Researching for sustained translation from site cluster permeability into building courtyard and interior atrium

FX Teddy Badai Samodra, Ima Defiana and Wahyu Setyawan
Department of Architecture, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

E-mail: fxteddybs@arch.its.ac.id

Abstract. Many previous types of research have discussed the permeability of site cluster. Because of interaction and interconnected attribute, it will be better that there is its translation into lower context such as building and interior scale. In this paper, the sustainability design performance of both similar designs of courtyard and atrium are investigated continuing the recommendation of site space permeability. By researching related literature review and study through Ecotect Analysis and Ansys Fluent simulations, the pattern transformation and optimum courtyard and atrium design could comply the requirement. The results highlighted that the air movement from the site could be translated at the minimum of 50% higher to the building and indoor environment. Thus, it has potency for energy efficiency when grid, loop, and cul-de-sac site clusters, with 25% of ground coverage, have connectivity with building courtyard compared to the atrium. Energy saving is higher when using low thermal transmittance of transparent material and its lower area percentages for the courtyard walls. In general, it was more energy efficient option as part of a low rise building, while the courtyard building performed better with increasing irregular building height more than 90% of the difference.

1. Introduction

Accelerating site wind through spaces and forms as part of urban geometry have been the main points related to site clusters and the permeability. In that studies, solar radiation is the most important parameter on an urban scale [1,2]. Meanwhile, one of air flow analysis related to site and settlement is real degree permeability and it could give rough information about air flow distribution [3]. Its combination with ground coverage results in the same greater accuracy. By using this method, the permeability map could recommend ventilation design method for low-rise settlements with many types of site orders.

The interaction between site clusters and the approaching wind to the settlement generates different flow patterns of air movement where it has great influence on the air flow within the street as site cavity of urban block [4]. Configurations that contain a square space articulated by buildings and oriented toward the prevailing wind can offer better exposure to air movements, not only for the optimum building layout patterns but also for trees arrangement [5]. The arrangement of inflow paths as site air movement inlet and the creation of wind paths have the potential improvement for outdoor thermal environment [6]. The investigation of various site clusters as urban geometry modifications showed that step up configuration was the most potential geometry. It should distribute the wind evenly allowing the wind to reach even for the leeward area in the high-density settlement [7].

According to design parameter like building height ratio, an abundance in the amount vegetation the courtyard can achieve an acceptable level of thermal comfort for the tropics [8]. Vegetation is the natural filter and creating the transitional area from hotter to cooler area in the settlement. Furthermore, the well-designed courtyards may represent a valid option for building. The definition for optimum courtyard ratio should which allows the form to receive minimum solar radiation for the tropical regions [9]. However, site cluster and its contribution to the building context should be designed first even without vegetation role. A set of ratio was recommended to achieve an efficient performance, depending on the climatic features and the general strategies to achieve comfort for every different climate. As for tropical region with hot and humid climates, the long axis orientation of the courtyard along the northeast– southwest is desirable to achieve reasonable performance.

2. Method

In this research, both similar designs of courtyard and atrium are analyzed continuing the recommendation of site space permeability. By examining related literature review and investigation through Ecotect Analysis and Ansys Fluent simulations, the pattern transformation and optimum courtyard and atrium design could reach the standard or requirement.

Figure 1. shows three kinds of site cluster models as the base of analysis, such as grid, cul-de-sac, and loop. That types (included the dimension) are very popular in many conditions, especially for the tropical region. In detail, the research process could be explained as follows:

(A) Site Clusters Analysis: Analysis for 15 models of three clusters, taken from Antaryama, Grammenos and Tasker-Brown [2,10] and separated by 6 m street width, related to air velocity in various wind direction and Mean Radiant Temperature (MRT) as representative of a thermal condition. All clusters are tested for 5 divided urban location of tropical latitude (0°-23.5°): 0°-5°, 6°-10°, 11°-15°, 16°-20°, and 21°-23.5°. Furthermore, it could be determined as the translation process, an analysis of site clusters effects to the lower scale: the inlet for courtyard and atrium and its air velocity. The resulted MRT and indoor air temperature for representative building block, as part of cluster (around 10 modules of housing) are also considered for further investigation;

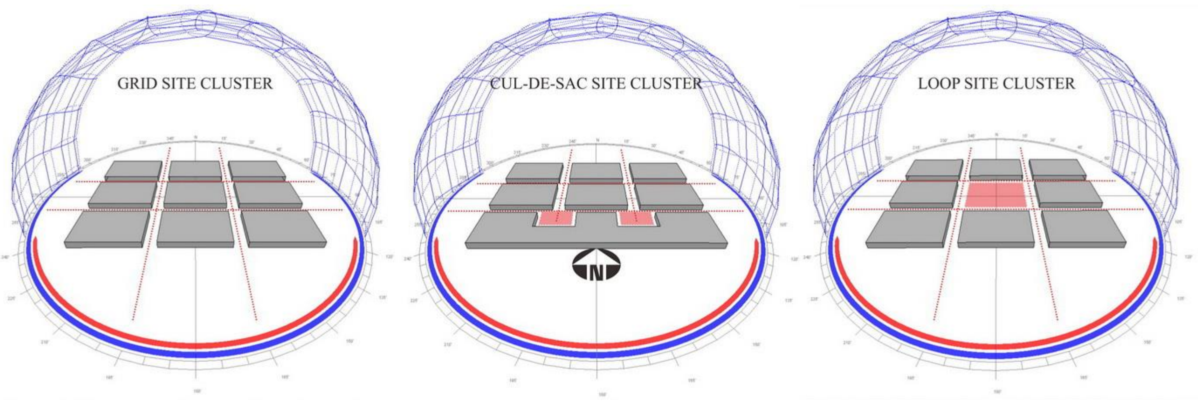


Figure 1. Model of site clusters.

