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Thermal Behavior of Double Skin Buildings

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Abstract
Most energy losses will be made by skins, so offering optimized solution helps in energy saving. Glass as outdoor skin is considered the weakest part of building from energy loss viewpoint. Therefore a solution should be found to minimize energy losses in building meanwhile providing natural light. Double skin facades as a suitable solution for achieving this goal are considerable. Buildings with double skin façade can have better function than normal skin façade. So, this article is focused on thermal function of different forms of these buildings. This article by studying behavior of different forms intends to analyze the effect of general form of building on thermal function of double skin façade and attempt to categorized different situations so that recognize situations and conditions which may tangle classic behavior of double skin facades. Research method is quasi-experimental. Statistical population includes studying features of 10 building forms. The result of this analytical approach indicates classic function of double skins changes with change of general form of building.
Keywords: energy saving, double skin facades, thermal behavior, building forms

1. Introduction

There are three main thermal sources in a normal building: Internal heat gain, building envelope heat gain, fresh air heat gain. One of thermal loads in building envelope heat gain is heat transfer by glass of window of outdoor wall of building. Glass as outdoor skin is considered the weakest part of building from energy loss viewpoint and cannot provide residents' welfare due to quick warming of indoor environment in summer and quick cooling of room in winter. On the other hand, it causes increasing sound pollution in building. So, the function of these buildings isn't compatible with policies of building industry in decreasing energy. So, a solution should be found to minimize energy loss in buildings meanwhile providing natural light.

Double skin facades as a suitable solution for achieving this goal are considerable. This façade as a solution for confronting with first energy crisis in decade 70 BC was firstly built in America and Europe and then was promoted in most countries. In recent years, concept and usage of double skin facades have been attracted the attention designers and researchers. Recently by increasing economic development, new buildings with double skin facades in regions with hot summer and cold winter will be used (Zhou, ChEN, 2010, 1322) which these regions with this climatic features (hot and dry) involved great range of Iran. Generally in double skin facades, airflow will be created on buoyancy due to temperature difference which happens inside and outdoor of cavity. Usually in through cavities, a simple indoor valve is settled in bottom and a simple outdoor valve on top. Thus, cool air enters from indoor valve in bottom of façade and hot air exits from outdoor valve on top of building. The hypothesis of this research is anticipated classic behavior for double skin skins may change with change of general form of building. This article attempts to find response for following questions:

- What is the effect of general form of building on classic behavior of double skin?
- Which situations and conditions can tangle classic behavior of double skin?

Along with said matters, it should be added that cost of double skin is more than normal facades but have advantages which accounts for cost increase of additional façade. Important factors like climate, construction type, construction cost, energy price and energy saving affect on economic feasibility of double skin façade and results of payback period have been obtained in 4-7 year range (Stribling, Stigge)

2. Research history

Different studies have been done on buildings with double skin which are going to be reviewed as following. Jiru and Haghighat have modeled a building with double skin and have done parametric studies for distinguishing the effect of height, flow rate and presence of venation blinds on inlet-outlet temperature difference.

Function of energy of double skin facades with different sizes of entrance and exit, colors and slat angle and different situations of shading blinds have been studied by Gratia and De Herde, Hanby et al. and Eicker and et al.

Wong et al have analyzed the effect of different gap sizes on indoor thermal comfort condition in building by naturally ventilated double skin façade (Wong et al, 2008, 1941-1945)

Thermal function of double skin facades with plants which are in air cavity has been studied by Stec et al (Stec et al. 2005, 419-427).

On the other hand, lots of studies have been done on building form and its relation with solar energy like:

Ling et al studied the effect of geometrical shape and building orientation in minimizing usage of solar insulator in high buildings in sticky air (Ling et al, 2007, 27-38).

Behsh studied the effect of building form as a choice for promoting thermal welfare in building in climatic conditions of Damascus (Behsh 2002, 759-766).

This article has studied the relation of morphological characteristics of buildings and climate parameters for improving thermal function of buildings in hot and dry air (Daoud et al, 2009).

AlAnzi et al have studied the effect of building form on thermal function of office buildings in Kuwait (AlAnzi et al, 2008, 822-828).

Hachem et al have studied effects of geometrical form on solar potential for electricity production of residential units (Hachem et al, 2011, 1864-1877).

2.1. Double skin characteristics

Generally, double skin façade is a system which is made to two glass layers. Outdoor glass is usually single hardened one and outdoor façade can be completely glass. Indoor glass is an insulated double one (solar glasses can be used) and may not be completely glass. Usually, double glazing material as inner pane and single glazing material as outdoor pane can be used in typical double skin façade system.

Air cavity between two glasses can be ventilated completely naturally or mechanically. Apart from ventilation type in cavity, air origin and destination can be different which depend on climatic conditions, kind of usage, the situation of building, office hours and strategy. The width of cavity is variable regarding lots of factors. The width of cavity is effective when the façade is as protector. Indoor windows can be opened by user. This method may allow natural ventilation. In addition, automatic setting of shadows can be entirely done among cavity.

Double skin façade classification based on middle cavity division is as follows:

Computational Fluid Dynamic (CFD), Box window type, haft box type, Corridor façade, Multi story.

Generally, key parameters in designing double skin facades are: depth of cavity (1 inch to 4-5 feet), width of cavity, height of cavity and situation of openers, structure of valves, kind of cavity, type of cavity, shadowing equipments (using plant, movable shadows) (Pappas, Zhai, 2008, 467) and finally thermal function of double skin facades can be distinguished by four indexes: the speed of airflow by cavity valves, moderate temperature of cavity, maximum temperature of cavity, heat transfer by indoor glass (Pappas, Zhai, 2008, 467).

3. Methodology

3.1. Research framework

In this paper, some double skin characteristics are stated and then general volume of buildings was divided in 5 groups and each group was considered full and empty by studying different forms of buildings. Then, the effect of each condition was analyzed on classic behavior of double skins and the conditions are stated which may tangle classic behavior of double skins.

