young cities

Developing Urban Energy Efficiency

Tehrān-Karaj

Young Cities Research Briefs | 07

Architectural Energy Efficiency

Farshad Nasrollahi

1 Introduction

Decreasing the energy demand of buildings by applying cost-intensive measures (such as the addition of insulation material, energy-efficient heating and cooling systems, renewable energy systems, etc.) leads to an increase of building investment costs. Investment costs, including user costs and governmental subsidies, for very low energy buildings, zero or plus-energy buildings are generally too high, and construction is not economically viable in consideration of the national capital in the present economic conditions of most countries. Therefore, in order to minimize the consumption of resources as well as building costs, cost-neutral energy-saving measures must first of all be applied in buildings.

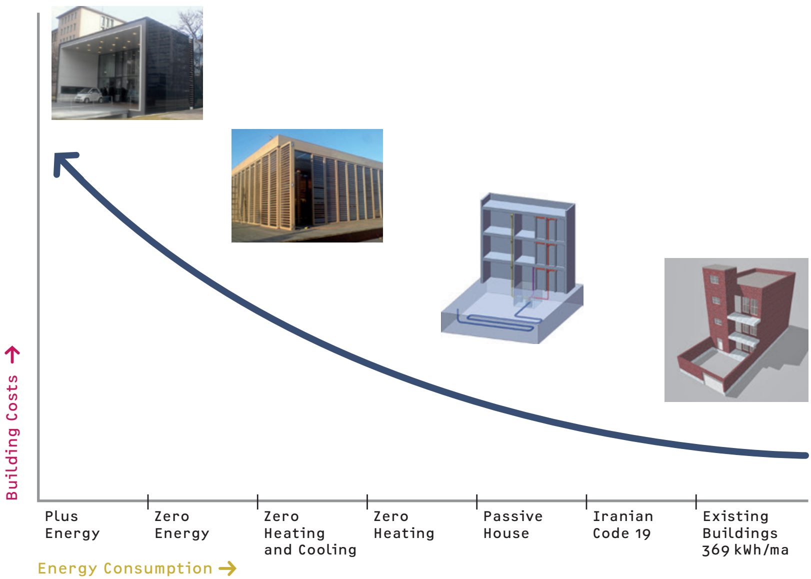

Fig. 1: Relationship between energy consumption and building investment costs

Architectural Energy Efficiency is a parametric method which studies the effects of various architectural factors on the energy demand of buildings by using dynamic energy simulation tools to find the optimum value for each architectural factor from an energy efficiency point of view. The factors include orientation, building elongation, building form, opening ratio in different orientations, sun shading, zoning of functions, natural ventilation etc. As the architectural design affects the heating and cooling as well as the lighting energy demand of buildings, the optimum value for each factor must be based on these three energy consumptions. The different energy carriers required for heating, cooling and lighting have different ecological and economic characteristics. The criteria for selecting the best variant can therefore be based on the total or primary energy demand, CO_2 emissions, energy costs (for heating, cooling and lighting), life cycle costs, etc. The application of the findings to provide energy saving measures in the architectural design will minimize the ecological or economic burden. As orientation, window-to-wall ratio and shading devices are the most important factors affecting the energy demand of buildings, these three factors are studied in the following.

2 Orientation

The orientation of a building has a significant impact on its energy demand. Among other architectural factors, it is one of the most important aspects regarding possible energy saving potentials. In order to study the effect of orientation on the heating, cooling and lighting energy demands of office buildings, a typical office building is simulated using different orientations and the climatic conditions of Hashtgerd New Town. The office building has predetermined characteristics in regard of building materials, elongation and window ratios. The simulation of the office building and the comparison of the energy demands show the energy-related behavior of office buildings according to different orientations. A simulation of the annual energy balance is made for the building in 10° steps. The orientation applies to the main façade with the biggest window area.

Heating energy demand

The lowest heating energy demand occurs when the building faces almost south, at 170°. If the building is turned away from this orientation, either east or west, the heating energy demand increases. The building has its highest heating energy consumption at 40° and 320°. The heating energy demand of the office building varies by about 24% according to the different orientations (see Figure 2).

Cooling energy demand

The cooling energy demand is at its lowest when the office building is set out in a north orientation. The highest cooling energy demand occurs when the building faces 110° and 260°. By turning the building from an east-west to a north–south direction, and vice versa, the cooling energy demand decreases. The described behavior is due to the sun's course throughout the day and year. In summer, the sun rises in the north-east, reaches its highest altitude in the south (which prevents extreme solar heat gains, which would then need to be removed) and sets in the north-west. On summer mornings (from sunrise to 10 a.m.), the sun moves from the north-east to the south-east of the building; the altitude is so low that the incident of solar radiation on vertical surfaces (walls) is much greater than on horizontal surfaces (roofs). Therefore, a building with a north-east, east or south-east orientation generates greater solar heat gains via the windows and the cooling energy demand