(B) Translation to Courtyard and Atrium Contexts: Analysis for representative housing module (6 m x 10 m and 3m height in average for single floor building) on Mean Radiant Temperature of building courtyard and atrium as the main factor in the tropical climate for various length and width ratio. The module could be seen in Figure 2. The significant difference between courtyard and atrium is that atrium is closed by transparent material as skylight when the courtyard is still opened area. The analysis could be separated as follows: (a). Courtyard Ratio: Analysis for air movement for the various open patio as the critical type of courtyard. In this type, the existence of building apertures is ignored in order to determine the ratio performance. Meanwhile, the closed patio, atrium, could be predicted as no wind acceleration because of its covered top area by a transparent material, and (b). Courtyard

Height Slope: Analysis for wind catching for various of building height difference on a single model. Furthermore, the comparison will be the answer of courtyard characteristics.

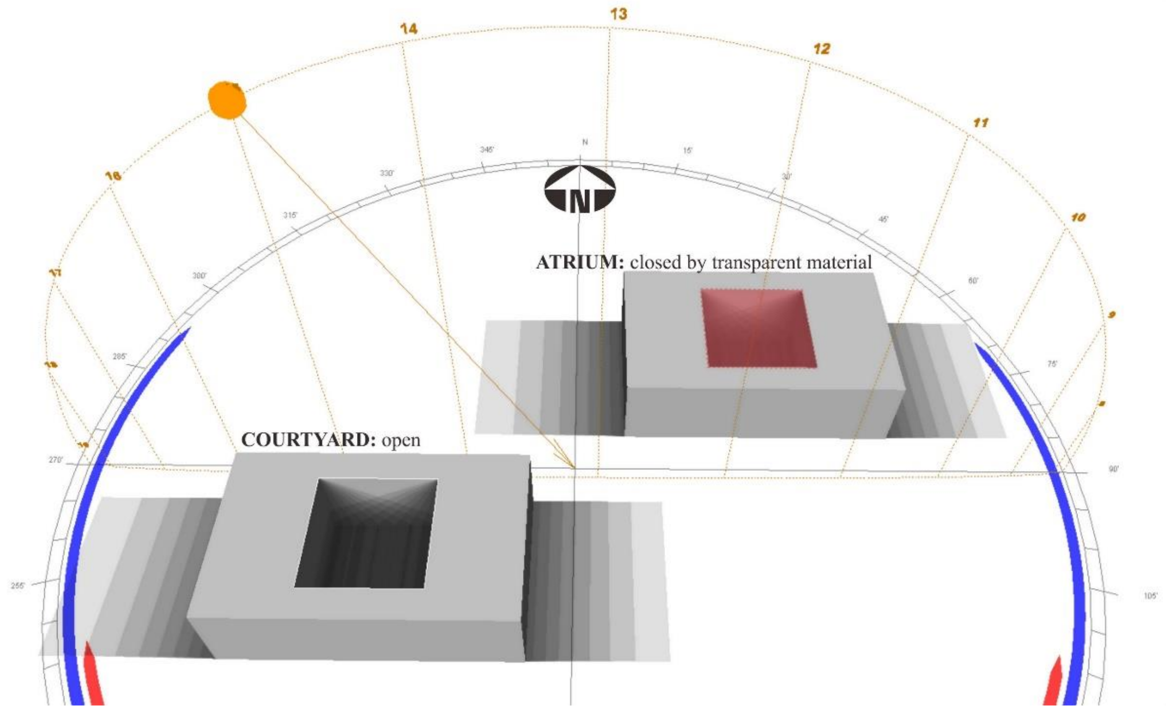


Figure 2. Model of courtyard and atrium.

3. Results and Discussions

As explained in previous section, the discussion related to housing order, site cluster, and its translation into lower contexts, building courtyard and atrium, will be investigated in the following sub-sections.

3.1. Site cluster analysis

Tropical climate, both in north and south hemispheres receives solar penetration in various condition. In general, the lower latitude position gets a higher impact on its environment, hotter condition-higher MRT even it is very depended on the micro or site condition of the clusters. Figure 3. compares air movement simulation using Ansys Fluent Program on the grid, cul-de-sac, and loop typologies in five locations in the tropical region. All types are analyzed with five types of wind direction from 0° to -90° with 8 m/s as the average of air velocity inlet, developed from available climate data (https://energyplus.net/weather). All are applied to all area in the tropical climate because they are influenced by terrain roughness more than latitude difference, and in this study, the sites for all objects are in the same surrounding density.

The results show that on all site clusters, 0° wind direction is received by wider perimeter site clusters perpendicularly. Comparing to -90°, the same perpendicular direction to the object-the same street path number and dimension, the 0° wind direction enhances air flow distribution better because of its short reach. Despite having lower air velocity, the diagonal wind directions have better distribution into the area with tolerated wind speed for all area evenly; -22.5° is the best performance on grid and cul-de-sac when -22.5°, -45°, and -67.5° directions on loop site cluster have similar best results.