3.2. Research goals

Analysis of effect of general form of building on classic behavior of double skins

Recognition of situations and conditions which may tangle classic behavior of double skins

3.3. Research method

Theory testing is the main scope of this research therefore it is to examine competency of a famous theory which called "classic thermal behavior" in buildings. Thus quasi- experimental research strategy has been adopted rather than experimental strategies. Descriptive – analytical research method as well as comparative techniques adopted to analyses thermal behavior of selected forms. Samples designed regarding to platonic forms which may be considered as basic forms in architecture.

3.4. Research goals

Wind speed and direction are parameters which definitely affect on the way of airflow in skin. Wind speed causes surface cooling of façade and that façade has different conditions when wind doesn't blow. On the other hand, the direction which wind blows is also important. For example, if wind blows to façade which is hot façade of building and causes the façade will be the coldest façade, the conditions will be changed. Furthermore, local airflow is also effective which will be discussed in future researches.

3.5. Typology – Case building and modeling

General volumes of building are divided to 5 forms: 1. Cube, 2. Cylinder, 3. Pyramid, 4. Cone, 5. Hemisphere which each group is made of two full and two empty forms and consequently, 10 forms will be studied. In table 1-1 for each form, sample of building with double skin is stated.

Table 1. Examples of the 10 case studies

Hemisphere	**Cone**	**Pyramid**	**Cylinder**	**Cube**	**For**
Dome home, Pensacola Beach	Swiss Re	One Angel Square	Office For KfW Bankengruppe	The Telus Headquarters	**Full**
Reichstag Dome	Wheelock Place	One Angel Square	The Ponte Building	Print Media Academy	**Hollow**

4. Classic behavior

In double skin facades, suitable radiation can be prepared required heat energy of cavity for decreasing thermal exchange between indoor and outdoor room in winter. Also, this radiation can provide suitable buoyancy for moving air of cavity on top for ventilating indoor air (by available valves in indoor skin).

Generally in double skin facades, airflow will be created on buoyancy due to thermal difference which is inside and outside cavity (this causes pressure difference in cavity). Usually in through cavities, a simple entrance valve in bottom and a simple exit valve is on top. So, cold air enters from entrance valve in bottom of façade and hot air exits from exit valve on top of building. In some cases, regarding regional conditions, various entrance valves are settled in outdoor façade. This increases airflow in cavity and function of natural ventilation.

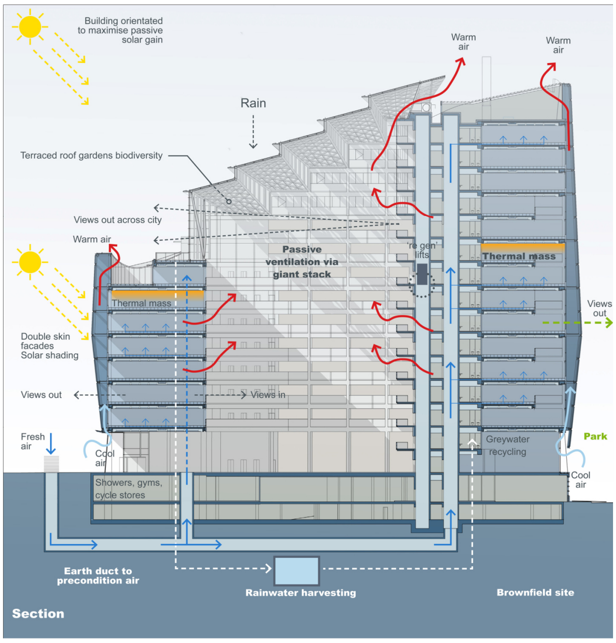


Figure 1. Classic thermal behavior, one angel square, Manchester, United Kingdom, 2012, (http://www.archdaily.com/337430/1-angel-square-3d-reid) (2014-08-12)

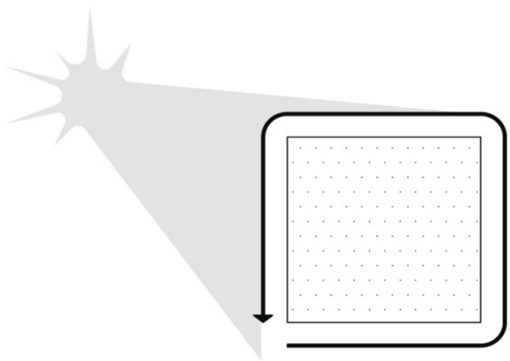
5. Discussion

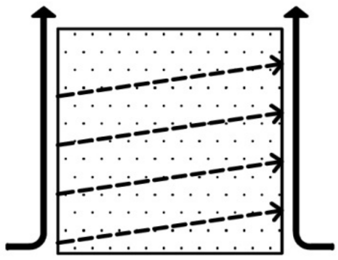
In this part, it's intended that the effect of different forms on classic behavior of double skin will be studied and analyzed and then, conditions which may tangle in classic behavior of double skin will be recognized. In analyzing classic behavior of different forms, cube is made of four parts from orientation to sun. the hottest façade which receives most solar energy, hot façade which receives less energy due to different angle, cold façade which receives less solar energy and finally the coldest façade which is in opposite of hottest façade and receive less solar energy.

1. The most important reasons which cause full cube shows classic behavior is considerable in following parts:

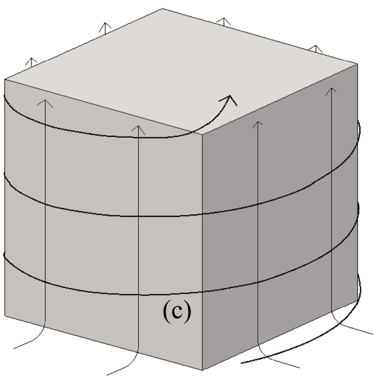
Difference of place of entrance of cold airflow and exit of hot air: as the coldest façade has more role in entering cold air and hottest façade in exiting hot air, this difference causes moving airflow to hotter façade and a circular flow will be formed around cubic facades.

Incompatibility between vertical function against horizontal function: vertical elongation of a cube causes intensifying cold flow to hot in vertical route and horizontal elongation in horizontal route and thus, in conditions which these two flows find similar pressure (in square cube form), their overlap in function of each other will be maximized.





