Proposing a More Efficient Model to Enhance Natural Ventilation in Residential Buildings

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Abstract: Increase in population is one of the main reasons for human to live in height but in construction of tall-buildings the energy supply has been ignored; moreover mismanagement of natural resources in Iran during recent years has been led to raise concerns among authorities. This article seeks to provide a model which is proposed to use wind-catchers which exists in traditional Iranian architecture to enhance natural ventilation in residential buildings. Therefore, wind catcher performance is analyzed by Carrier software in one proposed model in Tehran. The research approach is simulation, modeling and applied techniques to calculate a proposed model. Collecting information method also is library searching and physical studies. According to the data collected about the features and usage of the wind-catchers in Tehran, only some parts of this tall-building are naturally ventilated. Therefore, the traditional natural ventilation systems cannot be adequate unless the building mechanical systems are used.

Keyword: Economic and Environmental Issues, Energy Consumption, Natural Ventilation, Residential Tall-Building

1. Introduction

Constructing high-rise buildings and consequently living in height have led to emergence of new lifestyle of relationship between surrounding environment of buildings and human. Every tall-building can be regarded as a city within a city which should be analyzed socially, economically and ecologically.

Natural ventilation plays an important role in building stability and construction [18, 19] therefore those are very important in contemporary architectural design [28, 29] especially when interaction of tradition and future architecture is needed. [30] Usage of indigenous architectural patterns [15, 16] and modeling traditional achievements [14] are suitable ways to fulfill helpful strategies and tactics [12] for contemporary architecture [13, 14] which roots in traditional architecture of hot and dry climate. [15, 16] Theoretical framework of the paper focuses on reuse of traditional reflections in recent era for sustainability in architecture and planning [17, 18] and focus on practical issues [7] is to guarantee comprehensive approach toward environmental sustainability [10] and meet eco-friendly design and planning [19, 20]. Developing countries such as Iran are in need of this comprehensive approach more than other parts of the world. [12, 20] It seems that proposing a more efficient model to enhance natural ventilation in residential buildings may pave our way to more sustainable design. Because of the lack of fossil resources as well as population growth in the world, maintaining the source of energy is one of the main concern which human communities surely has been faced with. Therefore, building eco-friendly constructions and substituting the fossil resources of energy with other sources like environmental energy must be considered as a key factor in nowadays architecture. In this paper, some energy resources such as solar or wind energy are studied to find out architecture-led possibilities by replacing the common fossil resources with other kinds of energy.

2. Materials and Methods

The research in this study is approached experimentally and quasi-experimentally. Techniques are related to climatic potentials and green design. Information was collected through library research methods and physical studies. [11] For obtaining a building with zero energy or with minimum energy consumption, we can use natural resources instead of fossil resources. One of the benefits is the advantage of having natural ventilation in building. In the proposed model, natural ventilation is used and amount of required airflow in some selected spaces is calculated by the Carrier software.
After obtaining the amount of required air for natural ventilation, the proposed model applies some wind-catchers with some fixed features. Other related works [21, 22 … 33] emphasize on role of mathematical approach to resolve architectural design process issues in climatic manner. We intend to find out how many wind-catchers are needed in selected spaces for having complete natural ventilation.

2.1. Analysis of Physical Status

Human life style has been one of the important issues from the beginning of civilization. During the last decades, many logical reasons led to construction of high-rise buildings. However, these reasons are not justifiable these days since some basic issues have been completely ignored by designers; moreover, these tall-buildings have proved to influence environment detrimentally.

A high-raised building must be as competent and comfortable enough as a house. Like zero-energy houses, the main challenge of high-rise buildings is to sustain the social, economic and ecological aspects. As each of the mentioned categories is regarded as a subject to be studied, the aim of this paper is to elaborate the usage of sun-light and natural ventilation in residential buildings to consider some economic and ecological issues.

