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Strategies and Techniques for Optimized Design of Façade in High-rise Buildings: An Energy-Efficient Approach: A Case Study in a Residential Tower Located in Urban District 22, Tehran, Iran

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Abstract

A substantial portion of energy consumption by buildings is through its dissipation via building façade. All over the world, relatively 50% of the energy resources are utilized to create a "comfort zone" inside buildings; a splendid goal that, if realized, can play a significant role in reducing energy waste. This is the underlying idea which prompted the present study to search for systematic solutions for energy waste by buildings. In Iran, designer architects have restricted the design of building façade solely to the placement of openings and selection of material type regardless of the fact that building façade plays a major role as a mediator for energy exchange between interior and exterior spaces of a building. The present study aims at obtaining practical solutions for designing façade in high-rise buildings in Tehran through emphasizing on energy saving, which is one of the three main categories associated with designing in sustainable architecture. To do so, related literature and studies in different climates and similar buildings in this regard are reviewed initially and technical and theoretical strategies and propositions are, then, dealt with. In order to improve and adapt the proposed strategies to the available technologies and climatic conditions, these two variables are studied more exclusively. The method adopted as the major method of investigation is case study in addition to a combination of techniques which is discussed later. To analyze the obtained data, multiple document sources are used which account for qualitative research method. Therefore, existing potentials are evaluated to be adapted to the new strategies. These potentials as asserted in upstream documents and laws, specify the possibility of adjustment to the technical and theoretical strategies and predict the outcomes. By analyzing the case study and creating adaptability between the obtained results, it became clear that installing PV windows not only reduced heat consumption by 30%, but also it lowered the need for consuming electricity up to 54% via controlling building illumination. Moreover, it was realized that a series of variables such as: window type, building orientation, area under cover of the building units, placement of internal windows, in addition to electricity consumption and environmental load on each unit determine the amount of cooling load in summer. Therefore, the type of glass applied was assessed and it was concluded that glazed glass with shading coefficient of 0.025 is expected to reduce the cooling load significantly. It means that by using glass with a low index of shading coefficient, fewer amount of energy would be required during hot seasons.

Keywords: High-rise building, Optimized design techniques, Double skin façade, Energy-efficient design

Introduction

The dilemma of "energy crisis" in our modern world has received worldwide consideration. How to produce and consume energy by resources and consumers is a popular topic of discussion which has led to the emergence of several branches in scientific studies. Buildings as major consumers of the produced energy, have been reported to consume almost half of the world's energies. Within the domain of architectural studies, various trends have appeared recently concentrating on energy-related discussions, the outcomes of which might be labels such as green buildings, zero-energy buildings, etc. Thus, it seems quite obligatory to embark on studies with energy-oriented targets, specifically in architectural discussions. With regard to the increasing rate of the construction of high-rise buildings in Iranian capital, Tehran, a number of research projects should be conducted emphasizing on the methods and manners of energy consumption inside such buildings. Urban District 22 of Tehran is the most newly- constructed residential zone where considerable numbers of high-rise buildings have been constructed, or, are expected to be.

Review of Literature

Definition of the Term High-rise Building

A major element determining the height of a high-rise building is its accessibility for fire-fighting equipment. The standards established for this issue vary in different countries. In Iran, according to the Article no.112 published by the National Organization for Planning and Management (issuing instructions and regulations for protecting buildings against fire), the definition of high-rise building is as follows:

Any building or construction having a height (vertical distance between the level of the highest floor to be occupied and the lowest accessible level for fire engines and trucks) is more than 23 meters. A building entailing such characteristics shall be realized as high-rise. (National Organization for Planning and Budgeting, 1992)