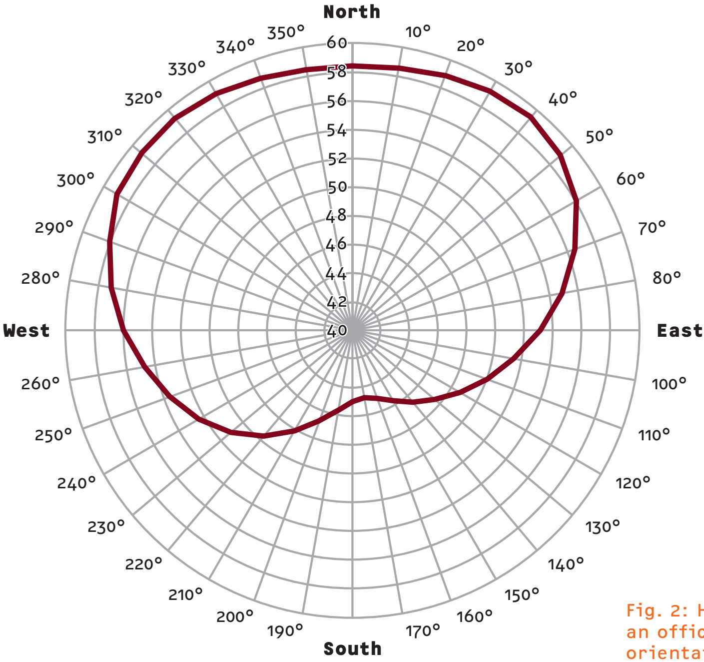

Fig. 2: Heating energy demand of an office building with different orientations (kWh/m²a)

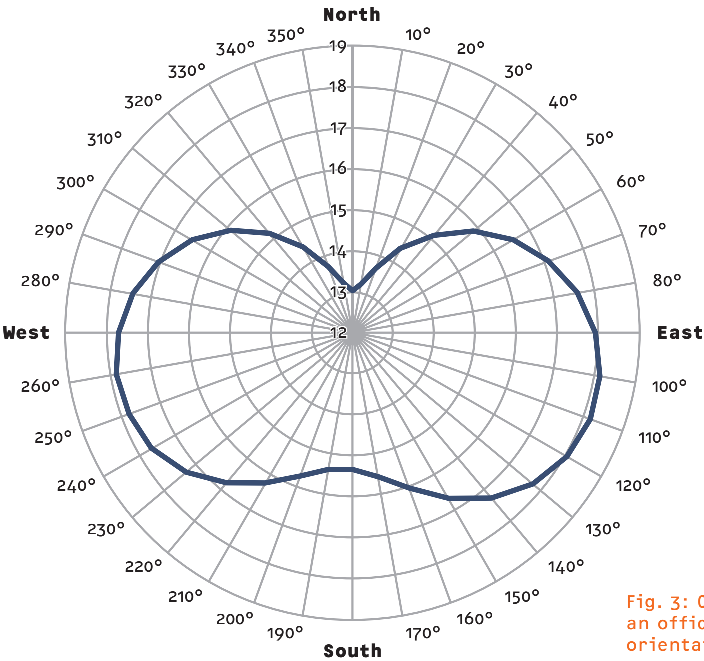

Fig. 3: Cooling energy demand of an office building with different orientations (kWh/m²a)

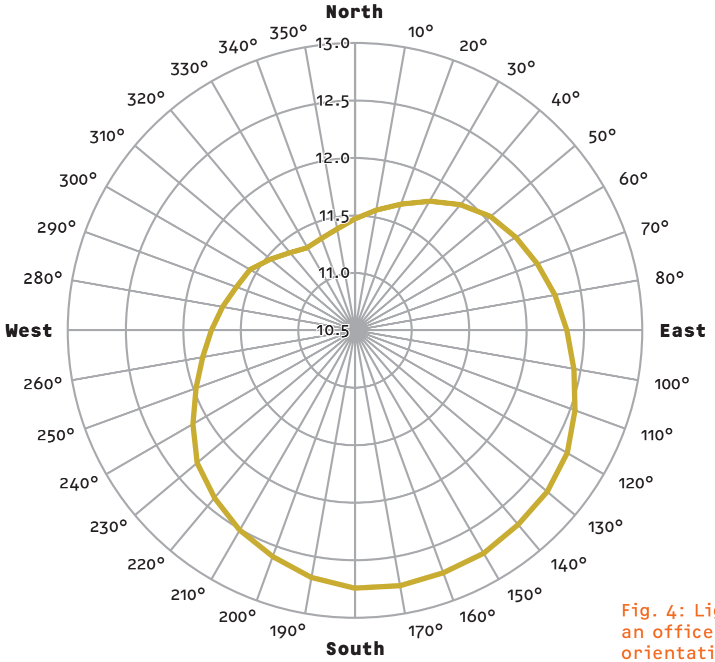

Fig. 4: Lighting energy demand of an office building with different orientations (kWh/m²a)

is similarly high. For buildings with an orientation between south-west and north-west, the same phenomenon occurs on summer afternoons. At two points during the course of the sun, both in the south-east and the south-west, the sun's altitude produces maximum solar heat gains in summer. The value of the building's cooling energy demand varies by about 28% according to the different orientations (see Fig. 3).