2.1.1. Economical Issues

The reports of the World Commission on Environment and Development (WCED) are stated on the basis of economic sustainability axis. Economical sustainability has led to increase in space quality at a long period of time according to:
- Economy based on environment
- Recognition of environmental impacts on the design of plans
- The relation between economic activity of project and surrounding environment
- The use of energy-efficient architecture
- Productivity
- Ultimate use of maximum efficiency from consumed sources
- The decrease in pollution and un-recyclable waste.

2.1.2. Environmental Issues

Some reasons have led to the emergence of the modern environmental movement as a logical starting point. They include: population explosion (1960s), energy crises (1970s), environmental backlash (1980s) and international ecological concerns (1990s to present) [2] By-product of this architectural process is the space which has optimal environmental functions such as:
- Saving energy: The natural use of raw materials (It is noteworthy that the energy consumption should be considered from the extraction to transportation phases);
- Climatic design: Design via meeting the criteria of the environmental conditions;
- Energy efficiency: Decrease energy consumption during the building lifetime without losing of residential comfort and also the efficiency of building;
- Recycling: Minimizing the consumption of non-renewable energies and decrease pollution and trash by using renewable energies;
- Pollution reduction: Eliminating or minimizing interior environmental pollution in residential buildings (For instance, installing healthy air conditioners without adverse moisture, eliminating pollution of ventilation systems and using some specific features in buildings);
- Comprehensiveness: Symbiotic relationship between buildings and natural environment as a living-organism (The energy and materials which are imported to and exported from buildings should be considered);
- Quality of site: reconciliation of building and the surrounding environment.

2.2. Proposed Model

Man-made constructions should be a part of natural environment which does not aim to destroy the natural habitats. Moreover, constructions must be both structurally and aesthetically designed in eco-friendly format. The nature, itself can be regarded as a model. So, we can be inspired by the organism living in natural habitants in designing such green buildings. In this paper, we have considered the shape of a pine cone as a model to design a green building with appropriate enough sun light and natural ventilation. Its center core is an appropriate place for installing some parts such as air circulation channels.

Furthermore, there is another way for natural ventilation by which the wind can enter into each room by passing through the channels terminated to the floor of each room. Afterward, the air directly runs into the channels located beneath the twin-shell walls. [Fig. 14] Circulating the air into the walls can lead to the decrease in the wall temperature as well as room temperature which can be consider as a second alternative that has not been included in the calculation.

2.2.1. Climatic Design and Energy Efficiency

Part 1. Design of Site [5]
- Reduction and increase in reflection by plants in the summer and reflective surfaces in the winter respectively.

![Figure 1](image_url)
Proposing a More Efficient Model to Enhance Natural Ventilation in Residential Buildings

- Create shade with plants in the summer for cooling.

![Image](image1.png)

**Figure 2.** Increase in reflection.

- Using plants for making the best use of the summer breeze.

![Image](image2.png)

**Figure 3.** Create shade with plants

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Part 2. Form of Building [5]
- The Increase in light in the winter by the shape and orientation of building.
- Use of Semi-protected spaces for more controlling of weather in building.

![Image](image3.png)

**Figure 5.** Absorption of light by plants

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Part 3. Plan [5]
- Use of maximum sunshine by sunrooms.
- Creation corridor or windbreak wall in entrance of house.

![Image](image4.png)

**Figure 7.** Absorption of heating energy in the green-house

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Part 4. Shell of Building [5]
- Use of retaining spaces
- Lots of windows for using natural ventilation.

![Image](image5.png)

**Figure 8.** Natural ventilation

- Use of thermal insulation in walls.
- The implementation of solar-walls and solar-collectors on southern roof.

![Image](image6.png)

**Figure 9.** Solar-walls and solar-collector

- The management of the heating insulation through the heating transfer.
- Placing a garden on the roof as thermal insulation contributes to less heat loss.

![Image](image7.png)

**Figure 10.** The roof garden in the winter

- Creating shades for sun exposed walls in the summer.

![Image](image8.png)

**Figure 11.** The roof garden in the summer

- Use of controllable awnings
- Placing plants near the exterior walls of building for increasing of moisture and shade.

- Use of two-shell walls for ventilation through building shells.

