The model of designing solar wall for optimizing the use of daylight and energy focused on movable design in an office building

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Abstract: Despite the first world countries, considering the state of optimized application of solar light and energy in the buildings has become more prevalent in Iran due to the increase of energy cost such as gas and electricity in recent years. The purpose of designing a solar wall is to combine thermal comfort and day lighting strategies by applying movable design in two elements of the façade, walls and windows. It is assumed that the maximum use of daylight approaches need to be integrated with strategies of applying sun heat in such an effective procedure that while maintaining the advantages of daylight into the building, reduce the possible adverse consequences of sunlight such as overheating. The significance of achieving a balance between thermal comfort and daylight for improvement of efficiency and productivity of the employees in an office building has been studied. An office building in Tehran has been designed and by emphasizing on zoning in plan and façade, solar wall with unglazed materials and movable louvers (as an movable insulation for summer) and double glazed windows filled with polystyrene beads as a movable insulation have been used to reduce the energy consumption of the building. The design has been simulated with Design Builder software to calculate the summer and winter energy savings.
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Introduction

Energy crisis and finite fossil sources in addition to Environmental problems caused by fossil fuel consumption, motivated countries to reduce consuming energy, increase the use of renewable energies and provide innovative solutions to optimize energy consumption, especially in the buildings which the most energy in the countries is dedicated to them. Perhaps one of the reasons of high consumption of energy which leads in negligence of applying saving solutions is the energy cost. One of the considerations would be an architectural design in which combining modern and old architecture leads to the better usage of energy. Office buildings in Iran have no discernible pattern to provide thermal comfort and this causes dissatisfaction and inefficiency in employees. Also not applying a specific thermal comfort condition in these buildings leads to improper thermal condition like over heating or over cooling which it is of a reason of consuming more energy. Since the amount of sunlight in Tehran is good and enough, it is optimal to use renewable sources of energy particularly sunlight in large-scale buildings with high consumption of energy like offices. The goal of this article is to create a new vision and approach to the design of the façade and a study on energy savings only by designing the southern facade in Tehran. The result of this research which is based on movable design could lead in providing thermal and visual comfort and optimizing the use of daylight and energy.

Necessity of considering office buildings

The official buildings in Tehran are ill buildings in planning. Most of them are made of curtain walls with no attention to energy supply. Glass is a structural element with a high heat transfer coefficiency which causes the most loss of energy. The uncontrolled daylight in the building may also cause adverse effects such as loss of thermal and visual comfort. With a simple field study in seven office buildings in Tehran and in 12 office spaces with different layouts remarkable results obtained. According to statistics, the majority staffs of seven office buildings specially the people who work at a desk near the window have no adequate consent of their visual and thermal comfort. For a closer look, it is tried to select the office rooms with nearly identical dimensions (20-28m^2) and to prevent the effect of the heating and cooling systems the samples are gathered in the first two weeks of the fall with mechanical systems turned off. To ignore the clothes coefficiency, selectees (all in the range of the age 20-30s) were wearing approximately the same autumn clothes. People replied the questionnaire depending on the information they had in that period.

To adjust the study condition to the obtained statistics, the schematic plan of each of the office rooms are given in the tables. (1, 2, and 3).

Table 1. Comfort field studies for office spaces (All the diagrams are schematic and they are off-scale. (Shaded areas are corridors)

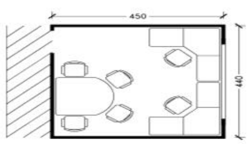
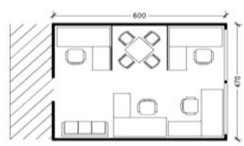
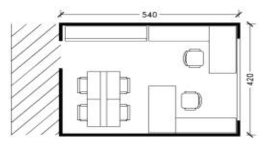
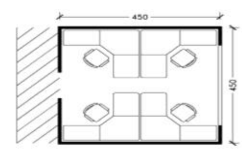
19.80	Office space Area (m^2)	28.2	Office space Area (m^2)	22.68	Office space Area (m^2)	20.25	Office space Area (m^2)
8h	Average hours during the day	9 h	Average hours during the day	8h	Average hours during the day	8h	Average hours during the day
6	Number of people	4	Number of people	8	Number of people	15	Number of people
6	The number of persons next to the exterior wall	2	The number of persons next to the exterior wall	8	The number of persons next to the exterior wall	8	The number of persons next to the exterior wall
1	Number of persons with thermal comfort	1	Number of persons with thermal comfort	0	Number of persons with thermal comfort	8	Number of persons with thermal comfort
3	Number of persons with visual comfort	2	Number of persons with visual comfort	4	Number of persons with visual comfort	11	Number of persons with visual comfort
							

