INVESTIGATION OF THERMAL ENVIRONMENT ON TRADITIONAL BALINESE BUILDINGS

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ABSTRACT

Air conditioning is one of the most important factors that determine human comfort, especially in a hot and humid climate. The development of housing complex tends to increase in this decade, but the thermal environment and human response have not yet been analyzed very well. The aim of air conditioning in traditional Balinese houses is to create a comfortable, healthy and stable thermal condition since some traditional Balinese buildings may not be suitable for inhabitants health and are possible to create several diseases, although less energy consuming. The improvisation of air conditioning systems in traditional Balinese houses by using passive thermal design is needed, especially when people considering energy saving. This paper will describe the improvisation of air conditioning system by passive design in order to contribute more effective control of the environment, to improve the relationship between the artificial environment and human beings, and perhaps can be used to developing the standard code of building design in Bali.

Keywords *Air conditioning, heat transfer and traditional building*

INTRODUCTION

In a tropical country with a warm climate and high relative humidity, natural ventilation proves to be a realistic alternative for thermal comfort of building occupants. This study aims to reduce the cooling loads of buildings and improve the indoor thermal comfort by redesign the buildings location. Since the aim of the study is to find a suitable correlation between buildings location and air motion around buildings, the effects of orientation and infiltration are not considered.

Air conditioning is one of the most important factors in which determine human comfort especially in a hot and humid climate. The aim of air conditioning is to create a comfortable, healthy and stable thermal condition. It is natural to design air conditioning to create a stable thermal condition, but it is no useful to have a flexible view point about the relation between such an environmental condition and its related to human response.

The failure of air conditioning causes this unstable condition in two methods. First is through physical factors in which means the condition of a space is unstable, but the occupant is in a stable condition. The second method is when the inhabitant is not in a stable condition such as walking, passing or moving.

Traditional Balinese building is a space with an unstable thermal condition since used not only for living but also as passageways for where many entrances and exits without doors can caused this unstable thermal condition.

The purpose of this research is to investigate thermal environment characteristics existing in those spaces, according to comfortable, healthy and stable thermal condition for unstable thermal conditioning. This information can contribute more effective control of the environment and can be used to improve the relationship between the artificial environment and human beings.

Thermal comfort of occupants approximated by using Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). Since the PMV/PPD model was developed in mid-latitude climatic regimes with North American and Scandinavian, a critical appraisal of its applicability for heat acclimatize subject in the humid tropics should be more investigated.

Thermal environment can be approached by understand the air motion and heat transfer phenomena around buildings, for where these parameters then be used to predict the air motion and heat transfer inside buildings. Air motion and heat transfer around buildings will be achieved by using numerical investigation, since the method can be done more quickly and capable to delivering more detailed and comprehensive information about the flow structure.

The external design conditions are affected by the thermal mass of the building, the average diurnal range of dry bulb temperature (the difference between the average daily maximum and the average daily

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minimum temperatures for the warmest month which is the month for which the summer design conditions are specified). For a big diurnal temperature difference, the buildings can be cool overnight by using outdoor air. At high temperatures, when the wind flow with a greater velocity, this will increase the convective heat loss from the body in which will cause a reduction in the skin temperature and lead to improve comfort conditions.

Indoor comfort at the hot humid area depends on air speeds at locations away from openings and outside the main airflow jet. The air speeds in these locations cannot be estimated using wind pressure difference methods, but it can be solve by arranging partition in a space to direct the airflow jet into occupied areas.

Ambient air temperature in Bali is greater than 33^0 C and relative humidity of about 80%, therefore the minimum airflow around buildings needed to indices thermal comfort is 1.125 m/s. The predicted mean vote (PMV) for moderate thermal environments of ISO 7730 is $-0.5 < \text{PMV} < 0.5$, for 0.5 clothing (light summer clothing). This value can be achieved if relative velocity is around 1.2 m/s. However, the minimum speed of airflow around buildings required for thermal environment is about 1.2 m/s.

