Sustainable Buildings with Their Sustainable Facades

Özlem Eren and Banu Erturan

***Abstract*—The intelligent facade reduces the primary energy consumption of a building, use of natural, renewable energy sources, such as solar radiation, air flows and creates a comfortable environment for the occupants. For that reason ecological intelligent facade can be defined as changing light and weather conditions using self- regulating thermal protection and solar control measures. Considering that energy consumption is one of the foremost issues of our time, energy-saving measures have become of vital importance. This particularly applies to buildings, since the amount of non-renewable energy resources they consume is considerably higher than in other areas of consumption. The energy consumption level of a building is contingent on that building's specific structure as well as the thermal properties of the building and its environment, the climatic conditions prevailing at the building's location, the times when the building is used, and the specifications of the systems employed for heating and cooling. A building skin design tuned to energy-efficiency criteria allows both conservation and generation of energy. In addition, by employing renewable energy resources for heating, cooling, and lighting, it contributes to reduced use of depletable energy resources, accounting for the responsibility towards the global community. Energy-efficient facade design, which starts with decisions at a building's initial design stage, directly affects a whole array of factors, including the choice of system. This study focuses on those parameters and alternatives for energy-efficient building skin design that support the concept of ecological building, and presents practical examples for feasible systems. In this study ecological building skins will be classified as single skin facades, double skin facades (Corridor facades, building high double skin facades, building high controllable double skin facades, box windows) and combined facades.**

***Index Terms*—Intelligent facades, architecture, technology**

I. INTRODUCTION

Sustainability is a term that has become an integral part of our vocabulary. By this word we understand the protection of the ecosystem through protection of its resources. The economic sustainability of buildings can be divided into two parts: the investment, which in the case of buildings and buildings stocks should be considered as long term resource productivity problem, and the running costs. Instead of minimizing the investment cost through low cost highly customized solutions, it is preferable to find for a given investment the solution which has the highest durability and reusability. Solutions which can be repaired and used in several ways have the highest long term potential. On the other hand, solutions with low energy consumption, easy to clean, to operate and easy to maintain have generally low running costs (and a feasibly low environmental impact at the same time). The social and cultural aspects of sustainability include comfort, wellbeing and safety of the building occupants. Human health protection, which is often wrongly associated with protection of the ecosystem, is in fact much more closely related to comfort problems (indoor air quality, etc.). The protection of cultural resources, above all building stocksand historic urban systems, protected biotopes and man-made landscapes gives a common framework for architecture, city planning, regional planning and landscape architecture. Environments which have a high cultural and social quality do not become obsolete [1], [2].

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II. THE DESIGNING OF INTELLIGENT FACADES

Facades are crucial to energy consumption and comfort in buildings. Incorporating intelligence in their design is an effective way to achieve low energy buildings. Three strategies are examined: the first is dependence on active systems and element performance, the second implements intelligent passive design strategies only, while the third combines passive design strategies with early integration of active elements. Their impact on energy performance and visual comfort are compared. A design tool that suggests good starting solutions is presented, which takes into account how architects work during conceptual phases [2], [3].

According to Wıggıngton and Harris the study of examples of building intelligence showed that the façade was performing up to different functions, which influenced the passage of energy from both external environments to the internal environment, and the other way around. The manipulating functions were idenfied as;

The enhancement of daylight (e.g. light shelves/reflectors)

1) The maximization of daylight (e.g. full-height glazing/atria)
2) Protection (e.g. louvres/blinds)
3) Insulation (e.g. night-time shutters)
4) Ventilation (e.g. automatic dampers)
5) The collection of heat (e.g. solar collectors)
6) The rejection of heat (e.g. overhangs/brise soleil)
7) The attenuation of sound (e.g. acoustic dampers)
8) The generation of electricity (e.g. photovoltaics)
9) The explotation of preassure differentials (e.g. ventilation shimneys) [4]-[6].

In 1981, working for Richard Rogers ans Partner, Mike

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Davies already formulated the idea of polyvalent wall in his article titled "A wall for all seasons".

Here, several functional layers within a glass element were to provide sun and heat protection, and to regulate the functions automatically according to current conditions [5].

III. The Classification of Intelligent Facades

Intelligent façade types are single façade, double facade and combination of these systems (Table I).

