Building design recommendation for thermal comfort in cities on the island of Java, Indonesia

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Abstract. Thermal comfort is a person's state of mind that expresses a person's level of satisfaction with his environment. Optimal thermal comfort can be achieved by considering several factors, including building orientation, air conditioning, position and size of openings, building materials, and others. The purpose of this study is to find recommendations for designing thermal comfort in cities on the island of Java using Mahoney Tables. Mahoney Tables is a collection of reference tables used in construction as climate-friendly design references. In this study, climate and meteorological data will be taken in certain cities on the island of Java. From the results of the above discussion, it can be concluded that the building must pay attention to 4 aspects, namely openings, the building must have wide openings located on the south-north side of the building and the openings must be as high as the human body; The room must be one room without a partition; Building envelopes, buildings must be protected from direct sunlight and rain by paying attention to the selection of materials; and building utilities must pay attention to drainage. The recommendations above are expected to be used by architects/researchers who will design/research buildings to be comfortable.

1. Introduction
Climate and environmental conditions are very important parameters in building planning. The purpose of the building is to respond to activities and provide comfort to users [1]. Comfort is described because the whole bodily and intellectual health of someone in an awake environment [2].

Thermal comfort is a process that involves physical, physiological, and psychological processes, thermal comfort is a person's state of mind that expresses a person's level of satisfaction with his environment. Several factors that affect a person's thermal comfort are air temperature, humidity, and wind speed. Optimal thermal comfort can be achieved by considering several factors including building orientation, air system, position and size of openings, building materials, and others [3].

The aspect of thermal comfort has basically become part of human life in order to interact with the physical environment [4]. In addition, the aspect of thermal comfort can also affect human activities and productivity [5-6].

In designing a building with a bioclimatic design, certain design strategies are needed by taking into account climatic conditions. A recommendation can be made using the Mahoney Table. Mahoney Tables offers the outcomes of thermal consolation evaluation the usage of temperature and humidity facts and pointers from initial layout guidelines.

The purpose of this study is to find design recommendations for thermal comfort in cities on the island of Java using the Mahoney Table. It is hoped that the design recommendations made in this
study using the Mahoney table can be used as a basis and reference for energy-efficient bioclimatic building designs, and can be used to overcome building problems to become comfortable and can be used to research/evaluate buildings in certain cities in Central Java.

Mahoney tables are a collection of reference tables used in construction as a climate-appropriate design reference plus meteorological data to incorporate appropriate design recommendations. So, the Mahoney table can assess the climate to be more accurate on environmental conditions in the dry season. In addition, they can be aware of passive heating from natural ventilation techniques used in the construction of energy-efficient buildings [7].

Mahoney Tables was designed by Carl Mahoney, a British architect who specializes in designing in developing countries, especially in the tropics. He has experience in architecture and computers. He has extensive knowledge of economic development, climatology and statistics. He is very active in passive and low energy architecture (PLEA) and is best known for his work at the Mahony Table (created for the United Nations in 1971).

Mahoney tables use to be had weather records and easy calculations to offer layout guidelines, in a comparable manner to a spreadsheet. There are six sections; 4 had been used to go into weather records for contrast with necessities for thermal comfort, and to examine the ideal layout criteria [8]. The Mahoney tables are given in Figure 1 to Figure 11.

- Choose the Location and then according the location find Longitude, Latitude and Altitude.

**Figure 1. Location Data**

| Air temperature : °C | J | F | M | A | M | J | A | S | O | N | D | High | AMT |
|-----------------------|---|---|---|---|---|---|---|---|---|---|---|------|-----|
| Monthly mean max.      |   |   |   |   |   |   |   |   |   |   |   |      |     |
| Monthly mean min.      |   |   |   |   |   |   |   |   |   |   |   |      |     |
| Monthly mean range     |   |   |   |   |   |   |   |   |   |   |   | Low  | AMR |