Reducing Energy Waste in High-rise Buildings

A large body of research in this regard has been conducted globally (Bojik et al, 2001; Miyasuki et al, 2004). Originally, in the second half of the 20th century, the “energy crisis” became a universal concern. Architectural styles such as ecotect came into existence which aimed at preserving energy in construction industry. The idea became more outstanding in high-rise buildings which were erected in different cities of the world every now and then. The façade of these buildings was mostly covered by glass. In cities located in hot regions, a large portion of energy was consumed due to the flow of hot air; similarly, in cold regions, the waste of heat produced inside the building meant energy loss as well. Therefore, a number of proposals were put forward by experts in different fields of science, aiming to improve the technology of constructing high-rise buildings with regard to the analyses carried out on existing buildings. However, as the time passed, previous recommendations were altered and modified to adapt to recent technologies namely with regard to the materials applied in construction. Generally speaking, designer architects are equipped with a number of strategies to take advantage from and select the ones which suit the conditions and apply them based on ecological architecture techniques. Thus, literature relevant to this area is discussed here and a number of suggestions regarding the mentioned techniques is expressed as follows:

While reviewing previously-conducted studies on energy efficiency by building façade, certain variables are of utmost importance such as:

- Adding a second skin layer to the façade,
- Optimized design of the illuminative walls (curtain walls) and openings,
- Reducing the number of transparent walls in building façade,
- Utilizing materials with high thermal capacity and heat resistance,
- Using appropriate façade tint for building exterior,
- Creating green walls on the main façade,
- Using moisture-control techniques (e.g., damp proofing) during hot seasons.

In the present study, a number of the above-mentioned techniques were selected based on the methodology to specify appropriate strategies (e.g., addition of 2nd skin to façade and optimized design of illuminative walls and openings).

Double Skin Façade (DSF)

Double skin facades (DSFs) are defined as: “A pair of glass layers which are apart by an airflow in the intermediate cavity. The main layer of glass is normally insulated while the air flowing between the two layers acts as an insulator against maximum and minimum temperatures, wind and noise. Special sun-block sets are usually arranged between the two layers. All of these elements can be arranged in various placements and configurations of transparent laden membranes (Seyyedi, 2010).

In a research conducted by Gertia and De Herde (2003) on a 5-storey office building in Belgium, the following results were drawn:

- In winter, presence of double skin façade (DSF) reduces energy waste through heat convection by internal layer, preventing the building from being affected by infrared radiation heat loss. Moreover, during sunny days in winter, the temperature of air between two layers increases rapidly which can act as a means of natural ventilation in non-sunny days.
- In hot summer days, however, benefitting from natural ventilation seems to be unattainable. Actually, ventilation by extracting from DSF in daylight is very rare in this period, since it is a function of wind direction as well as the type of wind-protection the building is equipped with. To control the flow of wind between two skins (up to down or the opposite), it is essential to set the lower weather stripping valve (Geratia and De Herde, 2003, p.59)

In this study, in addition to the techniques proposed for application during hot and cold seasons, a number of solutions are also suggested for natural ventilation as follows: The airflow would be appropriate if it is not perpendicular to the main skin, upper wind flow valve is open and the building is insulated against wind flow and only the upper valve is open.

Optimized Design of the Illuminative Walls and Openings

Transparent and semi-transparent parts of façade such as openings and the like play a crucial role in determining the rate of energy loss inside building. Moreover, these parts are fundamental elements absorbing the energy produced by sunlight. The other significant role happens when these openings affect ventilation. Adopting an energy-efficient approach, the first two roles are our priorities here. In a research on a high-rise office building in Tokyo, Miyazaki, Akisawa & Kashiwagi (2005) found that:

- Along with controlled illumination, optimized transmittance of solar cell (photovoltaic cell) with 30% of WWR (window to wall ratio) equals 80% whereas in 40% and50% of WWRs, the amount of transmittance is calculated to equal 60% and 40% respectively.
- Combination of solar cell transmittances of 40% and 50% of WWR yielded minimum of primary energy consumption in uniform transmittance by windows in different directions.
- Total electricity consumption reduced significantly due to controlled illumination.
- A 2.4% reduction was recorded because of the optimized design of solar cell in different zones in comparison with uniform design in 40% and 50% of WWR. The reduction is evaluated to equal 55% compared to the standardized model (Miyazaki et al, 2005, p. 302)

The two research projects indicated above specify the approaches to waste-of-energy-related issues, highlighting specific keywords to be studied and investigated in future studies.