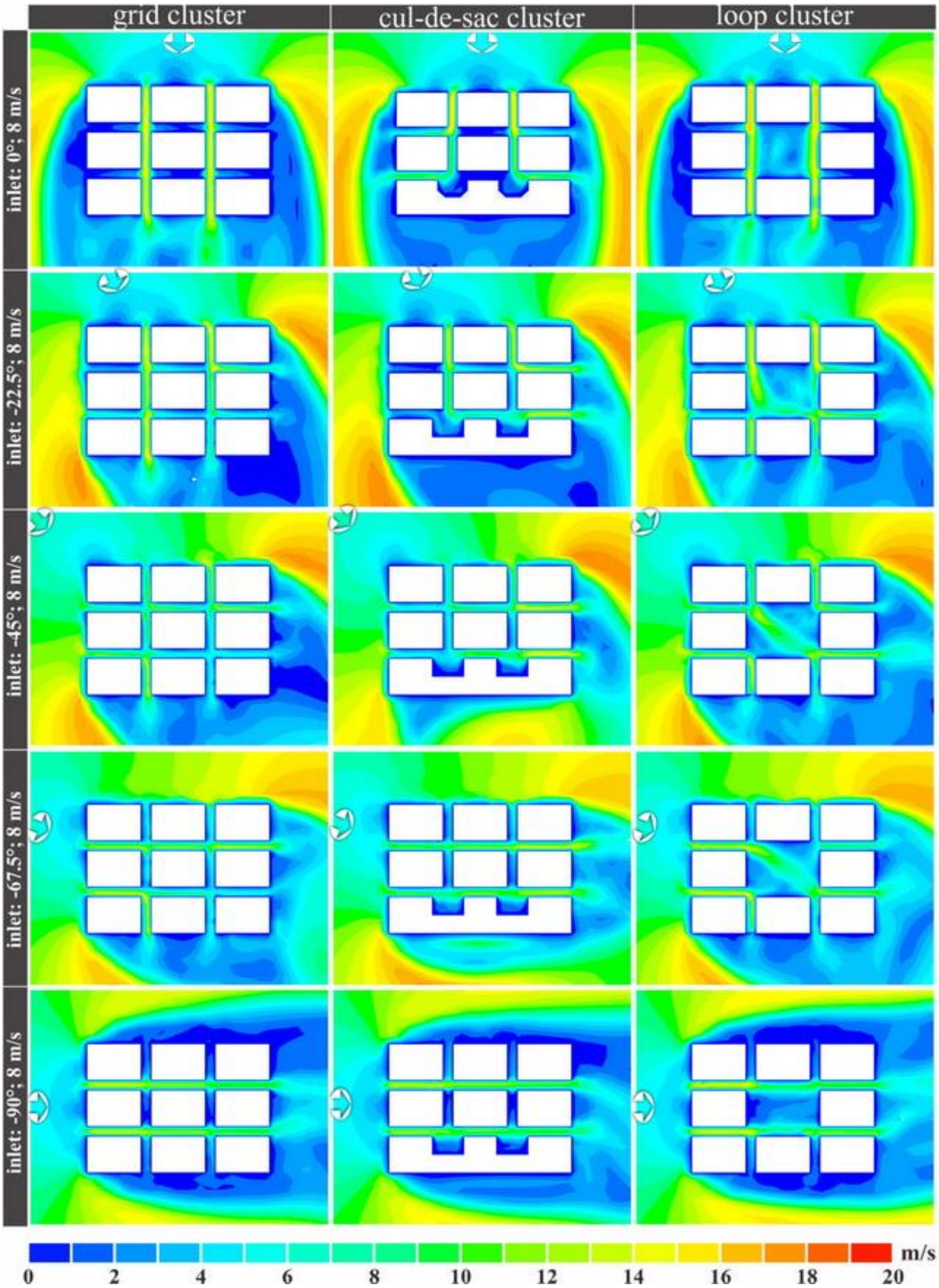


Figure 3. Air velocity in various wind direction and site clusters.

Because of larger opened area, loop model has more alternatives. Those indicate that diagonal, especially from wider area angle (-22.5°) offers potential wind distribution into the site with the street as the main regulator for its deep acceleration. Moreover, opened area include street path is the most factor in better wind distribution and its velocity. It succeeds to translate air movement from the site to the building context as findings of 8 m/s of site cluster inlet translated into 12 m/s in average closed to the building for all kind of site clusters and orientations. The air movement from the site could be translated in minimum 50% higher to the building and indoor environment. However, it is different from Ramponi et al [11] that for wind directions perpendicular to the main street, the presence of this main street improves the ventilation efficiency because the main street acts as a sink of clean air on site clusters.

Discussing clusters, grid and loop objects perform similarly when they take up air flow perpendicularly. The role of open space in the loop does not signify improving translation, it is a consequence of the air velocity also. The higher intake, nevertheless, still penetrates better because controlling higher speed for tropical wind is easier than generating the weak inlet in creating better windward and leeward in the settlement. On the other hand, the diagonal intake differs the distribution because it determines 2 ways of inlet generally. The open space of loop cluster is empowered by more than 1 alternative direction. Meanwhile, by trapping the wind for not all site part, the cul-de-sac potentially results in the same performance, does not matter the wind direction.

Air flow characteristics for such an urban permeability of air flow could be translated by parallel buildings [12]. The other ways are making blockage and deflection of local wind by frontal of lateral buildings. The accelerated air flow at building corners during flow separation and sideways deflection of an oblique wind along the windward elevation of a building are the others. Due to proximity buildings, this study also considers an achieving of the sheltered zone at the rear of a building. The other research showed that air velocity at the pedestrian level is affected by the presence of buildings [13]. In line with this research that with 6 m of Width (W) and 3 m of Height (H) in average, H/W more than 1, and it has a positive impact on air movement. The pedestrian level could be defined as human standing reference height which is useful for determining inlet for building scale. When $0 < H/W \leq 1$, the street as wind path effect can be seen as lower pedestrian reference height for air movement. In addition, the uniformity of building heights is the disadvantage on enhancing air movement in pedestrian comfort.