**Figure 2. Air Temperature, °C**

| Monthly mean max. a.m. |   |   |   |   |   |   |   |   |   |   |   |      |     |
| Monthly mean min. p.m. |   |   |   |   |   |   |   |   |   |   |   |      |     |
| Average               |   |   |   |   |   |   |   |   |   |   |   |      |     |
| Humidity group        |   |   |   |   |   |   |   |   |   |   |   |      |     |

**Figure 3. Humidity, %**

| Humidity group: |   |   |   |   |
|----------------|---|---|---|---|
| 1              | If average RH: below 30 % |
| 2              | 30-50 % |
| 3              | 50-70%  |
| 4              | Above 70 % |

**Figure 4. Humidity Group**
Rain and Wind

Rainfall, mm

|          | J   | F   | M   | A   | M   | J   | A   | S   | O   | N   | D   |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Total    |     |     |     |     |     |     |     |     |     |     |     |

- Enter the monthly average rainfall value in the fifth line. Adding these twelve values find the annual total rainfall and enter this in the separate box at the end of the line.

Wind, prevailing

Wind, secondary

|          | J   | F   | M   | A   | M   | J   | A   | S   | O   | N   | D   |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|

**Figure 5. Rain and Wind**

| Comfort limits | AMT over 20 °C | AMT 15-20 °C | AMT below 15 °C |
|----------------|----------------|--------------|-----------------|
| Humidity groups | Day | Night | Day | Night | Day | Night |
| 1              | 26-34 | 17-25 | 23-32 | 14-23 | 21-30 | 12-21 |
| 2              | 25-31 | 17-24 | 22-30 | 14-22 | 20-27 | 12-20 |
| 3              | 23-29 | 17-23 | 21-28 | 14-21 | 19-26 | 12-19 |
| 4              | 22-27 | 17-21 | 20-25 | 14-20 | 18-24 | 12-18 |

Table represents relation between comfort limit (in term of temperature) and the humidity group

**Figure 6. Comfort limits**

|          | J   | F   | M   | A   | M   | J   | A   | S   | O   | N   | D   |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Monthly mean max. |     |     |     |     |     |     |     |     |     |     |     |
| Day comfort: upper |     |     |     |     |     |     |     |     |     |     |     |
| lower |     |     |     |     |     |     |     |     |     |     |     |
| Monthly mean min. |     |     |     |     |     |     |     |     |     |     |     |
| Night comfort: upper |     |     |     |     |     |     |     |     |     |     |     |
| lower |     |     |     |     |     |     |     |     |     |     |     |
| Thermal stress: day |     |     |     |     |     |     |     |     |     |     |     |
| night |     |     |     |     |     |     |     |     |     |     |     |

- Enter the first and fourth lines the monthly mean minimum and maximum temperature
- Find the upper and lower comfort limits for the day and night of each month, on the basis of the above table, as defined by the annual mean temperature and the humidity group for each month. Enter these values in 2, 3, 5 and 6 respectively
- Compare the day comfort limit with the mean maxima and the night comfort limit with the mean minima and establish the nature of thermal stress by entering the following symbols in last two lines:
  - H (hot) – if mean is above limit
  - O (comfort) – if mean is within limits
  - C (cold) – if mean is below the limit

**Figure 7. Diagnosis**
| Meaning: | Indicator | Thermal stress | Humidity | Monthly mean range |
|---------|-----------|----------------|----------|--------------------|
| Air movement essential | H1 | H | 4 |
| Air movement desirable | H2 | O | 4 |
| Rain protection necessary | H3 | Over 200 mm |
| Thermal capacity necessary | A1 | 1,2,3 | More than 10 |
| Out-door sleeping desirable | A2 | H | 1,2 |
| Protection from cold | A3 | H | 1,2 |

- Certain group of symptoms (nature of thermal stress, some climate characteristic and the duration of both) indicate the remedial action the designer could take. The method developed uses six indicators (three humid indicator H 1, 2, 3 and three arid indicator A 1, 2, 3)

**Figure 8. Indicators**

| Humid: H1 |
|-----------|
| H2 |
| H3 |
| Arid: A1 |
| A2 |
| A3 |

- The process to be followed is to check thermal stress indices (day and night) the humidity group, the rainfall and the monthly mean range of temperature against the definition of the indicators and place a tick in the line of the appropriate indicator where the month’s data corresponds to the definition.