Table 2. Comfort field studies for office spaces

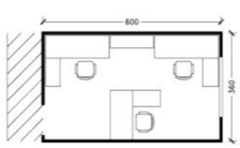
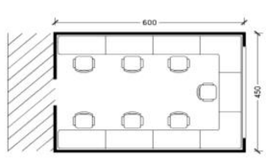
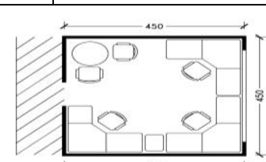
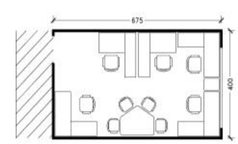
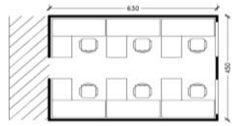
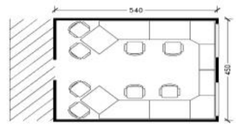
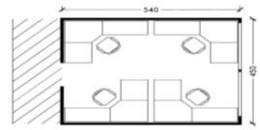
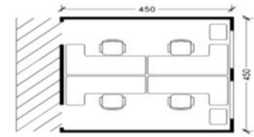
21.60	Office space Area (m^2)	27	Office space Area (m^2)	20.25	Office space Area (m^2)	27	Office space Area (m^2)
8.30h	Average hours during the day	8h	Average hours during the day	9h	Average hours during the day	8h	Average hours during the day
11	Number of people	18	Number of people	9	Number of people	20	Number of people
7	The number of persons next to the exterior wall	2	The number of persons next to the exterior wall	6	The number of persons next to the exterior wall	8	The number of persons next to the exterior wall
6	Number of persons with thermal comfort	10	Number of persons with thermal comfort	3	Number of persons with thermal comfort	9	Number of persons with thermal comfort
8	Number of persons with visual comfort	12	Number of persons with visual comfort	3	Number of persons with visual comfort	12	Number of persons with visual comfort
							

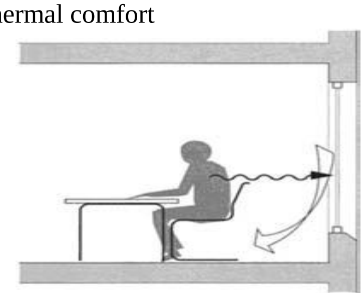
Table 3. Comfort field studies for office spaces

28.35	Office space Area (m^2)	24.30	Office space Area (m^2)	24.25	Office space Area (m^2)	20.25	Office space Area (m^2)
9h	Average hours during the day	9h	Average hours during the day	9h	Average hours during the day	8h	Average hours during the day
18	Number of people	12	Number of people	8	Number of people	14	Number of people
6	The number of persons next to the exterior wall	6	The number of persons next to the exterior wall	4	The number of persons next to the exterior wall	8	The number of persons next to the exterior wall

8	Number of persons with thermal comfort	3	Number of persons with thermal comfort	3	Number of persons with thermal comfort	7	Number of persons with thermal comfort
9	Number of persons with visual comfort	10	Number of persons with visual comfort	3	Number of persons with visual comfort	9	Number of persons with visual comfort
							

According to the above tables 143 of employees of the seven office buildings with the average of 8 working hours which is approximately equivalent of a day time are being studied and of these, half of the subjects (71 persons), spending their working time next to the exterior wall due to their desk location. Although they have expressed their satisfaction from having outdoor view, none of them felt thermal comfort. (Picture 1)

Picture1. Radiative heat losses next to the window reduce the thermal comfort



In some hours of the day when the sun angle changes, depending on the layout of the desks, the glare would cause people to use curtains and blinds which also block the exterior view. According to the statistics, in all of the studied office spaces the artificial light is being used during the day and in majority of the times the blinds are down. From the people subject of the study, only 38% feel thermal comfort. This rate in visual comfort increases up to 60% due to the use of artificial light.

The study shows that providing thermal comfort is the first and the most significant issues in an office space. The reason of selecting an office for the solar façade design is that employees almost spend half of the useful hours of their life in the working environments. The period of using these spaces are exactly the time that solar energy is available for space heating. In other words the times in the day that solar heat cannot be used, office buildings are also vacant and therefore due to the simultaneous use of these buildings with availability of the sun heat and light, the necessity to use renewable sources of energy in offices rather than residential buildings is revealed. Applying a proper insulation in the nights can also save the gained energy during the day and prevent the heating and cooling system to work.