The role of the street and its physical figures determine the capability of air movement and its potency for physiological cooling and problem in opened area of solar shading. As shown in Figure 4., the problem of solar radiation is on opened area which wind accelerates on. The difference of latitude in the tropical area not effects on the MRT (simulated by Ecotect Analysis Program). The site clusters type plays as the main factor in determining thermal environment. Compared to the other types, for an exception in lowest latitude (0°-5°), cul-de-sac arrangement has the best performance in reducing solar radiation indicated by lower MRT than the others. Meanwhile, latitude 15°-20° evidently gets better condition comparing the other latitude. It could be concluded that larger opened area as loop cluster effects directly on MRT. In contrast, the grid with the closer environment has weakness on physiological cooling by the wind. In relationships to latitude 15°-20° position, it needs further exploration for the site condition. In the case of this research, there is no more consideration in detail related to the site object features.

In detail, regarding 10°-15° location for similar order, grid, and loop cluster types, it is very distinct found in the building block where higher MRT is visible by those simulations. It indicates the site and micro climate effect and it also gives thermal consequences to the specific orders: grid and loop. The grid, the densest environment reaches advantages on providing outer shading but having weakness on distributing air movement. On the other hand, the loop has the best capability of accelerating the wind (for diagonal intake), but it has demerits on giving environment shadow without any supporting landscape design as vegetation utilization. Thus, the mid-ordering for site cluster, cul-de-sac, generates better than the others in compromising wind acceleration control and reducing solar radiation. Contradictory problem-solving in giving better environment should give attention more on translating all factors in providing thermal comfort and its optimization is having an important role.

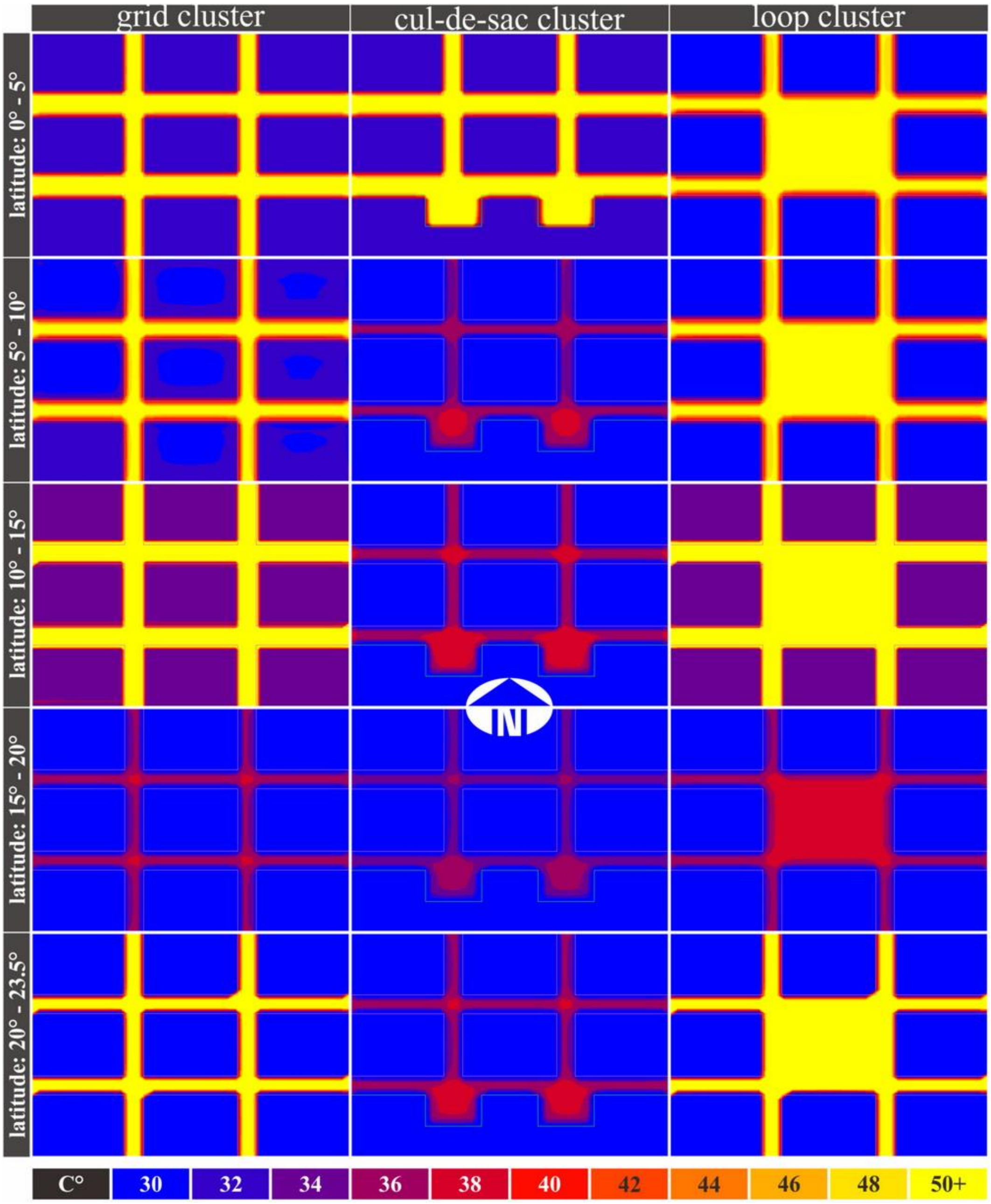


Figure 4. Mean Radiant Temperature of site clusters.

