Light, views and money:

Average perimeter distance and its relation to floor plate geometry

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Abstract

Environmental comfort in buildings with large floor plates is linked to the distance of workspaces to the building perimeter. This is particularly important with regard to natural light and views afforded by such arrangements. In order to measure or gauge the degree of this comfort, this paper introduces the index of average perimeter distance for any given floor plate. In definition, this index sums up distances to perimeter of all locations on a given floor plate. Locations found lying along polygons that are offsets of the plate perimeter have equal qualities associated with light and views, while the length of each offset polygon determines their precise number. In effect, the index is affected by the combination of the geometry and configuration of floor plate, atria and cores without a direct relation to the perimeter length. Therefore, by associating perimeter length with a considerable part of the building cost, it is possible to evaluate existing floor plates or design schemes with regards to improving natural light levels while reducing costs.

Introduction

The geometry of large floor plates is of paramount importance for the design of many building types, including offices. The complex relation between the shape of floor plate and the location of core and atria influences directly the proximity of workspaces to perimeter, thus the probability for natural light and views, which often results in hierarchical stratification of workspaces with regard to organization status of employees. In general, the environmental comfort of workspaces goes the opposite way with the building and maintenance cost of the edifice. In a practical sense, perimeter length is directly linked to building cost. Assuming that the cost of building one unit of indoor space does not depend upon the shape of the floor plate, while disregarding the nature of structural systems, modular building components and percentage of what can be covered with rectangular elements, we can relate building cost to perimeter length. At a glance, it seems that floor plates with long perimeters and concave shapes would produce shorter distances to perimeter for internal workspaces hence a greater comfort. However, a perimeter undulated in local scale with niches and turns will obviously have little improvement on the quality of workspaces, hence it is not clear whether the ratio between area and perimeter length can suffice to describe and evaluate the qualities of workspaces.

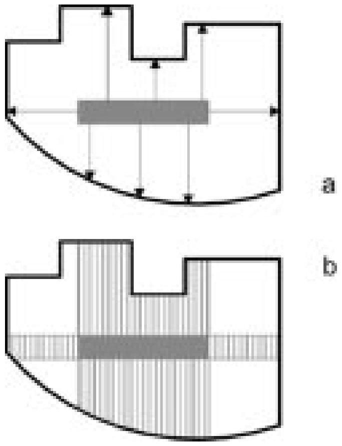

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Figure 1: Insufficiency of characterizing floor plates with the distance from core to perimeter only. (a) the distance changes due to the geometry of perimeter, (b) areas outside the shaded cross cannot be described

Previous studies on the geometry of floor plates have proposed descriptive measures such as distance from core to perimeter (Duffy, 1976), ratio between area and perimeter length, and the occurrence of high integration spots that can guide the generation of integrating circulation systems (Shpuza, 2001). The seminal study of Duffy on office buildings emphasizes the metric depth between perimeter and core for characterizing the main features of the shell. A small number of depths from perimeter to core can easily describe most of the workspace area in office buildings with rectangular floor plates. However, using such a measure is associated with two main issues. First, in cases where the depth between perimeter and core has more than one dimension, it is not easy to characterize floor plates due to the different percentages that these depths might cover. This is further complicated when the perimeter has a jagged or curvilinear shape, Figure 1a. Second, even in the case of rectangular regular floor plates, depths from perimeter to core account only for locations that fall inside the cross-like area between core and perimeter without covering four corner areas, Figure 1b. Instead of depth from core to perimeter, here I propose an index, which although metric, considers any shape of perimeter, and most importantly it regards all locations in the workspace area as contributors for evaluating the floor plate rather than just those falling inside the regions projected from the core.

How to reconcile two opposing trends of workspace comfort and building cost in the design of large floor plates? How to describe the complex relation between perimeter length, shape of floor plate, location of atria and core on one hand and proximity to light of workspaces on the other? To address these issues, I propose the measure of *average perimeter distance* that sums up the distance to perimeter of all location in a floor plate. This measure is used in a threefold manner. First, it describes the experiential quality of locations inside floor plates in regard to natural light and views that are directly linked to environmental comfort and often to the hierarchical stratification of office workspaces. Second, it characterizes the geometry of floor plate shapes in a far better way than the area to perimeter ratio; the latter is proved to have little significance for analyzing qualities of internal locations. Third, the measure pinpoints the relation between the shape of floor plate to the building cost. Without regard to internal partitions or corridors, it is suggested that the quality of floor plates as captured by the *average perimeter distance* influences directly the probability of any of its locations to have a given distance to perimeter and thus to afford natural light and views. In buildings with open plans and continuous conditions along the building skin such probability becomes a matter of fact. I suggest that the relation between the workspace area and the floor plate geometry involves not only perimeter length, but also something about its shape.