- Use of thermal insulation for windows.
- Adding more windows in the southern area.
- Increase in the reflection through windows by adding reflection surfaces outside the windows in the winter.

- Use of sun-pipe for receiving solar energy and natural light.
- Adding walls and louvers for infiltration the summer wind into building.

- Use of louvers for controlling circulation of air.

- Use of nanotechnology glasses with no need for curtains.

2.2.2. Recycling
- Resumption of waste: Use of trash-chute and renewable materials.
- Applying the water saving plan: a) Rains b) Surface waters c) Gray waters: The waters have been made from bathe, laundry and dishwasher. This water can use for flushing, irrigating plants, and washing yards or areas. d) Black waters: The waters have been come from toilets.

2.2.3. Pollution Reduction
- 1) Use of natural ventilation 2) ventilating by air capsules in center core 3) use of the materials which do not pollute the air and has caused cancers, respiratory diseases etc.

2.2.4. Quality of site
- 1) Prevention of negative effects on ecology of site as a by-product of constructing buildings 2) considering the design of buildings based on vertical length and exterior form: making balance between the site and the buildings so that the site is not dominated by the buildings.

2.2.5. Pine Cone as an Idea and Concept

A high-rise building could be an urban monument. Form of high-rise building is very important for architecture and all people. This aesthetics can be meaning through appropriate function. The pine cone idea includes many valuable functions, such as:
- Spiral form: The spiral forms of pine cone involve Fibonacci numbers. In the case of tapered pine cones, we see a double set of spirals – one going in a clockwise direction
and one in the opposite direction. [Figure 19] When these spirals are counted, the two sets are found to be adjacent Fibonacci numbers. [8] This form could help occupants to get much of natural light and ventilation in their homes, and also create a good view of the building surroundings. [Fig. 20]

Figure 19. A double set of spirals [9]

Figure 20. Spiral form in a high-rise building [6]

- Central shaft: The cone peduncle is an appropriate place for some infrastructure such as air conditioning channels, pipes, and vertical accesses such as stair cases, and elevators.

Cone

peduncle

Figure 21. The cone peduncle. [9]

- Green spaces in height: implementation of the green roofs and the green yards in height and the green corridors for residents’ congregation.

Figure 22. A location of infrastructure in tall-building [6]

Figure 23. Green house in each residential unit [6]

Figure 24. The position of the green houses and the air condition channels in tall-building section [6]
3. Post-Construction Analysis

Part of the economic and environmental problems can be resolved by using technical systems and natural resources. The previous parts discussed about some ways to conserve energy that natural ventilation can be regarded as one of them. Taking the advantage of natural ventilation in order to provide fresh and cooling air is the most important design objectives. So, in the proposed model, the amount of airflow was calculated by Carrier software, version 4.3. The purpose of this design is to study the channels which are placed in the center of the tall building to do natural ventilation of the interior spaces. To achieve a response several steps should be taken. The first step is analysis of wind-catcher with specific characteristics. The purpose of this test is to obtain the amount of circulated air in the wind-catcher. The second step is to specify some space on the lower floors of the building. These spaces are entrance space 1 and 2, auditorium 1 and 2, residential unit (the 7th floor). The aim of this work is to obtain the amount of required airflow for each of these spaces. Finally, according to the information obtained in the previous step, we can calculate how many wind-catchers are needed for each of spaces to provide the required airflow. It should be noted that with increasing in the height, the natural wind speed in the wind-catcher will decrease. Therefore, the chance to take advantage of natural ventilation by wind-catcher will be reduced.

The various residential units: The pine cone includes many wings with various dimensions. So, the residential units are constructed with various areas on the wings.

3.1. Analysis of wind-catcher

To obtain the proper amount of temperature and humidity of the indoor spaces in the building, we need to know about the comfort range. Figure 25 shows the human comfort range based on temperature and humidity in the summer and winter. On the first phase, the outside air must pass over water or a wet surface till get significantly cooler as a result of evaporating of some water. Then, this air is sent into space that needs the air ventilation. The temperature of the incoming air into the space which is consider in the examination equals to 23.9 °C (temperature of the damp air in Tehran [4]), the temperature which is needed in the interior space has to be within the comfort range and also, a few degrees above the internal air temperature. The interior space needs the appropriate temperature within the comfort range which is 26 °C as shown in figure 25.