Summary of reasons for choosing an office building to design a solar facade

- Dissatisfaction of the majority of the employees from the physical condition of their working environment, especially thermal comfort
- Prevalence of sick building syndrome in office centers in Iran
- Discontinuous use of the office buildings unlike residential zones along with the availability of the solar energy during the working time
- The significance and necessity of considering thermal and visual comfort on employees' efficiency and health during the day
- Extensive use of glass element in the office building facades in the world which has a high heat transfer coefficient

The significance of thermal comfort in office buildings

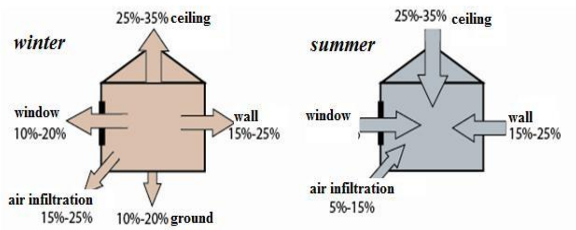
Studies have shown that dissatisfaction with the thermal heat or cold is the most common complaints in office buildings. Designers need standards for providing thermal comfort in the indoor environments. The suitability of indoor temperature for occupants not only provides thermal comfort but also saves energy, enhances the efficiency and health, improves staff morale and reduces the costs. Environmental factors such as humidity and heat resources in the workplace in combination with personal factors like clothes and amount of physical work will affect thermal comfort therefore the definition of thermal comfort seems to be complicated and instead thermal preference is a better substitution.

Since thermal comfort is a psychological issue, it may affect the overall employees' morale, Complaints can be increased, productivity would be dramatically reduced and in some cases people may avoid working in a specific environment which does not provide their thermal preference conditions. Overheating in a working place may lead to drowsiness and overcooling can brings lethargy and numbness in the occupants. Some thermal aspects of the environment like temperature, humidity, radiant heat and air movement may help to identify the symptoms of sick building syndrome.

The significance of visual comfort in office buildings

It is now generally believed that the increase in productivity is directly related to the design office environment. Work place should receive as far as possible sufficient natural light and to protect the health and safety of employees, the facility should be equipped with artificial lighting. The suggestive ratio of the artificial light to natural light in a long-term work is 1:5. The most effective way of providing light is to use daylight as a source because even the best incandescent lamp in compare to the daylight for providing a certain amount of illumination, requires a greater amount of energy per square meter and generates a greater degree of heat. Daylight is very important for human being and his health. Although this light is not constant, reliable and uniform but it's available in a large amount and for free. The best understanding of the advantages and disadvantages of the daylight would result in the best application of it. Vision, health, mood, productivity and efficiency may all be under the influence of the proper light. Eyestrain, blurred vision, dry eyes, eye irritation, headache, neck and shoulder pain, non concentration and stress are all can be the adverse effect of a poor light. Although in designing to use daylight, avoiding glare in hours of the day should be considered.

Designing a façade includes designing the wall, the windows and the curtain wall which will be explained separately in next parts.



Picture2. Heat loss in summer and winter

Solar wall

Introduction and History

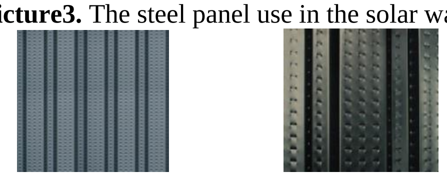
The solar wall air heating technology has always generated an impressive economic return for commercial & industrial buildings due to its high efficiency & low capital costs. It has been primarily used for ventilation heating or process applications, with a consistent track-record of delivering high energy performance in all projects around the world.

Solar wall is a heating system that uses solar energy to heat the indoor environment. This technology is about 20 years that has been produced and utilized by Conserval Inc. in Canada. When introduced in the early 1990's, solar wall's invention was hailed by the National Renewable Energy Laboratory (NREL) as "the most efficient active solar heating system ever designed". Since then it has been proven in use, monitored and analyzed in wide range of climates. Solar wall is the simple, cost-effective way to go green and reap the benefits of renewable energy.