**Figure 9. Thermal stress indices**

| Indicator Totals from Table 2 |
|-------------------------------|
| H1 | H2 | H3 | A1 | A2 | A3 |

| Layout  |
|---------|
| 0-10 |
| 11,12 | 5-12 | 0-4 |
| 1 | Orientation north and south (long axis east-west) |
| 2 | Compact courtyard planning |

| Spacing  |
|---------|
| 11,12 |
| 2-10 |
| 0,1 |
| 3 | Open spacing for breeze penetration |
| 4 | As 3, but protection form hot and cold wind |
| 5 | Compact lay-out of estates |
| Air movement | 3-12 | 1,2 | 6-12 | 0 | 2-12 | 0,1 |
|--------------|------|-----|------|---|------|-----|
|              | 0-5  |     |      |   |      |     |

| Rooms single banked, permanent provision for air movement |
|----------------------------------------------------------|
| Double banked rooms, temporary provision for air movement |
| No air movement requirement | 8 |

| Openings | 0,1 | 0 | 9 |
|----------|-----|---|---|
| Any other conditions | 11,12 | 0,1 |

| Large openings, 40-80% |
| Very small openings, 10-20% |
| Medium openings, 20-40% |

| Walls | 0-2 | 12 |
|------|-----|----|
| 3-12 |     |    |

| Light walls, short time-lag |
| Heavy external and internal walls |

| Roofs | 0-5 | 14 |
|------|-----|----|
| 6-12 |     |    |

| Light, insulated roofs |
| Heavy roofs, over 8 h time-lag |

| Out-door sleeping | 2-12 | 16 |
|-------------------|------|----|

| Space for out-door sleeping required |

| Rain protection | 3-12 | 17 |
|-----------------|------|----|

| Protection from heavy rain necessary |

**Figure 10.** Recommended specifications
Figure 11. Suggestions for Details

The outline for using the table is:

1. Air Temperature. The max, min, and average temperatures for each month are entered into this A2 table.
2. Humidity, Rainfall, and Wind. This field A3 is filled with the maximum, minimum, and general values for each month, and the status for each month is categorized into the humidity group, field A4.
3. Comparison of comfort and climatic conditions. The desired maximum / minimum temperature is entered in Table B1 and compared with the climate values in Table A2. Care should be taken when heat or cold stress occurs depending on the conditions (for example, when the building becomes too hot or too cold).

4. Indicators (wet or dry), Table B2. A combination of stress (Table B3) and humidity groups (Table A4) is checked in the box to provide rules for classifying monthly humidity and drought. For each of the six possible indicators (humidity indicators: H1, H2, H3, dry: A1, A2, A3), the number of months the indicators were surveyed is summed to give an annual total.

5. Schematic layout recommendations, Table C. The annual totals in Table B2 correspond to the rows in this Table C, including summary layout recommendations. 40% of wall area.

6. Design Development Recommendations, Table D. Again, the yearly totals from desk B2 are used to examine out the recommendations, e.g.: 'Roofs ought to be excessive mass and properly insulated'.

In a related study, Aashi and Kacker [9] studied in depth the relationship between vernacular architecture, Mahoney tables, bioclimatic diagrams, and psychometric charts to examine bioclimatic building design guidelines for considering hot and dry environments, namely the situation in the City of Jaipur, India. This situation is reviewed throughout the year concerning the environment. They have summarized the strategies for achieving thermal comfort by making a list of recommendations. The result is: Open areas should be constructed for adequate airflow; However, the living room must be considered; Window-to-Wall Ratio (WWR): on North and South walls, 20-40%, windows should be placed along the windward side. Openings should also be given to the internal walls. Bright sunlight may be left behind; High thermal density indoor and outdoor walls, thick roof with 8 hours lag time. Beds and outdoor seating are offered. Appropriate measures must be taken to protect against rain, and irrigation must be made properly [9].