Indoor and outdoor temperature comparison will answer further related to the site cluster above (Figure 5.). This figure is taken from the representative building block for the same model and location from all site clusters type. In line with MRT result, air temperature simulation for representative building block indicates that cul-de-sac with appropriate opened area contributes to the lower temperature. However, it is still higher compared to outdoor temperature; the building block could not improve the environment. Moreover, except taken for the hottest condition in the lowest latitude, it could be better performance. In this analysis, the vegetation role is not involved to check the contribution of the site cluster purely. Moreover, the hottest month is explaining the critical performance when the building block experiences the peak of overheating all the days. By this figure, it estimates that the grid site cluster has similar performance as the same plotting for about 20 hours in the hottest day. Furthermore, open area of loop site group results in a high impact on site MRT and direct translation to building block and the possible effect on building courtyard and interior atrium.

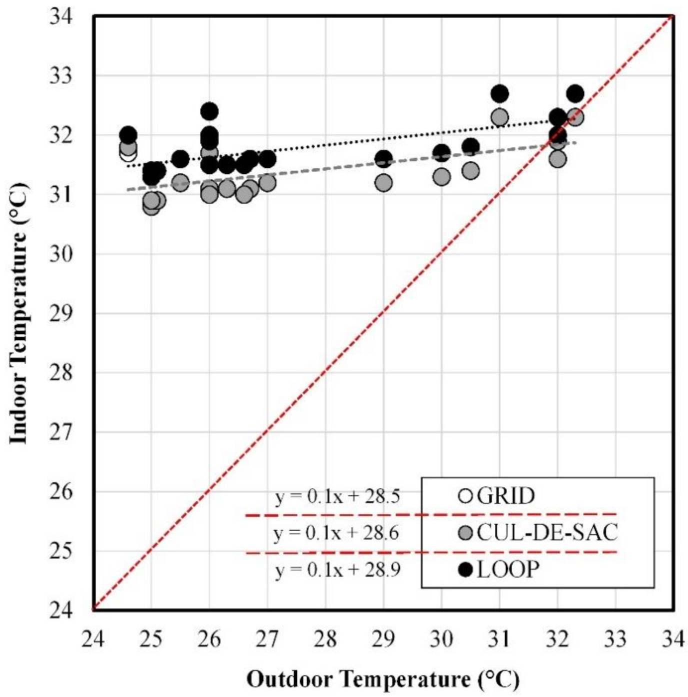


Figure 5. Indoor and outdoor temperature comparison for representative building block.

3.2. Translation to courtyard and atrium contexts

MRT analysis indicates the first translation model from site context to the building scale (Figure 6.). It is quite exploited by condition without any surrounding obstruction such as vegetation and neighborhood also. Again, the method is useful for exploring the original performance of courtyard and atrium. The Ecotect Analysis simulation results that with the same area, the higher ratio model produces the greater impact on MRT. The 1:5 is the hottest condition ratio indicated by the large upper grade of MRT area, both for courtyard and atrium. The range of direct solar radiation is the key point related to the inner shading. With orientation East-West as the smaller area, it has consequences to the courtyard or atrium shapes. In line with the previous finding related to the building orientation, North-South and East-West provide the least and most comfortable indoor environments [14]. It has potency for energy efficiency and a significant increase in energy efficiency when the grid, loop, and cul-de-sac site clusters, with 25% of ground coverage, have connectivity with building courtyard compared to the atrium.

Discussing the difference between courtyard and atrium is directed to the grade of MRT gap. A preliminary prediction, without opened area, the atrium will experience hotter than the courtyard. Figure 6. also shows that the MRT of the atrium has 8K higher than the courtyard because of its material. Regarding the building materials, the use of green roofs and the courtyard pavement are the most actual heat mitigation strategy [15]. The effects of wet and cool roofs are much useful than of dry roofs and the total energy consumption of the narrow, the rectangular atrium with the high ratio of length to width is significantly greater than the square shaped atrium. However, it should be noted that the high different gap between length and width effects on wider impact than opened area for both courtyard and atrium. Higher temperature (MRT) is found as consequences of very slim of width. Therefore, it is recommended that potential wind catching for very long turbulence with longer opened building patio (for courtyard) should pay attention to thermal environment impact and heat gain ventilation.