The operation system

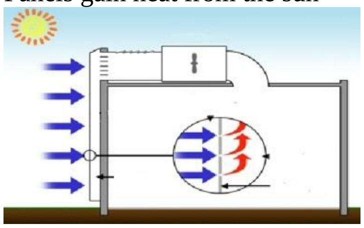
It works by harnessing the natural surface solar gain from one or more elevations of a building's exterior to pre-heat fresh air, which is drawn into the building's interior through tiny perforations on the exterior of the solar wall system. This pre-heated air is then distributed throughout the interior of the building via conventional or fabric ducting delivering fresh, free pre-heated air. In fact solar wall is just as effective as a retrofit to existing buildings as it is in new construction. The solar wall system is installed on an exterior wall, using specially-designed spacers that create a 100 to 200 millimeter cavity. The solar wall system can be installed over or around existing openings or over any non-combustible wall material. It's simple to incorporate and no special construction skills or tools needed. This applies to maintenance, too (though there is very little need for that).

Picture3. The steel panel use in the solar wall



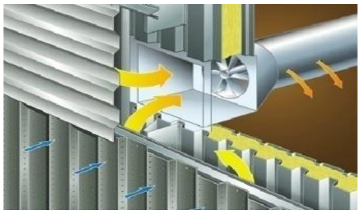
The outer solar wall surface absorbs the heat that comes naturally from the sun. a fan on inside creates negative air pressure that draws the solar heated boundary layer through the perforations in the solar wall system into the space between the exterior panels and the building. (Picture4)

Picture4. Panels gain heat from the sun

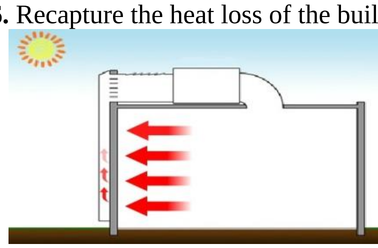


The fresh air can be heated by as much as 30˚C which can dramatically lower heating energy costs. This heated air travels to the building's air intake and into the heating, ventilation and air conditioning system. The heated air is then evenly distributed throughout the building via a conventional ducting system. (Picture5)

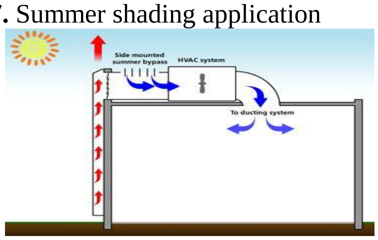
Picture5. Fan and ducts



Picture6. Recapture the heat loss of the building



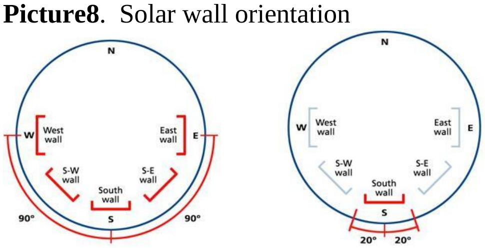
Picture7. Summer shading application



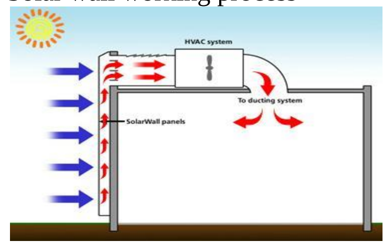
The same solar wall system that effectively warms the building during the winter months, also act as a sun screen during warmer periods. By harnessing solar gain, the southern elevation behind the solar wall system is effectively shaded, with the warm air being captured within the cavity. The warm air is then drawn up the side of the building and naturally vented out the top of the building. (Picture7)

A south facing wall is the ideal orientation but south east and south west work well too. Even east and west facing walls can also be used, though the solar gain will be somewhat lower. (Picture8)

Picture8. Solar wall orientation



Pictur9. Solar wall working process



The solar wall technology incorporates tiny perforations to allow outside air to be drawn in and it is available in 20 colors but the darker the color, the more effective the solar absorption, and increased cost efficiencies.

Picture10. Two different designed solar walls

Limitations

This systems only works with the solar energy and practically in nights cannot heat the air. Therefore this system can only be a supplementary heating system and not a substitution. Solar wall panels can be applied only on fire resisted walls.

Solar wall advantages

It's hard to believe the enormous advantages that solar wall can provide, including:

- Better insulating effect by attaching to the original building envelope as an extra skin and by this the air cavity between the two walls will effectively recapture any heat normally lost through the walls on which it is installed. The warmer air is then returned into the building, further reducing the overall heating load and effectively improving the R-value (increasing the insulation effect) of the solar wall elevation at no extra cost.

-Summer sun screen: solar wall helps moderate air temperatures year round.

- More balanced air: solar wall ducting overcomes heat stratification problems that are caused by poor heating and air circulation techniques which cause overheated pockets of air at the ceiling and central areas of the building. Solar wall ducting provides highly-efficient heat destratification throughout the entire building. The more even temperatures benefits both employees and equipment. The constant supply of fresh ventilated air improves indoor air quality, helping to eliminate sick building syndrome and free heating with minimal maintenance costs for the life of the building.