2. Methods

The method used in this study is descriptive and evaluative. The descriptive method was used in the first study to collect and present data on existing conditions. Evaluation methods are used to evaluate the research data obtained.

Descriptive studies are not intended to test specific hypotheses, but only to explain variables, phenomena, or states "as is" [10]. Descriptive methods are exploratory methods that attempt to describe and interpret an object according to the nature of the object. The purpose of this descriptive study is to systematically, factually, and accurately explain the facts and characteristics of the population [11].

After Sukmadinata and Nana [12], the assessment has two main activities: measurement or data collection and comparison of measurement results and data collection with the standards used. From the results of this comparison, we can only conclude whether a program, activity, or product is viable, relevant, effective, and efficient [12].

In this study, climate data will be taken from certain cities in Java (there are 14 cities) taking into account the geographical location of these cities. There are three criteria, namely:

1. City on the north coast of Java
2. City on the southern coast of Java
3. Cities on the plains of Java

While the selected city is a city which is a municipality or a district capital city. In this study, several samples of climate data were taken from cities based on the division above, namely the north coast: Jakarta Utara, Semarang, Pekalongan, Surabaya, Pasuruan, Situbondo, Sidoarjo; South Coast: Cilacap, Kebumen, Yogyakarta; Plain: Bogor, Surakarta, Sleman, Madiun.
3. Results and Discussion

Climatic data from these cities are entered and processed using Mahoney tables, the results are in the form of the recommended Specification Table (see table 1) as follows:

| No | City name    | Layout | Spacing | Air Movement | Openings | Walls | Roofs | Out-door Sleeping | Rain protection |
|----|--------------|--------|---------|--------------|----------|-------|-------|------------------|-----------------|
| 1  | Pasuruan     | 1      | 3       | 6            | 9        | 12    | 14    |                  |                 |
| 2  | Yogyakarta   | 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |
| 3  | Situbondo    | 1      | 4       | 6.7          | 11       | 13    | 14    |                  | 17              |
| 4  | Sleman       | 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |
| 5  | Madiun       | 1      | 5       | 7            | 9        | 12    | 14    |                  | 17              |
| 6  | Sidoarjo     | 1      | 4       | 6            | 11       | 13    | 14    |                  | 17              |
| 7  | Bogor        | 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |
| 8  | Surakarta    | 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |
| 9  | Pekalongan   | 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |
| 10 | Semarang     | 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |
| 11 | Surabaya     | 1      | 4       | 6            | 9        | 13    | 14    |                  | 17              |
| 12 | Jakarta Utara| 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |
| 13 | Cilacap      | 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |
| 14 | Kebumen      | 1      | 3       | 6            | 9        | 12    | 14    |                  | 17              |

Information:
1. North and south orientation (long east-west axis)
2. Compact courtyard layout
3. Open space for wind penetration
4. Like number 3, but protection from cold and hot wind
5. The compact layout of estates
6. Single chamber, provision for air movement is permanent
7. Double chamber, provision for air movement is permanent
8. No air flow requirement
9. Wide aperture between 40-80%
10. Small aperture between, 10-20%
11. Medium aperture between, 20-40%
12. Light walls, short time-lag
13. Heavy internal and external Walls
14. Light, insulated roofs
15. Heavy roofs, over 8 h time-lag
16. Need space to sleep outside
17. Need protection against heavy rain

From table 1 above, it can be seen that the recommended specifications for the majority of cities/districts consist of a south and north orientation layout (long east-west axis), open space for wind penetration, buildings have a single space, not insulated, providing permanent wind movement, wide opening (40-80%), light walls with short heat propagation time, light and insulated roof, not recommended to sleep outside, required protection against heavy rainfall.

