Effect of Architecture on Building Energy Demand in Cold Climates

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Abstract

Buildings consume roughly one-third of all energy consumed nationally every year[1]. Taking into consideration the climatic condition and circumstances of building location for designing a building will reduce effectively the energy consumption of buildings.
Architectural design has a great effect on energy consumption of buildings. In cold climates, the climatic conditions and especially solar radiation can be utilized for heating the buildings and thus reducing the amount of energy consumption.
In this research 30 different buildings are simulated with a dynamic energy modeling program and subsequently compared with each other to find the architectural factors, which reduce the energy demand of buildings in cold climates.
Simulation and comparison prove that the buildings in this climate can have very lower energy consumption, if they are architecturally well designed. The results show that the optimized design of a 3-stroy house has 0.075 lower energy consumption in comparison with the selected existing building in the completely same construction conditions and 0.04 less energy, if we make use of insulated envelope and triple glass, insulated frame windows.

Acknowledgments

Hereby I would like to thank Prof. Dr. Peter Herrle[2] and Prof. Claus Steffan[3] for their kind advice and guidance.

Introduction

To postpone the shortage of fossil fuel resources, the energy consumption has to be significantly decreased and due to the fact that energy consumption in buildings makes up a significant proportion of energy consumption worldwide, one way of tackling with this problem is to cut down the consumption of energy in buildings.
A significant portion of building energy consumption is used for heating buildings especially in cold climatic regions.

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[1]- US Department of Energy, Energy Efficiency and renewable energy.
[2] - Habitat Unit - Berlin University of Technology.
[3] - Building Technology and Design - Berlin University of Technology.

Therefore, the introduction of low-energy buildings suited for cold climates can effectively reduce the total energy expenditure.
Architectural characteristics also have a great effect on the amount of energy demand in buildings. Therefore, buildings properly designed to adapt with cold climates can have very lower amount of energy consumption in comparison with existing Buildings.

Methods and materials

To estimate the effect of architectural design on energy consumption of buildings, in cold climatic regions, a general available 3-stroy building in Tabriz[1] is selected and its heating and cooling energy demand is calculated through energy modeling. The building is then simulated with insulated thermal envelope[2]. Ultimately some other buildings under the same conditions but with different architectural design (characteristics) are designed and simulated.
In every case the new building is designed so that it is similar to the previous building but has only in one factor difference with it.
Subsequently, in order to minimize the effect of control variables on results, similar buildings, which have difference only in one factor, are compared with each other. Therefore, the change of energy demand is only the effect of difference factor.
For accurately simulating buildings, a dynamic energy modeling program is required. In this research, DesignBuilder is used to do so.
DesignBuilder is the first comprehensive user interface to the EnergyPlus dynamic thermal simulation engine and use hourly weather data for every location for simulation.

Energy Demand of existing and newly designed buildings

30 different buildings (existing building, this building with simulated wall and total envelop and other 27 designed buildings) were simulated in climatic condition of Tabriz (as a case study in Iran’s cold climatic region) and their heating and cooling energy consumption are calculated. The following table presents these buildings, their characteristics, their heating and cooling energy demand and two different perspectives of these buildings, which show the shading and sun radiation at walls and especially windows in winter and summer, appear in following table.

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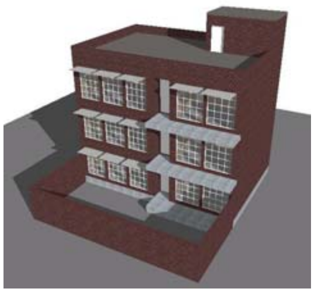
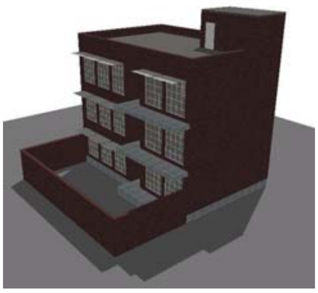
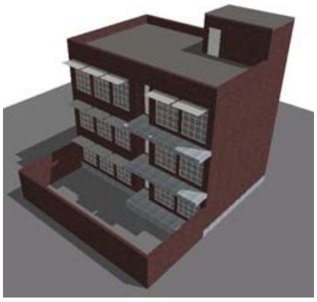
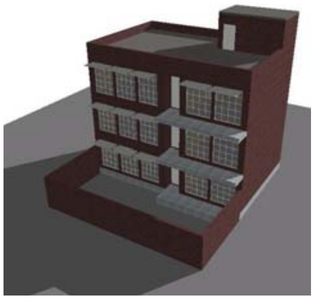
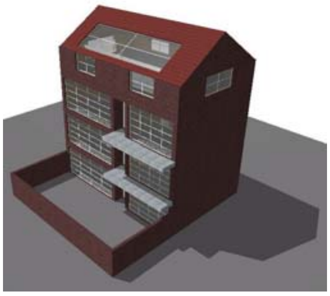
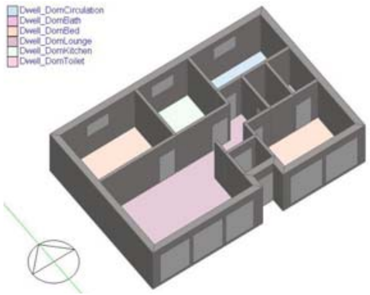
[1] – Tabriz is located in cold climatic region of Iran (Latitude: 38.13°, Longitude: 46.28°) and in this research is used as case study.
[2] – Insulated walls consist of 10.5 cm Brickwork (outer leaf), 11.8 cm polystyrene- CO_2 blowing and 10cm concrete block (medium) and its U-value is 0.25 W/m²K.
Insulated windows consist of these layers: 3mm LoE clear outermost pane, 13mm argon gas, 3mm clear pane, 13mm argon gas, 3mm Rev LoE clear innermost pane with 0.786 W/m²K U-value, 0.470 total solar transmittance (SHGC), 0.358 direct solar transmittance and 0.661 light transmittance.