Average perimeter distance

The concept for the *average perimeter distance* is based on the fact that any two locations equidistant to the perimeter will have equal qualities that derive from proximity to perimeter, such as natural light and views provided that we assume a continuous distribution of locations inside the floor plate and continuous qualities of the building envelope, such as window openings. Such two locations are found lying along polygons that are offsets of perimeter. For equal dimensions of workspaces or locations, the length of each offset polygon shows the number of workplaces, while the step number of each offset polygon shows their metric depth to perimeter. I assume a continuous state of openings in the building skin disregarding the actual location and dimensions of windows and mullions as well as a continuous state of the workspace area disregarding the possible location of corridors and cubicles. I offset consecutively inwards from perimeter until all area to the core is covered and calculate the *average perimeter distance,* or else the potential distance to perimeter of any location in a given floor plate, by combining the lengths of offset polygons with their depth from perimeter.

A sample of five speculative office buildings designed by the Atlanta-based architectural firm Cooper Carry Inc. *Centura Blvd., 1825 Century Center, City View I, Glenlake Bldg. 1, Huntcrest II* share common features of the rectangular shell, including floor plate area, core area, and the two main perimeter to core depths. A simplified version that incorporates these qualities, which I term *r-1*, has a rectangular floor plate of 225'x125' and a symmetrically positioned core of 105'x25'. I use it to describe the method of calculating the *adp* and later as a *prototype* for generating a theoretical sample. I assume a square shaped workspace with a size of 12'6" and I offset inwards from the perimeter consecutively with an offset distance *od* of 12'6". As I shall show later, the size of the workspace and the size of *od* do not have any effect on the overall calculation. In the first offset polygon with a length of 600' there are 600/12'6"=48 potential workplaces that are 1 step away from perimeter, Figure 2; in the second offset with a length of 500' there are 40 workspaces 2 steps away from perimeter; in the third one with a length of 400 there are 32 workspaces 3 steps away; and in the last one with a length of 300 there are 24 workspaces 4 steps away.

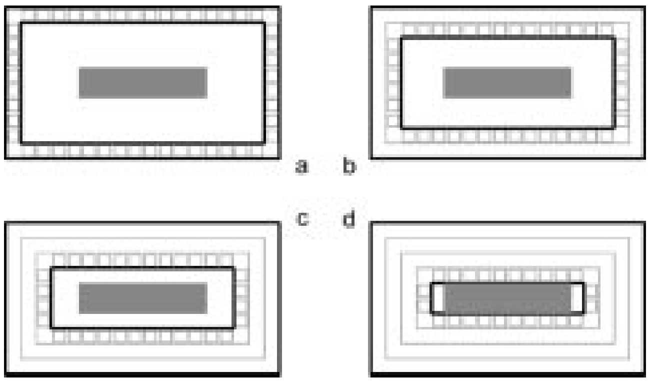

Figure 2: The concept of calculating the apd. (a) 48 workspaces alongside the 1st offset line shown in bold, (b) 40 workspaces along the 2nd offset line, (c) 32 workspaces located in the 3rd, (d) 24 workspaces located 4 steps deep

Each workspace contributes its depth to the overall depth: 48x1 + 40x2 + 32x3 + 24x4. If we divide the total of these products 320 with the number of all workspaces 144, we get an average distance of all potential workspaces from the perimeter of 320/144=2.22. This shows a step or unit distance that when multiplied with *od* of 12’6” gives the real average depth of 27’6”. Hence, I calculate the *average perimeter distance apd* with the formula below where *po* is the length of perimeter offsets, *od* is the offset distance, and *d* is the step depth from perimeter of an offset polyline.

unit average distance
$$uapd = \frac{\sum_i po_i * d_i}{\sum_i po_i} \qquad (1)$$

average perimeter distance
$$apd = uapd * od \qquad (2)$$

The measure is little affected by the offset step distance and converges for finer offset steps *od* as it is shown by calculating the *average perimeter distance* three times with *od* of 7’6”, 3’9” and 1’10 1/2” for the floor plate *c8-1*, Table 1. It is also possible to automate the calculation of the measure by summing up distances to perimeter of a large number of randomly placed positions in the workspace area.