(a) (b)



(c)

Figure 2. Analysis of the thermal behavior of full cube (a) Plan, (b) Section, (c) Three-dimensional volume.

2. In analyzing classic behavior of empty cube in addition to considered reasons in full cube, other reasons are considerable which avoid proper function of classic behavior which the most important ones are stated in following parts:

More plurality of facades with different facades and angles: in empty cube due to more sides and different angles, reception of solar energy is different in various sides. So, in addition to four outdoor sides in full cube, there are four indoor sides with those thermal degrees. So, in addition to vertical flow and circular flow, two flows from indoor facades will be created to outdoor facades and two flows from outdoor facades to indoor facades. So, in two hotter outdoor facades, there’s an overlap with classic vertical flows and will cause intensifying vertical flow in their indoor facades. On the other hand, in two outdoor cold and colder facades we see intensifying vertical flow and in their indoor facades, we see overlap with classic vertical flow.

Triangular abnormality and configuration: In analyzing classic behavior in pyramid form with triangle base, pyramid can be divided into three main parts based on the orientation of its façade against sun. The direction which receives most light, hottest façade; the direction which receives less light, coldest façade; and middle direction which have moderate temperature.

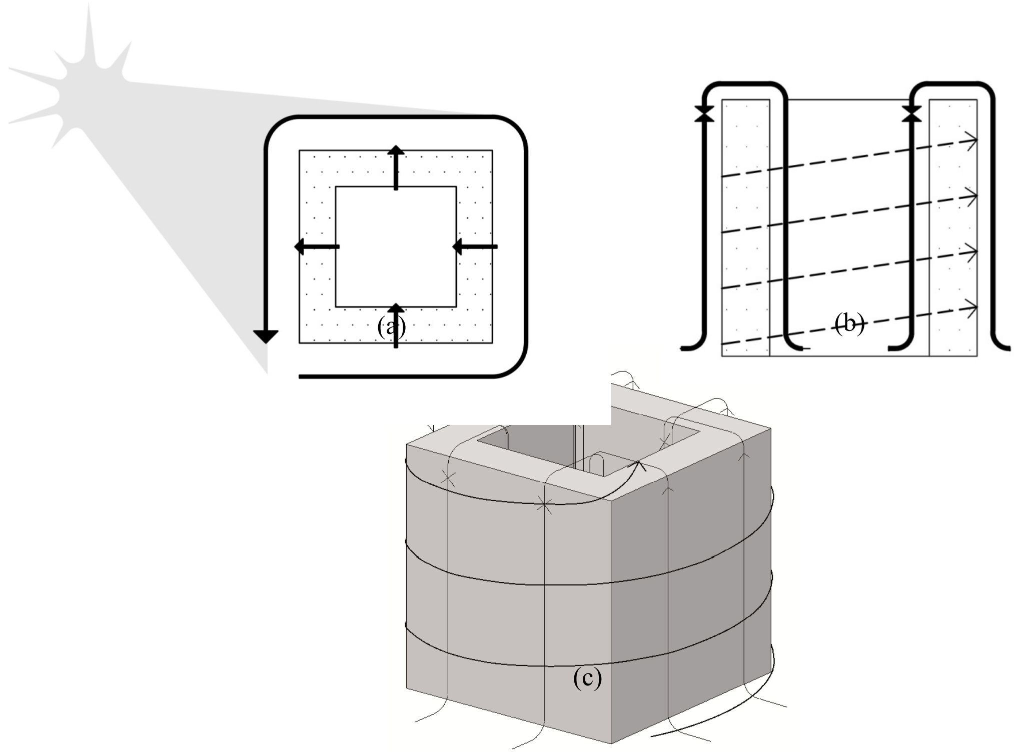


Figure 3. Analysis of the thermal behavior of hollow cube (a) Plan, (b) Section, (c) Three-dimensional volume.

3. Most important reasons which protect full pyramid showing classic behavior is considerable in following parts:
The difference of entrance of cold airflow and exit of hot airflow: cold air will enter from three main directions in bottom. So, coldest façade has more roles in entering cold air. Conversely, hottest façade has more roles in exiting hot air. This difference causes creating a circular flow as a result of disorder in classic behavior.
Incompatibility between vertical function against horizontal function: vertical elongation of a pyramid encourages moving cold to hot flow in vertical route and horizontal elongation of a pyramid encourages moving cold to hot flow in horizontal route. So, in conditions which these two flows find similar pressure, their overlap in function of each other will be maximized.