Lighting energy demand

The lighting energy demand in the office building differs from the heating and cooling demand. It has the lowest lighting energy demand when it faces 330° and the highest when it faces 170°. The energy demand for lighting varies by 11% (see Fig. 4).

Comparison between heating, cooling and lighting energy demand

The following graph shows the extent of heating, cooling and lighting energy demands in the examined office building. It highlights that the orientation of the office building affects the lighting energy demand of the building very slightly compared to that of heating and cooling. The effect of the orientation is most significant in the case of the heating energy demand (see Fig. 5).

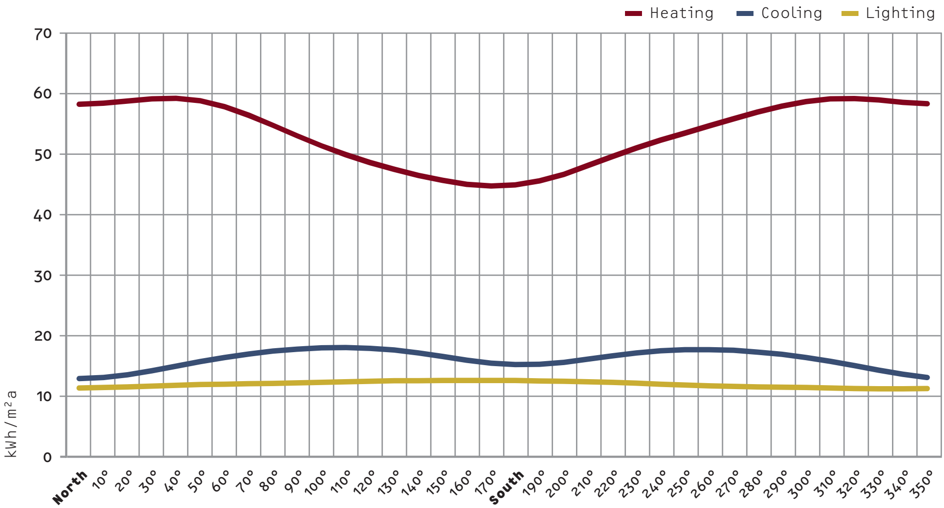

Fig. 5: Heating, cooling and lighting energy demand of an office building with different orientations (kWh/m²a)

The office building has the lowest heating energy demand when it faces south. In the case of a south orientation, the cooling energy demand is low too. However, the cooling energy demand is not at its lowest with a south orientation. If the building is turned from the south slightly more towards east or west, the heating and cooling energy demands of the building are approximately the same on either side. However, the energy demands are not identical. The amount of heating energy demand is always higher than that of both the cooling and lighting, which is also the reason why it is being affected much more in absolute values. By way of comparison, the orientation has the biggest impact on the cooling energy demand.

Total energy demand

Because the heating energy demand of office buildings is greater in this climate than both the cooling and lighting energy demand, the total energy demand is similar to that of the heating demand. The south-facing office building has the lowest total energy demand. It increases when the building is turned north either east or westwards. The model building has its maximum energy demand at both 300° (northeast) and 50° (northwest). The main result of the simulation is that the optimum orientation of the building regarding its overall energy demand is south. According to these results, only the office building's perfect orientation in the climatic conditions of Hashtgerd New Town can save up to 16% energy in comparison to the highest possible value (see Fig. 6).

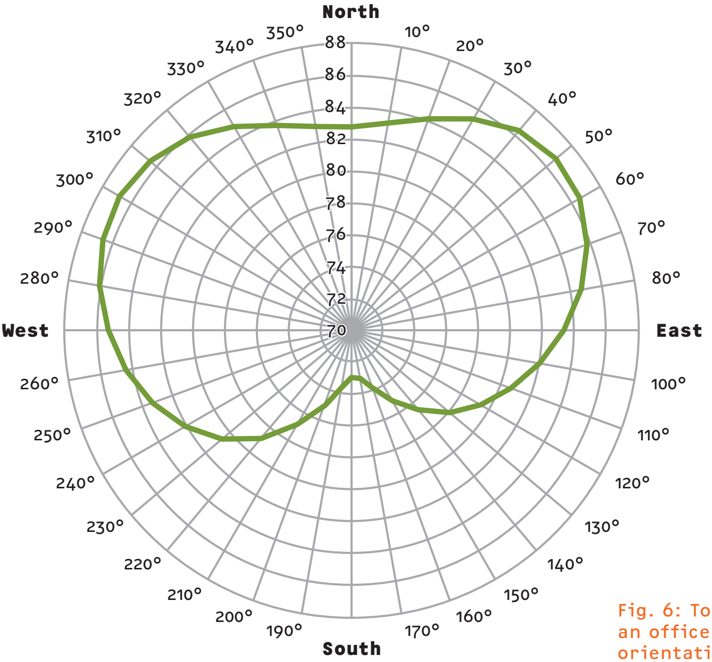

Fig. 6: Total energy demand of an office building with different orientations (kWh/m²a)

Primary energy demand

Similar to the total energy demand, the primary energy demand of office buildings with different orientations is at its lowest when facing either south or north. The low primary energy demand in the south is due to the low heating energy demand and the fairly low energy demand for cooling. The primary energy demand of office buildings with a north orientation is low because the building has a minimum cooling energy demand, which has a high primary energy factor.