TABLE I: THE CLASSIFICATION OF INTELLIGENT FACADES

1. SINGLE SKIN FACADES	Perforated facades
	Elemental facades
2. DOUBLE SKIN FACADES	Corridor facades
	Building high double skin facades
	Building high controllable double skin facades
	Box windows
3. COMBINED FACADES	Alternating facades
	Baffle Panel Facades

A. Single Skin Facades

To achieve a certain level of solar control in a single skin façade, coating can be applied to the glass, such as infrared reflecting coatings and/or coatings to absorb and reflect wavelengths in the visible range (Fig. 1) [1], [7], [8], [9].

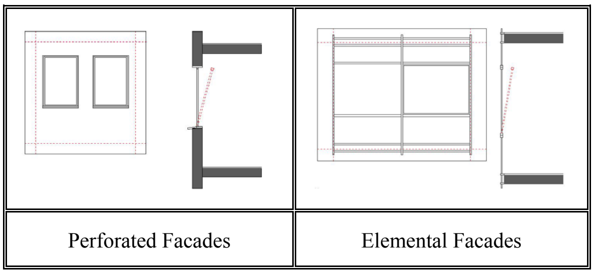


Fig. 1. Examples of perforated facade and an elemental facade [2], [4].

1) Perforated facades (Table II)

Perforated walls, panels and screens have been used for centuries as a way to control the level of light entering a building or to offer privacy to the occupants. The functions of perforations have remained largely the same, but the materials and methods of manufacture have altered considerably [10], [11].

2) Elemental facades (Table III)

To achieve a certain level of solar control in a single- skin façade, coatings can be applied to the glass, such as infrared-reflecting coatings and/or coatings to absorb and reflects wawe lenghts in the visible range. As their properties are fixed, they also restrict solar gain in the colder months and reduce dayligting levels [3].

B. Double Skin Facades

The term double skin facade refers to an arrangements with a glass in front of the actual building a facade. Solar control devices are placed in the cavity between these two skins, which protects them from the influences of weather and air pollution, a factor of particular importance in high rise buildings or ones situated in the vicinty of busy roads. A further advantages of the double facade is the solar shading it affords in the summer. As reradiation from absorbed solar radiation is emitted into the intermadiate cavity, a natural stack effect result, which causes the air to rise, taking with it addiitonal heat. Computer simulation and test have shown that natural air circulation can reove up to %25 of the heat resulting from solar radiaition in the cavity.Genarally, given appropriate panes and solar control devices, g-values of proximately 0.10 can be achieved. As the temperature of the air increases a sit rises upwards., it is usual to restict the height of the continous opening to two or three floors. Technical considerations concerned with fire protection and acoustic insulation also play a role. The reduction of wind pressure by the adiditon of the extra pane of glass means that the windows can be opened even in the uppermost floors of a high rise builidngs. Natural ventilation of officies by fresh air is much more acceptable to the builidng's users an dit has the adiditonal benefits of reducing investments in air handling systems and also reducing Energy consumption. A double skin facade also reduces heat loses because the reduced speed of the iar flow and the increate temperature of the air in te cavity lowers rate of heat transfer on the surface of the glass. This has the effect of maintaining higher surface temparatures on the inside of the glass, which in turn means that the space closet o the window can be bettwe utilised as a result of increate thermal comfort conditions. Energy frm the echaust air stream using a heat exchanger (Fig. 2) [1].

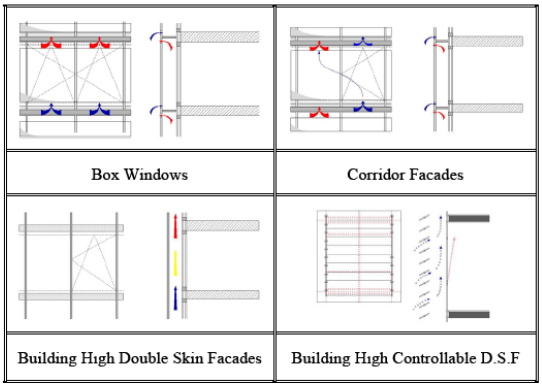


Fig. 2. Example of double skin facades [2], [4]

1) Box windows (Table IV)

The box window is probably the oldest form of a two layered façade. Box windows consist of a frame with inward-opening casements. The single glazed external skin consists openings that allow the ingress of fresh air and the egress of vitiated air, thus serving to ventilate both the intermediate space and the internal rooms. The cavity between the two façade layers is divided horizontally along the constructional axes, or on a room-for-room basis. Vertically the divisions occur either between stories or between individual window elements. Continuous divisions help to avoid the transmission of sounds and smells from bay to bay and from room to room. Box type windows are commonly used in situations where there are high external noise levels and where special requirements are made in respect of the sound insulation between adjoining rooms. This is also the only form of construction provides these functions in facades with conventional rectangular openings. Each box window element requires its own air intake and extracts openings, which have to be considered when designing the outer façade [9].