The influence of outlet openings on internal airflow patterns is small, except in regions very close to the outlet. In the case of openings in a windward wall, the velocity of the jet inside the room is higher than velocity outside. To predict the internal flow and thermal environment indoor, the average air velocity and heat transfer on building surface will be used since it represents the occupied zone.

SIMULATION OF TRADITIONAL BALINESE BUILDINGS

The human bodies maintain a balance with its environment through minor physiological changes. The heat from the people should be taken into account in heat gain analyses for cooling requirement system. Body heat losses are primarily by convection, evaporation and radiation. Heat loss by evaporation is caused by change of moisture into vapor and depends on relative humidity, wetted area of body and velocity of surrounding air. Heat loss by convection is affected by motion of air and depends on skin and surrounding air temperature difference, area of body exposed to moving air and velocity of surrounding air. Heat loss by radiation depends on mean radiant temperature and radiation area of body. There is a small heat loss by conduction in which usually occur via physical contact. Since the greatest heat losses of human body caused by convection, for where its affected by air motion and surrounding air temperature difference, then the airflow around buildings, heat transfer and thermal environment of buildings can be used to predict thermal comfort of occupants.

The airflow around a cluster of traditional Balinese buildings is extremely complicated and difficult to determine by modeling an isolated building (via symmetric conditions), since the buildings are linked to each other. Full-scale models of traditional buildings in Figure 1 have been investigated by using *CFD* to predict the above aspects. Numerical simulations of traditional Balinese buildings are set as incompressible, three-dimensional, viscous and turbulent flows. The flow around buildings is modeled by using the Navier-Stokes equations and the standard k-ε turbulence model. The momentum, k and ε turbulence model equations are solved by successive over-relaxation point iteration with an under-relaxation parameter. On the truncated walls and building surfaces, the wall treatment is a combination of logarithmic and no-slip boundary conditions.

To simulate a cluster of traditional Balinese buildings, a complex arrangement is introduced in Figure 1. The first and fourth buildings are aligned, as well as the third and fifth buildings. In the present study, no open surfaces at walls or roofs are considered. In modern arrangements, the distance between buildings is usually uniform. This contrasts to that in traditional arrangements where the distances vary depending on the building's function. A uniform distance equal to one building height, *H*, is used on the simulation. The distance *H* is longer than that in modern sites, but shorter than the reattachment length (around 1.2-1.7 *H*). In modern sites the windward building side faces the main street, but in traditional arrangements all buildings are oriented to the center. Therefore, in order to better understand the building orientation, all buildings are facing to the windward side in Figure 1.

There are two aspects will be carried out by using this configuration. First, to show that although housing complexes are now built using modern techniques, traditional concepts should be taken into consideration. Second, this configuration can also be applied to traditional Balinese buildings since some features of traditional buildings may not be suitable for thermal comfort. By using similar arrangements to modern complexes, the weaknesses of traditional architecture can be corrected, improved and developed without loss of its identity. The air motion will be achieved by analyze the streamline flow, and the heat transfer can be accomplished by dissipation energy since dissipation will cause exhaust of human body by dispersion.