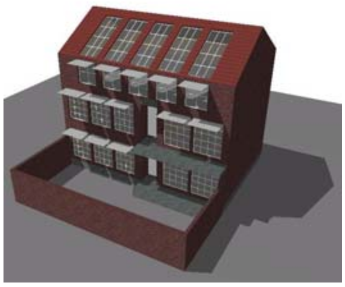
Perspective: Summer (15 June14h)	Perspective: Winter (15 December,14h)	Case	Energy Demand (kWh/m²a): Heating	Cooling	Total	Description
		1 (Existing Building)	268.10	11.40	279.51	Uninsulated wall & Roof Single glazing Inside Blind
		1+Insulated wall	60.67	5.53	66.20	Insulated wall & Roof Single glazing Inside Blind Best practice wall
		1+ Insulated wall & window	59.17	4.63	63.80	Insulated wall & Roof Triple glazing Inside Blind
		2 (West-facing)	44.18	16.30	60.49	West-facing 1m Overhang Inside Blind
		2 (East-facing)	39.82	18.43	58.25	East-facing 1m Overhang Inside Blind
		2 (North-facing)	47.71	10.21	57.92	North-facing 1m Overhang Inside Blind

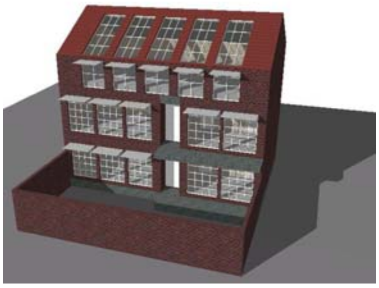




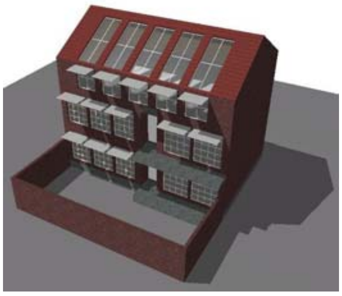
Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
40.33	**17.35**	**57.68**
9 + N+E+W window (4 story)		
Pitched Roof - Skylight Non Overhang External Controlled Blind 4 story		

Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
43.35	**9.85**	**53.20**
2 (1 Story)		
1m Overhang Inside Blind 1 Story		



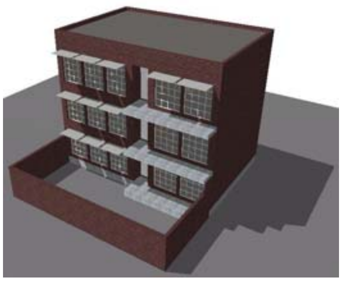


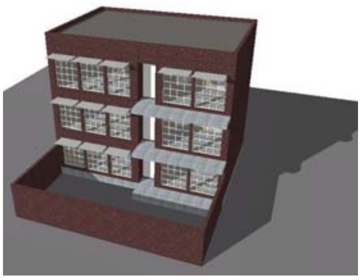
Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
21.94	**30.41**	**52.35**
4 + Attic + Big skylight (5)		
Pitched Roof - Skylight 1m Overhang Inside Blind		



Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
21.39	**28.37**	**49.76**
5 + Controlled blind		
Pitched Roof - Skylight 1m Overhang External high reflective controlled Blind		

Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
30.70	**11.20**	**41.90**
2 + Non door buffer zone		
Non door buffer zone 1m Overhang Inside Blind		





Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
28.66	**11.50**	**40.16**
2 + Non Staircase		
Non Staircase 1m Overhang Inside Blind		


Energy Demand (kWh/m²a)		
Heating	Cooling	Total
28.47	11.13	39.60

2 (Designed Building)

