar Data

Latitude: 3.1°
Longitude: 101.7°
Timezone: 120.0° [+8.0hrs]

Local Time	Solar Time	Altitude January	Altitude July
07:10	06:10	14.1°	3.5°
07:40	06:40	21.1°	10.6°
08:10	07:10	28°	17.6°
08:40	07:40	34.9°	24.7°
09:10	08:10	41.6°	31.7°
09:40	08:40	48°	38.7°
10:10	09:10	54.1°	45.6°
10:40	09:40	59.7°	52.3°
11:10	10:10	64.3°	58.8°
11:40	10:40	67.4°	64.8°
12:10	11:10	68.3°	69.8°
12:40	11:40	66.7°	73.2°
13:10	12:10	63.2°	73.7°
13:40	12:40	58.3°	71.1°
14:10	13:10	52.6°	66.4°
14:40	13:40	46.3°	60.7°
15:10	14:10	39.8°	54.3°
15:40	14:40	33.1°	47.7°
16:10	15:10	26.2°	40.8°
16:40	15:40	19.3°	33.9°
17:10	16:10	12.4°	26.9°



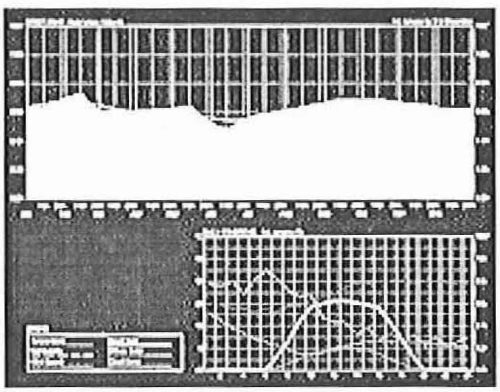


Figure 3:
Records of hourly and monthly mean of temperature, humidity, latitude sun angles and solar Radiation for Kuala Lumpur climate based on 30 years weather data records (Malaysian Government, 2003)

Analysis of the Effect of Roof Angles on the Indoor Air Temperature

This study has considered the effects of the different roof angles on reducing solar gain and indoor temperature through eight directions within 24 hours. To analyse and explain the effects, five different angles have been tested in the simulations. All the five angles were accepted due to their architectural design perspective. The angles start from zero degree as a horizontal flat roof and 15 degrees, 30 degrees, 45 degrees and 60 degrees, with increasing every 15 degree. This study also considered the effects of the different ceiling heights on reducing solar gain and indoor temperature through eight orientations within 24 hours.

Based on the different orientations, the effects of each angle were studied and finally compared their reduction in temperature values with the existing indoor air temperature. This is executed to choose the best roof angle. Different roof angles lead to different heat gain and as a result such differences lead to different indoor air temperatures. All the eight displays in Figure 4 show the reducing temperature values and the temperature values and the difference in five curves ranging from 0.5 degree C to 1.5 degree C. Generally, it is found that increasing roof angle has reduced the indoor temperatures. The study between January and December also indicates that the change of roof angle from zero degree to 60 degrees would reduce the temperature by 1.5 deg. C. While for the north west and north east sides the temperature reduces between 0.5-1.0 degree C. That means the effect of roof angles is more for the north, north east and north west sides. For all other orientations, the indoor air temperature behaviour would increase about 0.5 degree C resulting in negative effect. While, in June–July the opposite image would happen that the best effect of the roof angles will be for the south as the best than the south east and south west. Table 2 and Figure 4 (Appendix 1) indicate the findings