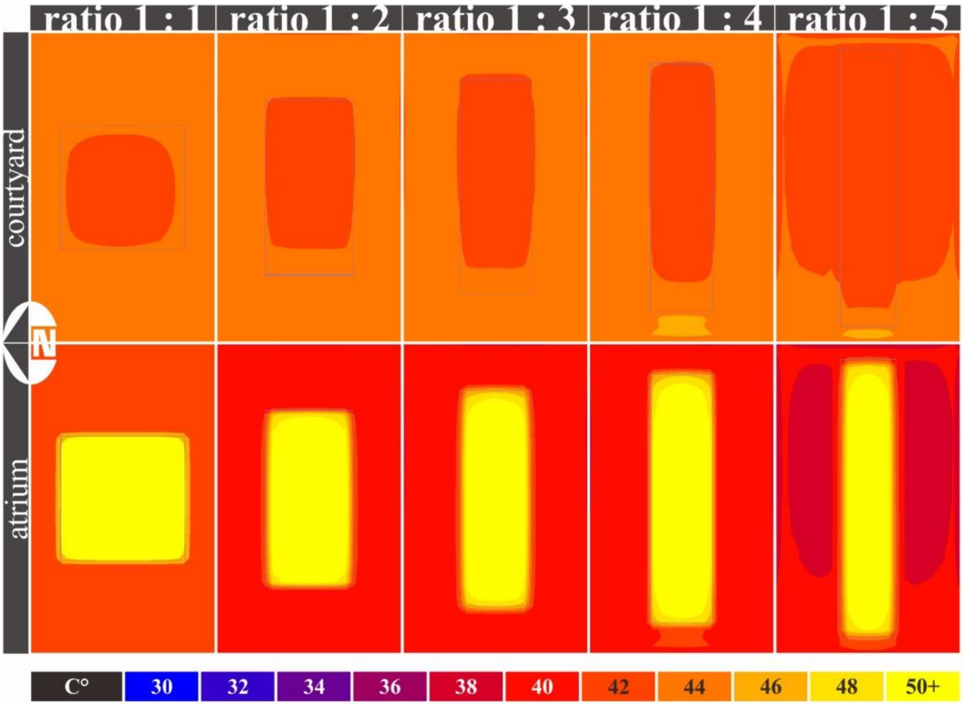
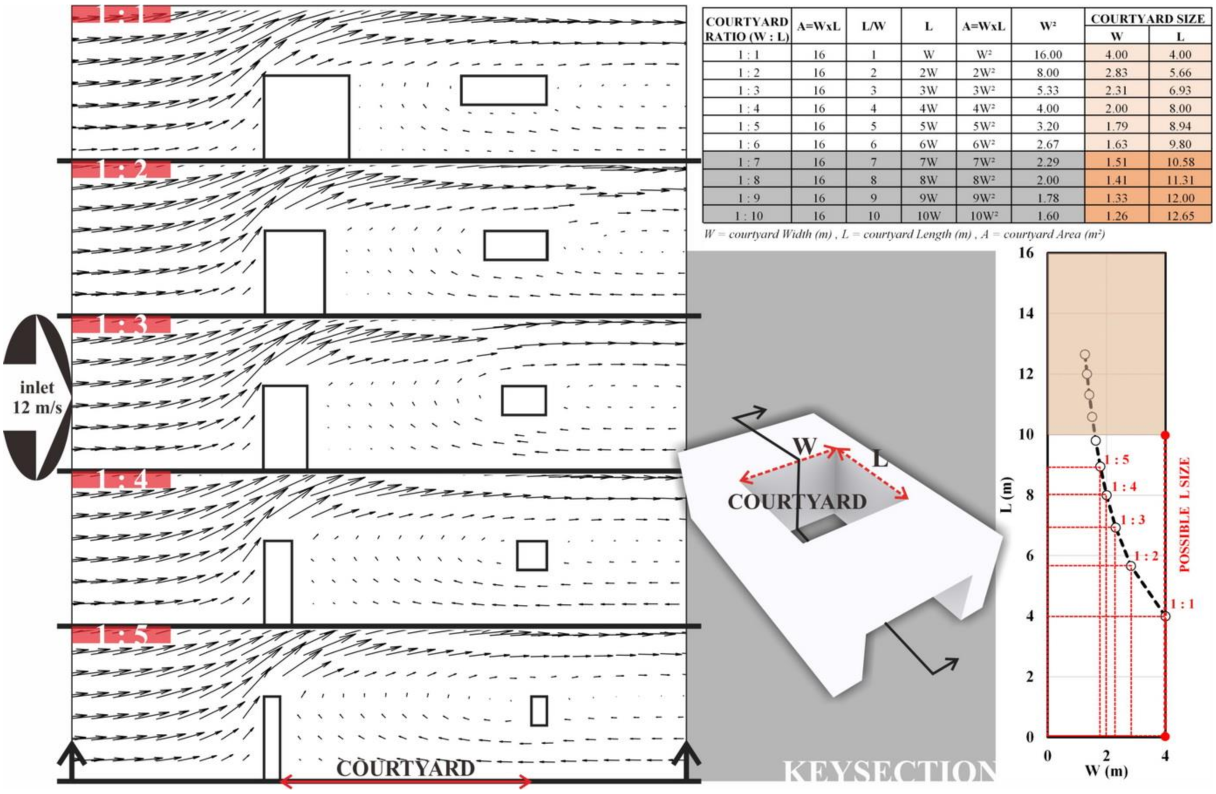


Figure 6. Mean Radiant Temperature of building courtyard and atrium.

Although the atrium area has higher MRT, the around indoor environment shows better condition than the courtyard. It has 2K lower than indoor MRT around courtyard has. It indicates that protected roof using transparent reduces direct solar radiation even increases heat accumulation in the atrium area. Energy savings is higher when using low thermal transmittance of transparent material and its lower area percentages for the courtyard walls. Meanwhile, the open courtyard building exhibits a better energy performance for the shorter buildings. As the building height increases, however, at some point, the enclosed atrium also reveals a better energy efficiency. It recommended that using buoyancy-driven ventilation alone has an insignificant effect for atrium [16]. Meanwhile, for the most comfortable zone, the utilization of solar-assisted buoyancy-driven ventilation should develop the thermal conditions in the occupied areas of the building [17,18].