1m Overhang
Inside Blind


Energy Demand (kWh/m²a)		
Heating	Cooling	Total
27.45	12.08	39.54

3 + Skylight (4)

Pitched Roof - Skylight
1m Overhang
Inside Blind


Energy Demand (kWh/m²a)		
Heating	Cooling	Total
27.11	11.02	38.12

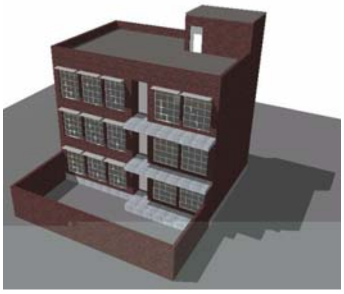
2 + Pitched roof (3)

Pitched Roof
1m Overhang
Inside Blind


Energy Demand (kWh/m²a)		
Heating	Cooling	Total
26.74	11.28	38.02

2 + Non Blind

1m Overhang
Non Blind




Energy Demand (kWh/m²a)		
Heating	Cooling	Total
25.42	12.32	37.74

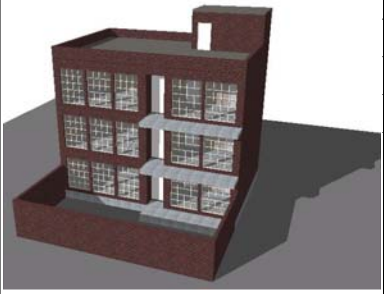
2 + 0.5m Overhang

0.5m Overhang
Inside Blind


Energy Demand (kWh/m²a)		
Heating	Cooling	Total
22.59	14.50	37.09

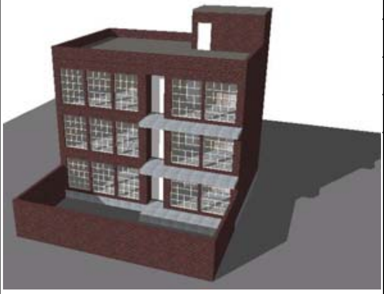
2 + Big South window

Big South window
1m Overhang
Inside Blind



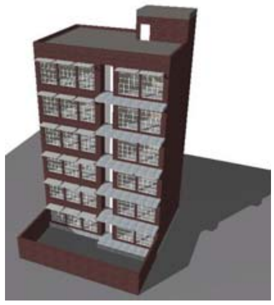
Energy Demand (kWh/m²a)		
Heating	Cooling	Total
20.92	15.99	36.91
2 + Non Overhang		

Non Overhang
Inside Blind



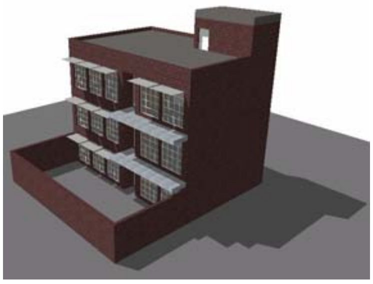
Energy Demand (kWh/m²a)		
Heating	Cooling	Total
18.77	16.26	35.03
2 + Non Overhang & Blind		

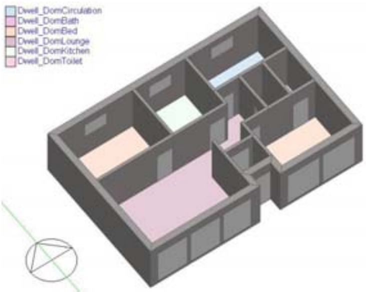
Non Overhang
Non Blind



Energy Demand (kWh/m²a)		
Heating	Cooling	Total
21.70	11.38	33.08
2 (6 Story)		

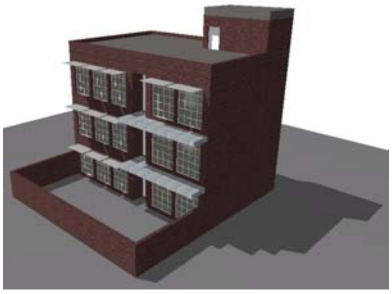
6 Story
1m Overhang
Inside Blind

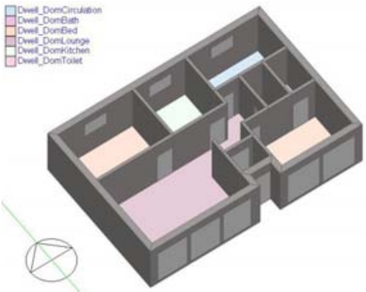




Energy Demand (kWh/m²a)		
Heating	Cooling	Total
20.31	10.39	30.69
2 + on earth		

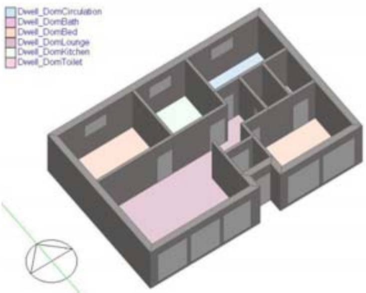
on earth
1m Overhang
Inside Blind





Energy Demand (kWh/m²a)		
Heating	Cooling	Total
19.80	10.52	30.31
2+ on earth (short wall)		