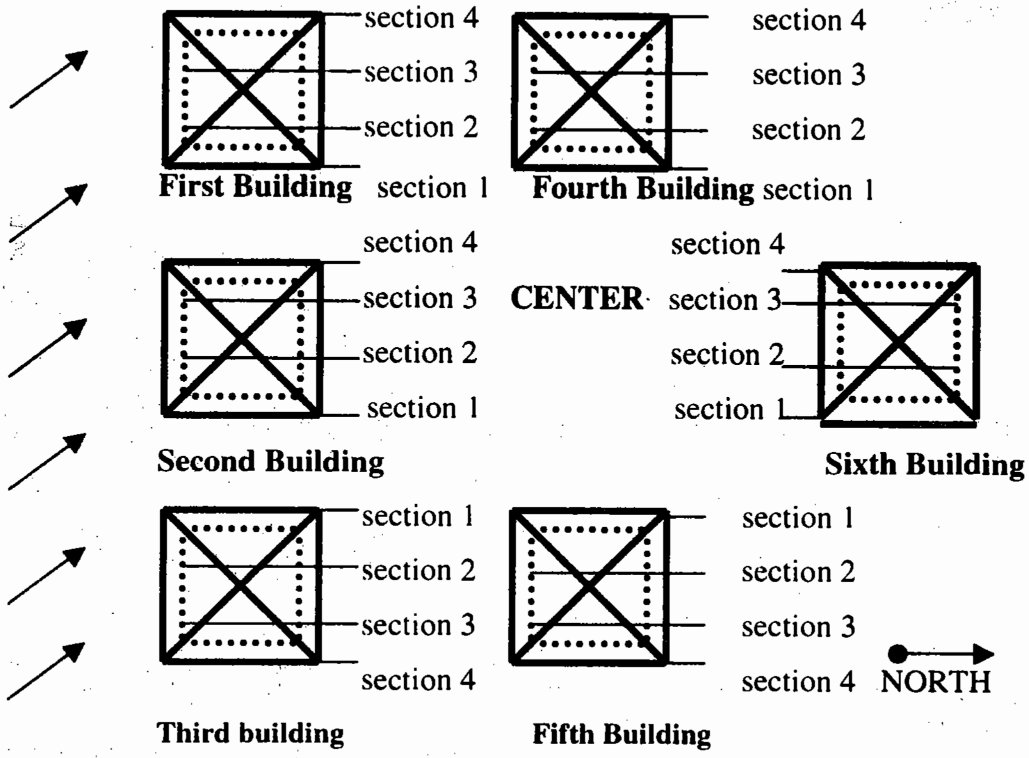

Figure 1. Model of building configuration

RESULTS AND DISCUSSION

It can be seen in Figures 2 that the streamlines merge in the leeward side of the second building (or the area between the second, fourth, fifth and sixth buildings), and increase again after the sixth building. The airflows around buildings vary from 1.86 m/s to 3.50 m/s. The air speed is about 1.86 m/s in the area between buildings, but 3.50 m/s in the passages way. It seems that the minimum air speed required for thermal environment is available on traditional Balinese buildings. Therefore, this arrangement predicted will produce thermal comfort for occupants indoor.

In Figure 3, it can be seen that dissipation energy is reduced in the leeward side of the second building, but in the corner between the fifth and sixth buildings has relatively high dissipation energy. The dissipation energy at the corner, between the third and fourth buildings is relatively high as well as at the leeward side of the second building.

The pressure distribution around buildings is presented in Figures 4 to 9. Pressure distribution on the first building is relatively high at the windward side. It is clear that section 1 has the greatest value and that section 4 has the lowest pressure value in which is affected by flow passages between the first and second buildings. Pressure distributions for all sections of the first row building are similar at the top of roof, indicating that the flow profile at this level is not affected by the buildings arrangement. Since pressure variations on section 1 are relative high at the windward side, it is recommended that an open surface must be placed on section 1 for natural ventilation. At roof level, an open surface can also be placed on section 1. At the leeward side of the first building, an open surface can be placed on any section since pressure variations are similar.