The building reaches its maximum primary energy value at 270° (west) and 80° (10° north of due east). The reasons are the following: Firstly, independent of the orientation, the building already has a relatively high heating and high cooling energy demand; secondly, the high primary energy factor of cooling energy amplifies the initially low cooling energy demand. The difference between the highest and the lowest value is about 10% (see Fig. 7).

Comparison of total energy demand and primary energy demand

The comparison between the total energy demand and the primary energy value has led to the following three major observations. Firstly, it can be noted that the primary energy demand is almost twice as high as the total energy demand. Secondly, the absolute differences in the set of primary energy values are greater than those of the total energy values. Finally, it has

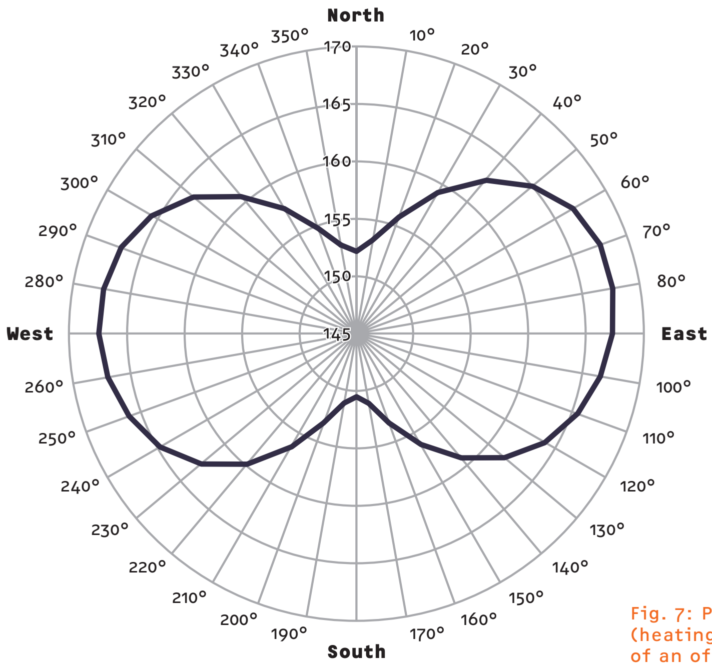

Fig. 7: Primary energy demand (heating, cooling and lighting) of an office building with different orientations (kWh/m²a)

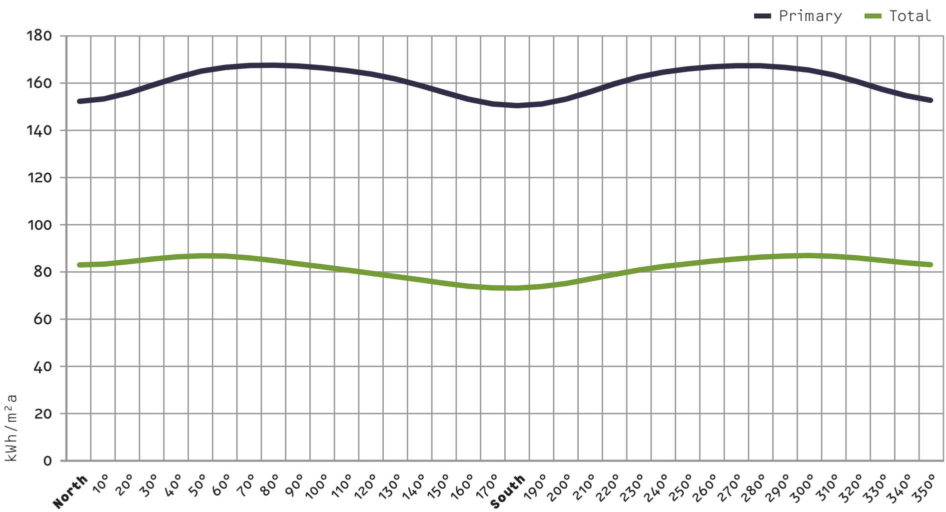

Fig. 8: Total and primary energy demand of an office building with different orientations

to be stated that, even though both demands differ in volume and absolute variance, their relative characteristics are extremely alike except in a north orientation. Both demands are at their lowest in a south orientation and at their highest in an east or west orientation. Nevertheless, the primary energy demand of a north-facing office building, compared to other orientations, is not as high as the total energy demand of a north-facing office. Because the cooling energy demand of north-facing offices is low and the primary energy factor of electricity (cooling) is high, the primary energy demand of offices facing north is also relatively small.