Orientation 0

Roof Angles	0 Degree	15 Degree	30 Degree	45 Degree	60 Degree
1	31.41	31.29	31.15	30.96	30.80
2	31.21	31.10	30.96	30.80	30.65
3	31.01	30.90	30.78	30.62	30.48
4	30.81	30.71	30.59	30.45	30.31
5	30.62	30.53	30.41	30.27	30.14
6	30.44	30.35	30.24	30.11	29.99
7	30.28	30.19	30.09	29.97	29.85
8	30.25	30.15	30.03	29.91	29.80
9	30.43	30.29	30.12	29.96	29.83
10	30.64	30.48	30.35	30.14	29.95
11	31.26	31.06	30.90	30.59	30.28
12	31.87	31.64	31.51	31.09	30.64
13	32.43	32.17	32.05	31.58	31.08
14	32.90	32.63	32.50	32.00	31.47
15	33.16	32.88	32.73	32.23	31.68
16	33.35	33.07	32.89	32.39	31.86
17	33.39	33.12	32.90	32.42	31.95
18	33.25	32.99	32.74	32.33	31.95
19	32.96	32.73	32.48	32.15	31.85
20	32.67	32.47	32.25	31.99	31.73
21	32.41	32.24	32.05	31.82	31.60
22	32.16	32.02	31.84	31.64	31.44
23	31.93	31.80	31.64	31.45	31.27
24	31.70	31.58	31.43	31.25	31.09
MEAN	31.8	31.6	31.4	31.2	30.9
MIN.	30.3	30.2	30.0	29.9	29.8
MAX.	33.4	33.1	32.9	32.4	32.0
STDV	1.1	1.0	1.0	0.9	0.8

Orientation 45

Roof Angles	0 Degree	15 Degree	30 Degree	45 Degree	60 Degree
1	31.90	31.81	31.71	31.57	31.49
2	31.69	31.61	31.51	31.38	31.31
3	31.49	31.40	31.32	31.19	31.12
4	31.28	31.20	31.12	31.00	30.93
5	31.08	31.00	30.92	30.81	30.74
6	30.89	30.82	30.74	30.63	30.57
7	30.72	30.65	30.58	30.47	30.41
8	31.11	31.08	31.04	30.95	30.90
9	31.40	31.40	31.37	31.29	31.23
10	31.65	31.65	31.72	31.63	31.54
11	32.34	32.32	32.51	32.34	32.15
12	33.03	32.97	33.10	32.70	32.45
13	33.38	33.29	33.39	33.00	32.68
14	33.88	33.71	33.72	33.27	32.85
15	34.12	33.90	33.80	33.29	32.88
16	34.20	33.91	33.71	33.20	32.91
17	34.08	33.76	33.49	33.08	32.89
18	33.75	33.47	33.22	32.94	32.79
19	33.35	33.15	32.97	32.74	32.62
20	33.15	32.98	32.81	32.61	32.50
21	32.91	32.76	32.61	32.43	32.33
22	32.66	32.54	32.41	32.25	32.15
23	32.42	32.31	32.19	32.04	31.95
24	32.23	32.12	32.02	31.87	31.79
MEAN	32.4	32.3	32.2	32.0	31.9
MIN.	30.7	30.7	30.6	30.5	30.4
MAX.	34.2	33.9	33.8	33.3	32.9
STDV	1.1	1.1	1.0	0.9	0.8

Orientation 90

Roof Angles	0 Degree	15 Degree	30 Degree	45 Degree	60 Degree
1	33.48	33.46	33.40	33.33	33.27
2	33.20	33.18	33.13	33.06	33.00
3	32.92	32.91	32.86	32.80	32.74
4	32.65	32.64	32.59	32.54	32.48
5	32.39	32.38	32.34	32.28	32.23
6	32.15	32.14	32.10	32.05	31.99
7	31.93	31.92	31.88	31.83	31.78
8	33.16	33.23	33.25	33.25	33.23
9	34.16	34.35	34.52	34.57	34.58
10	34.96	35.16	35.40	35.45	35.44
11	35.54	35.73	36.01	36.03	35.97
12	35.77	35.96	36.51	36.39	36.27
13	36.52	36.64	36.83	36.68	36.48
14	36.77	36.84	37.01	36.79	36.51
15	36.90	36.86	36.92	36.59	36.24
16	36.77	36.65	36.58	36.20	35.91
17	36.45	36.27	36.10	35.79	35.61
18	35.94	35.78	35.60	35.41	35.29
19	35.37	35.28	35.15	35.01	34.92
20	35.08	35.01	34.90	34.81	34.72
21	34.77	34.73	34.64	34.55	34.47
22	34.47	34.44	34.37	34.28	34.20
23	34.17	34.15	34.08	34.00	33.93
24	33.88	33.86	33.80	33.72	33.66
MEAN	34.6	34.6	34.6	34.5	34.4
MIN.	31.9	31.9	31.9	31.8	31.8
MAX.	36.9	36.9	37.0	36.8	36.5
STDV	1.6	1.6	1.6	1.6	1.5