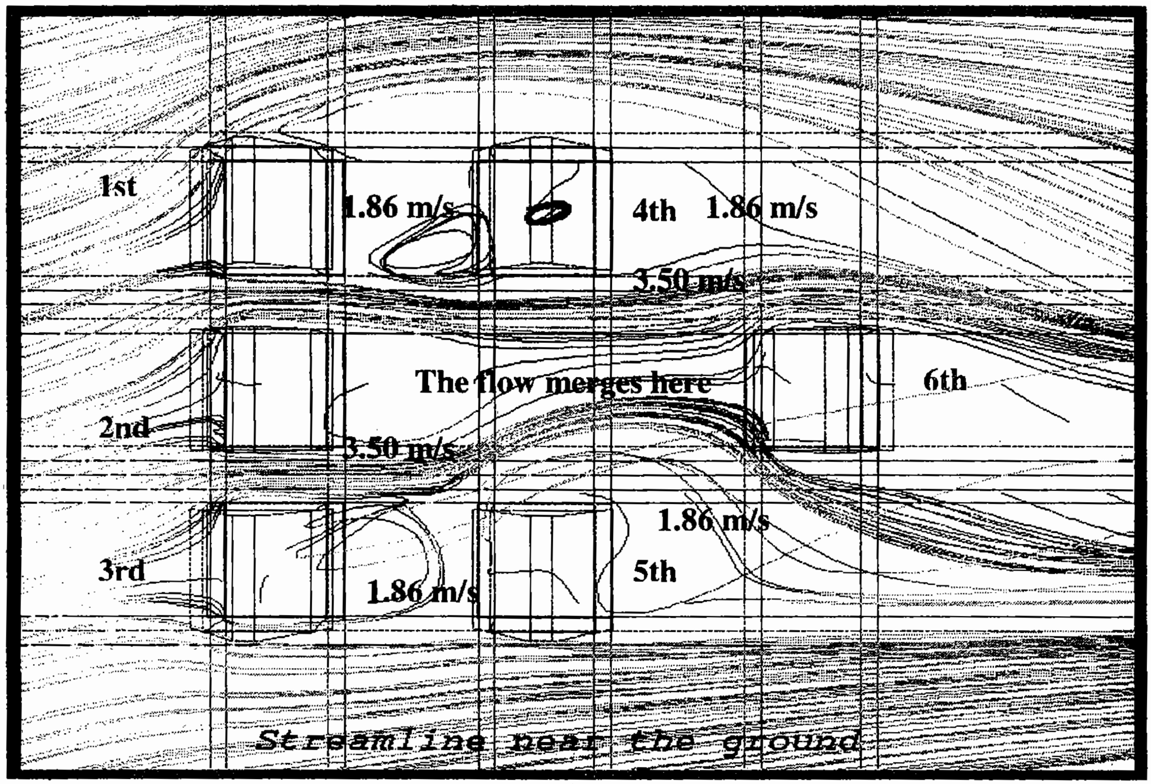

Figure 2. Streamline flow around a cluster of traditional buildings

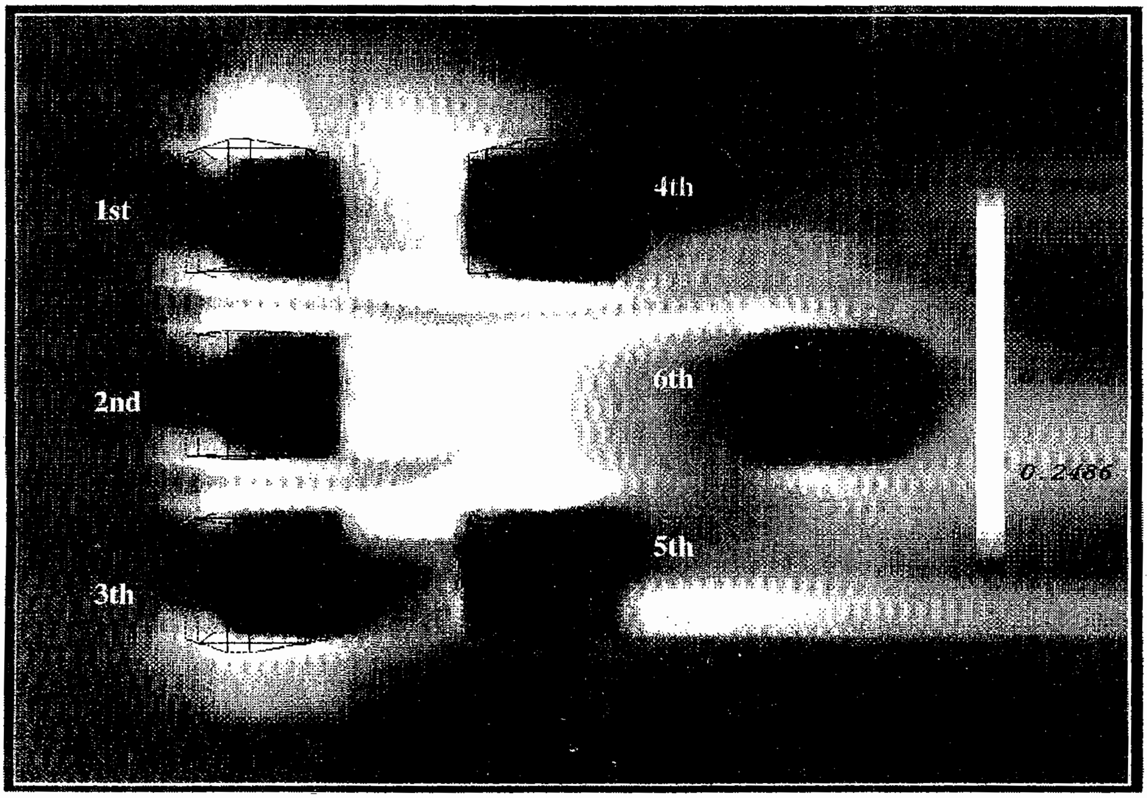

Figure 3. Energy dissipation around a cluster of traditional buildings

The highest pressures distribution in the second building is on section 1, but section 4 is the lowest. This feature is explainable. Since the air flows at an angle, therefore, the windward side of the first building receives the highest momentum, especially on section 1. The adverse pressure gradient at section 1 of the first building produces opposite profiles to that in the second building, especially on section 4. Therefore, section 4 of the second building now receives the lowest momentum. It is also recommended that natural ventilation at the windward side should be placed on section 1. At roof level, an open surface should also be placed on section 1. Similar to the first building, an open surface can be placed on any section, at the leeward side. These conditions will minimize the wind load effects on the building but produce good natural ventilation to the occupants.

The same explanation is valid for the third building. Pressure distribution on section 1 is the lowest one (note: section numbers of the third building are opposite to that in the first and second buildings). An open surface at the windward side should be placed on section 3, but an open surface at roof level is recommended on section 4. At the leeward side, natural ventilation should be placed on section 3.

Pressure distribution in the fourth building is very low at the windward side on section 1. Since the pressure distribution at the windward side is lower than at the leeward side, open surfaces at this side are not necessary. At roof level, we recommend an open surface on section 1. Since the pressure variation on section 1 is a bit lower than on the other sides, an open surface on section 1 is preferred at the leeward side.