TABLE II: DESIGN CRITERIA OF PERFORATED FACADES [2], [4]

Construction	-Structural facade -Reinforced concantre -Masonry -Timber-stud construction	*Typical Applications*	-Administration buildings -Residential buildings -Low wind-speed locations
Room climate in summer	-Smaller proportion of window area -External solar scrrening exposed to wind -Thermal storage mass available with solid construction	*Sound insulation*	-Poor sound insulation with window ventilation -Good sound insulation with closed windows -Little sound transmission from room to room by the façade
Heating energy demand	-Low U-values -High surface temperatures at facade inner side -Few problems from heat bridges -Low solar gain	*Daylight*	-External glare protection -Possible dark room corners -Usually window lintels -Deeper window reveals -High light transmission through glass
Ventilation	-Thermal discomfort in winter ($T_a < 5$ C°) -Heat entry in summer ($T_a > 24$ C°) -Wind force in window -No transmission of odour from room to room	*Functional aspects*	-Direct view out -Low cleaning cost -Low maintenance cost -Difficult to modify or retrofit
Advantages	-Good sound insulation with closed windows -Direct view out -Low cleaning cost -Low maintenance cost	*Disadvantages*	-Natural ventilation may be unconfortable -External solar screening exposed to wind

TABLE III: DESIGN CRITERIA OF ELEMENTAL FACADES [2], [4]

Construction	-Non-load bearing, additional supports need inside room -Elemental, prefabricated construction -Mullion and transom construction	*Typical Applications*	-Administration buildings -High-rise buildings with mechanical ventilation -Low wind-speed locations -Low noise-load locations
Room climate in summer	-Usually high proportion of window area -External solar screening exposed to wind -No thermal storage mass	*Sound Insulation*	-Little sound transmission from room to room -Poor sound insulation with open windows
Heating energy demand	-U-value depends on glazing fraction, -Lower surface temperaturas at facade inner side -Heat bridges especially at frames opaque elements and between storeys	*Daylight*	-High proportions of window area is possible -High light transmission throught glass -Small window reveals
Ventilation	-Thermal discomfort in winter ($T_a < 5$ C°) -Heat entry in summer($T_a >$ 24 C°) -Wind force on window No transmission of odour from room to room	*Functional aspects*	-Poor thermal insulation -Lower surface temperatures at facade inner side -No noise reduction for ventilation -Solar screening difficult to incorporate
Advantages	-Can be prebaricated -Short construction time -Little space requirement	*Disadvantage*	-Poor thermal insulation -Lower surface temperatures at facade inner side -No noise reduction for ventilation -Solar screening difficult to incorporate

2) Corridor facades (Table V)

The corridor facade is a double-skinned facade in which the facade cavity is separated storey by storey with bulkheads. Air exchange in the facade cavity is eighter vertically at a floor level, horizontally at the corners of the building, or both vertically and horizontally. If the double skinned facade is ventilated horizontally it is often designed so as to be able to control the pressures in the facade cavity. In this way the facade flaps can be opened or closed depending on the desired pressure conditions (over-or underpressure), wind direction and speed. This allows specific pressure conditions to be set up in the building and the ventilation drive energy demand to be minimised. Facade corridors can transmit unwanted odours and sounds between rooms [4], [10], [11].

TABLE IV: DESIGN CRITERIA OF BOX WINDOWS [2], [4]