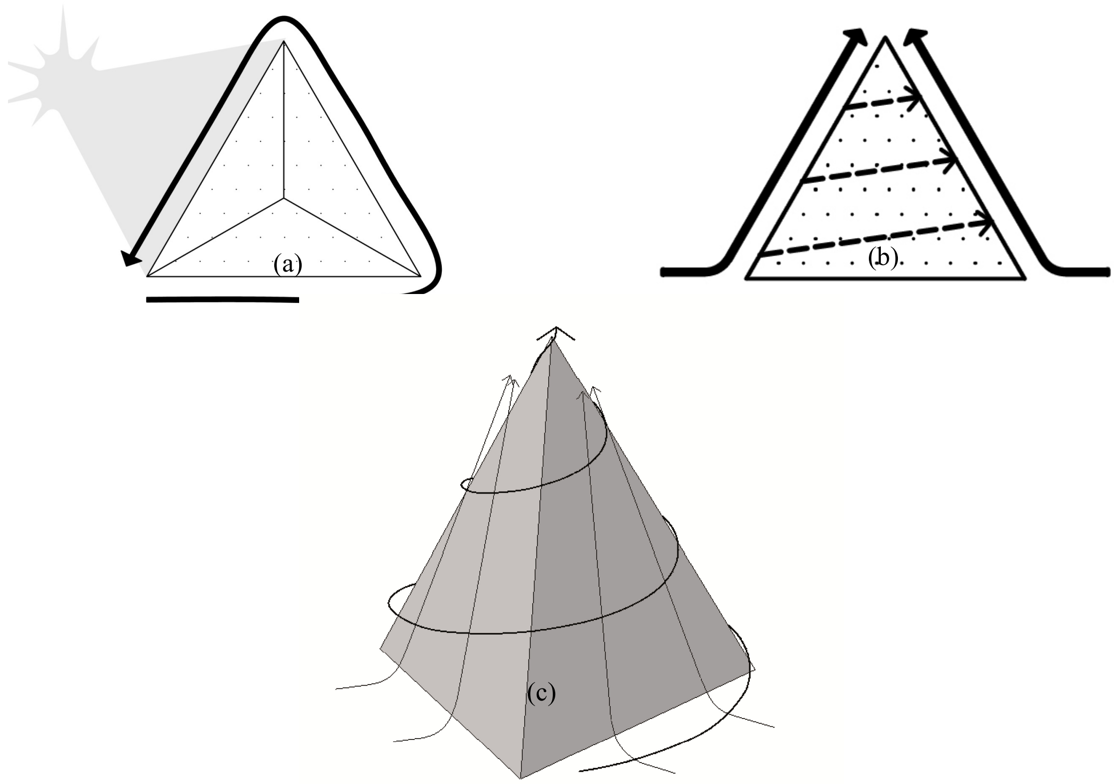


Figure 4. Analysis of the thermal behavior of full pyramid (a) Plan, (b) Section, (c) Three-dimensional volume.

4. In studying classic behavior, empty pyramid in addition to considered conditions in full pyramid, there are other reasons which avoid function of classic behavior which is considerable in following parts:
The number of more facades with different angle and temperature: in empty pyramid due to more facades and different angles, reception of solar energy of different facades is various. So, in addition to three outdoor facades with different temperatures in full pyramid, there are three indoor façade, inward façade against hottest will be coldest façade, indoor façade against coldest one will be hottest indoor façade while opposite façade of outdoor façade with moderate temperature will be middle façade. In addition to circular flow and classic vertical flow, a flow will be created from coldest façade to their indoor façade and a flow from coldest indoor façade to its outdoor façade which is hottest one. About façade with moderate temperature, opposite indoor façade is also with moderate temperature and has no effect in natural function of airflow. So, in hottest outdoor façade, there's the possibility of overlap with classic vertical flow and causes intensifying vertical movement in its opposite indoor façade. On the other hand, this airflow causes intensifying vertical movement in coldest outdoor façade and overlap with vertical movement in its indoor façade.

This is different about cylinder. Cylinder will be divided to three parts based on circular sectors. 1. Hot part: almost equal to 120 degree sectors opposite sun, 2. Moderate part: equal to two 60 degree sectors along two hot sector and cold sector, 3. Cold part: almost equal to a 60 degree sector opposite sunlight

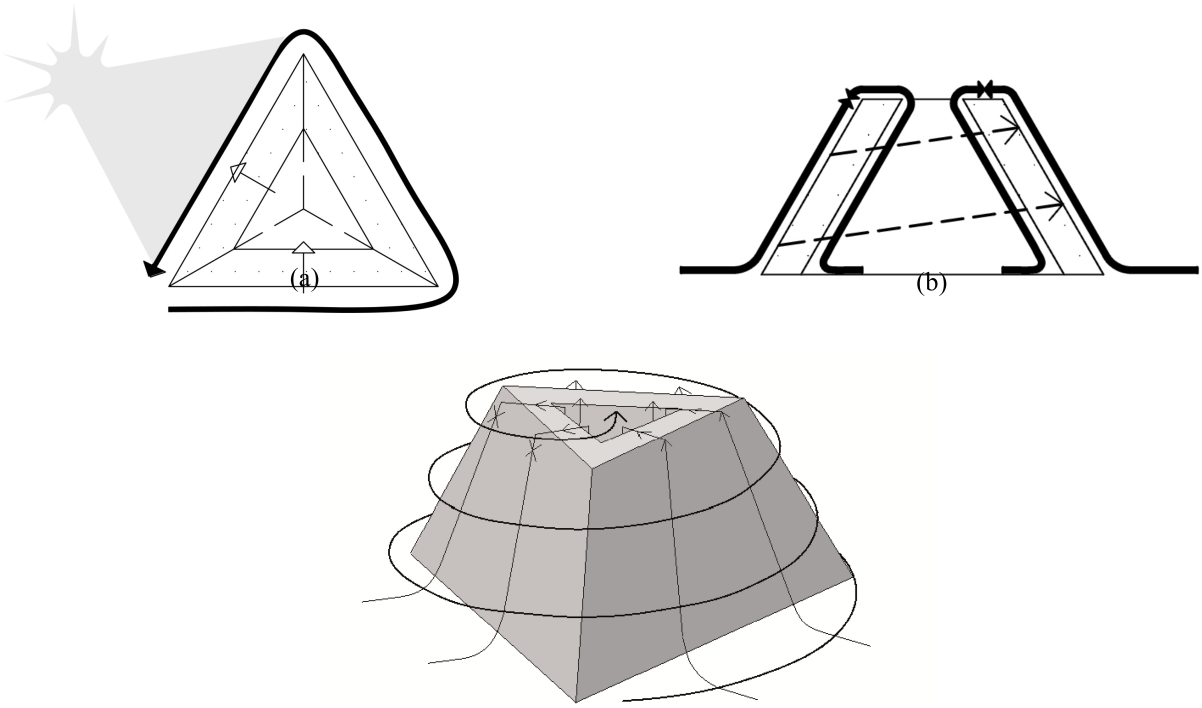


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Figure 5. Analysis of the thermal behavior of hollow pyramid (a) Plan, (b) Section, (c) Three-dimensional volume.

5. Most important reasons which protect full cylinder showing classic behavior is considerable in following parts:
Forming two horizontal flows along cylinder: from cold façade, two flows (from left or west and right or east) move to hot façade. These two flows interfere in middle of hot façade and decrease the force of each other. So, there's a conflict with classic behavior.
Incompatibility between horizontal and vertical airflows: horizontal flow in cylinder is a two-sided flow while vertical flow is a coherent and one sided one. Interfere of these two flows causes creating a movement in cold cylindered side and avoid emerging a classic behavior.