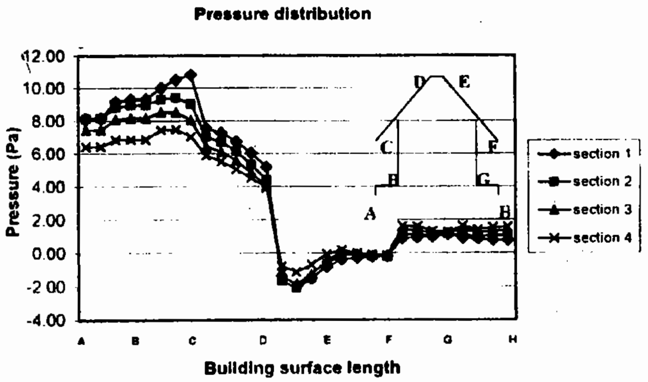

Figure 4. Pressure distribution on the first building

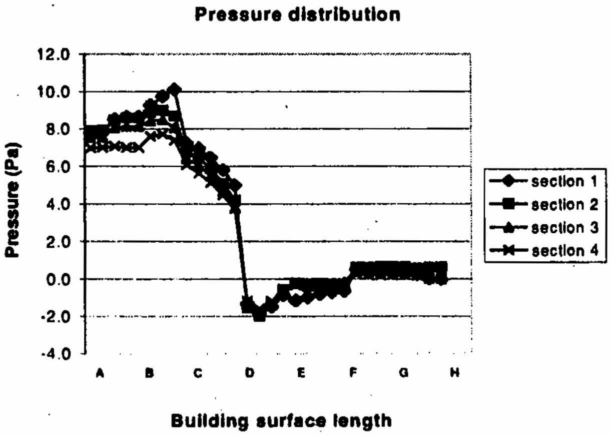

Figure 5. Pressure distribution on the second building

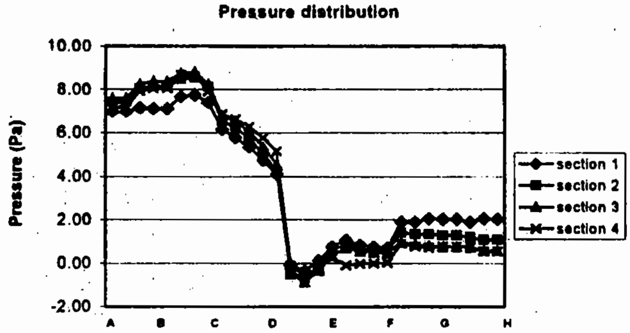

Figure 6. Pressure distribution on the third building

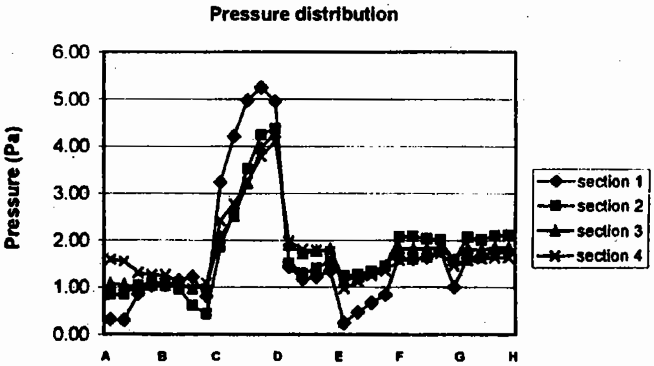

Figure 7. Pressure distribution on the fourth building

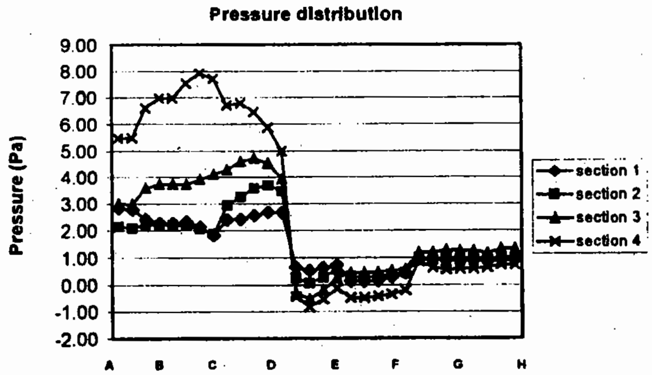

Figure 8. Pressure distribution on the fifth building

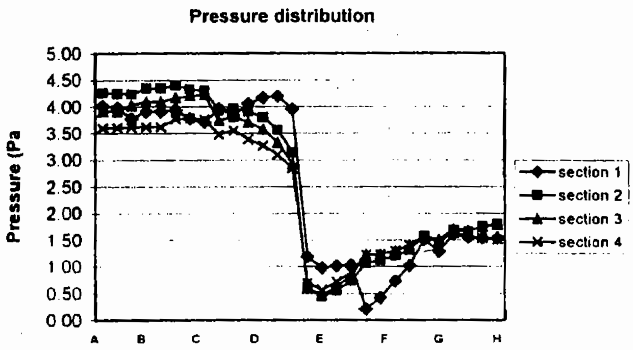

Figure 9. Pressure distribution on the sixth building

Pressure distribution on section 4 is the highest one at the fifth building. Therefore, an open surface on section 4 is recommended for better natural ventilation. The maximum pressure is lower than that in the third building, indicating that air momentum decreases after hitting the first obstacle (*i.e.*, the third building). The pressure distribution on section 1 is also different from that on section 1 of the fourth building. It can be noted that the flow pattern on section 1 of the fourth building tends to be fully developed, but not in the fifth building. This phenomenon leads to producing high momentum on the fourth building.

