An Approach to Reduce Cooling Loads in Transparent Facades

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Abstract. The possibilities offered by the developing technology in terms of materials and construction systems, the requirements of today's user profile and living conditions and user demands have caused the facade systems of the buildings to change as well. The facades of the buildings, which are very effective in the energy efficiency of the buildings and constitute a large proportion of the building envelope, are built independently of all the contexts of its location and the spatial needs based on comfort conditions. Glass curtain facades, which are especially located in the facade systems of multi-storey office buildings, are constructed with similar qualities on each facade of the buildings and cause problems in the efficient consumption of energy as they cannot respond adequately to the comfort conditions of the spaces. Increasing cooling loads of buildings due to excessive heat gain from large transparent surfaces, is one of these problems.

1. Introduction
Energy use in all sectors has been one of the most important issues due to the effects of the industrial revolution that started in the second half of the 18th century and the oil crises since the 1970s. As in the all of the world, total energy in Turkey is being used for heating, cooling, ventilation and lighting. Energy efficient designs are increasing day by day because fossil based fuels, which cannot be renewed, are used as energy sources in the building sector as in other sectors.

With the rise of tall structures, the development of new construction materials and construction technologies has accelerated. Transparent façade systems, which are widely used in high-rise buildings, have an important place in contemporary architecture.

Office buildings are reconsidered in the context of green criteria in terms of high-energy consumption profiles, heating as well as cooling requirements, resource consumption and waste generation potentials. In this context, all systems that form office buildings must be handled with a new perspective. [1] The effect of transparent facade systems preferred in office buildings on the cooling load is one of the issues that should be addressed.

The purpos when designing the building envelope is create energy efficient systems that allow fresh air to enter the indoor environment and adapt to user requirements while making maximum use of daylight. In the design of high-rise office buildings, the number of which is rapidly increasing, it is
possible to minimize the cooling load with solutions designed to prevent excessive heat accumulation within the building during the cooling season.

2. Parameters Affecting the Energy Performance of Transparent Facades and Design Contexts

As a result of the rapid decrease of energy resources in the world, the concept of energy efficiency has started to gain importance. For this reason, the search for energy efficient building has an important role in architecture day by day. This approach requires a review of architectural design decisions.

Transparent facades have become an indispensable building envelope especially for high buildings due to their lightness, aesthetic appearance, easy to manufacture and install, and resistance to climatic conditions. In buildings with translucent facades, despite the positive effects of daylight on interiors, problems with daylight are also encountered. In the summer period, uncontrolled and indirectly reaching the interior causes overheating and increasing the cooling loads of the building, and thus the energy consumed for cooling purposes. Daylight dispersing uncontrollably and directly in the interior causes glare. [2, 3] It is possible to control these problems with the measures to be taken at the design stage of the building.

There are certain parameters that play an active role in the energy performance of transparent facades. It is important to know these parameters to produce problem-oriented solutions. Designer should be careful in the selection of these effective design decisions from the early stages of architectural design. These parameters and design contexts are shown in the table 1.

**Table 1.** Design parameters and design contexts that support the energy performance of transparent facades

| Parameters Affecting the Energy Performance | Design Contexts |
|--------------------------------------------|-----------------|
| **Climatic and Seasonal Conditions**       | Temperature, Moisture, Rainfall, Wind speed and direction, Sunbathing time, Solar radiation data, Atmospheric pollution |
| **Direction of Facade**                    | North, South, East, West, Northeast, Northwest, Southeast, Southwest |
| **Building Form /Design Facade**           | Building Form; Plan, Cross section, Appearance, Balance and simplicity, Ratio and scale, The relation of spaces with each other, Visual effect, Style, Ornament and deco |
| **Glass Selection**                        | Glass type - Glass properties - Glass thicknesses |
| **The use of solar control Systems**       | Type - Location - Material - Angle - Color |
3. Cooling Load Strategies in Buildings
Keeping the cooling and heating loads under control is one of the prominent goals in the design of the building facade. The cooling load is defined as the amount of heat that must be drawn from the environment to achieve a constant air temperature. In the absence of any additional systems in the space, the change of indoor air temperature and average heating temperature are the most important factors in the formation of cooling load in the hottest period.