Table 2:
The effects of different roof angles on the indoor air temperature in all directions.

Orientation 135

Roof Angles	0 Degree	15 Degree	30 Degree	45 Degree	60 Degree
1	33.82	33.86	33.82	33.82	33.77
2	33.50	33.53	33.50	33.50	33.45
3	33.19	33.22	33.19	33.19	33.14
4	32.88	32.92	32.89	32.89	32.84
5	32.59	32.62	32.60	32.60	32.55
6	32.32	32.35	32.33	32.33	32.29
7	32.08	32.10	32.08	32.09	32.04
8	33.29	33.39	33.43	33.45	33.47
9	34.36	34.53	34.72	34.81	34.84
10	35.26	35.47	35.74	35.85	35.86
11	36.07	36.30	36.62	36.70	36.67
12	36.67	36.89	37.22	37.25	37.16
13	37.21	37.40	37.77	37.65	37.50
14	37.52	37.69	38.01	37.87	37.67
15	37.70	37.83	38.08	37.92	37.66
16	37.67	37.74	37.91	37.71	37.42
17	37.26	37.27	37.33	37.10	36.83
18	36.90	36.90	36.65	36.47	36.45
19	36.15	36.15	36.02	36.08	35.83
20	35.52	35.54	35.45	35.43	35.52
21	35.24	35.26	35.19	35.17	35.18
22	34.89	34.93	34.87	34.85	34.83
23	34.55	34.58	34.53	34.52	34.49
24	34.21	34.24	34.20	34.19	34.15
MEAN	35.0	35.1	35.2	35.1	35.1
MIN.	32.1	32.1	32.1	32.1	32.0
MAX.	37.7	37.8	38.1	37.9	37.7
STDV	1.8	1.9	2.0	1.9	1.8

Orientation 180

Roof Angles	0 Degree	15 Degree	30 Degree	45 Degree	60 Degree
1	34.05	34.12	34.12	34.09	34.01
2	33.69	33.76	33.76	33.73	33.66
3	33.34	33.41	33.40	33.38	33.31
4	33.01	33.07	33.07	33.04	32.98
5	32.69	32.75	32.75	32.72	32.67
6	32.40	32.45	32.45	32.43	32.37
7	32.13	32.19	32.18	32.16	32.11
8	32.35	32.42	32.44	32.43	32.38
9	32.66	32.76	32.80	32.79	32.73
10	33.37	33.49	33.63	33.60	33.52
11	34.10	34.23	34.44	34.38	34.25
12	34.86	35.00	35.25	35.17	35.00
13	35.59	35.74	36.15	36.05	35.83
14	36.40	36.56	36.92	36.81	36.57
15	37.02	37.18	37.54	37.43	37.19
16	37.35	37.52	37.85	37.74	37.51
17	37.56	37.73	38.01	37.93	37.73
18	37.49	37.66	37.88	37.83	37.67
19	36.73	36.87	37.06	37.02	36.86
20	36.36	36.49	36.39	36.35	36.24
21	35.71	35.81	35.79	35.76	35.66
22	35.11	35.19	35.19	35.15	35.07
23	34.81	34.89	34.89	34.86	34.77
24	34.47	34.54	34.54	34.51	34.43
MEAN	34.7	34.8	34.9	34.9	34.8
MIN.	32.1	32.2	32.2	32.2	32.1
MAX.	37.6	37.7	38.0	37.9	37.7
STDV	1.8	1.8	1.9	1.9	1.8