Pressure distribution at the windward side of the sixth building is high on section 2. It can be noted that the flow at the windward side also tends to be fully developed. Theoretically, the flow at the leeward side of the first obstacle should be fully developed after one and a half reattachment lengths (or about two and two-thirds the building's height). Since the wind direction is at an angle, it affects the flow pattern near the windward side of the sixth building and does not produce a fully develop turbulent flow, similar to the fourth building. On the sixth building, an open surface on section 2 is recommended at the windward side. An open surface at roof level is recommended on section 1. At the leeward side, an open surface on section 1 will produce a higher pressures difference between the room and it's surrounding.

Pressure distribution and dissipation energy have strong correlation with convection heat transfer. Greater pressure distribution and dissipation energy will produce greater convection heat transfer. To minimize the effect of convection heat transfer, the area that has strong pressure distribution and dissipation energy should be fully open. This method will directly reduces the cooling loads on building surfaces and produces a better thermal environment and thermal comfort of occupants.

It can be seen clearly in Figures 2 and 3 that the airflow increases after separation point (the point where the flow merges in Figure 2, or in the center). The separation point occurs at the first row of buildings (in this case at the second building), where the fluid near surfaces lacks sufficient momentum to overcome the pressure gradient and produces wakes at the separation regions. After separation, the flow tends to be fully developed. This can be seen in Figure 2 that air speed is different between in the passage way and the area between two buildings since depending on the Reynolds number.

A greater pressure distribution usually produces greater energy dissipation. Since in the center (the area where flow merges) the flow produces higher energy dissipation but lower pressure, it is predicted that the flow at the center is not fully developed turbulent. This feature can also be understood from the streamline plot in Figure 2. It is clear that there is a high eddy vortex at the windward side of the fourth building in which tends to produce higher turbulent energy. Energy dissipation on the sixth building also increases because of the jet flows merging and producing high energy at the windward side of the sixth building. In order to increase thermal comfort of occupants, the modified design of buildings on the first row described in Figure 10. The suggested design allows airflow toward directed to the living room but with low convection heat transfer. The design will produce a greater convection energy transfer from surrounding to the living room, vice verse, and directly produce a greater thermal comfort for occupants.

CONCLUSIONS

According to the pressure distribution and dissipation energy around buildings, it can be seen clearly that airflow around traditional buildings has a strong relation to the thermal comfort of occupants. Since pressure distribution and dissipation energy transfer in the fourth and fifth buildings are the lowest and need open surface at the roof, therefore the fourth and fifth buildings are capable for conference rooms, ceremonial rooms, meeting rooms or auditorium. Since pressure distribution and dissipation energy transfer in the sixth building are greater than that on the fourth and fifth buildings but does not need to fully open at the roof, therefore the sixth building is convenient for residences apartment, convalescent home and home for the aged. Since pressure distribution and dissipation energy transfer in the first row buildings are the highest and need to fully open at the walls, the first row buildings suggested for kitchens, granaries and stores, for where the heat transfer rate is very high and adequate for goods. Therefore, there is a relation between the position of buildings and their function, with the thermal comfort of occupants. Storage rooms and kitchens should lie at the front side (the first row buildings), ceremonial and meeting halls should lie in the middle and the parent's sleeping quarters should lie at the rear of the site.

It appears that traditional Balinese buildings has a relation with wind engineering and heat transfer, and designed for improving thermal comfort of occupants. The numerical investigations conducted here provide a contribution to a better understanding of traditional Balinese architecture and some design modifications to improve thermal comfort of occupants.

REFERENCES

Aynsley, R.M., Melbourne, W and Vickery, B. J. (1977), *Architectural Aerodynamics*, Architectural Science Series, Applied Science Publisher Ltd., London.