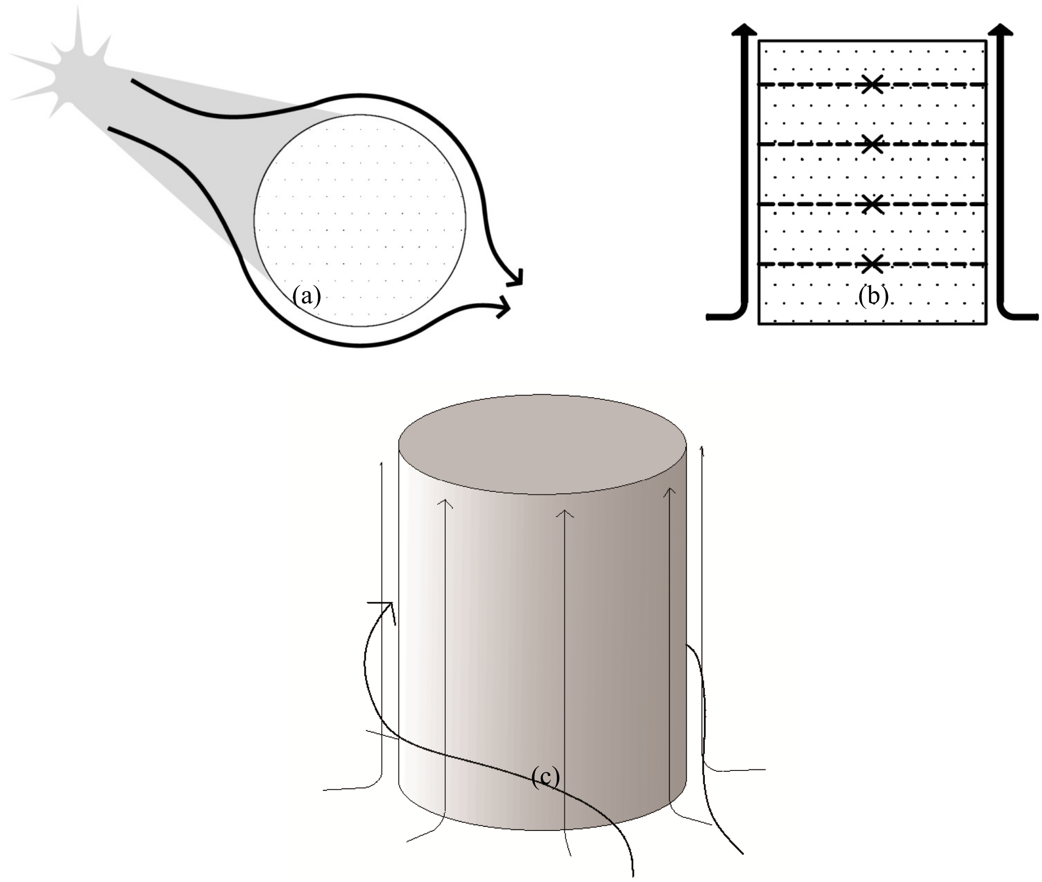

Figure 6. Analysis of the thermal behavior of full cylinder (a) Plan, (b) Section, (c) Three-dimensional volume.

6. In analyzing classic behavior of empty cylinders in addition to considered characteristics in full cylinders, other conditions are considerable:
More parts and different directions: in empty cylinder in addition to three outdoor parts in full cylinder, there are three indoor parts. So, opposite hot outdoor part in indoor levels, cold part with receiving less light in the opposite of cold outdoor part in indoor levels, hot part with receiving most light and finally in the opposite of moderate part in middle, there’s moderate part with moderate temperature. In analyzing empty cylinder this is considerable in addition to horizontal flow along cylinder and vertical flow, movement of airflow between indoor and outdoor parts will be added, so, a flow will be created from cold outdoor part into indoor and a flow from cold indoor to outdoor. In moderate parts, two parts are almost in a temperature range and so there's no conflict with natural function of airflow. These flows cause intensifying vertical flow in cold outdoor part and conflict with vertical flow in opposite indoor part cause conflict in hot outdoor part and intensifying vertical flow in cold indoor part.

By studying classic behavior in cone, we consider that behavior of airflow is somewhat similar to cylinder. So, based on circular sectors, cone will be divided to three parts: 1. Hot part: almost equal to 120 degree sector in opposite part of sun, 2. Moderate part: equal to two 60 degree sectors along hot sector and cold sector and 3. Cold part: almost equal to a 60 degree sector in opposite sector of sunlight.