Conclusion

The optimization of the architectural design in regard of the building's orientation can lead to very high energy savings. The degree of this potential varies according to the climate conditions, the building utilization, the characteristics of thermal envelope etc. This survey has shown that building orientation can affect the heating, cooling, lighting, the total as well as the primary energy demand of office buildings. Therefore choosing the ideal orientation for the building will reduce the total energy consumption without using any additional materials or technologies. The energy saving potential of the perfect orientation in office buildings in this climate region is 16% and 10% for the total and primary energy demand respectively. These results show that it is possible to save large amounts of energy in office buildings solely through adjusting the building orientation. The analysis of the variations in the primary energy demand showed that this method can contribute significantly towards saving resources and minimizing CO_2 emissions. The choice of the perfect orientation requires no further materials or technologies, and thus has no effect on the life-cycle costs of the building.

3 Window Area

The proportion of window area on a building's façade has a significant effect on the energy demand and is one of the most important aspects in terms of energy efficiency achieved through architectural design.

Windows are the most crucial elements of a building from an energy point of view. In comparison to other components of the thermal envelope, these building elements often have a lower thermal resistance. Furthermore, windows, as a transparent component, provide solar heat gain as well as daylight. It is always beneficial to make use of daylight since it reduces the energy demand for artificial lighting. While solar heat gain is advantageous in the heating period, it is a disadvantage in the cooling period. Windows are, therefore, a vital constructional element with the most complex behavior in regard of heating, cooling and lighting energy demand.

The properties of the windows, including the heat transfer coefficient (U-value) of both the glass and the frame, the solar heat gain coefficient (SHGC), the light transmission coefficient (T or τ) as well as the type of shading device and its shading factor, influence the way in which this building element affects the energy demand of the building. Therefore, it is necessary to determine a suitable window-to-wall ratio for a minimum energy demand which takes into consideration the climatic conditions, the building's main features as well as the characteristics of the windows and their shading devices.

In order to demonstrate the effect the window area has on the energy performance of office buildings in the climate conditions of Hashtgerd New Town and eventually to determine the perfect proportion of window area as a possibility to save energy, various simulations have been made using different window-to-wall ratios. This study is carried out for both a building without shading devices and a building with external blinds.

Since the amount of solar radiation incidence during the different times of day and year depends on the façade's orientation, a building must have different proportions of window area in different directions. In a second step, this study will, therefore, establish the ideal window ratio for the individual orientations: the north, east and west-facing façades.

Window-to-Wall Ratios in all Façades without Shading Devices

In order to find the ideal window-to-wall ratio in regard of energy efficiency, a building is simulated with different window areas. The building, which faces southwards and is elongated in the east-west axis, has the same window-to-wall ratio on all sides; there is no shading. The building is simulated under the same conditions (climate, construction and architecture) and all characteristics of the building are the same except the window area. The energy demands each for heating, cooling and lighting are the main focus of attention.

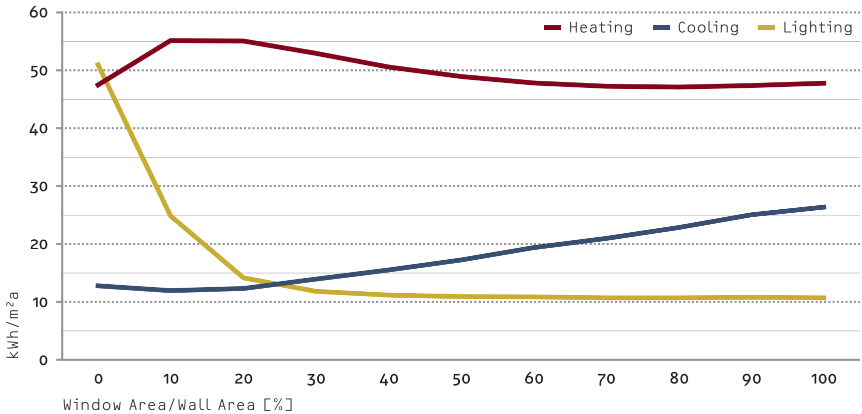

Fig. 9: Energy demands of office building with external blinds without different window -to-wall ratio (kWh/m²a)

Heating energy demand

The office building with a 10% window-to-wall ratio has a higher heating energy demand than a building without any windows. This means that the building's heating energy demand rises by increasing the window area from 0 to 10%. This is due to the fact that the heat loss through windows in winter is greater in the case of a building with a 10% window-to-wall ratio than the solar heat gain compared to a building without any window area.

The heating energy demand of the office building decreases by increasing the window-to-wall ratio from 10 to 80%. The rise of the window-to-wall ratio from 80 to 100% has little effect on the heating energy demand.

Cooling energy demand

Since the window area is increased equally on all façades, the solar heat gain in summer rises, in particular in the case of the east and west façades. Thus, the cooling energy demand of office buildings also goes up by increasing the window-to-wall ratio from 10 to 100%.