Construction	-In perforated facade -In elemental facade -Inner skin 2-pane insulation glazing -Inner skin single-pane insulation glazing -Distance between panes varies to suit the required function -Pane offset 10-50 cm	*Typical Applications*	- Administration buildings and residential buildings - High rise buildings with natural ventilation - For high wind speeds for high noise-load areas - Night cooling
Room climate in summer	-Wind protected solar screening -Overheating in the facade cavity -Night cooling	*Sound insulation*	-Comfortable ventilation in winter and in the transition months -Can be prefabricated -Suitable for renovation
Heating energy demand	-Transmission heat loss dynamic, dependent on the openings -Improvement compared to a single-skinned facade -Use of solar gain	*Daylight*	-Reduction of daylight by depth of facade -Reduction of natural light transmittance by second pane -Light direction systems may be installed in facade cavity
Ventilation	-Comfortable introduction of supply air in winter -Heated supply air in summer -No transmission of odour from room to room -Attenuation of wind effects Impairment of air exchange	*Functional aspects*	-Weather protection -Intruder protection -Limited view out -Difficult to clean outer face of facade -Possible condensation formation on outside glass pane
Advantages	-Comfortable ventilation in winter and in the transition months -Can be prefabricated -Suitable for renovation	*Disadvantages*	-Direct view out limited -Purge ventilation limited -Overheating in the facade cavity -High construction costs

TABLE V: DESIGN CRITERIA OF CORRIDOR FACADES[2], [4]

Construction	-Elemental facade -Distance between panes to suit the required function -Inner facades are often made of wood -Pane offset 20-120 cm	*Typical Applications*	-Administration buildings -High-rise buildings with natural ventilation -For high wind speeds for high noise-load areas -With aerodynamic ventilation concepts
Room climate in summer	-Wind-protected solar screening -Overheating in the facade cavity -Night cooling	*Sound insulation*	-Good noise reduction with natural ventilation -Transmission of sound from room to room
Heating energy demand	-U-value dynamic, depends on air exchange and insulation -Improvement compered to a single skinned facade -Possible use of solar gain -Possible movement of energy around the building	*Daylight*	-Reduction of daylight by depth of facade -Reduction of natural light transmittance by second pane -Integration of light redirection systems possible
Ventilation	-Comfortable introduction of supply air in vinter -Risk of summer overheating -Transmission of odorur from room to room Pressure conditions can be defined with suitable controls	*Functional aspects*	-Facade cavity can carry pedestrian traffic -increased space requirement -Intruder protection -Possible condensation formation on outside glass pane
Advantages	-Pressure conditions can be controlled -Natural ventilation is possible even under difficult outside conditions -Homogenous appearance to the facade	*Disadvantages*	-Overheating in summer -High construction cost -Limited view out -Transmission of sound and odour -High fire safety requirements

3) Building high double skin facades (Table VI)

Building high double skin facades the intermediate space between the inner and outer layers is adjoined vertically and horizontally by a number of rooms. In extreme cases, the space may extend around the entre building without and intermediate divisions. The ventilation of the intermediate space occurs via large openings near the ground floor and the roof. During the heating period, the façade space can be closed at the top and bottom to exploit the conservatory effect and optimize solar energy gains. Building high double skin facades are especially suitable where external noise levels are very high, since the type of construction does not necessarily requires openings distributed over its height. As a rule, the rooms behind building high double skin facades have to be mechanically ventilated, and the façade can be used as joint air duct for this purpose. As with corridor facades, attention should be paid to the problem of sound tranmission within the intermediate space [7]-[9].

TABLE VI:DESIGN CRITERIA OF BUILDING HIGH DOUBLE SKIN FACADES[2], [4]

Construction	-In front of perforated facades -In front of elemental facades -Distance between skins varies to suit to required function -Outer skin can be self-supporting -Panel offset 1-5 m	*Typical Applications*	- Administration buildings, residential buildings in high noise-load areas - Building with mainly mechanical ventilation - İn building renovation, heritage buildings
Room climate in summer	-Wind-protected solar screening -Unwanted heat entry from severe overheating in the facade cavity -Can provide night cooling	*Sound insulation*	-Very good noise reduction with natural ventilation -Transmission of sound from room to room
Heating energy demand	-U-value dynamic, depends on air exchange and insulation -Formation of a climatic buffer zone -Possible use of solar gain	*Daylight*	-Reduction of natural light transmittance by the second glass skin and construction of the outer skin -Diffuse light admitted by the arrangement of solar screening on the outer skin
Ventilation	-Comfortable introduction of supply air in winter -Considerable risk of summer heating -Transmission of door from room to room -Can be incorporated into the ventilation concept Mechanical ventilation is normally required	*Functional aspects*	-View out limited depending on offset -Increased space requirement -Intruder protection -Cavity useable if offset large -Possible condensation formation on outside glass pane
Advantages	-Very good noise reduction -Natural ventilation is possible even under difficult outside conditions -Homogenous appearance to the facade -Can be simply retrofitted	*Disadvantages*	-Considerable summer overheating -High construction costs -Severely limited view out -Transmission of sound and odour -High fire-safety requirements