Given this comfort range, temperature of room can be classified in both thermal comfort conditions and economic class (not a luxury) of air conditioning.

To find out whether the proposed model for ventilation could be able to implement or not, it is necessary to obtain the supply air volumetric flow rate for cooling the selected spaces. Then, it should be compared with the amount of airflow the wind-catcher can supply.

First we should obtain the amount of space cooling loads, for achieving the airflow rate. So, we need some parameters like local weather conditions, latitude, longitude, direction and speed of wind, types of material, dimensions and type of doors- windows- ceiling- floors- walls, number of people and type of their use of building and all changing in these parameters. Then, the airflow rate will be obtained by using these cooling loads.

Table 1. compare of the soft wares with each other

| Having the knowledge to User Interface | Carrier HAP | Elite HVAC | HVAC Solution |
|--------------------------------------|-------------|------------|---------------|
| Software Accuracy for estimating air conditioned loads | *           | *          | *             |
| sufficient experience for using the soft wares | *           | -          | -             |
| score | 3           | 1          | 1             |

For estimating the amount of cooling loads and the airflow rate a software is used. There are a lot of commercial soft wares which are applied for heating load and cooling load calculation. Some of them are widely used such as: Carrier HAP, Elite HVAC and HVAC Solution.

Most of the engineers in Iran use the Carrier HAP for estimating the cooling load, the heating load, selective type of device, sizing of various parts of HVAC and analyze in engineering. Therefore, it is more known between the same software in Iran. Table 1 shows some reasons for selecting Carrier software.

Therefore, Carrier HAP was used for doing analyze in this paper.

The supply air volumetric flow rate can be calculated by using the following equation:

\[ cfm_{sa} = \frac{RSH}{1.08(t_{rm} - t_{sa})} \]

\(cfm_{sa}: supply\ air\ Volumetric\ flow\ rate\)
\(RSH: Room\ sensible\ heating\)
\(t_{rm}: room\ temperature\)
\(t_{sa}: supply\ air\ temperature\)

The first step to achieve results is that a channel with dimensions specified 1(m) by 2(m) has been tested as air channel samples in carrier software.
Proposing a More Efficient Model to Enhance Natural Ventilation in Residential Buildings

3.2. Analysis of the Selected Spaces

The entrance space 1 and 2, auditorium 1 and 2, and a residential unit (the 7th floor) are the selected spaces which have been investigated by Carrier software. First, the necessary information should be entered to the software. These information are the weather and geographic conditions in Tehran that include (longitude and latitude, elevation, summer design dry-bulb, summer coincident wet-bulb, atmospheric clearness number, average ground reflectance, design cooling months) which are shown in figure 27. This step is done just for specifying the project status in Carrier software.

We can get dry and wet air temperature in various hours in July in Tehran by Carrier software. The wet and dry bulb is used for examining the weather conditions and the initial and final air conditions. Also, the difference between the outside temperature and the inside temperature, amount of solar heat that is getting into the building through doors, windows and walls, and other factors have been considered in calculating the heat load of the building. Figure 28 shows the dry and wet bulb in various hours in July, Tehran.
Figure 27. Design weather parameters [3]

Figure 29 shows the area of HVAC heating and cooling load of the building and the contribution of each of the external factors (sun, heat being transferred from the walls, doors and windows) and internal factors (lamps according to ASHRAE Association estimates for using the amphitheater) in this calculation. The number of people who have been proposed is equal to 1000. These calculations have been done by Carrier software.

Figure 30 shows the changing of cooling load in July hourly. The minimum cooling load is at 5:00 a.m. and the maximum cooling load is at 3:00 p.m. in July.

Figure 28. Dry and wet air temperature in various hours in July, Tehran [3]

Figure 31 shows amount of cooling load that air conditioning (here means the evaporative cooling method by natural ventilation) must provide. Also, it shows the amount of airflow required to provide this load.