The cooling energy demand of office buildings decreases slightly by increasing the window-to-wall ratio from 0 to 10%, it then increases very slowly between 10 to 20% and rises more steadily after 20%.

Lighting energy demand

The larger a building's window area, the more daylight is let in and the less artificial lighting is required. Thus, increasing the window area from no windows to an office building with fully-glazed façades increases the amount of daylight and decreases the amount of artificial light. In terms of lighting energy demand *only*, a 100% window-to-wall ratio would be best.

According to the graph: By increasing the window-to-wall ratio of the office building from 0 to 30%, the energy demand for lighting is reduced considerably. However, a window-to-wall ratio greater than 30% makes little difference.

Because the window area also affects the heating and cooling energy demands of the building, the window-to-wall ratio of all façades, especially the north, east and west-facing ones, should only be more than 30%if the better ratio has an advantageous effect on the overall energy demand and leads to a decrease of the total or primary energy demand of the building.

Total energy demand

By increasing the window-to-wall ratio from 0 to 50%, the total energy demand of office buildings without shading devices decreases. However, window-to-wall ratios higher than 50% lead to an increase of the total energy demand.

This shows that, if the windows are without external shading devices, the optimum window-to-wall ratio for office buildings is 50% (see Fig. 10).

Primary energy demand

The building's primary energy demand is influenced mainly by its lighting and cooling energy demands (due to the relatively high primary energy factor of electricity). By increasing the window-to-wall ratio from 0% to 30%, the primary energy demand decreases significantly due to the extreme fall

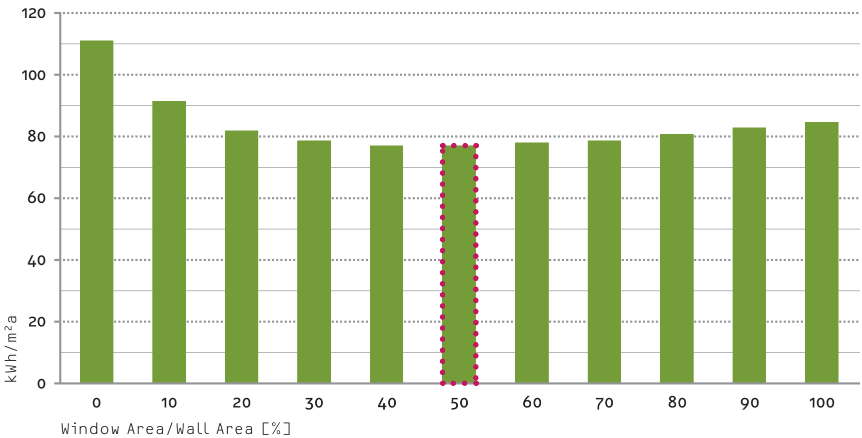

Fig. 10: Total energy demand of office building without external shading devices with different window-to-wall ratio (kWh/m²a)

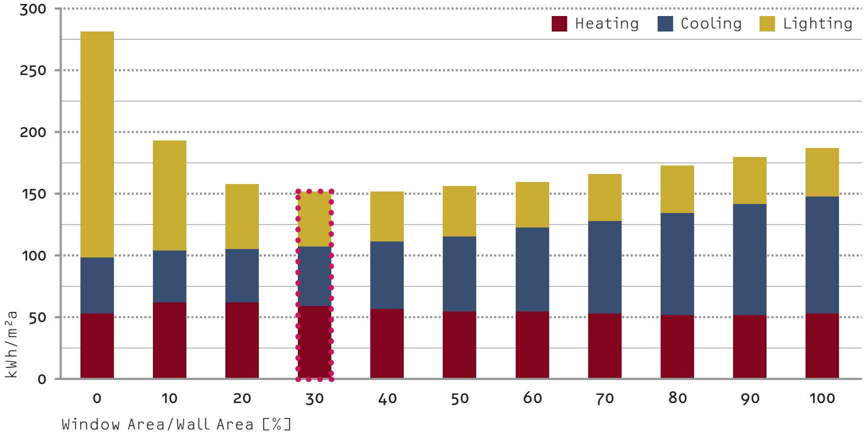

Fig. 11: Primary energy demand of office building without external shading devices with different window-to-wall ratio (kWh/m²a)

in the lighting energy demand. Any window area greater than 30% increases the primary energy demand, which is mainly affected by an increase in the cooling energy demand.

Window-to-wall ratios in all Façades with External Blinds

Because the most suitable window area differs for buildings with and without shading devices and it is necessary to determine the impact of the windows on the energy balance of the building, a similar analysis is performed with external blinds at the windows. The results show that the energy performance of office buildings differs by changing the window area and adding external shading devices.