Research Methodology

Interpretation of Research Procedure

In the present study, the research objectives were established after investigating upstream documents (Climatic zoning map of Iran). Next, hypotheses were formed based on these objectives, the selection of which was the offspring of a temporary study on the established objectives. Initially, the keywords asserted in the hypotheses were investigated and looked up by reviewing the related literature in 3 case studies. These were selected based on climatic coordination with Tehran and the intensity of evaluations done in these studies with regard to our keywords. The process ended up in distinguishing techniques which were then compared and adjusted to the instructions asserted in upstream documents to assess the possibility of implementing them. The techniques which had the potential of being practically applied were recognized as influential ones. During the later steps of research process, these techniques acquired a more physical form based on nature-oriented ideas, examples of which can be: creating ventilation and HVAC, shading and double- skin under specific conditions.

Combining these techniques and putting them into practice at proper settings led to preserving certain portions of the produced energy inside buildings by preventing its loss. These techniques not only help achieve the respective objectives but also they are endowed with industrial compatibility for application and in line with the asserted instructions of upstream documents. Diagram 1 represents the steps of conducting the present research (diagram 1).

Recognition of the research objectives based on

⇩ Priorities

⇩ Keywords

Review of ⇩ related literature

Adjustment ↙ to the ↘ regulations Recognition of techniques

⇩

Proposed techniques

Introducing Upstream Documents

Climatic Zoning Map of Iran

The most important document in this research is the climatic zoning map of Iran published in 1991 by the Iranian Ministry of Housing and Urbanization (fig.1). Tehran is categorized under group 2-5 on the map whereas its different districts enjoy different micro-climates. Thus, a high-rise residential building in district 22 was chosen as the base case study here.

National Plan on the Codification of Regulations and Standards for Constructing High-rise Buildings

This project is one of the sub-categories realized by the Comprehensive Project of Tehran Urban Area, major goal of which is to reduce environmental damages caused during construction of high-rise buildings. This goal seems to be relatively synonymous ton the objectives undertaken by the present study. The document primarily focuses on zoning and locating high-rise buildings in Tehran and, meanwhile, it asserts the necessity of observing certain criteria for designing the façade of such buildings. The criteria include a variety of elements such as height, form and shape, type and quality of materials, façade decoration, physical characterization of neighboring buildings, sky-observant point (angle) and coordination. (Center for Urban Planning Studies of Tehran, 2013).

Fig.1: Iranian climatic zoning map (Housing and building research center, 1991)

Strategy-based Document for Designing Façade of Distinguished Buildings in Tehran

This document was originally prepared and expressed by Tehran Municipality Organization. The document, in turn, entails a number of upstream documents such as: twenty-year urban preview of Tehran, 5-year urban preview of Tehran municipality, comprehensive urban plan (1970), Tehran reorganization plan (1991) and Tehran comprehensive prospect plan. The document discussed here symbolizes an attempt to offer novel practical techniques to take advantage from previously-introduced plans while analyzing the existing conditions.

National Bill on the General Rules and Instructions for Designing Façade and Utilizing Localized Materials

The bill was generated by Tehran Municipality Organization to describe rules and regulations concerning building construction in different parts of Tehran (Tehran Municipality Organization, 2013).

The Case Study Model

The sample model building selected for case study analysis is a residential building located in urban district 22 of Tehran which is in north-eastern part of the city. The respective building consists of a ground floor, a four-story basement and 17 floors of residential occupation above the ground floor. To analyze the building characteristics, four facades of the building were considered which include solely the exposure of residential floors. In this analysis, all the surfaces of external walls were taken into account in addition to all the exterior parts of spaces which are exposed to outdoor weather. It is worth mentioning that the external spaces of walls situated behind joint spaces such as corridors and staircase are NOT counted for in these calculations.