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Table 1: Convergence of average perimeter distance for finer offset steps

od	7’6”	3’9”	1’10 1/2”
uapd	2.34	4.49	8.97
apd	17.57’	16.84’	16.82’

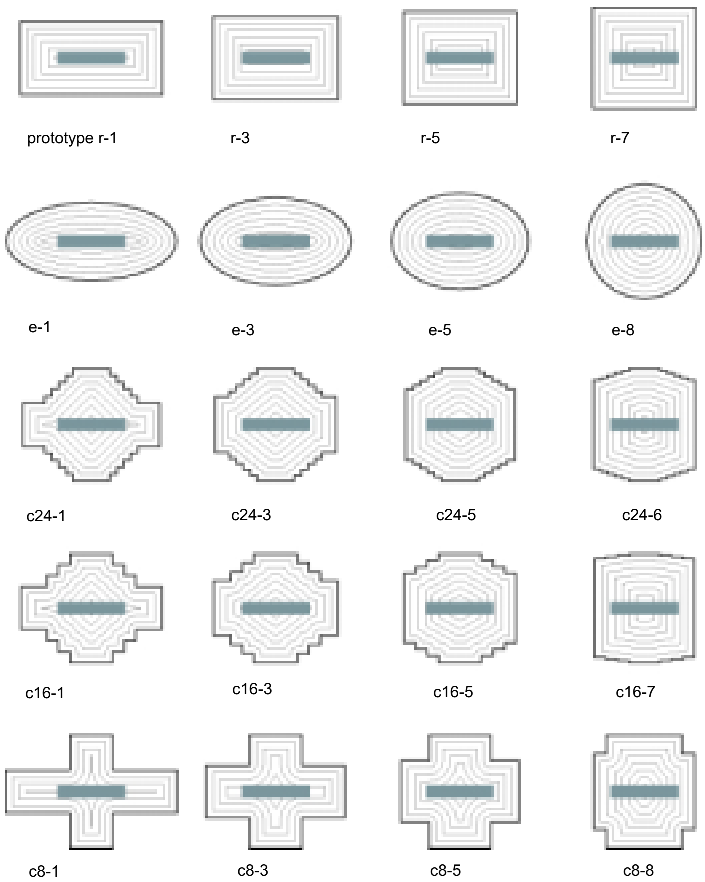


Figure 3: Calculation of the apd index for families of theoretical floor plates derived from the prototype. Only 20 out of 36 calculated examples have been displayed. For clarity, only 1 out of 3 offset polygons built with offset distance at 3”9” has been shown.

Relation of average perimeter distance to perimeter length

Starting with the *prototype r-1*, I generate a theoretical sample of 36 floor plates by stretching the perimeter while preserving the same total area and conforming to distances allowed by fire regulations. I stretch two sides of *r-1* inward and outward with comparatively equal increments from case to case while preserving the original area of 27600 sq’ and keeping the core intact to produce a family of rectangular floor plates *r-1* to *r-7*. Starting from an elliptical floor plate with area equal to the *prototype*, I stretch until the perfect circle is reached to produce a family from *e-1* to *e-8*. Similarly, I construct three more families named *c8* for the cross with 8 corners, *c16* for the cross with 16 corners, and *c24* for the cross with 24 corners, Figure 3, with members which shapes range from elongated to most compact. The theoretical floor plates share the same area, same cores, and differ only in the geometry of perimeter, its length and number of corners.

I offset inwards from perimeter with an offset distance *od* of 3’9”, which is half of a common 7’5” cubicle, until all the workspace area has been covered by offset lines. The results for the *average perimeter distance apd* and perimeter length for all of them are shown in Table 2 and Table 3 and their relationship is expressed in Chart 1.