on earth
short courtyard wall
1m Overhang
Inside Blind



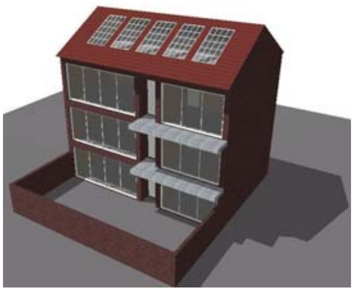
Energy Demand (kWh/m²a)		
Heating	Cooling	Total
19.61	10.58	30.19
2 + On earth (-1m)		

On earth (-1m)
1m Overhang
Inside Blind

Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
17.94	11.68	29.63
7 (6 + external Blind)		
On earth Pitched roof - Skylight 1m Overhang Outside Blind		

Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
13.57	14.86	28.43
6 (Optimum)		
On earth Pitched roof - Skylight 1m Overhang Inside Blind		

Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
14.98	12.05	27.03
8 + Fin		
On earth Pitched roof - Skylight 1m Overhang - 1m Fin External controlled blind		



Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
8.25	18.30	26.55
9+ high reflective Blind		
On earth Pitched roof - Skylight External high reflective controlled Blind - Non Overhang		

Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
12.13	11.33	23.47
7 + Controlled Blind (8)		
On earth Pitched roof - Skylight External controlled Blind 1m Overhang		

Energy Demand (kWh/m²a)		
Heating	**Cooling**	**Total**
7.76	15.36	23.12
8 + Non Overhang (9)		
On earth Pitched roof - Skylight External controlled Blind Non Overhang		

Energy Demand of Simulated Buildings

The following diagram compares the amount of heating and cooling energy demand of different simulated buildings. All these buildings have similar constructional characteristics and have only different architectural design.
The amount of energy demand of last building is 64% less than the first building in similar condition and only with different architectural design. It shows that, architectural characteristics have a great effect at cooling and heating energy demand.

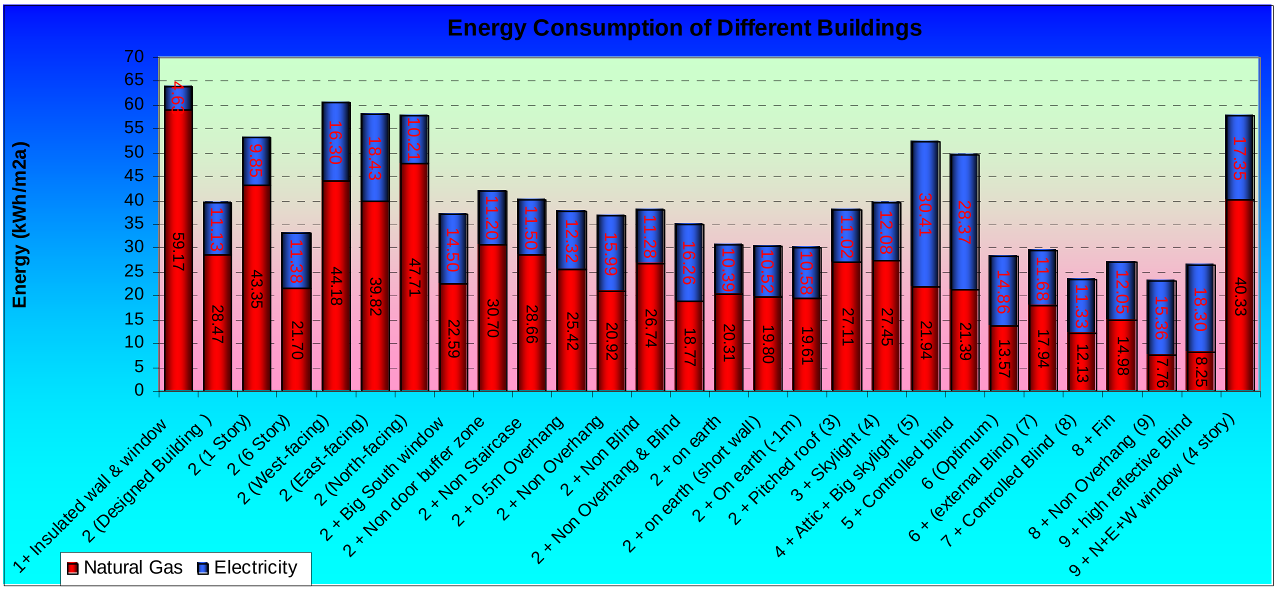


Diagram No. 1: Comparison of Energy Demand of All insulated Buildings

Diagram No. 2 compares the energy demand of an available building, the same building with insulated thermal envelope and a well designed building.
According to the following diagram, the amount of energy consumption of a residential building (for heating and cooling) in Tabriz will decrease effectively through the application of insulation material for thermal envelope and it decreases especially in the insulated well designed building.
The amount of energy consumption of an existing building in Tabriz is 12 times higher than the similar well-designed and insulated building (without using any other equipment in it).