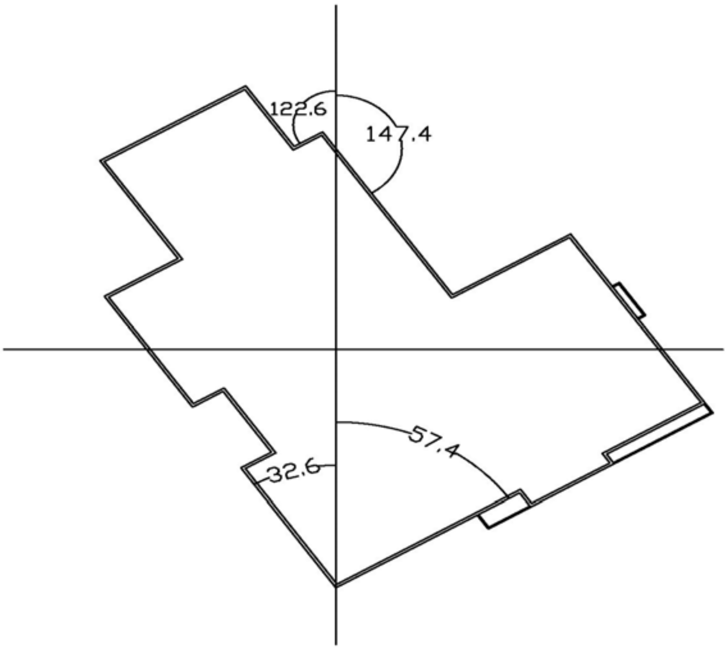

Fig.2. Spatial position of the building with regard to the main geographical directions

Fig.3. **South-eastern building façade**

Findings of the study

South-eastern Façade

This section of the façade keeps a 57.4° angle with regard to the north direction. Its total are under cover equals 1524 square meters. Further details of the analysis of this façade are stated in Table 1.

Table 1. Characteristics of south eastern facade

Total Area	Plus shading area	Minus shading area	Open to closed ratio
1524	637.5	886.5	0.251
Material applied			
UPVC-Covered surface of windows	Area of illuminative façade or glazed window	Area covered by coating B	Area covered by coating A
58.5	306.1	485.3	288

All the area calculations were done based on square meters.

Results Obtained on a Sunny Day in Winter

- Presence of DSF in winter and on a sunny day helps preserve the warm weather indoor. The process happens when the temperature of DSF increases during the day due to sunlight and thermal exchange between indoor and outdoor is minimized.
- The flow of wind is assessed and evaluated with regard to energy saving properties and it has no role in building ventilation.
- Utilizing DSF will mitigate the building dependence on daily heating load.

Results Obtained for a Non-sunny Winter Day

- Utilizing DSF reduces the required heating load during the day, provided that the DSF remains completely closed.

Results Obtained for a Sunny Summer Day

- Regardless of the presence of DSF, required cooling load per day enhances, which means that not utilizing DSF might be a better solution. However, there are two remedies for this problem: a) using air ventilation (either at night or during the daytime); b) using shading equipment.
- If ventilation is used as a solution for reducing cooling load during the day, both the upper and lower valves of DSF should be open.
- If ventilation is utilized to reduce cooling load at night, it should be done interruptedly.
- Generally, creating 24-hour pleasant ventilation has a positive effect on stabilizing comfort zone in indoor spaces, unless the direction of wind blowing is perpendicular to the DSF, and the difference between the indoor and outdoor temperature is zero.

Results Obtained for a Non-sunny Summer Day

- Presence of DSF might enhance the required cooling load.
- Shading equipment should not be used on these days since the sun is not shining.
- Air ventilation through the upper valve of the DSF is suggested unless the wind direction is perpendicular to the DSF.
- Interrupted ventilation at night is recommended unless the difference between the indoor and outdoor temperature is zero.
- In general, it is advisable to use ventilation temporarily because the wind direction

Discussion and Conclusion

Hypotheses testing

Regarding the first hypothesis, the obtained data are in accordance with the information asserted therein. Utilizing the proposed techniques uniformly and in line with the time of day or season can reduce energy consumption. A proper pattern is the one which can be adjusted to the climatic variations and create the most pleasant conditions for life. Simultaneously, utilizing modern technologies and materials such as glass with emissivity index of (**Sc 0.75** and **Sc 0.50**) and PV glass has some advantages: it helps control the amount of brightness and illumination as well as produce electricity for building consumption. Moreover, by benefitting from modern technologies such as adjustable shading devices has led to a significant reduction in required cooling load during summer while meeting aesthetic needs as well. In the past, using utilities in the façade exposure created a “shabby” appearance for the buildings. The recent buildings, however, enjoy visual aesthetics even in different hours of the day by utilizing different techniques.