- Reduced green house gas emissions: each square foot of the solar wall technology saves up to 75 kWh/year of thermal energy. This lowers the need to use other energy sources, helping to reduce greenhouse gas emissions. Worldwide, solar wall installations prevent over 50,000 tons of CO^2 from being released into the air. That's the equivalent of taking about 10,800 cars off the road, each and every year.
- It is easy to install and can be readily included in new or retrofit construction.
- It's virtually maintenance free (it uses no liquids; fans are its only moving parts)
- Reduces heating energy needs immediately and improves ventilation while reducing heat stratification
- Helps with summer cooling and can be adapted for just about any design (many colors, can be shaped, etc.)
- Immediate and significant energy savings with rapid payback

Windows main functions in the buildings

Thermal function: For those sitting next to the window, feeling thermal comfort is relatively lower than other occupants. In summer the temperature of the inner glass of the window will be increased due to the radiation of the long-length waves. Direct radiation of short-length waves from the window along with heat exchange of the glass will lead to the complaints from the thermal comfort. The opposite happens in winter and the heat transfers from the body to the cold glass of the window and heat loss from the body causes thermal discomfort.

Acoustic function: unwanted noise leaves a great impact on human body and creates a sense of resentment, anger, frustration, causes inconvenience in communicating with others, Health and hearing damage and disruption to daily work. All these resulted in permanent changes in the normal functioning of the human organism which ended in physical and mental decline. Being exposed to loud noise can cause headaches, nausea, fatigue, nervousness, irritability, aggression, loss of concentration and performance. And all these effects, directly and indirectly, reduces the ability of an individual to focus on a certain task. To eliminate the noise from the indoor environment, it is necessary to consider an air layer between two glasses. For optimum sound insulation, 150 mm of air between the two glasses in needed although for optimum thermal insulation this rate descend to only 15 mm. Therefore it is essential to make a compromise between sound and thermal insulation.

Visual function: Window with a visual connection between the outside environment and the user can create a variety and non-uniformity and this practically has its effect on employees' morale and productivity. It is important to consider not interrupting this function by covering the windows with blinds all the day.

Lighting function: By using daylight coming through the windows, the efficiency of the staff will be increased dramatically and also it may save a lot of energy by turning off the artificial lights during the day.

Designing window with movable Polystyrene beads as an insulation

Since an office building is generally used only during the day, the optimum application of the south façade is only possible by maximizing the use of day lighting in the building and to save this energy at night. This cannot be happened without the use of a movable insulation in external transparent envelope of the south façade. Considering this fact resulted in designing a window which only plays the role of a transparent element during the day and acts as an insulated wall in night and saves the energy received in daytime. Definitely different types of the windows filled with various gases could decrease the heat transfer coefficient significantly but the researches and computer simulation in this study shows that this kind of windows not only decreases the U value of the glass but also lower the good use of the daylight and this means that this windows perform better during the nights rather than days. In analyzing the recent technology for the movable insulation, Polystyrene beads have been selected to be studied. (Picture11)

Picture11. Beadwall window

The way this system works, is by placing a storage tank in any available area of your structure and piping it to the window. When it is turned on to fill, a vacuum sucks the beads from the storage tank and blows them into the window from the top (Picture 12). When this cycle is reversed the motor creates a suction going from the window to the storage tank, this pulls the beads out of the window from the bottom thus emptying the window.

Picture12. Blowing Polystyrene beads

Beadwall self-insulating window panels are twin glass panes with at least 2.5 inches of separation that are able to fill with 1.5 lb density expanded poly-styrene beads creating a insulating factor of R-11, comparable to a standard fiberglass insulated stud wall. The insulation value is whatever the depth of the space is times R3 per inch. Because it's at atmospheric pressure and uses a vacuum, there is no trapped water vapor to fog up the glass either. And because it is not low-e glass, can gain all that free heat in the winter (and conversely lose the excess heat in the summer evenings from the space) if operated correctly. Beadwall windows are a great application for greenhouses with the ability to drain and let the sun in during the day and then fill up to maintain temperature at night. Since the beads can conform to any shape they will fill up and completely shade and insulate a curved window.