Table 2: Average perimeter distance for families of theoretical shapes measured in feet

	1	2	3	4	5	6	7	8
r	23.464	24.169	24.698	25.343	25.793	26.258	26.558	
e	26.134	26.19	27.203	27.701	28.14	28.526	29.018	29.584
c24	23.43	23.625	25.62	26.535	27.424	27.803		
c16	22.451	23.52	24.57	25.444	26.314	26.479	27.158	
c8	16.841	18.248	19.736	21.116	22.301	23.978	25.328	26.64

Table 3: Perimeter length for families of theoretical shapes measured in feet

	1	2	3	4	5	6	7	8
r	700	687	678	673	668	666	664	
e	656	635	621	611	602	596	591	589
c24	814	784	762	744	722	698		
c16	812	782	760	740	720	700	680	
c8	926	869	821	783	753	729	711	697

The common sense prediction about the relation between *adp* and perimeter length would be that the more compact shapes would produce longer *average perimeter distance*. Therefore, the lines of five families stretch diagonally in the chart from the circle *e-8* in the lower right corner to the cross-shaped *c8-1* in the upper left corner. As the perimeter becomes longer due to the making of shape more concave, *average perimeter distance* tends to get smaller.

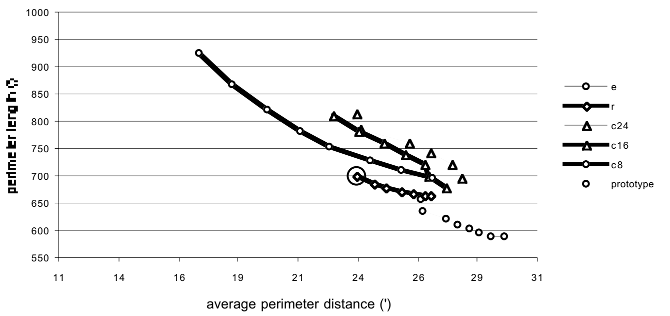


Chart 1: Relation between average perimeter distance and perimeter length for theoretical floor plates derived from the prototype. Lines connect members of 5 families of floor plates.

It is important to note that equal perimeter lengths for certain shapes produce different *average perimeter distances*. As we move horizontally in the chart while keeping the perimeter length constant, we cross curves of different families. For instance, a length of 700’ can result in *average perimeter distance* as varied as 26.5’ to 27.8’ from *r-1* to *c24-6*. Similarly, different perimeter lengths can produce the same *average perimeter distance* as can be seen while crossing curves of different families while moving vertically through the chart.

Given the fact that the area has been kept constant throughout the sample, the variation of perimeter length shows at the same time the variation of the ratio between area and perimeter length. Often such a ratio is used to define the compactness of a shape. For instance, a normal cross perimeter *c8-5* can have almost the same perimeter length of 753' as a cross with 24 corners *c24-4* with perimeter of 744', therefore the same compactness if it is defined as a ratio between area to perimeter length. However, as shown by the scatter chart, the *average perimeter distance* for these two cases differs from 22.3' to 26.5'.

The length of perimeter can be attributed to its features in both local and global scale. Both of them affect the overall length. Nevertheless, with regard to this discussion, local features in the geometry of perimeter have less impact on the qualities of indoor space in comparison to global ones. Small turns, corners and niches in the building skin, which increase perimeter length, do not have a major effect in the qualities of spaces inside the building. On the contrary, what matters is the topology of the shape in the larger scale. While accepting this, it is possible to suggest that perimeter length cannot be used as a reliable measure for analyzing qualities of indoor spaces. Nor can compactness be defined realistically as a ratio between perimeter length and area. In contrast, *average perimeter distance* could be associated better with the idea we have about compactness addressing directly real qualities of workspaces.