Figure 7. sets the air movement on different types of courtyard ratio. It tests the capability of turbulence wind in the various potential building. The site cluster simulation results in 12 m/s of velocity inlet. With maximum building length, 10 m, it needs to design the courtyard lower size. From 10 alternatives courtyard ratio, 1:1 to 1:6 have a potential output of air movement simulation, but because of its effect on room dimension, this study skips the 1:6. The simulation results show that all prospective building alternatives could not be able to accelerate the wind directly. In line with the analysis of courtyard for Eddy Area (leeward) that the range is 3 to 3.75 of building height [19]. By three times building height (around 3 m), it needs 9 m turbulence distance to create direct air penetration to the courtyard and reducing leeward area, but it is impossible for reducing building height or room width around the courtyard. However, the turbulence through building after passing all building could run back to the building even it reduces the essence of the courtyard design. Therefore, the roof height difference is the further suggestion to catch the wind, especially by adding the height of across building from the wind direction.

In general, it was more energy efficient option as part of a low rise building, while the atrium building performed better with increasing building height. The embedded closed and cross ventilated courtyards achieve indoor thermal comfort and avoid excessive humidity in hot-humid climates [20]. Meanwhile, it was also recommended that as for nocturnal cooling, it needs a potential source by designing a staggered form courtyard with V-shaped roofs [20]. However, in this study, it is focused on the slope formed by building height difference for the room around the courtyard. Moreover, the effectivity of the advantage of the courtyard, shaping of courtyard should be developed more than the other building elements. As consequences, the flat roof is implemented for this analysis and it is expected to inform the building performance based on the various criteria.



COURTYARD RATIO (W : L)	A=WxL	L/W	L	A=WxL	W^2	COURTYARD SIZE	
						W	L
1 : 1	16	1	W	W^2	16.00	4.00	4.00
1 : 2	16	2	2W	$2W^2$	8.00	2.83	5.66
1 : 3	16	3	3W	$3W^2$	5.33	2.31	6.93
1 : 4	16	4	4W	$4W^2$	4.00	2.00	8.00
1 : 5	16	5	5W	$5W^2$	3.20	1.79	8.94
1 : 6	16	6	6W	$6W^2$	2.67	1.63	9.80
1 : 7	16	7	7W	$7W^2$	2.29	1.51	10.58
1 : 8	16	8	8W	$8W^2$	2.00	1.41	11.31
1 : 9	16	9	9W	$9W^2$	1.78	1.33	12.00
1 : 10	16	10	10W	$10W^2$	1.60	1.26	12.65

W = courtyard Width (m) , L = courtyard Length (m) , A = courtyard Area (m^2)

Figure 7. Courtyard ratio.

For the analysis of building slope height, Figure 8. shows that the 100% (or 45°) of building slope is the optimum model. It means that capability of that height in capturing the wind is very operative. However, it does not direct that higher slope percentage, higher wind acceleration (air velocity). As evidence that 25% height of slope is worse performance compared to lower one. It indicates that the air velocity at inlet setting and turbulence model area are not working for insignificant different height. Furthermore, the critical reference height should refer to human activities height (0-2 m). For this point, 25% slope height could not be able to accelerate higher air velocity. The turbulence might be affected by the wind direction, or how the connection between the outer flow organized turbulent forms and providing wind-escape device [21,22]. Furthermore, Figure 9. shows how the slope factor is not only accelerating the wind into the courtyard but also controlling unexpected high air velocity. At all for the minimum height of slope, 90% (or 40.5°), the object accommodates 12 m/s of velocity inlet, the rests or lower percentages are reducing but still maintaining the air rate. Designing significant difference between courtyard distance and surrounding room height might be easier than providing larger courtyard. By small open space created in the building and potentially translated back into site cluster context, the requirement for 90% will be logically tolerated by both of them. Despite reducing the essence of courtyard position, allowing air movement through horizontal ventilation by building aperture could be a wise choice in order to predict air flow turning back from leeward of building or changing role from the outlet to the inlet.