Picture13. Beads can conform any shape

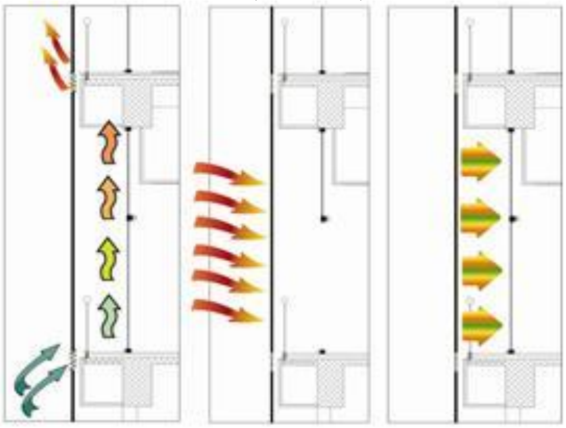
Although beadwall self-insulating window panels are ideal for greenhouse applications they are also great for other buildings. Being that they fill from the bottom up allows to fill the window half way giving privacy but still allowing light to enter the room. Then once the window filled all the way, one can achieve room darkening privacy while stabilizing the temperature. By stopping the fill cycle before the beads get tightly packed, total privacy with medium light filtration can be achieved.

Appropriate timing in the use of removable insulating windows

According to the theoretical and computer simulation, the results are as follows: Winter nights are the best times to make full use of movable insulation to cover the entire window and increase the R value to save the energy obtained during the day. During the day in winter, considering the favor of receiving daylight and energy, insulation is restored in tanks. In summer days, given the desirability of daylight and undesirability of solar heat, using the insulation in only half top of the window, also as a shade, is suggested to prevent the glare and reduce the transparent part of the façade. In cool summer nights in Tehran which the heat transfer is desirable to cool the interior, using the insulation is not recommended. This pattern is simulated in computer software.

Curtain walls and the constraints

In Iran almost all offices are suffering from the sick building syndrome. Majority of the curtain walls in façade are single glazed and this increases the U-value significantly. At best that the designers use double glazed windows, Access to the inner layer of the outer glass is practically impossible; therefore temperature and moisture fluctuation affect this glass and makes vapors. Water drops causes stain and devastates the façade. In addition in double glazed buildings, there is no movable part. Simply designing a double-glazed curtain wall, although in winter helps to reduce the heat transfer, in summer the greenhouse effects of the curtain wall would still remain. All these factors added up will results in neither ignoring to place a curtain wall nor a proper designing. Considering movable parts in designing a curtain wall should be a focus. (Picture14)



Picture14. Curtain wall in summer (left), in winter days (middle), in winter nights (right)

Case study; designing an office building

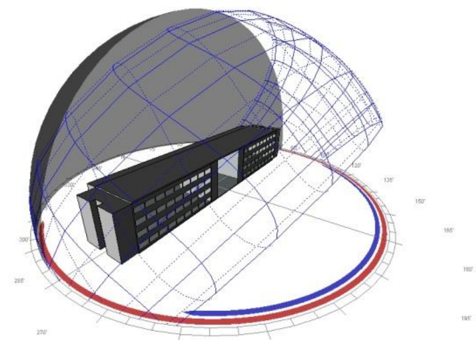
The main goal of this study is to analyze the efficiency of an office building façade, designed with all common elements such as large windows and curtain wall. Only the effect of the south façade is considered; other facades, floors and ceilings are all assumed adiabatic. The other assumption is separating the designed façade to three different zones: office, lobby and mechanical zone. The latter zone is an uncontrolled zone and therefore the impact of the design only considered on office rooms and lobby. Due to the different nature of these two zones and consequently their design, the effect of them will be analyzed separately and the annual energy saving for each component is obtained.

In designing office zone, the movable Polystyrene beads are applied in large windows with the area of 7.6 sq.m. This movable insulation, in winter days which receiving solar energy is desirable, helps to transfer the heat from the uninsulated windows and assist to save this energy in winter nights when there is no sunlight by insulating the glazed envelope and decrease the U-value up to $0.46 {}^{W}/_{m2.K}$. In summer days which solar energy is undesirable for increasing the cooling load and daylight is desirable for decreasing electrical energy, by filling half of the window with Polystyrene beads the area of the window will be reduced and still daylight is available. Also in summer days when we need shading, this movable insulation by filling half top of the window works as a shading and prevents solar radiation to transmit and thus avoids glare. In cool summer nights which heat transfer is desirable and concludes in natural ventilation, it is better to restore Polystyrene beads in tanks and let heat transfer occur.

In this simulation, the term "*uninsulated window*" is used for double glazed window when the Polystyrene beads are stored in tanks and the term "*insulated window*" refers to the double glazed window filled with Polystyrene beads.

It is important to mention that Facts and figures given in this chapter do not represent the heating and cooling load of the building. The simulation is based on a comparison and only in the southern facade and other building surfaces are assumed adiabatic. The only target of this study is to analyze the heat loss and infiltration from the south façade before and after the design.