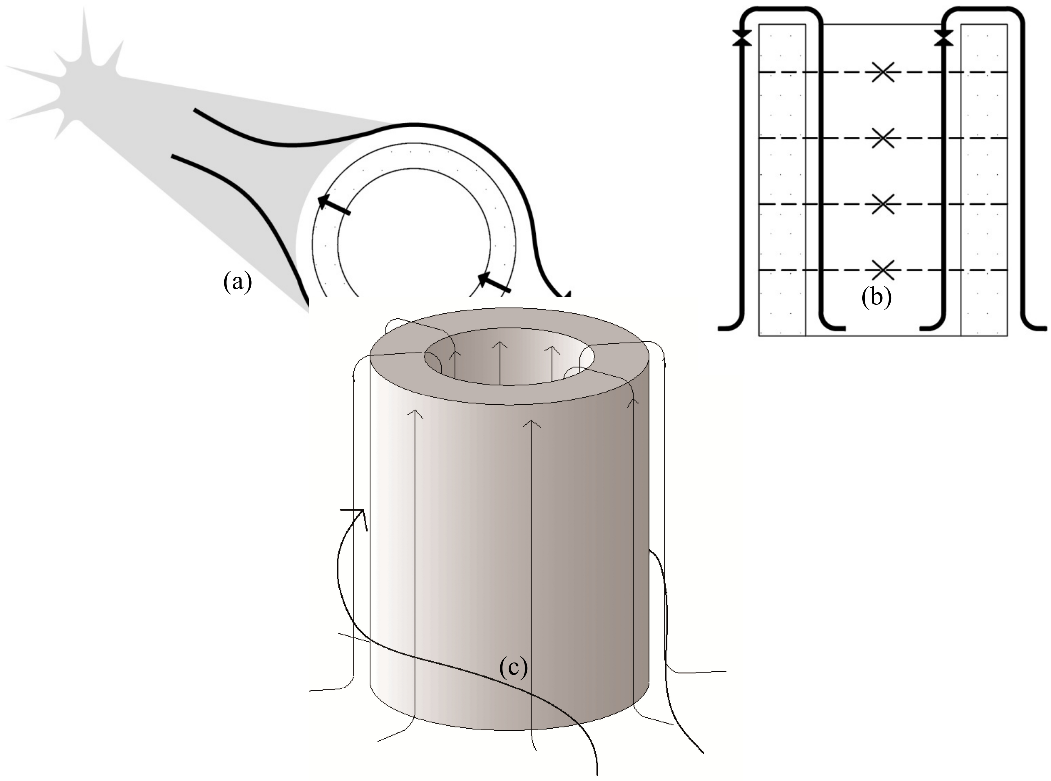

Figure 7. Analysis of the thermal behavior of hollow cylinder (a) Plan, (b) Section, (c) Three-dimensional volume.

7. Most important reasons which protect full cone showing classic behavior is considerable in following parts:
Forming two horizontal flow along cylinder: from cold facade, two flows (from left or west and right or east) will move to hot facade. These two flow interfere in middle of hot facade and decrease force of each other. So, a conflict will be created with classic behavior.
Incompatibility between vertical and horizontal flow: horizontal flow in cylinder is a two-sided flow while vertical flow is a one-sided and integrated flow. Interfere of these two flows cause creating a movement in coned cold facade and avoid emerging classic behavior.

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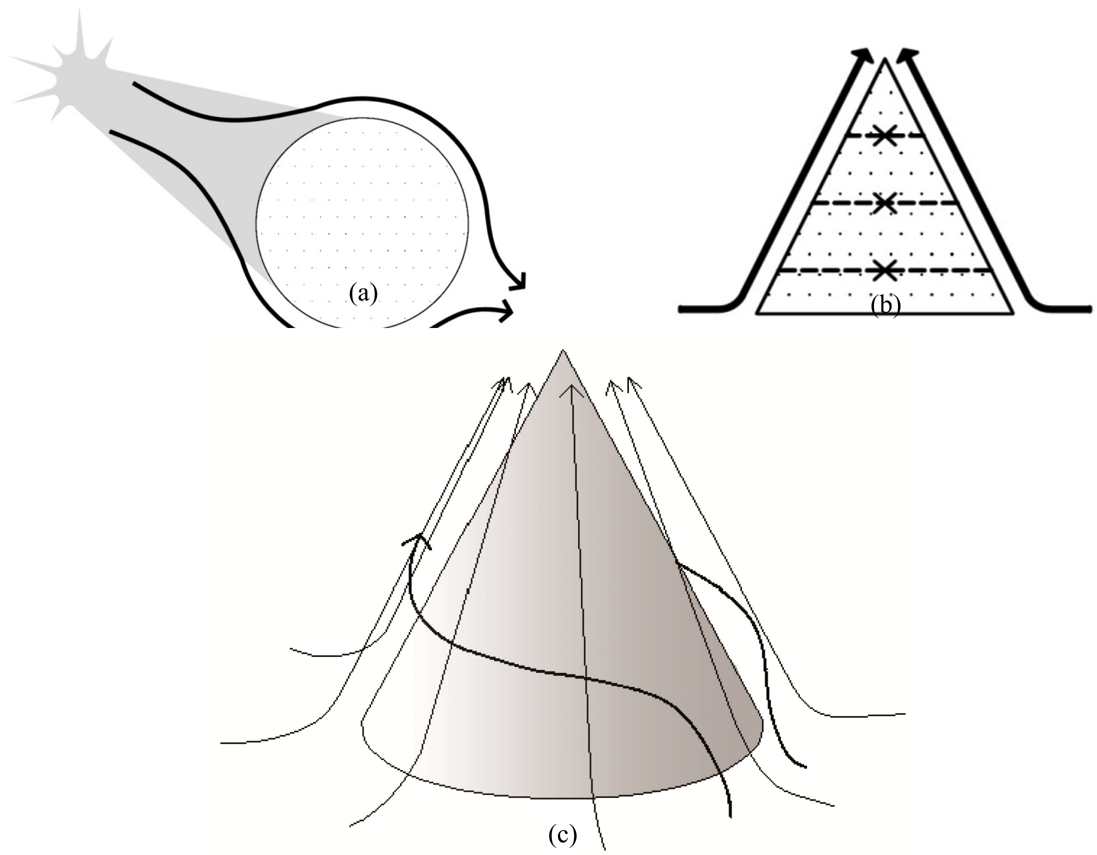

Figure 8. Analysis of the thermal behavior of full cone (a) Plan, (b) Section, (c) Three-dimensional volume.

8. In analyzing classic behavior of empty cones in addition to considered characteristics in full cylinders, other conditions are considered:

More parts with different angles and temperature: empty cone is made from more parts with different thermal degrees. So, in addition to three outdoor parts in full cone, indoor level of empty cone will be divided to three parts and thus, there's cold indoor part opposite hot outdoor part which receives les light while there's hot part in indoor level opposite cold outdoor part of cone which receives most solar energy and two other parts have moderate temperature. So, in addition to considered flows in full cone, flows from outdoor parts to indoor and from indoor parts to outdoor will be considered and so, there's airflow from cold outdoor part and airflow from cold indoor part to outdoor part. Regarding considered matters, there's intensifying vertical airflow in cold outdoor part and conflict with vertical flow in hot indoor part. On other side of cone, there is conflict with vertical flow in hot outdoor part and intensifying flow in cold indoor part. In moderate parts, thermal difference is low. So, it won't be

In analyzing classic behavior of full hemisphere based on circular sectors, hemisphere will be divided to three parts: 1. Hot part: almost equal to 120 degree sector opposite sun, 2. Moderate part: equal to two 60 degree sector along two hot and cold sectors and 3. Cold part: almost equal to a 60 degree sector opposite sunlight.