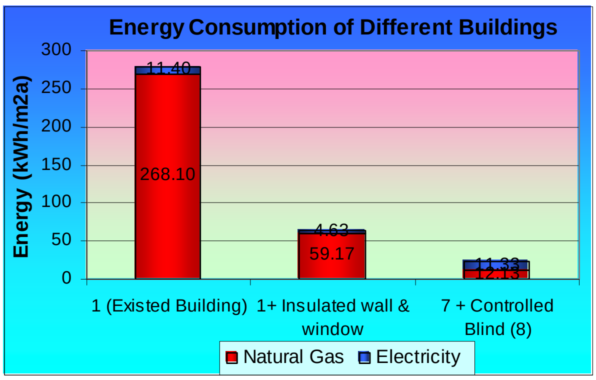


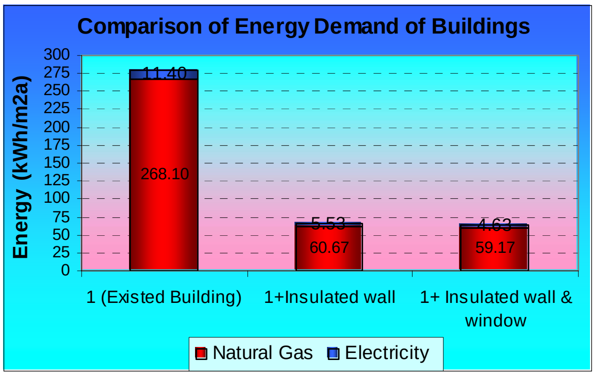
Diagram No. 2: Comparison of Existing Building with the best designed Buildings

Comparison of Energy Demand of Similar Buildings

Diagram No. 3 compares the amount of energy demand of existing building and the same building with the insulated opaque envelope and also with triple glass window.

It shows that Insulating of windows and especially opaque thermal envelope (walls, roofs and floors) effectively reduce the amount of energy consumption.

Diagram No. 3: Comparison of Existing Building with Similar Buildings



Comparison of energy demand of buildings in diagram No. 4 shows that:
Increasing the number of floors of a building reduces the amount of energy expenditure and vice versa.
Orientation of the building (elongation, the amount of windows in every direction etc.) has a great effect on energy consumption of a building. Among the 4 main directions, the south is the best orientation for buildings in Tabriz.
Increasing the amount of south-facing windows increases the cooling energy, however, it reduces more effectively heating energy and total energy consumption.
Thermal buffer zone of external doors reduces the amount of energy consumption.
Locating of the building on the ground level or a part of the building under the ground reduces the amount of energy consumption.
Having pitched roof instead of flat roof reduces the amount of energy consumption.