Especially in hot humid and temperate climates, it is possible to reduce the thermal effects of the sun by using cooling systems due to the overheating, solar radiation and the negative effects of moisture on the users.

Short wave radiation from the sun causes unwanted thermal increases in the space in the hottest period. Solution strategies designed at the facades are effective in reducing the cooling load. The strategies that reduce the cooling load are presented in Table.2 along with their advantages and disadvantages.

Table 2. Advantages and disadvantages with strategies that reduce the cooling load

| STRATEGIES TO REDUCE THE COOLING LOAD |
|---------------------------------------|
| Strategies | Usage Types / Application Systems | Advantages | Disadvantages |
| Natural Ventilation | Windows, Floor Gardens, Cross ventilation in interiors, Ventilation shafts, Wind bucket, Solar stack, Atriums, Eco cells | User comfort increases through natural ventilation. The amount of energy spent on the air conditioning system decreases. | Pop-up windows cause wind pressure in high-rise buildings. |
| Night Ventilation | Ventilation covers, Vents, Double skin facades, Box Windows | The structure of the building, which warms up during the day, is cooled with the outside air, which is at a lower temperature during the night, and the temperature of the structure during the day is reduced. | In cases where sufficient air velocity cannot be achieved, the energy load increases by using a fan. Global warming can degrade night ventilation performance. Performance decreases when the insulation is not on the outer wall (Yildiz, 2014) |
| Building Form / Geometry | Buildings / Facade Design | Determining appropriate geometry to prevent incoming sunlight provides passive protection from the sun. | |


**Table 2. Continue**

| Strategies               | Usage Types / Application Systems                  | Advantages                                                                                       | Disadvantages                                      |
|--------------------------|----------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------|
| **Direction**            | Buildings / Facade Design                          | The long facade of the building and the facades where the openings are intensely placed, in the direction of the active wind in the direction of the active wind, allow air circulation to occur with the effect of positive pressure and negative pressure. |                                                     |
| **Double Skin Facade**   | High rise buildings                                | By allowing natural ventilation, it reduces the cost of using HVAC systems. It provides sound insulation. Provides natural ventilation by allowing windows to be opened in high-rise buildings. | It causes overheating. It increases the cost of building. |
| **Solar Control Systems**| Building facades                                   | They protect the building from unwanted heat gains. They have the ability to redirect light or change its direction. They have anti-glare feature | The elements used on the exterior are affected by bad weather conditions. |
|                          | Building interiors                                 |                                                                                                    |                                                     |
|                          | In the buffer zones of double-skin facades         |                                                                                                    |                                                     |
| **Dynamic Facades**      | Building facades                                   | Energy savings in heating and cooling by managing the energy flow through the glass                  | It does not restrict unnecessarily natural daylight and outside scenery. |
| **Sky Gardens**          | Building interiors                                 | In tall high-rise buildings, sky-gardens, transition areas, balconies can be created to protect against the unwanted effects. | These spaces provide natural ventilation and illumination of interior spaces with glass doors that can be opened as well as shading function (Yeang, 1998). |
| **Cold Roofs**           | Building roofs                                     | Cold roofs covered with light colored surface protection elements cause 10-16 °C less heat on hot days. (Yeang, 2012). | High waterproofing is required. |
### Table 2. Continue