4) Building high controllable double skin facades (Table VII)

The building high controllable double skin façade is very similar multi-storey ventilated double façade. Indeed its cavity is not partitioned either horizontally or vertically and therefore forms one large volume. Metal floors are installed at the level of each storey in order to allow access to it, essentially for reason of cleaning and maintenance. The difference between this type of façade and the building high controllable double skin façade lies in the fact that outdoor façade is composed exclusively of pivoting louvers rather than a traditional monolithic façade equipped (or not) with openings. This outside façade is not airtight even when the louvers have all been put in closed position, which justifies its separate classification [6], [12], [13.].Building high controllable double skin facades are divided to horizontally and vertically for ventilating and for cleaning aims.

TABLE VI: DESIGN CRITERIA OF BUILDING HIGH CONTROLLABLE DOUBLE SKIN FACADES [2], [4]

Construction	-Elemental facade -Variable opening of angle outer skin -Many moveable parts required -Panel offset 30-120 cm	*Typical Applications*	Administration buildings High-rise buildings with natural ventilation Higher noise-load locations Front curtain wall in building refurbishment
Room climate in summer	-Wind-protected solar screening -Overheating of the cavity avoided by opening the outer skin -Can provide night cooling	*Sound insulation*	Very good noise reduction depending on the setting of the ventilation flaps Little noise reduction with open facade Possible transmission of sound from room to room
Heating energy demand	-U-value dynamic, depends on settings of the ventilation flaps and insulation -Formation of a climate buffer zone -Possible use of solar gain	*Daylight*	Reduction of natural light transmittance in the depth of the room Reduction of natural light transmittance by the second glass skin and construction of the outer skin
Ventilation	-Comfortable introduction of supply air in winter -Little risk of overheating in summer -Possible transmission of door from room to room Less noise reduction when ventilation flaps opened	*Functional aspects*	Direct view out depending on ventilation flap setting Increased space requirement Very high maintenance costs High cleaning costs".
Advantages	-Variable facade settings -No overheating in summer -Improvement of view out possible -Can be controlled to adjust to outside climate	*Disadvantages*	Very high construction costs Very high maintenance costs High technical costs

C. Combined Facades

This type of facade, is a combination of single and double skinned facades (Fig. 3)

1) Baffle panel (Table VIII)

A baffle panel is an additional panel that is fixed a short distance in front of a window in a perforated or an elemental facade. It is means of minimizing the disadvantages of single skinned facades with respect to sound insulation and ventilation. Baffle panels also provide protection to solar screening, allowing it to be operated in almost any wind conditions. They are simple to incorporate and offer reliable protection against weather and intruders during night cooling. Baffle panels restrict the user's view out only to a limited extent. The effective cross-section for ventilation may be considerably reduced if the gap between the baffle panel and the facade is too small [4], [14].

TABLE VII: DESIGN CRITERIA OF BAFFLE PANEL FACADES [2], [4]

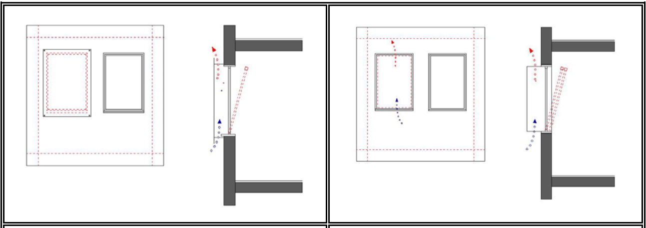
Construction	-In front of perforated facade -In from of elemental facade -Size and distance of the baffle panel depends on the desired function -Panel offset 5-25 cm	*Typical Applications*	- Administration buildings, residential buildings - High-rise buildings with natural ventilation - Medium wind-speed locations - Higher noise-load locations
Room climate in summer	-Very little sound transmission from room to room -Improved noise reduction with natural ventilation	*Sound insulation*	-Cost-effective way of optimizing a facade -Can be retrofitted -Simple night cooling -Little overheating in summer
Heating energy demand	-Transmission heat loss dynamic, depends on panel offset and insulation -Little improvement on single skin facades -Little reduction of solar gain	*Daylight*	-Reduction of natural light transmittance by second pane -Possible integration of light-related functions into the baffle panel
Ventilation	-Comfortable introduction of supply air in winter -Increased entry of heat in summer -No transmission of door from room to room -Attenuation of wind effects Possible impairment of air exchange	*Functional aspects*	-Possible limited purge ventilation -Weather protection -Intruder protection -View out restricted -Difficult to clean outer face of facade
Advantages	-Cost-effective way of optimizing a facade -Can be retrofitted -Simple night cooling -Little overheating in summer	*Disadvantages*	-View out restricted -Purge ventilation limited