Regarding the second hypothesis, the necessity of adopting glazed DSFs to reduce energy consumption and energy waste has been confirmed. When the shading devices are off, these facades create a reflective appearance which from the aesthetics point of view, seems to be smaller than the real size and in accordance with the surrounding environment to reflect adaptability to the regulations of designing urban facades. Moreover, when shading devices are on, the façade seems aesthetically appealing and because of its flexibility, the view has the capability of reflecting different images any moment of the day. Using recent technologies such as PV windows which both reduce the sun light entering the indoor space and increase its absorption and producing electricity, lowers the amount of energy consumption by the building. Implementing up-to-date technologies in glass manufacturing can establish a reasonable balance between the required lighting and the light radiated by sun to control the amount of emitted light during hot seasons.

Recommendations and Suggestions for Optimized Designing

The recommendations concerning this topic are concentrated on the type of materials applied in façade and how to design and arrange its elements which differ based on the timing of day/night and seasons. Generally, flexible designing would lead to creating the most appropriate façade for different times and conditions. This flexibility of design has the advantage of keeping the comfort zone indoors in a steady mode.

A Sunny Day in Winter: In winter, the most crucial objective is to preserve the produced heat indoors. Thus, an ideal façade would be the one which minimizes thermal exchange of interior and exterior spaces. Moreover, utilizing solar energy for heating may aid heat production to some extent.

Table 2. Proposed techniques for a sunny day in winter

Objective	Suggestion
-Reducing energy waste by building Reducing the impact of wind on energy waste	Utilizing DSF
Utilizing solar energy for heating	Not using shading devices
Reducing heat loss in building	Not using ventilation
Producing energy through optimized design techniques	Using PV windows
Lowering heat loss by the building	Using thermal insulator on the piers

A Non-sunny Winter Day: The difference between this situation and the previous one is to be sought in sunlight exposure since it is not possible to benefit from solar energies for heating and producing electricity

Table 3. Techniques proposed for a non-sunny winter day

Objective	Suggestion
Reducing energy waste by building Reducing the impact of wind on energy waste	Utilizing DSF
Reducing heat loss in building	Not using ventilation
Reducing heat loss in building	Using thermal insulator on the piers
Producing energy through optimized design techniques	Using PV windows

A Sunny Summer Day: Since the major goal of this study is lowering heat loss by the buildings, the sample case under investigation requires DSF. The possible disadvantage of its utilization might be creation of greenhouse effect in summer which leads to the building heating up. To prevent this type of unpleasant heating and even reducing the required cooling load for the building, other techniques have been added to DSF. In Iranian classical architecture, two techniques were simultaneously applied for regions which were extremely hot; shading and air ventilation. In this research, the two techniques were utilized simultaneously.

Table 4. Proposed techniques for sunny summer days

Objective	Suggestion
Reducing heat loss by building	Using thermal insulator on the piers
Protecting building against sunlight	Creating ventilation
Protecting building against sunlight	Using shading devices
Producing energy through optimized design techniques	Using PV windows
Protecting building against sunlight	Using glass with medium emissivity index

Non-sunny Summer Day: This case leads to fewer heating energy for the building. In this case, the need for utilizing shading devices is eliminated. Yet, interrupted use of ventilation during the 24 hours causes a circulation of air which in turn, contributes to a pleasant flow of air.

Table 5. Proposed techniques for non-sunny summer days

Objective	Suggestion
Lowering heat loss by building	Utilizing insulator in external building walls
Protecting building against sunlight	Creating interrupted ventilation
Gaining electricity through building design techniques	Utilizing PV windows

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