There are no cities that require sleeping outside, because the K2 indicator is not met (see table B2), namely the first condition: hot night thermal stress and humidity group 1 or 2 are not met or the second
condition: hot daytime thermal stress and normal night thermal stress, group humidity of 1 or 2 and a monthly average temperature range above 10 degrees Celsius is not met.

Only the cities of Pasuruan and North Jakarta do not require rain protection, because in these cities there are no minimum 3 months of rainfall above 200 mm (the H3 indicator is not met).

While the results of the suggestions for details can be seen in Table 2 below:

| No | City name      | Size of opening | Location of opening | Protection of openings | Walls and floor | Roofs | External features |
|----|----------------|-----------------|---------------------|------------------------|-----------------|-------|-------------------|
| 1  | Pasuruan       | 1               | 6                   | 8,9                    | 10              | 12    | 16                |
| 2  | Yogyakarta     | 1               | 6                   | 8,9                    | 10              | 12    | 16                |
| 3  | Situbondho     | 2               | 6                   | 8,9                    | 11              | 13    | 16                |
| 4  | Sleman         | 1               | 6                   | 8,9                    | 10              | 12    | 16                |
| 5  | Madiun         | 1               | 7                   | 8,9                    | 10              | 13    | 16                |
| 6  | Sidoarjo       | 2               | 6                   | 8,9                    | 11              | 13    | 16                |
| 7  | Bogor          | 1               | 6                   | 8,9                    | 10              | 12    | 16                |
| 8  | Surakarta      | 1               | 6                   | 8,9                    | 10              | 12    | 16                |
| 9  | Pekalongan     | 1               | 6                   | 8,9                    | 10              | 12    | 16                |
| 10 | Semarang       | 1               | 6                   | 8,9                    | 10              | 12    | 16                |
| 11 | Surabaya       | 1               | 6                   | 8                     | 11              | 13    | 16                |
| 12 | Jakarta Utara  | 1               | 6                   | 8,9                    | 10              | 13    | 16                |
| 13 | Cilacap        | 1               | 6                   | 8,9                    | 10              | 12    | 16                |
| 14 | Kebumen        | 1               | 6                   | 8,9                    | 10              | 12    | 16                |

Information:
1. Wide 40%-80%
2. Medium 25%-40%
3. Small 15%-25%
4. Very Small 10%-20%
5. Medium 25%-40%
6. In south and north walls at body height on windward size
7. As above, opening also in internal walls
8. Exclude direct sunlight
9. Provide Protection from rain
10. Light low thermal capacity
11. Heavy over 8h time lag
12. Light, reflective surface, Cavity
13. Light, well-insulated
14. Heavy over 8h time lag
15. Space to sleep outside
16. Drainage required

From table 2 above, it can be seen that the suggestions for detail in the majority of cities/districts are in the form of large openings (40-80% of openings), the location of openings in the north and south as high as the human body when the wind comes, avoiding direct sunlight and protection from rainfall. rain, light walls, and floors with low heat capacity, light roofs with glossy and hollow surfaces, some need to be heat insulated, another recommended feature is sufficient rain drainage.

Related to existing research in the city of Jaipur, India. Most of them are the same, but some are slightly different, namely, in cities in Java, the width of window openings is recommended to be 40-
80% wider than the city of Jaipur which is only 20-40% of the wall area. Another difference is that in Jaipur it is recommended to sleep outside, while in cities in Java it is not recommended.

4. Conclusion
Recommendations for building design using the Mahoney table consist of two parts, namely the recommended specifications and suggestions for details, where suggestions for details are the implementation of the recommended specifications that must be applied to the building.

From the results of the above discussion, it can be concluded that buildings must pay attention to 4 aspects, namely openings, space, building envelopes, and utilities, where for openings, buildings should have wide openings located on the south-north side of the building with the height of the opening as high as the human body. The space should be a single room without a partition. Building envelopes, buildings must be avoided from direct sunlight and rain by paying attention to material selection and for utilities, buildings must pay attention to drainage.

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