Orientation 225

Roof Angles	0 Degree	15 Degree	30 Degree	45 Degree	60 Degree
1	34.70	34.66	34.73	34.65	34.60
2	34.16	34.33	34.39	34.31	34.26
3	33.84	33.98	34.04	33.96	33.91
4	33.51	33.62	33.68	33.61	33.56
5	33.18	33.28	33.33	33.27	33.22
6	32.87	32.97	33.02	32.95	32.91
7	32.59	32.67	32.72	32.66	32.62
8	32.45	32.51	32.53	32.47	32.43
9	32.52	32.53	32.50	32.40	32.34
10	32.63	32.64	32.68	32.51	32.38
11	32.96	32.95	32.97	32.77	32.59
12	33.54	33.56	33.64	33.41	33.16
13	33.94	34.21	34.37	34.14	33.87
14	35.11	35.21	35.56	35.23	34.98
15	36.28	36.46	36.82	36.64	36.39
16	37.32	37.55	38.01	37.90	37.73
17	38.20	38.47	38.89	38.86	38.75
18	38.43	38.72	39.09	39.17	39.12
19	37.37	37.77	38.07	38.08	38.05
20	37.24	37.47	37.67	37.44	37.40
21	36.59	36.77	36.91	36.78	36.73
22	35.95	36.09	36.20	36.10	36.05
23	35.46	35.58	35.70	35.61	35.56
24	35.13	35.25	35.33	35.24	35.19
MEAN	34.8	35.0	35.1	35.0	34.9
MIN.	32.5	32.5	32.5	32.4	32.3
MAX.	38.4	38.7	39.1	39.2	39.1
STDV	1.9	2.0	2.1	2.2	2.2

Orientation 270

Roof Angles	0 Degree	15 Degree	30 Degree	45 Degree	60 Degree
1	34.45	34.47	34.43	34.39	34.35
2	34.09	34.11	34.07	34.03	33.99
3	33.74	33.76	33.72	33.69	33.65
4	33.41	33.42	33.39	33.35	33.31
5	33.09	33.10	33.07	33.03	33.00
6	32.79	32.80	32.77	32.74	32.70
7	32.52	32.53	32.50	32.47	32.44
8	32.31	32.29	32.26	32.23	32.20
9	32.47	32.34	32.22	32.19	32.16
10	32.76	32.65	32.38	32.24	32.22
11	32.97	32.77	32.60	32.41	32.32
12	33.36	33.17	33.22	32.73	32.55
13	33.95	33.79	33.58	33.42	33.15
14	34.31	34.18	34.49	34.14	33.86
15	35.47	35.43	35.69	35.47	35.20
16	36.61	36.65	36.93	36.78	36.59
17	37.51	37.62	37.90	37.86	37.74
18	37.83	37.98	38.25	38.26	38.21
19	36.83	36.95	37.31	37.34	37.31
20	36.76	36.86	36.98	36.98	36.95
21	36.19	36.25	36.32	36.30	36.25
22	35.82	35.86	35.74	35.71	35.67
23	35.15	35.18	35.16	35.13	35.08
24	34.87	34.89	34.87	34.84	34.80
MEAN	34.6	34.5	34.6	34.5	34.4
MIN.	32.3	32.3	32.2	32.2	32.2
MAX.	37.8	38.0	38.3	38.3	38.2
STDV	1.7	1.8	1.9	1.9	1.9