| Strategies                  | Usage Types / Application Systems                                             | Advantages                                                                                     | Disadvantages                                                                 |
|-----------------------------|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Using Insulated Glass       | Windows consisting of two or three layers of glass                            | Insulated glasses absorb daylight while reducing the heat of the sun. Blinds, film layer, etc. between glass layers. Solar shading elements are protected against contamination, thus, maintenance and cleaning costs are reduced. |                                                                                 |
| Using Reflective (reflective) Glass | On the outer glass facades of buildings, especially in office buildings         | It has high performance in terms of solar control.                                             | They increase the need for artificial lighting                                 |
| Using Coated Glass          | On the outer glass facades of buildings, especially in office buildings          | They reduce reflection on the glass surface. Light transmittance can be controlled according to the thickness of the coating. | They can increase the need for artificial lighting depending on the thickness of the coating. |
| Using Colored Glasses       | On the outer glass facades of buildings, especially in office buildings          | This type of glass has the ability to absorb all short-wave rays in different proportions depending on the color and thickness of the glass. | They increase the need for artificial lighting                                 |
| Using photochromic glasses  | On the outer glass facades of buildings                                       | Light transmittance varies depending on the amount of light on it. It is suitable for providing visual comfort by preventing glare. | Absorption increases and transmittance decreases when the amount of light increases. Artificial lighting requires in the space. |
| Using of thermo chromic glasses | On the outer glass facades of buildings                                       | While it is transparent in the cold, its transparency decreases and its reflective properties increase when the temperature increases. | A non-homogeneous color distribution is formed. The decrease of the light transmittance of the glass also eliminates the duty of the window to provide visual relation with the external environment. Cost is high. |
Table 2. Continue

| Strategies              | Usage Types / Application Systems | Advantages                                                                 | Disadvantages                                                                 |
|-------------------------|----------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Using electrochromic glasses | On the outer glass facades of buildings | Depending on the applied voltage, they change from color to medium and completely colorless. | They react slowly. Their lifetime is short. The costs are high. They can cause glare. |
| Using gazochromic glasses     | On the outer glass facades of buildings | Hydrogen is introduced between the glass layers to color the glass when the temperature rises and combined with oxygen to return the transparency to its original state. | In the colorful case, the daylight indoors decreases.                        |
| Using photovoltaic glasses   | On the facades in the direction of the sun, Roofs, On blinds that can move with the sun. | They provide effective sun protection.                                       | Cost increase.                                                               |
| Using light shelves         | On the inner or outer surface of the window | While protecting the area near the window in sunlight from sunlight, reflected light reflects from the ceiling and illuminates the depths of the room. By reducing the intense daylight level in the areas in front of the window, glare is prevented and visual and thermal comfort is provided. |                                                                 |
| Planting                  | Interiors of the building, Floor gardens, Balconies, Courts and terraces | It minimizes the glare that will occur in the building while shading the interior and exterior walls of the building. In temperate climates, deciduous trees provide excellent shade in summer and maximum solar heat gain in winter. | Expected shading cannot be achieved if it is not selected according to the climate type. Place selection should be made without increasing artificial lighting. |

4. Examination of Cooling Strategies On Applied Samples
In the study, contemporary and pioneering building examples (3 building examples) that have been implemented and accepted as a sustainable and ecological structure have been determined. Other parameters that are effective in determining the samples are that all the facades of the building are glass, high-rise office use, and at least one of the cooling strategies specified in Table 2. should be used.
Table 3. Cooling strategies of solaris building.

| SOLARIS BUILDING | Sample 1 |
|------------------|----------|
| Use of the building | Office Building |
| Architect of the building | Ken Yeang |
| Location of the building construction date | Singapore −2008-2011 |
| Number of floors of the building | 18 |
| Definition of the facade used in the building | Type: Single Skin Facade |
|                  | Building Facade Number:4 |
| **COOLING STRATEGIES USED** | |
| **Roof gardens and corner sky terraces** | It acts as a buffer between the outdoor and the indoor, preventing the interior from overheating. |
| **Atrium** | The naturally ventilated atrium ensures that the indoor environments in the building get daylight. The atrium can be opened, covered with movable, sun-protected glass blinds. |
| **Light Shaft** | Natural daylight can reach the depths of the building. Offices are ventilated from the terraces facing the light shaft. |
| **Using (Low-e) glass** | Double layer Low-e glass (Low emission) is used. |
| **Solar Control Systems** | Fixed solar shades used on the exterior also serve as a light shelf, their structure and depth have been designed taking into account the solar orbit |
| **Planting** | Planting on the terrace provides shading |
| **Building Form** | The project is comprised of two tower blocks separated by a grand naturally-ventilated central atrium. Office floors are linked by a series of sky bridges which span the atrium at upper floors. |
Solaris has been certified BCA Green Mark Platinum, the highest possible green certification granted by Singapore’s sustainable building benchmark (eg. LEED, GBI, Green Star, BREEAM, etc.). The building’s overall energy consumption represents a reduction of over 36% compared to local precedents and the high performance façade has an External Thermal Transfer Value (ETTV) of 39 W/m². [4] Night lighting is not required due to the office building. The photovoltaic panels (active system) used in the building support passive systems in reducing the cooling load.