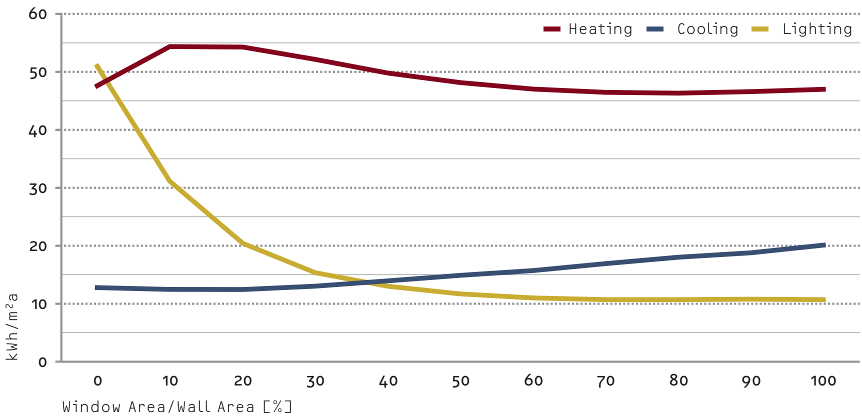

Fig. 12: Energy demands of office building with external blinds with different window-to-wall ratio (kWh/m²a)

Heating energy demand

By increasing the window-to-wall ratio from 0 to 20%, the heating energy demand of office buildings increases by about 10kWh/m2a, which is a rise of about 20%. By increasing the window-to-wall ratio from 20 to 80%, the heating energy demand decreases by approximately10 kWh/m2a. A window-to-wall ratio between 80% and 100% has little impact on the heating energy demand due to the fact that the heat loss in the heating period is greater than the solar heat gain that can be achieved through a window-to-wall ratio that is greater than 80%.

Cooling Energy demand

The cooling energy demand of office buildings rises by increasing the window-to-wall ratio from 10 to 100%. The total variation is a little less than 10 kWh/m2a, which means a relative increase of slightly less than 50%.

Lighting energy demand

By increasing the window area, the lighting energy demand is reduced significantly. The reduction of lighting energy consumption is very high for a window-to-wall ratio between 0% and 40%. Above 40%, the lighting energy consumption decreases only very slightly. In comparison to the situation without windows, a 40 to 50% window-to-wall ratio means a low lighting energy demand. A window area greater than 50% does not have any further effect.

Total Energy demand

By increasing the window-to-wall ratio from 0 to 60% on all façades, the total energy demand of office buildings in Hashtgerd decreases noticeably by about 30%. Greater window areas, however, cause the total energy demand to rise again. Therefore, it can be concluded that, in the case of office build-

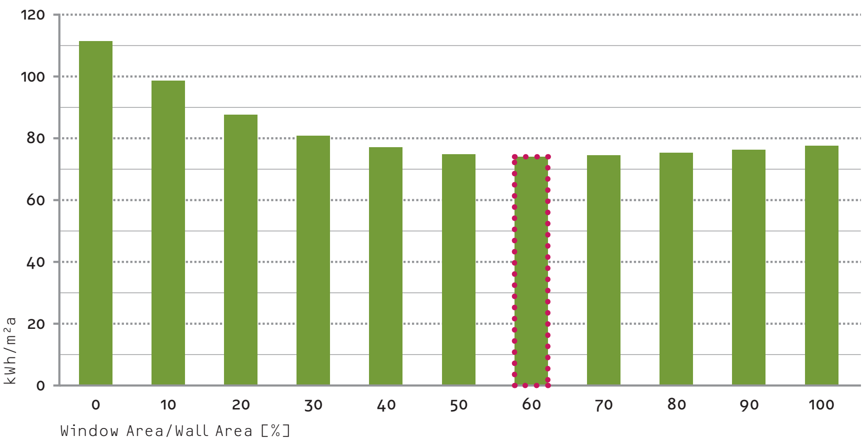

Fig. 13: Total energy demand of office building without external shading devices with different window-to-wall ratio (kWh/m²a)

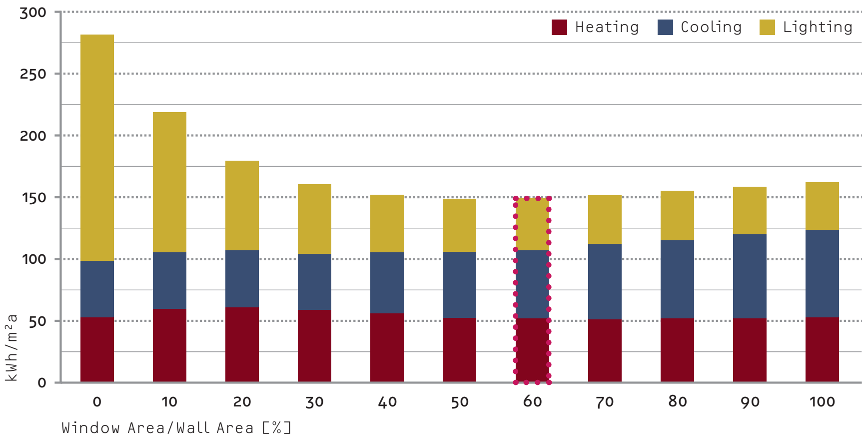

Fig. 14: Primary energy demand of office building without external shading devices with different window-to-wall ratio (kWh/m²a)

ings with external blinds, a window-to-wall ratio of about 60% on all façades is ideal regarding the building's total energy demand.