Picture15. Sun path diagram

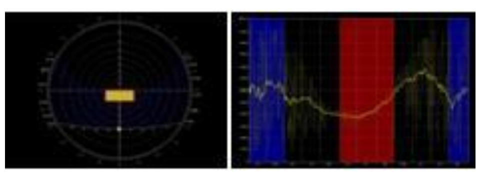


Physical material properties	Thermal capacity	SHGC	U-value	R-value	Thickness
units	$KJ/m2.K$	—	$W/m2.K$	$m2.K/W$	Cm
Uninsulated wall	158/25	—	2/58	0/38	20
DryWall	28/77	—	0/35	2/85	20
Single glazed window	—	0/86	5/90	0/17	0/6
Double glazed with Polystyrene beads	—	0/048	0/45	2/22	8/2
Double glazed without Polystyrene beads	—	0/44	2/28	0/44	8/2

Chart1. Material properties

Design builder simulation

From the theoretical point of the view, windows only need insulation when solar energy and light is not available or this energy is not desirable in warm months. Thus considering this condition, in office window simulation, the assumption is that the movable insulation is stored in tanks in winter days and summer nights and applied in winter nights and summer days. But because in summer daylight is needed and only solar heat is undesirable, only half of the window would be filled by Polystyrene beads.
First we model the building with no insulation in walls and windows. In this mode, the heat transfer coefficient of the wall is $2.58 {}^{W}/_{m2.K}$ and the wall is consists of a layer of concrete (15 cm), 5 cm of interior and exterior finishing and no insulation. The window is also single glazed with a 3 mm glass with the U-value of $5.894 {}^{W}/_{m2.K}$. (Chart2)



Picture16. The building optimum direction (Ecotect Simulation) is east-west.

Uninsulated wall, single glazed window	summer	winter	annual
Air temperature(°C)	26.935	22.07	24.52
Radiant temperature (°C)	28.94	23.27	26.13
Operative temperature (°C)	27.94	22.67	25.32
Outside dry bulb temperature (°C)	25.82	10.31	-
Solar gain external windows (kWh)	160498	163524	324021
Zone sensible heating(kWh)	349.2	70363.44	70712.64
Zone sensible cooling (kWh)	-285255.36	-50831.28	-336086.64

Chart2. Uninsulated wall with single glazed window simulation

Now for evaluating the effect of wall insulation on cooling and heating, we assumed that the wall is insulated but the window will still remain with the same characteristic. The selected wall in this project is Drywall with the heat transfer coefficient of $0.35 ^{W}/_{m2.K}$, approximate weight of $47 ^{Kg}/_{m2}$ and 8 cm mineral fibers insulation. The thickness of the wall is 15 cm with a 5 cm air gap between the Drywall and the Cement board as the final finish of the façade. (chart3)

Insulated wall, single glazed window	summer	winter	annual
Air temperature(°C)	27.45	22.72	25.087
Radiant temperature (°C)	29.485	23.90	26.693
Operative temperature (°C)	28.47	23.31	25.89
Outside dry bulb temperature (°C)	25.82	10.312	18.068
Solar gain external windows (kWh)	175813.92	175585.2	354399.12
Zone sensible heating(kWh)	110.16	16176.24	16286.4
Zone sensible cooling (kWh)	-234399	-93561.12	-327960

Chart3. Insulated Drywall with single glazed window simulation

For analyzing the efficiency of movable insulation in window, we assume the wall is uninsulated with the U value of $2.58 ^{W}/_{m2.K}$ and collect the data for four different times (winter and summer days and nights). The heat transfer coefficient of the double glazed window filling with Polystyrene beads is $0.45 ^{W}/_{m2.K}$ and for the same window without Polystyrene beads are $2.81 ^{W}/_{m2.K}$. (chart4)

Uninsulated wall, window with movable insulation	summer	winter	annual
Air temperature(°C)	26.38	20.73	23.56
Radiant temperature (°C)	27.49	21.042	24.266
Operative temperature (°C)	26.94	20.903	23.92
Outside dry bulb temperature (°C)	25.706	10.371	18.038
Solar gain external windows (kWh)	16986.24	40401.36	57387.6
Zone sensible heating(kWh)	235.32	60801.36	61036.68
Zone sensible cooling (kWh)	-230201.28	-32362.56	-262563.84