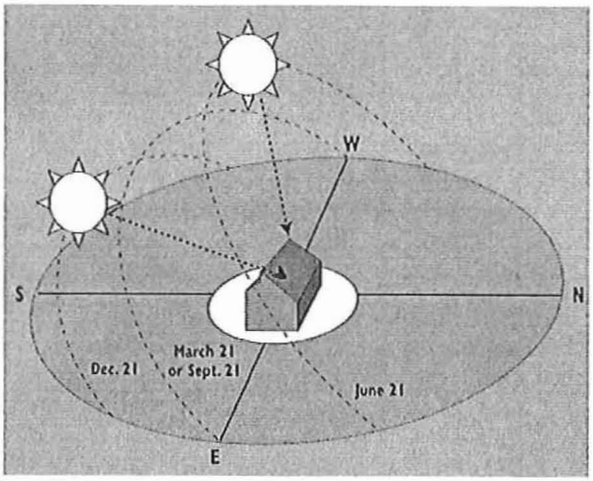
Orientation 315

Roof Angles	0 Degree	15 Degree	30 Degree	45 Degree	60 Degree
1	32.27	32.21	32.16	32.05	31.96
2	32.02	31.96	31.91	31.81	31.72
3	31.78	31.72	31.67	31.57	31.49
4	31.54	31.48	31.44	31.34	31.27
5	31.31	31.25	31.21	31.12	31.05
6	31.10	31.04	31.00	30.92	30.85
7	30.90	30.85	30.81	30.73	30.67
8	30.80	30.72	30.68	30.62	30.56
9	31.02	30.85	30.71	30.64	30.59
10	31.37	31.13	30.93	30.77	30.72
11	31.84	31.56	31.33	31.05	30.94
12	32.15	31.86	31.66	31.32	31.14
13	32.87	32.59	32.45	32.03	31.46
14	33.22	32.96	33.06	32.64	32.18
15	33.69	33.49	33.41	33.01	32.56
16	33.95	33.78	33.79	33.60	33.22
17	34.25	34.14	34.31	33.96	33.79
18	34.43	34.36	34.44	34.22	34.02
19	33.97	33.92	33.94	33.78	33.63
20	33.79	33.73	33.70	33.55	33.42
21	33.51	33.45	33.41	33.28	33.15
22	33.21	33.15	33.10	32.97	32.86
23	32.92	32.85	32.80	32.68	32.58
24	32.62	32.55	32.50	32.39	32.29
MEAN	32.5	32.4	32.4	32.2	32.0
MIN.	30.8	30.7	30.7	30.6	30.6
MAX.	34.4	34.4	34.4	34.2	34.0
STDV	1.2	1.2	1.2	1.2	1.1

Conclusions and Recommendations

The findings of this study have indicated that it is necessary to increase the roof angle of the terraced houses in Malaysia with north side in January and south in June in order to reduce the temperature by approximately 1.5 degree C during the day hours from 12.00 till 16.00. The effect of increasing the roof angle in this case would give positive effect as the incident solar radiation angle reaches zero degree. That means the roof surface is parallel to solar radiation beams. Nevertheless, increasing the roof angles from zero to 60 degrees for all other directions will lead to negative effect as it increases the indoor air temperature between 0.5 deg. C to 1.5 deg. C from 12.00 till 16.00 during the day. The effect of increasing the roof angle in this case will be negative because of the incident solar radiation angle reaches 90 degree, i.e. the roof surface will be perpendicular and vertical to the solar radiation beams.

Subject to the roof directions in Malaysia, the effect of the roof angles on indoor air temperature is significant. There is also significant relationship between the roof angle parameters, orientations and the times. This is because of the sun path nature, solar radiation, sun altitude angle and the incident solar radiation angle that have greater influence on the roof and building forms.



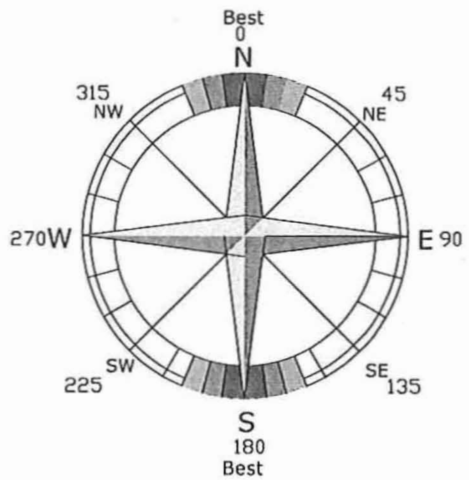


Figure 5:
The effect of the sun path position on the roof in different months.

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