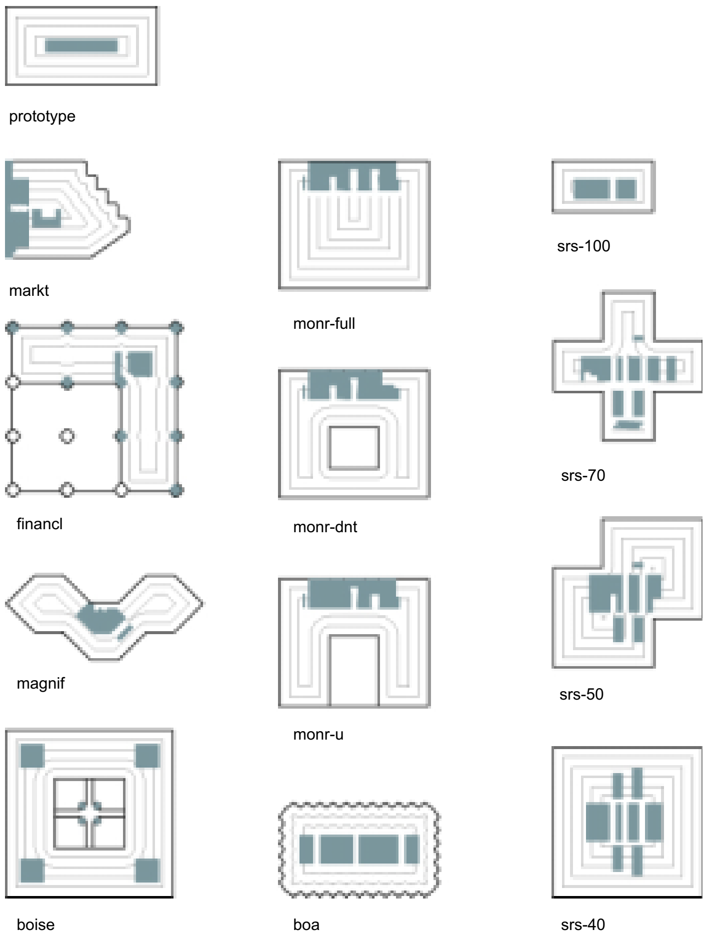
Considering that the cost of building one unit of indoor area is not affected by the geometry of the floor plate, we can attribute a considerable share of the overall building expenditure to the cost of the enveloping skin of the building, thus to perimeter length. Under the light of the earlier discussion, the *average perimeter distance* could be used to evaluate the quality of workspaces in relation to building cost. For instance, the costs of building *c8-5* or *c24-4* are comparable to each other, but the quality of indoor spaces, as measured by the *average perimeter distance* index, is potentially higher in the case of *c8-5*. The *apd* can thus be used to evaluate how well the geometry of a floor plate performs with regard to both building cost and the quality of natural light and views.

Evaluation of floor plates using the *Average Perimeter Distance* Index

What is the best geometry of floor plate that minimizes the distance to perimeter while minimizing the building cost for a certain built area? I use the *apd* index to evaluate buildings with regard to maximizing the proximity to natural light and views and minimizing the building cost of the skin. For this, I analyze a sample of seven office buildings designed by the US architects firm SOM for corporate and speculative clients: *444 Market Street (markt), Fourth Financial Center (financl),* *One Magnificent Mile (magnif), 33 West Monroe Street (monr-full) (monr-dnt) (monr-u), Bank of America World Headquarters (boa), Boise Cascade Home Office (boise), and Sears Tower (srs-40) (srs-50) (srs-70) (srs-100),* Figure 4. Two of the buildings have different floor plates in various heights, thus the sample comprises twelve office floor plates. For a fair comparison, measurements for each floor plate have been modified with a *scaling factor* that reconciles its floor plate areas with the built area of the *prototype* at 27600 sq'.

$$scaling.factor_i = \sqrt{\frac{area_{prototype}}{area_i}} \qquad (3)$$

Figure 4. Calculation of apd index for floor plates of the prototype and offices designed by SOM. For clarity, only 1 out of 3 offset polygons built with offset distance at 3'9" has been shown



For the analysis, I use the BOMA standards to define the location of perimeter and consider its properties continuous by disregarding columns and mullions and interrupting only when parts of the core touch the skin. Table 4 shows values of *adp* and perimeter length modified with respective *scaling factors*.

Table 4: Modified apd and perimeter length for 12 office building floor plates measured in feet

	prototyp	markt	financl	magnif	monr-full	monr-dnt	monr-u	boa	boise	srs-40	srs-50	srs-70	srs-100
sc-apd	23.464	26.972	16.979	16.805	28.981	13.67	14.645	14.037	11.963	20.972	19.248	12.901	16.314
sc-per	700	691	987	825	666	705	736	796	731	665	751	882	703

I superimpose these results onto the previous chart of the theoretical floor plates to enable comparisons both among real floor plates and among theoretical shapes derived from the *prototype,* Chart 2. With consideration to short perimeter length, thus low building cost, and low *average perimeter distance*, thus high potential of workplaces being close to windows, the region in the lower left corner would include the favorite exemplars. Due to a combination of factors such as the overall shape of floor plate, the size and position of atria and core components, most of the cases fall in the lower left half of the chart having in general shorter perimeter lengths and *average perimeter distance* than the *prototype* and its variations that occupy a poor position in the upper right border of the scatter. Only three cases fall above the diagonal defined by the prototype variations: *monr-full*, *market* due to having a core that abuts the perimeter, and *financl* due to an extremely stretched shape of the floor plate.