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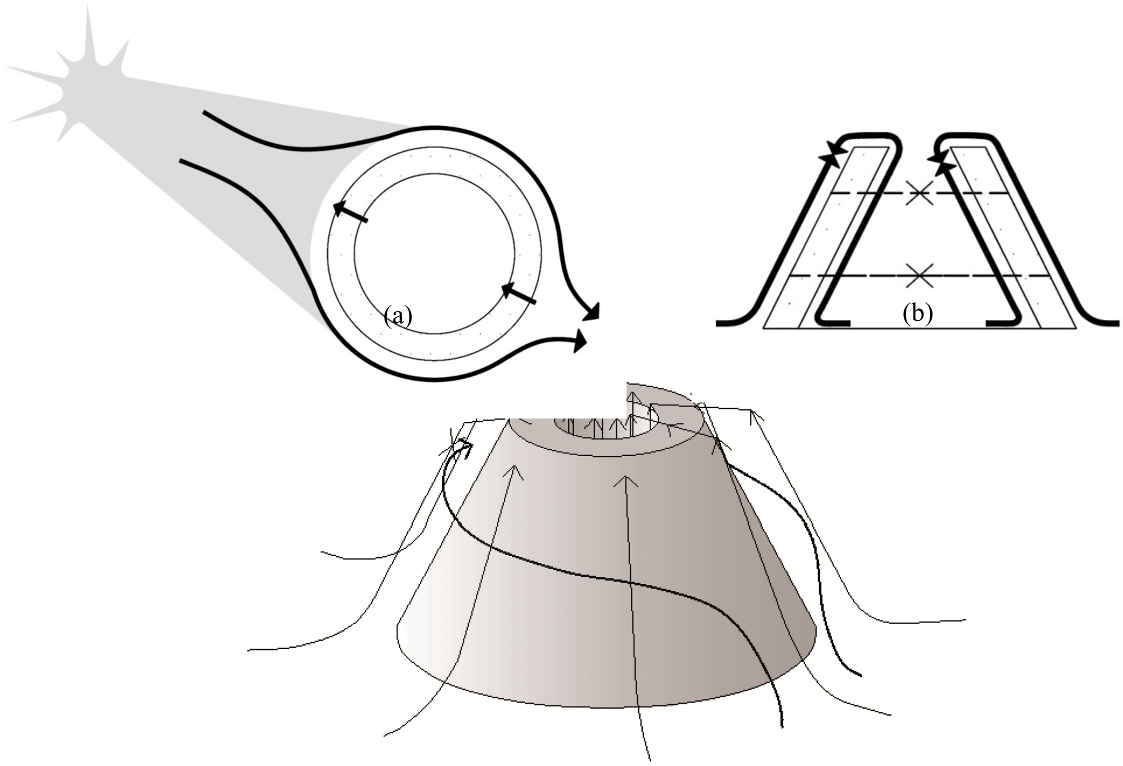

Figure 9. Analysis of the thermal behavior of hollow cone (a) Plan, (b) Section, (c) Three-dimensional volume.

9. Most important reasons which protect full hemisphere showing classic behavior is considerable in following parts:

Forming two horizontal flows along sphere: from cold facade, two flows (from left or west and right or east) move to hot facade. These two flows interfere in middle of hot facade and decrease force of each other. So, a conflict will be created with classic behavior.

Incompatibility between vertical and horizontal airflow: horizontal flow in sphere is a two-sided flow while vertical flow is a one-sided and integrated flow. Interfere of these two flows cause creating a movement in spherical cold side and avoid emerging classic behavior.

Change of angle against sun radiation direction: whenever we move from base to top of sphere, according to angle of sun radiation, its temperature will be different and there's highest reception of solar energy in a point. So, a flow will be created to hottest point which interferes in vertical flow.