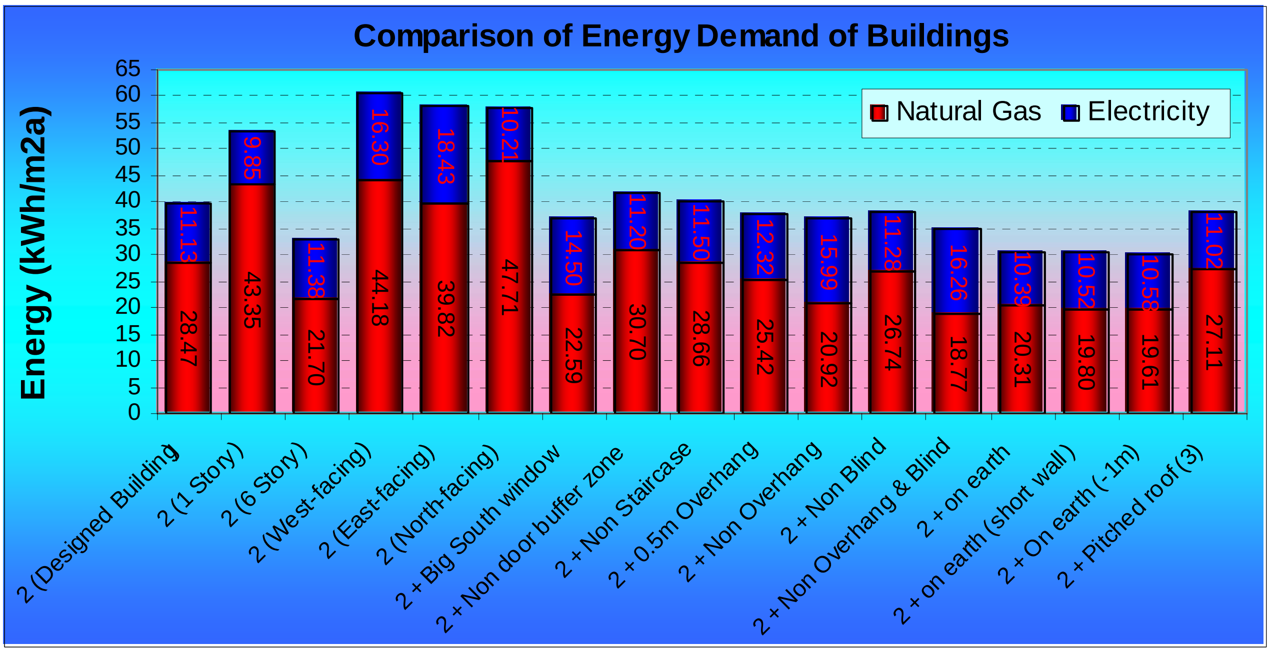


Diagram No. 4: Comparison of Designed Building (Building No. 2) with Similar Buildings

The building, which has some uncontrolled skylights at its pitched roof of non-residential attic, has more heating and also cooling energy demand. Therefore uncontrolled skylights increase the amount of energy consumption (Diagram No.5).

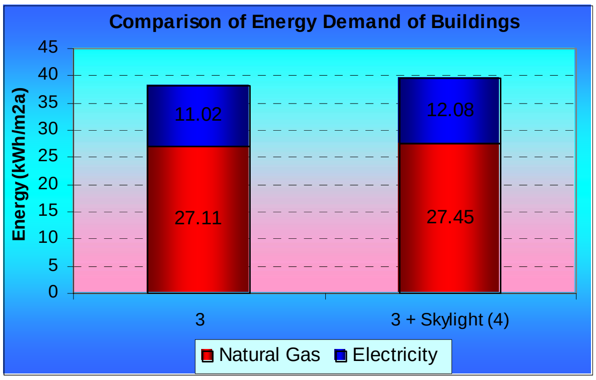


Diagram No. 5: Comparison of Building No. 3 with Similar Building

Comparison of buildings of Diagram No. 6 with and without attic and big skylights at its roof shows that big skylights at pitched roof of residential attic decrease heating energy demand but increase the cooling energy much more and thus lead to increase in total energy demand of building.

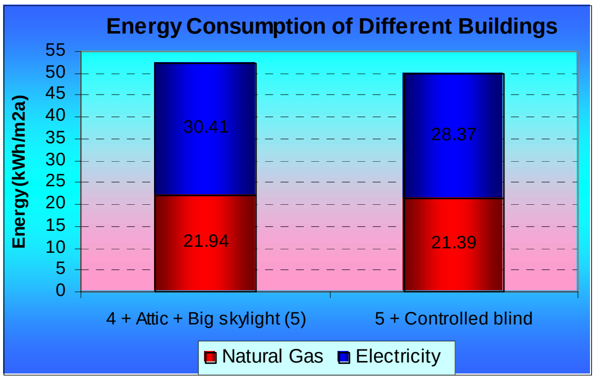


Diagram No. 6: Comparison of Building No. 4 with Similar Building

According to diagram No. 7, external blinds controlled with regard to cooling and heating energy need reduce both heating and cooling energy consumption of the building.

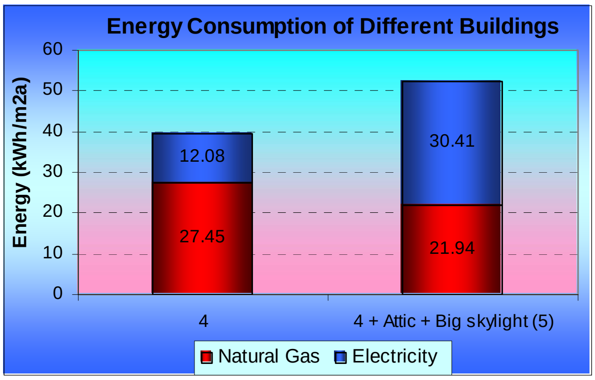


Diagram No. 7: Comparison of Building No. 5 with Similar Building

Comparison of energy demand of building No. 6 and the similar building with external blind shows that, though the external uncontrolled blinds (closed blinds) reduce cooling energy but at the same time lessen much more heating energy and total energy consumption is reduced as a result. It also shows that in comparison with internal shading devices, external shading devices are also more effective in reducing cooling energy.