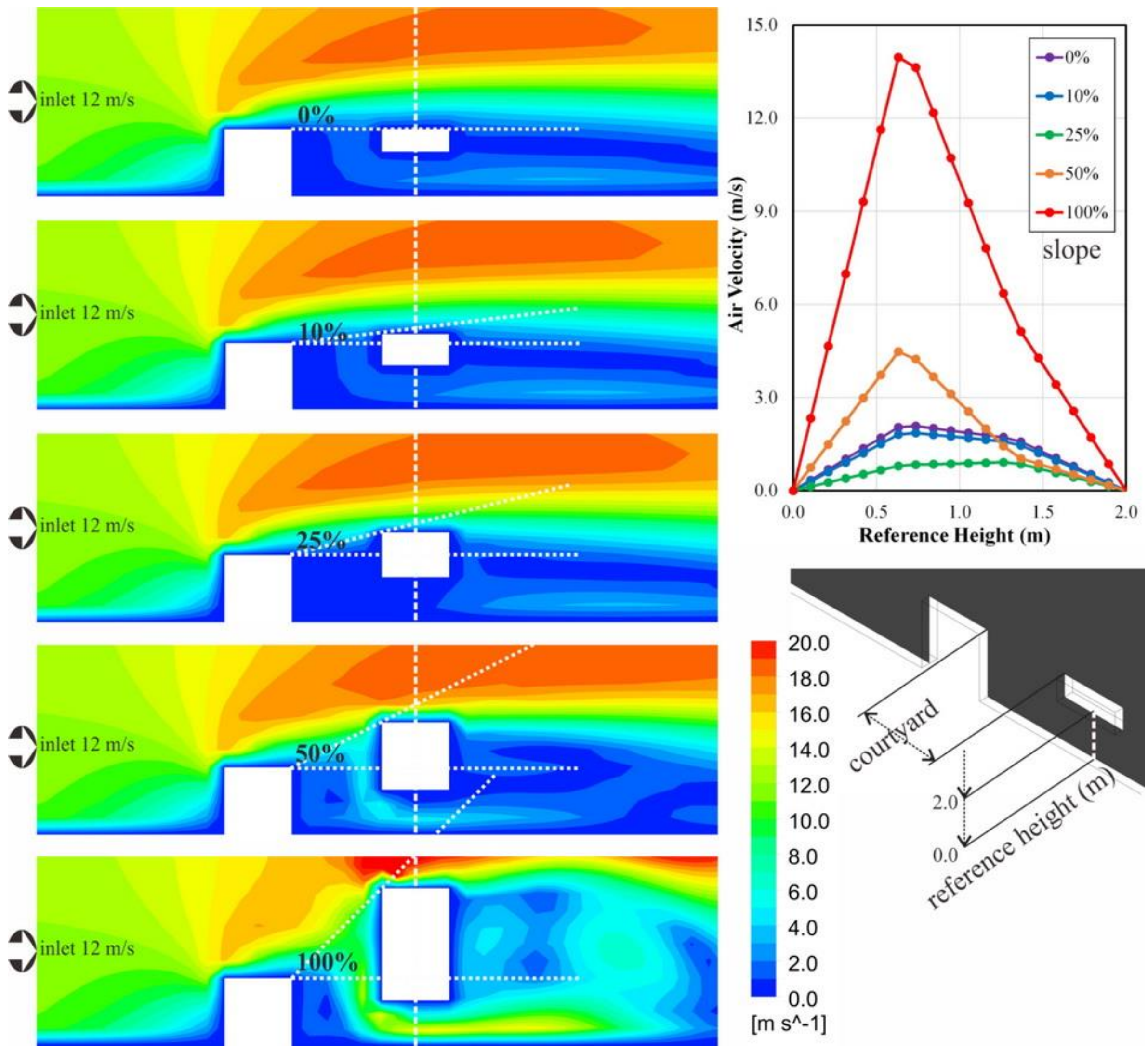


Figure 8. Slope factor.

As general analysis and found in many references, irregular building height instead of irregular site cluster or building layout might be considered as the best way for capturing air movement. By that strategy, all kind of courtyard layouts related to shape and ratio are accommodated. Moreover, the urban area usually does not provide the chance for wider open space like loop site cluster, but denser environment such as cul-de-sac with limited opened space, both the site and building performance are not quite different even better than the larger one. However, basically, it should be realized that air movement results in both heat gain and heat loss. Therefore, landscape treatment is recommended to make the transitional area for reducing air temperature for high air movement that promoted from site cluster into the building. Nevertheless, this study contributes much and deep information when the site cluster and building courtyard or atrium are absent of vegetation condition, opened area with optimization of the site and building shapes.

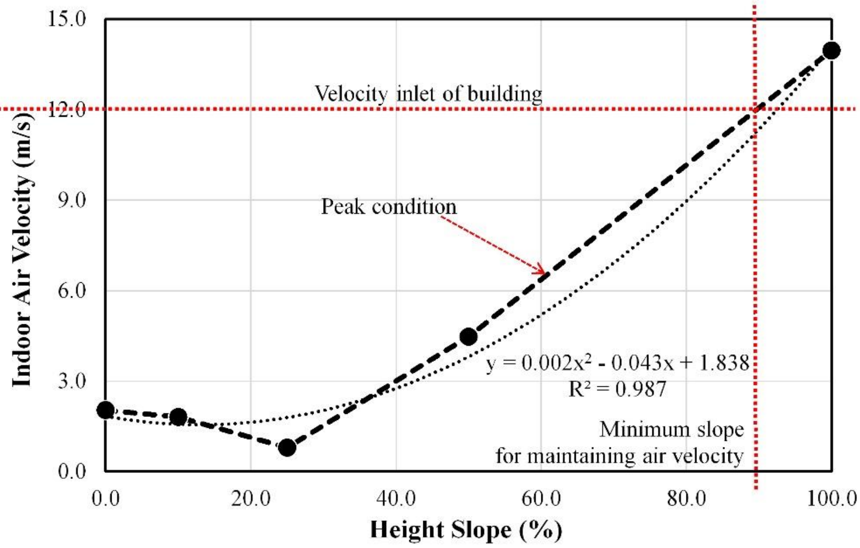


Figure 9. Height slope comparison for optimum intake.

4. Conclusions

Based on all discussion above, the air movement from the site could be translated for minimum at 50% to the building and indoor environment for all velocity inlet direction. The better wind direction comes to the site cluster from angled way (not perpendicular or parallel). Therefore, a significant increase in energy efficiency when the grid, the loop, and the cul-de-sac site clusters, with 25% of ground coverage, have connectivity with building courtyard compared to the atrium. Furthermore, energy savings is higher when using low thermal transmittance of transparent material and its lower area percentages for the courtyard walls. In general, it was more energy efficient option as part of a low rise building, while the courtyard building performs better with increasing building height. The slope factor is not only accelerating the wind into the courtyard, but also controlling unexpected high air velocity. At all for the minimum of 90% height of slope, all models accommodate 12 m/s of velocity inlet, the rests or lower percentage are reducing but still maintaining its performance. In line with Muhaisen, Ahsanullah and Van Zandt [9, 23], the shading of the internal envelope around the courtyard is significantly depended on the proportions, location latitude, and available climatic conditions. In general, as Safarova et al [24] suggestion related to a valid translation, it should consider building cultures and national economic conditions for the future studies to implement the findings to the local context.

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