Baskaran, A. and Kashef, A. (1996), *Investigation of air flow around buildings using computational fluid dynamics techniques*, Engineering Structures, Vol. 18, 861-875.

Egan, M. D. (1975), *Concepts in Thermal Comfort*, Prentice-Hall Inc., New Jersey.

Murakami, S. and Mochida, A. (1995), *Turbulent vortex shedding flow past 2D square cylinder predicted by CFD*, J. Wind Engineering and Industrial Aerodynamics, Vol. 54-55, 91-211.

Patankar, S.V. and Spalding, D.B. (1972), *A calculation procedure for heat, mass and momentum transfer in three-dimensional parabolic flows*, International Journal of Heat and Mass Transfer, Vol. 15, 1787.

Wieringa, J. (1992), *Updating the Davenport roughness classification*, J. Wind Engineering and Industrial Aerodynamics, Vol. 41-44, 357-368.

Zhou, Y. S. and Stathopoulos, T. (1996), Application of two-layer methods for the evaluation of wind effects on a cubic building, ASHRAE Transaction, Vol. 102, 754-764.

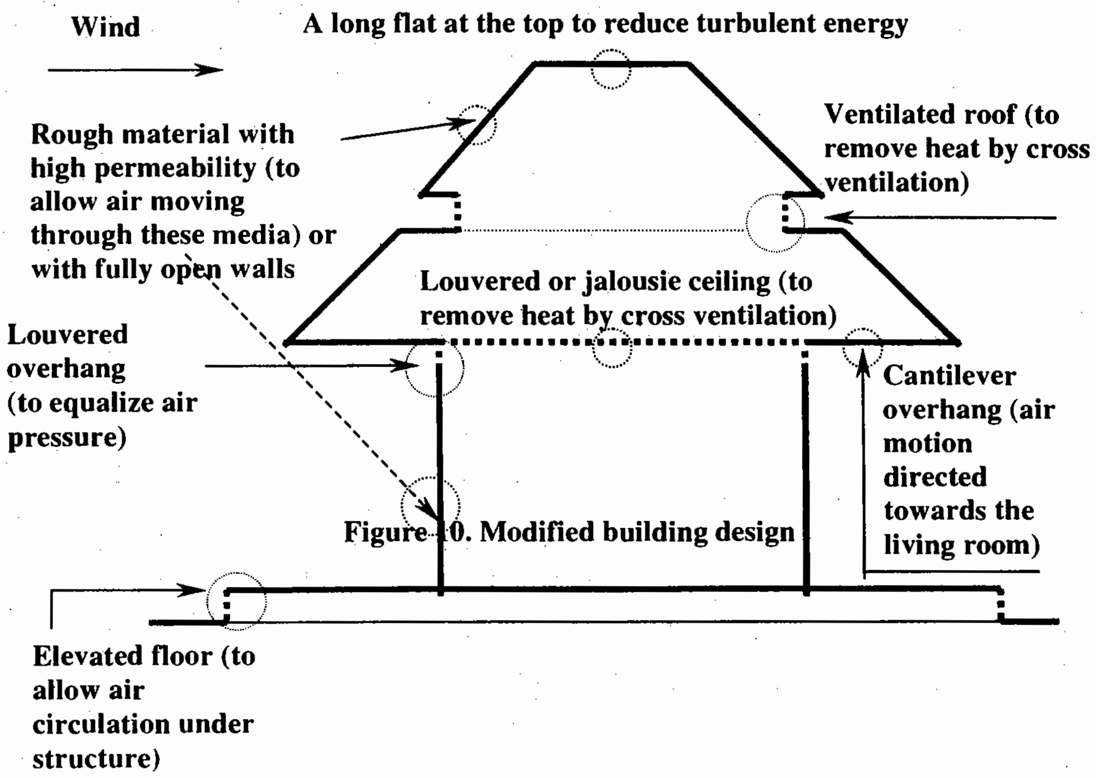

Figure 10. Modified building design