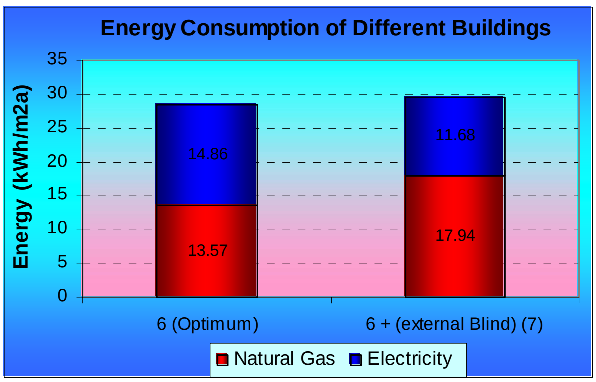


Diagram No. 8: Comparison of Building No. 6 with Similar Building

In graph No. 9 one building with controlled and uncontrolled external shading devices is compared. It shows that controlling the blinds with respect to cooling and heating energy need reduces effectively energy consumption (especially heating energy). Opening and closing the blinds with reference to heating and cooling energy need during different seasons and day and night, is very crucial in reducing energy consumption of building.

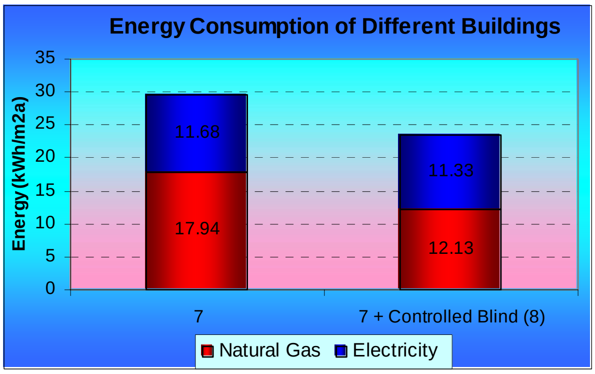


Diagram No. 9: Comparison of Building No. 7 with Similar Building

Comparison of energy demand of three buildings with and without overhang and also with fin in diagram No. 10 proves that using fins at south facing windows increase the amount of energy consumption.

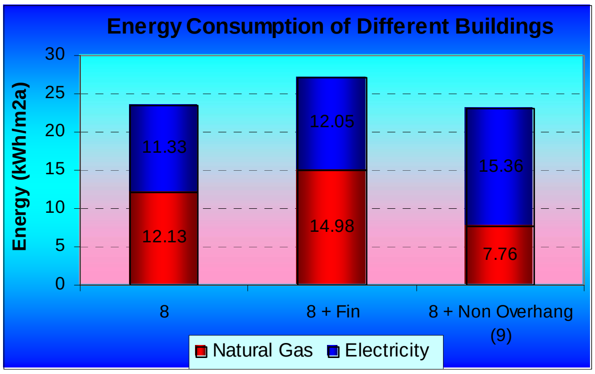


Diagram No. 10: Comparison of Building No. 8 with Similar Buildings

Using overhangs at south-facing windows reduces cooling energy consumption but increases heating energy consumption, therefore the dimension of overhangs with regard to windows dimension is very important for decreasing energy consumption of building.

Simulation of buildings presented in graph No. 12 shows that north-, east- and west-facing windows and also high reflective blinds increase the amount of energy consumption.

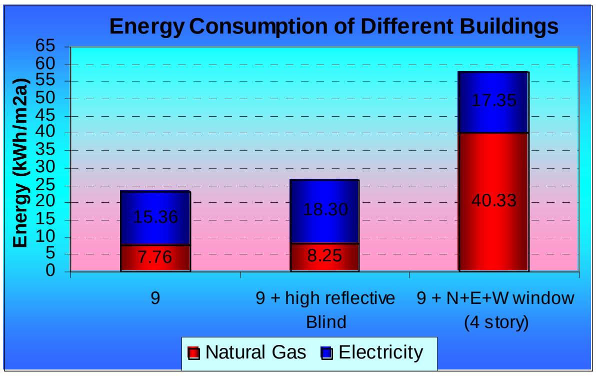


Diagram No. 11: Comparison of Building No. 9 with Similar Buildings

Comparison of Heating and Cooling Energy Demand

Comparison of existing building and other insulated buildings

The following diagram (No. 12) compares the amount of heating and cooling energy in existing building and in insulated buildings, which have less energy consumption. It shows that the insulated buildings have only less heating energy consumption but not less cooling energy consumption.

By designing a climatic responsive house for cold climates, only the amount of heating energy will be effectively decreased.

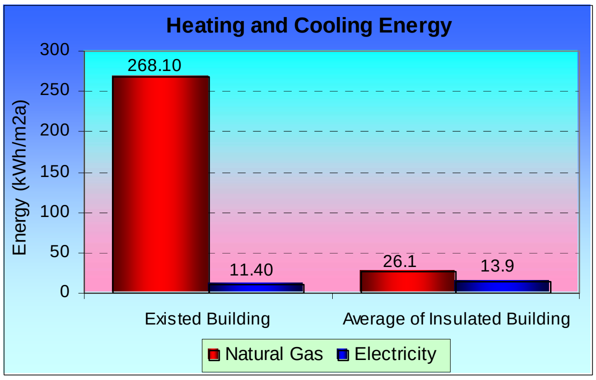


Diagram No. 12: Heating and Cooling Energy of Existing Building and others Buildings

In a general uninsulated building in Tabriz the amount of heating energy consumption is 23.5 times more than its cooling energy but in climatic designed buildings, the amount of heating energy is not much more than its cooling energy.