Table 4. Cooling strategies of city hall.

| CITY HALL | Sample 2 |
|-----------|----------|
| Use of the building | Office Building |
| Architect of the building | Norman Foster |
| Location of the building construction date | London−1998-2002 |
| Number of floors of the building | 10 kat |
| Definition of the facade used in the building | Type: Single Skin Facade |
| Building Facade Number:4 |
| **COOLING STRATEGIES USED** | |
| **Direction** It is located in the south-north plane. In London, there is almost no sunlight coming to the north facing surfaces, although the sunlight and heat coming from the south is high in summer. | |
| **Building Form** Building form has been shifted step by step to the south in order to prevent sunlight from the south and the floors to provide shade to each other. | |
| **Solar Control Systems** User controlled venetian blinds are available on the facades | |
| **Natural Ventilation** East, west and south facade windows are openable and there are culverts in the entire building vent that can be controlled by building automation. When the vents are opened, heating and cooling systems are disabled and passive ventilation of the building is ensured. | |
| **Using coated an colored glasses** Depending on the orbit followed by the sun Clearly green color coating was applied to the 9th floor glasses that see west, east and south directions. Over 75% of the building glasses were made with silver aluminum coating to prevent unwanted overheating. | |
The combination of these energy-saving cooling strategies eliminates the need for mechanical chillers and reduces the annual energy consumption of the building’s mechanical systems by approximately 25% that of a typical office building. [5]

Table 5. Cooling strategies of tekfen oz office building.

| COOLING STRATEGIES USED | Sample 3 |
|-------------------------|----------|
| **Planting** | The skin consisting of these plants used in the building is designed as a skin sub-element whose density and dimensions vary according to the facades. Shading is provided on the south and west facades by increasing the density and height of the plants. |
| **Using Double Skin Facades** | This system provided natural ventilation with the opening windows. |
| **Using Low-e Glass** | Solar Low-E Glass is used on the facade. |
| **Solar Control Systems** | There are fixed sun shades designed as part of the facade. |

5. Conclusions
Energy efficient facade design, which gains importance in response to rapidly increasing energy requirements, makes it necessary to find solutions to the overheating problem, which is the disadvantage of transparent facade systems. Architectural design decisions that play a decisive role in the energy performance of transparent facade systems and which should be taken into consideration at the beginning of the design are of great importance. Climate data surrounding the building in the transparent facade design is one of the most important parameters affecting the energy performance of the building. On the facades designed independently from the climate data; heat gains from the sun cause overheating in the summer, which increases cooling loads. In summer, the location of the building is of great importance, especially in determining the heating and cooling energy. The design of the building geometry and the transparent facade system shaped according to this geometry is an
important architectural design decision that affects energy performance. Regardless of the solar movements and the wind, the design of a building facing in every direction with a similar character brings problems in this context. Although the double-skin facade design allows natural ventilation in high-rise buildings, the problem of overheating caused by the hottest period is an issue to be questioned. It can be seen that over-heating problem, which is accepted as a big disadvantage, can be prevented by choosing suitable glass and solar control systems on transparent facade surfaces. Various variations can be derived with the combination of design parameters to reduce the cooling load in transparent facade design. Many strategies can be used together. However, the determined cooling strategies should be comprehensively studied at the design stage based on experiments or simulations.

When applied good examples are analyzed, the presence of passive cooling techniques that come with the design provides great benefits in the cooling loads of transparent facades.

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