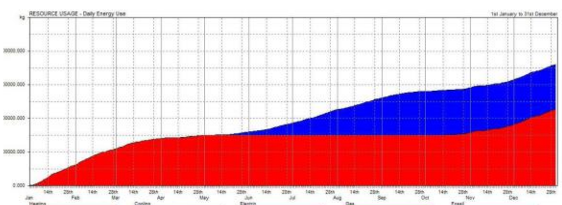
Chart4. Uninsulated wall with insulated window by movable Polystyrene beads

In last situation for figuring out the effect of wall insulation and window movable insulation on each other and on cooling heating load of the office zone, the Drywall with mineral fibers insulation is selected and windows with movable Polystyrene beads chosen to collect data for four different times of the year (winter and summer days and nights) and calculate the zone sensible heating and cooling in Design builder software. (chart5)

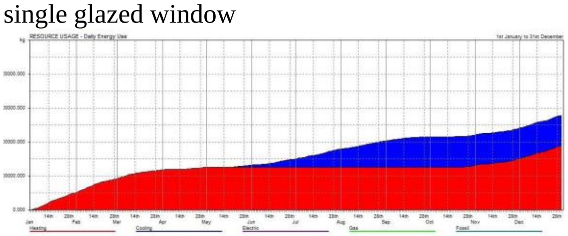
Insulated wall, window with movable insulation	summer	winter	annual
Air temperature(°C)	26.158	22.585	24.372
Radiant temperature (°C)	27.267	23.342	25.304
Operative temperature (°C)	26.712	22.964	24.838
Outside dry bulb temperature (°C)	25.886	10.465	18.176
Solar gain external windows (kWh)	16986.24	40401.36	57387.6
Zone sensible heating(kWh)	86.4	11302.56	11388.96
Zone sensible cooling (kWh)	-157810.32	-78789.6	-236599.92

Chart5. Insulated Drywall and window with Polystyrene movable beads for insulation

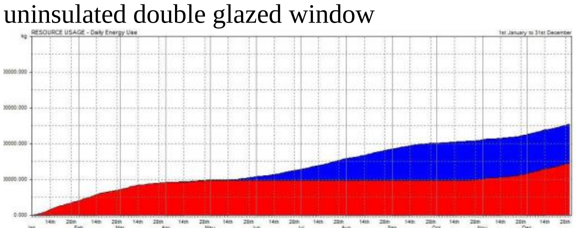
Data analysis shows that insulating the wall would decreases heating load 76.97% and cooling load 2.42% in a year. And this amount demonstrates that insulating the wall has most effect on zone sensible heating rather than cooling. Also it can be observed that movable insulation in windows if applies properly will save 21.88% cooling load and 14% heating load annually. Adding up two data will be resulted in a significant saving energy in a year. 83.9% of the heating load and 30% of cooling load could be saved by applying the insulations and this is a huge difference in annual consuming energy.



Picture17. Energy consumption in uninsulated wall, single glazed window



Picture18. Energy consumption in insulated wall, uninsulated double glazed window



Picture19. Energy consumption in insulated wall, insulated double glazed window

Designing the lobby zone is based on a the double glazed curtain wall to reduce the greenhouse effect in summer on the lobby space which causes an increase in heating sensible zone in winter due to the prevention of transferring solar heat from the exterior to the interior. To solve this problem the inner glass should be movable to remove in winter days and apply in winter nights. To reduce the greenhouse effect in summer, natural ventilation should be designed which in this case, 10 cm louvers are placed in the exterior glass of the curtain wall to ventilate the air between two glasses in summer days and avoid heat transfer.

Further Studies

It is clear that each of the details mentioned in this survey can be a comprehensive research topic. Although there have been already a lot on some research areas such as wall insulation but movable insulation for windows is a new topic to investigate about it vastly and from different points of view. For instance the quantity and quality of dividing windows for achieving the optimum use of the movable insulation in summer and winter and for maximizing daylight access and minimizing heat transfer, the proper thickness for the insulation and the space needed in between the two glasses of the double glazed window are all details that need more consideration in design with the complicated models and software simulations.

Conclusion

Designing a solar wall may seem vague firstly but with a closer look by designing each part of south façade, one by one, with the purpose of saving energy, the model of solar wall could be accessible. In general considering each small part of the building and approaching the design from parts to whole building is the main focus of this research. Designing south façade needs consideration and concentration and architecture should be read in each lines of the façade not only in diversity of the materials and colors but in the purpose of saving energy. Movable design is one of the best solutions for the building to cope with the climate and this helps significantly in providing thermal and visual comfort for occupants. Societies need to consider the new technologies of movable design and this could be a beginning for a new generation of modern architecture.

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