Figure 32 illustrates the amount of air required for the ventilation based on the size of the space and the number of people in each space.

Figure 29. HVAC heating and cooling load of the building (calculated by Carrier software)
Proposing a More Efficient Model to Enhance Natural Ventilation in Residential Buildings

Figure 30. The hourly changing of cooling load in July (calculated by carrier software)

| Air System Information |
|------------------------|
| System                 | SCAV |
| Equipment Class        | UNDEF |
| Air System Name        |     |
| Number of zones        | 1    |
| Floor Area             | 2715.8 ft² |
| Location               | Tehran, Iran |

Figure 31. Air system sizing summary for system (calculated by Carrier software)

| Central Cooling Coil Sizing Data |
|----------------------------------|
| Total load                        | 81.4 Tons |
| Sensible coil load                | 73.6 MBH |
| Cooling coil at 1500              | 11679 CFM |
| Sensible coil load                | 1.900 |
| BTU/h                             | 442.1 |
| Water flow @ 10.0°F rise          | 147.39 gpm |

| Central Heating Coil Sizing Data |
|----------------------------------|
| Load occurs at                   | Aug 1500 |
| Sensible coil load               | 73.6 MBH |
| Cooling coil at 1500             | 11679 CFM |
| Sensible coil load               | 1.900 |
| BTU/h                             | 442.1 |
| Water flow @ 10.0°F rise          | 147.39 gpm |

| Supply Fan Sizing Data |
|------------------------|
| Actual max CFM         | 11679 CFM |
| Standard CFM           | 10891 CFM |
| Actual max CFM/mb      | 4.30 CFM/m² |
| Fan motor BHP          | 0.00 BHP |
| Fan motor kW           | 0.00 kW |
| Fan static             | 0.00 in wg |

| Outdoor Ventilation Air Data |
|-----------------------------|
| Design airflow CFM          | 19951 CFM |
| CFM/person                  | 18.35 CFM/person |

Figure 32. Ventilation sizing summary for each space (calculated by Carrier software)

### 1. Summary

Ventilation Sizing Method: Sums of Space OA Airflows

Design Ventilation Airflow Rate: 16851 CFM

### 2. Space Ventilation Analysis Table

| Zone Name / Space Name | Max. Occupants | Max. Supply Air (CFM) | Maximum Supply Air (CFM/Person) | Required Outdoor Air (CFM/person) | Required Outdoor Air (CFM) | Required Outdoor Air (% of Supply) | Uncorrected Outdoor Air (CFM) |
|------------------------|----------------|------------------------|---------------------------------|-----------------------------------|---------------------------|------------------------------------|-------------------------------|
| Lobby 1                | 250            | 2574.2                 | 16.95                           | 0.00                              | 0.00                      | 0.00                               | 4227.6                       |
| Lobby 2                | 250            | 26234.7                | 16.95                           | 0.00                              | 0.00                      | 0.00                               | 4227.6                       |
| Theater 1              | 250            | 30628.0                | 16.95                           | 0.00                              | 0.00                      | 0.00                               | 4227.6                       |
| Theater 2              | 250            | 26538.4                | 16.95                           | 0.00                              | 0.00                      | 0.00                               | 4227.6                       |

Totals (incl. Space Multipliers): 116798.3 CFM

16851 CFM
Figure 33 shows the time of peak cooling load for the entire region, each space and its size, the amount of cooling load and the amount of the air required for its air conditioning.

After analyzing all spaces by the Carrier software, we could use the results of it. Table 2 includes the information of airflow quantity that is needed for air conditioning in each space that they achieve from Carrier software.

Table 2. Analysis of the ventilated Spaces

| The name of space       | Maximum supply air (CFM) | Maximum supply air (m³/s) |
|-------------------------|--------------------------|--------------------------|
| Entrance space 1        | 29248                    | 13.80515                 |
| Entrance space 2        | 29235                    | 13.79878                 |
| Auditorium 1            | 30028                    | 14.17322                 |
| Auditorium 2            | 28288                    | 13.35212                 |
| A residential unit (the 7th floor) | 18056 | 8.52 |

4. Discussion

In part 3.1, we assumed that the wind-catcher had the dimensions of 1 m by 2m, and obtained the internal air velocity from outside to inside which was about 4 kg/s or 3.63 m³/s. So, for finding out how many wind-catchers are needed in selected spaces for having natural ventilation, we should divide the maximum supply air for each space to 4 kg/s or 3.63 m³/s.