TABLE VIII:DESIGN CRITERIA OF ALTERNATING FACADES [2], [4]

Construction	-In perforated facade -Elemental facade -Area proportions and panel offsets varied to suit the required function -Panel offset 10-30 cm	*Typical Applications*	- Administration buildings, residential buildings - High-rise buildings with natural ventilation - High wind speeds high noise-load areas
Room climate in summer	-Wind-protected solar screening -Possible unwanted entry of heat from overheating in the facade cavity -Purge ventilation at high temperatures	*Sound insulation*	-Additional sound level reduction with natural ventilation -Very little sound transmission from room to room

2) Alternating facades (Table IX)

Alternating facade is a combination of single and doubleskinned facades with the advantages of both. In each room there is at least one element of each type. Depending on the outside and inside climate conditions, ventilation can be provided through the single or double skinned facade to ensure confortable conditions in the room almost any time of year. If the surface area of single skinned facade is small it can be also fitted with internal solar screening [4], [15], [16].



Baffle Panel	Alternating Facades

Fig. 3. Examples of a baffle panel and an alternating facade [2], [4]

TABLE IX: DESIGN CRITERIA OF ALTERNATING FACADES [2], [4]

Construction	-In perforated facade -Elemental facade -Area proportions and panel offsets varied to suit the required function -Panel offset 10-30 cm	*Typical Applications*	- Administration buildings, residential buildings - High-rise buildings with natural ventilation - High wind speeds high noise-load areas
Room climate in summer	-Wind-protected solar screening -Possible unwanted entry of heat from overheating in the facade cavity -Purge ventilation at high temperatures	*Sound insulation*	-Additional sound level reduction with natural ventilation -Very little sound transmission from room to room
Heating energy demand	-U-value dynamic, depends on propotion of double-skinned facade and entry of solar radiation -Only a slight improvement compared with a single-skinned facade	*Daylight*	-Reduction of daylight by depth of facade -Reduction of natural light transmittance by second pane -Uneven room lighting -Light redirection systems may be installed in facade cavity
Ventilation	-Comfortable introductions of supply air in winter -Direct ventilation in summer -No transmission of odour from room to room Attenuation of wind effects	*Functional aspects*	-Flexible user intervention possible -Uneven effects in room -Possible increased space requirement -Difficult to clean outer face of façade
Advantages	-Very high user-acceptance -Very good level of comfort -Many ventilation options -Can be prefabricated	*Disadvantages*	-High construction costs

IV. CONCLUTION

Because of reduction energy resources and increasing cost in the world every day, energy conservation in buildings primarily focused on building systems. After 1990, targeting the energy crisis, which can produce its own energy, ventilation, heating and cooling that provides "intelligent facades" came up. Many researches have been done about efficient using energy in building industry. The research consist of heat loss and gains on builidng envelope and also energy consumption. Basic features of energy efficient building envelope are as follows;

Use of optical properties of glasses,

Use of double facades which hot and cold air circulation between the layers of glass facades, and the use of transparent insulation materials,

Use of active and passive solar energy systems.

The degree of user control which may or may not coincide with improving actual comfort conditions or energy efficiency, must be reconciled with building management

Use of high-performance coating, heat mirror glass types systems that may more rigidly control these factors.

Conventional curtain wall systems considering only the cost of desıgn crıterıa of alternatıng facades [4].

One of the researches which undert the mnema of intelligent facades is double facades. The aim of this facades is masimize of energy efificiency, decreaese of energy lose. Double skin facades on building, are arelaive new technolologies in constructon field. This façades are significantly more expensive to install than the installed facade. This research is increasing everyday and it will also increase rapidly in the future.

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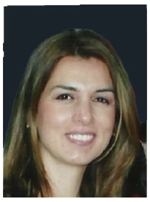

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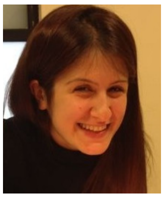

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