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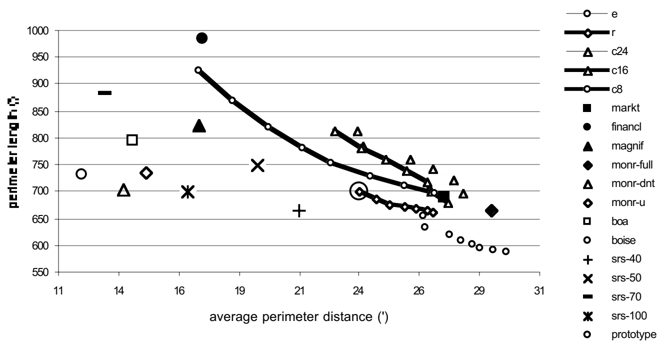

Chart 2. Relation between average perimeter distance and perimeter length for a sample of office buildings designed by SOM. Twelve cases have been superimposed on the chart 1 of theoretical floor plates

Bearing in a mind the criterion of achieving the shortest distance to perimeter for the shortest perimeter length thus lowest building cost, the above examples can be ranked using the product of relative *average perimeter distance* with relative perimeter length from best to poor. Table 5 confirms the earlier observation of *monroe-full*, *market*, *financial* and *prototype* having the lowest performance. The best cases are *boise*, *monroe-donut* and *monroe-u* confirming the benefits of atria. In a second facet, the chart enables to quantify improvements in *average perimeter distance* index. For instance, for the same perimeter length, thus the same expenditure, using the donut shaped floor plate like *monr-donut* rather than the rectangular *srs-100* will potentially improve the quality of workspaces as measured by the *average perimeter distance* at the amount of 19%.

Table 5: Ascending order by product of relative perimeter length with relative average perimeterdistance

	boise	monr-dnt	monr-u	boa	srs-70	srs-100	magnif	srs-40	srs-50	prototyp	financl	markt	monr-full
product	8748	9638	10785	11170	11384	11462	13857	13937	14449	16425	16765	18648	19314

Conclusions

The design of floor plates for office buildings takes into account a variety of determinants including the constraints of site, budgetary considerations, organizational profile of client, elevation and tectonics, fire regulations and furniture standards. In any given scenario, the resulting geometry of the floor plate and configurations of core and atria directly determine the potential of individual workplaces to be in proximity to the building perimeter thus having access to natural light and views. This paper proposes a method to characterize floor plates through the index of *average perimeter distance* that considers the average value of the distance to perimeter of the entirety of the possible workspaces on the floor plate. The new index is based on the fact that locations that lie on polygons that are offsets of the perimeter potentially share the same levels of natural illumination, while the length of the polygons determines their number. Significantly, however, it has been discovered that there is no direct relationship between the proposed measure and perimeter length. While perimeter length is influenced by features of the floor plate shape -at the global scale of atria and wings, and at the local scale of small indents and corners - it is the global features that have an impact on qualities of indoor spaces in comparison to local ones. It is suggested that perimeter length cannot be used reliably to analyze qualities of floor plates nor can compactness be defined realistically as a ratio between perimeter length and area. Rather, it is the *average perimeter distance* that can best describe the idea we have about the compactness of shape of floor plate, while directly addressing real qualities of indoor spaces. Most importantly, this particular measure pinpoints ways of quantifying the relation between two opposing trends - the comfort of workplaces with regard to natural light and views, and the financial aspect of building cost and maintenance of the skin. This is achieved through investigating the variance of the *average perimeter distance* and length of perimeter for theoretical and real cases after reconciling the size of their areas, therefore giving useful insight for improving qualities of indoor spaces for design proposal schemes while reducing cost.

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