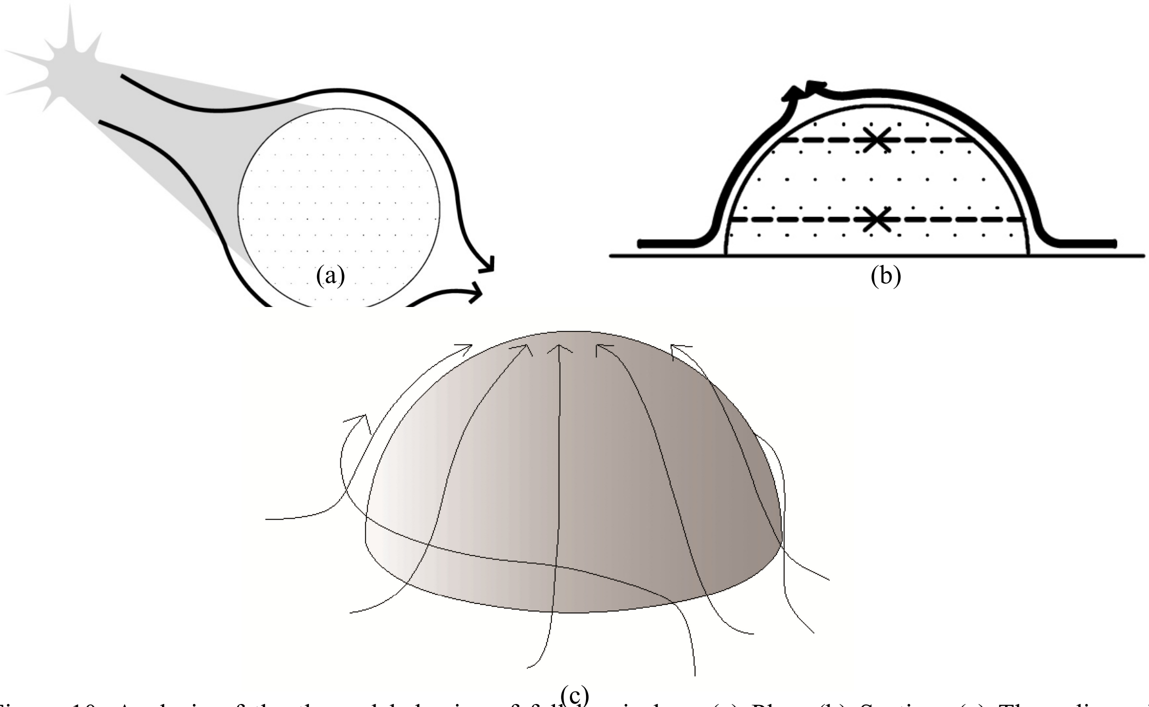

Figure 10. Analysis of the thermal behavior of full hemisphere (a) Plan, (b) Section, (c) Three-dimensional volume.

10. Most important reasons which protect empty hemisphere from showing classic behavior is considerable in following parts:

More parts with different angles and temperatures: empty hemisphere is made from more parts with different angles and temperatures in comparison with full hemisphere. In addition to considered parts in full hemisphere, there are three parts in indoor levels in empty hemisphere. So, opposite hottest outdoor part, there's coldest part in indoor level of hemisphere and opposite coldest outdoor part in hottest part and finally there's parts with moderate temperature opposite moderate parts in indoor levels. About parts with moderate temperature regarding that there's no thermal difference has no effect in natural function of airflow.

Change of angle against sun radiation direction: In addition to hottest point in outdoor level, there's other point as hottest point in indoor level. Regarding natural airflow outside and attraction to outside, movement route will be to hottest outdoor point.

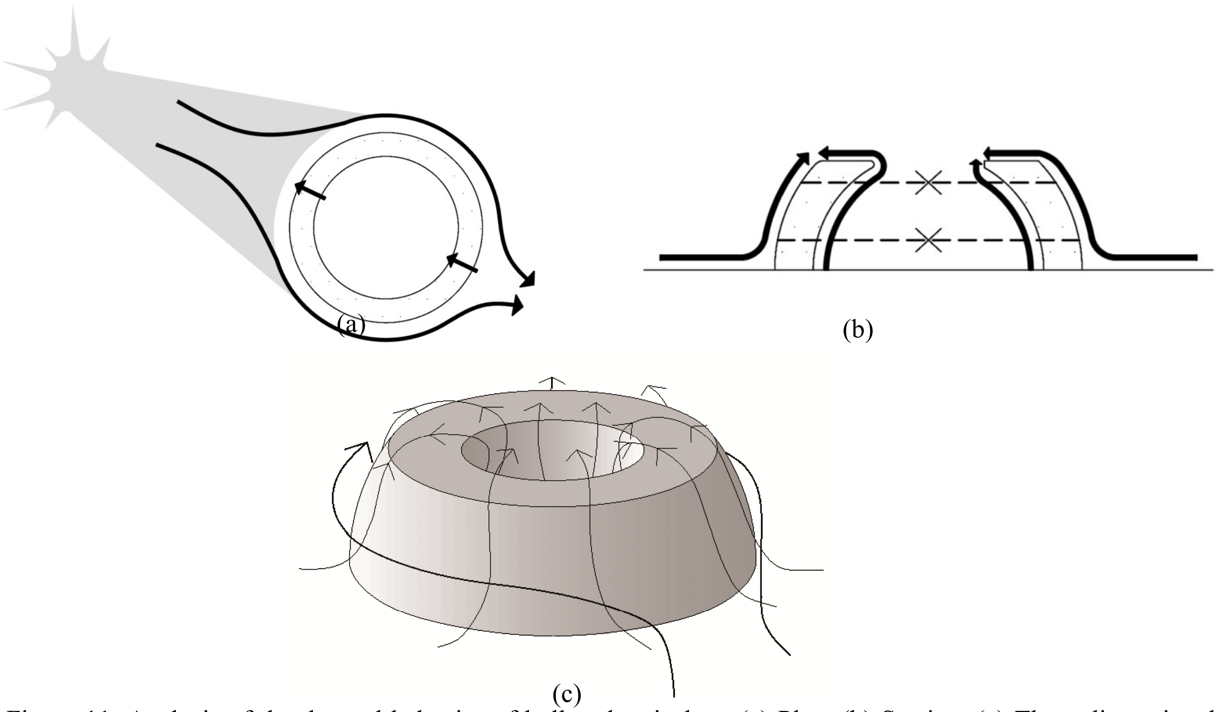

Figure 11. Analysis of the thermal behavior of hollow hemisphere (a) Plan, (b) Section, (c) Three-dimensional volume.

6. Conclusions

In this article, building forms were divided to 10 conditions and analysis of classic behavior of double skin in different forms was considered. Observations show that it can't be expected that classic behavior based on simple models will be accomplished in action. Regarding typologies and studies, it seems that cone and cylinder forms have more similar behavior from movement of airflow. On the other hand, spherical levels due to change of angle against sun have completely different behavior in comparison to other forms.

Conclusions resulting from studies and tests meanwhile approving role of form on thermal function of double skin facades and considered hypothesis indicate that classic behavior hasn't been approved in any analyzed samples. So, parameters which affect classic behavior of double skin can be categorized: angle of different facades of from against sun radiation angle, cold sides, sun radiation time (hour, season), angle of outdoor wall against earth, ratio of volume to base square, quality of plurality of airflows, building height, building length, building orientation, size of entrance and exit valves (being open or closed), shadows, number of cavity entrances (plurality of more entrances, more ventilation, speed of more airflow), shadow of adjacent buildings. Based on available studies, it seems that these parameters while are in optimized manner can have better result from thermal function of double skin.

What is obtained from studies of present article is that proper designing and considering effective parameters on classic behavior of double skin, these facades can be effective in each region and these challenges will be solved. Related strategies should be in a manner that disturbing factors in classic behavior can be organized and general form will be directed so that most productivity will be created.

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