According to the mentioned issues, each space needs two or more wind-catchers for having natural ventilation as is shown in table 3.

Implementing ventilation via natural methods provides economical and environmental benefits, [24, 25] 94.4% of energy consumption in buildings is used by HVAC systems within the life cycle period of buildings [50] Natural ventilation (NV) is very common alternative in compare with HVAC systems. [26, 27] But in some climates air conditioning with natural ventilation cannot meet the criteria of human comfort range. [33]

Table 3. The numbers of wind-catcher in each space

| The name of space       | The number of wind-catcher |
|-------------------------|---------------------------|
| Entrance space 1        | 4                         |
| Entrance space 2        | 4                         |
| Auditorium 1            | 4                         |
| Auditorium 2            | 4                         |
| A residential unit (the 7th floor) | 3     |

Tehran is located in a hot-dry climate. [30, 31] If a building in this climate includes double-glazed glasses and its exterior walls are insulated, it needs 100wh- 120wh energy in per square meter. [10] So, we can calculate the amount of energy which is need for each selected space. It is illustrated in table 4.

Totally, the required energy for the selected spaces is 4881.8 (kWh). Therefore, natural ventilation can help to save energy. This method has positive effects on economic growth.

Cooling systems (HVAC systems) run on electricity which is achieved through combustion of fossil fuels. This way is not sustainable since it uses nonrenewable resources and pollutes the environment.

Therefore, the proposed ventilation shaft is confirmed can be regarded as an effective wind-induced ventilation strategy to maximize indoor air velocity and enhance human comfort range in high-rise residential buildings located in hot-dry climates.
Proposing a More Efficient Model to Enhance Natural Ventilation in Residential Buildings

Table 4. The amount of energy which is need for each selected space

| Selected spaces                  | Entrance space 1 | Entrance space 2 | Auditorium1 | Auditorium2 | A residential unit (the 7th floor) | Total energy (kWh) |
|----------------------------------|------------------|------------------|-------------|-------------|-----------------------------------|--------------------|
| Space (m2)                       | 1270             | 430              | 1310        | 1211        | 210                               | 4881.8             |
| Required energy (kWh)            | 127              | 43               | 131         | 121.1       | 21                                |                    |
| work in 8 hours (kWh)            | 1048             | 968.8            |             |             |                                   |                    |
| work in 15 hours (kWh)           | 1905             | 645              |             |             |                                   |                    |

5. Conclusions

Energy saving is an essential factor especially at home since the most energy consumption almost happens in residential building. So, use of wastewater, sewage recycling, the collected rainwater, passive and active solar energy systems, and electricity generation are some ways that could help human to conserve the energy efficiently.

Ventilation can serve as a method which naturally can lead to decrease in using of air conditioning systems which results in reduction of electricity energy consumption. According to the previous data, the use of natural ventilation is not possible for all spaces (residential building, commercial etc.) of high-rise building. There are some reasons as follow:

- The upper floors cannot have the natural ventilation since the velocity of internal airflow is low.
- The occupied spaces by the wind-catcher for each floor will be about 250 -300 m² that is too much and not appropriate.

This model can provide natural ventilation in some stories. So, more research should be carried out to complete this model because there are many items which need to be investigated and analyzed such as:

- Cooling the airflow
- Moisturizing air for human use.
- Removing pollutants from the internal air such as dust.
- Controlling wind speed and optimizing it to appropriate airflow for human use.
- Controlling the internal airflow due to changes in wind direction from up to down and vice versa during a day.

It is realized that the research has some limitations. Thus, some possible future works can be done to find out alternative solutions for developing more economical models and studying the issues related to natural ventilation more thoroughly.

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