Comparison of insulated and uninsulated existing building and other insulated designed buildings

This diagram shows the amount of heating and cooling energy in uninsulated existing building, insulated existing building and some climatic designed buildings.

It shows that insulating of the building reduces the amount of cooling (59%) and especially heating (78%) energy demand [this amount is different depending on the type of the buildings].

But cold climatic responsive buildings, which have been designed for cold climates, have less heating and total energy demand, but not less cooling energy demand, because these buildings have also more outside heat gains in summer. Therefore in these buildings cooling is very important.

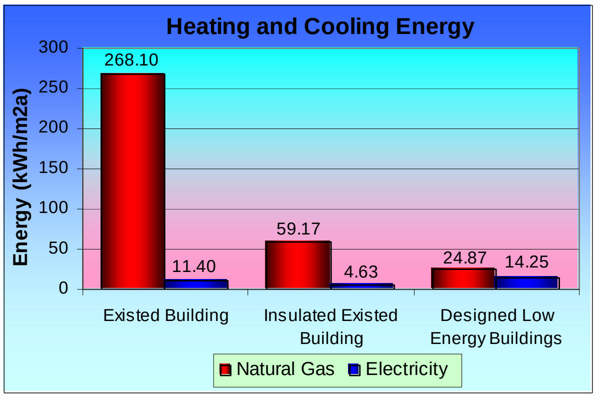


Diagram No. 13: Heating and Cooling Energy of Existing Building and designed Buildings

Comparison of insulated designed buildings (in four groups)

This diagram compares the amount of cooling, heating and total energy demand of 4 groups of buildings, which have different amount of total energy demand. It shows that reducing the amount of energy demand in these buildings is done only because of reducing heating energy demand.

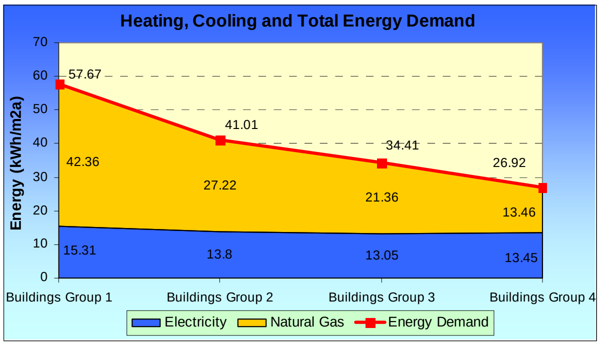


Diagram No. 14: Heating and Cooling Energy of designed Buildings

Results

Simulation and analysis shows that insulation of thermal envelope of buildings and use of insulated windows will effectively reduce the energy demand of the building. For example the amount of energy demand of existing building is reduced about 77% only by use of insulated thermal envelope.

The architectural design of buildings has also a great effect on their energy demand, which is rarely paid attention to. In simulated buildings the architectural design has reduced the amount of energy demand of the building from 63.80 to 23.12kWh/m²a

These factors reduce the energy demand of buildings in cold climates:

- Insulating of thermal envelope of building
- Increasing the number of floors of building
- Orientation of the building to south and east-west elongation
- Increasing the amount of south-facing windows

- Thermal buffer zone of external doors
- Locating the building on the ground level or a part of the building under the ground
- Having pitched roof instead of flat roof
- Use of external shading devices instead of internal shading devices and especially external movable shading devices
- Controlling the movable shading devices with respect to cooling and heating energy need

The following factors increase the energy demand of buildings in cold climates:

- North-, east- and west-facing windows
- Uncontrolled skylights at pitched roof of non-residential attic
- External uncontrolled blinds (closed blinds)
- Big and uncontrolled skylights at pitched roof of residential attic
- Using fins at south-facing windows

The size/amount of following architectural elements should be separately calculated for every building with paying attention to different factors:

- The size of windows in every orientation
- The size of skylights
- The size of overhangs at south-facing windows

Discussion and Conclusion

The heating energy consumption of the last building is 7.76kWh/m²a which accounts for a passive house and thus it needs no conventional heating system, which effectively reduces the building cost.

This amount of heating energy demand can be supplied by passive or hybrid methods such as use of subsoil-heat-exchanger or air to air heat exchanger for heat recovery from outlet air and thus the heating energy demand of this building can be reduced up to 0.

For cooling, it is also possible to use of evaporation and vegetation cooling especially in dry climates for passively reducing the cooling energy consumption of buildings.

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