Primary energy demand

The response of the building's primary energy demand to different window areas in buildings with external blinds is similar to that of the total energy demand. The primary energy demand decreases significantly in the case of a window-to-wall ratio between 0 and 60%, which is mainly due to the lighting energy demand's performance. Window-to-wall ratios greater than 60%, however, lead to a greater primary energy demand, which is the result of an increase in energy demand for cooling.

Comparison of window-to-wall ratios with and without external shading devices

To identify whether the influence of the window-to-wall ratio is stronger with or without external shading, the previous results are compared. The following figure displays the examined building's total energy demand both with and without external blinds. Both graphs have similar characteristics, but differ in form and the value of their lowest point. If external blinds are applied, the minimum total energy demand occurs at a window-to-wall ratio of 60%, which is 10% greater than for a building with no shading devices.

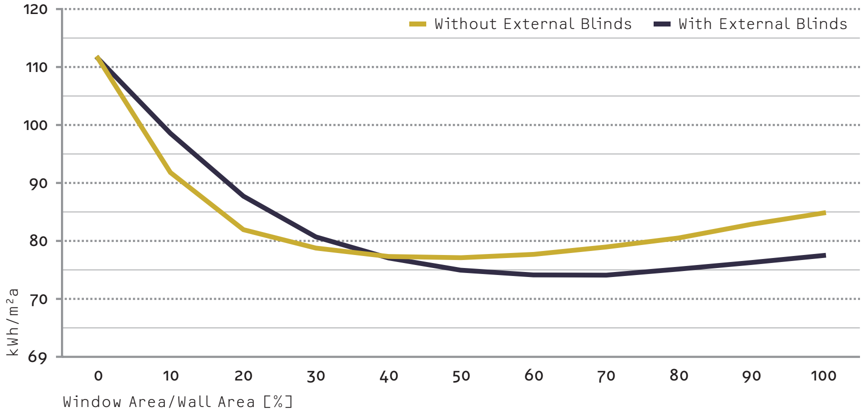

Fig. 15: Total energy demand of building with different window-to- wall ratios with and without external blinds (kWh/m²a)

Window-to-wall ratio of the north-facing façade (south, east and west with a 60% ratio)

As the previous simulations demonstrated, a 60% window-to-wall ratio in all directions is the best solution regarding the total energy demand of buildings. However, to determine the optimum window-to-wall ratio for each individual façade of the building, each individual envelope surface must also be analysed. In the following, the window-to-wall ratio of all sides is kept at 60% while the one on the north side is varied.

The following graphs show how the building's energy demands change with different north-facing window-to-wall ratios.

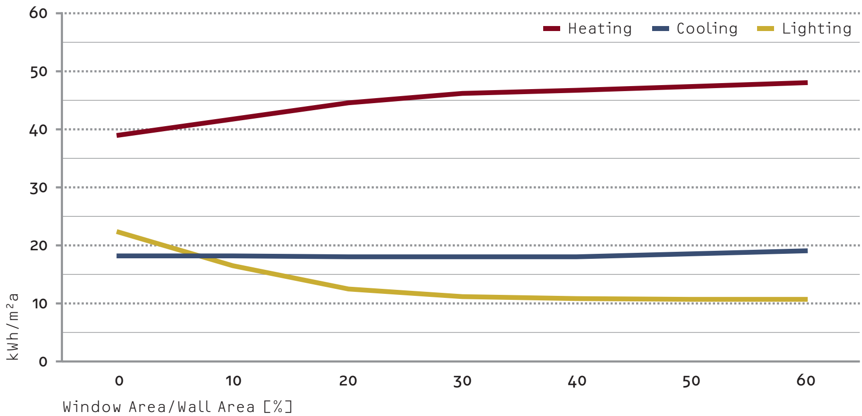

Fig. 16: Energy demands of office building with different north-facing window-to-wall ratios (kWh/m²a)

Heating energy demand

The heating energy consumption of the office building rises by increasing the north-facing window-to-wall ratio from 0 to 60%. Ratios higher than 60% would further increase the heating energy demand, which is why these ratios have been excluded from the diagram. There are two reasons for the increase of the heating energy demand: Due to the relatively high U-value of windows, in comparison to other wall components, the building's heat loss increases with a larger window area. At the same time, a larger window area cannot contribute any noticeable heat gains through solar radiation due to the sun's course throughout the day and year. The only time the north-facing side of the building is directly illuminated by the sun is either in the morning or evening in summer. Therefore, the north-facing windows can only generate very low solar heat gains in the heating period, which is via diffuse solar radiation.

Cooling energy demand

The building's cooling energy demand decreases marginally at a window-to-wall ratio of 0 to 20%. Ratios higher than 20% increase the cooling energy demand. However, the overall effect of the north-facing window area on the cooling energy demand is very slight.

Lighting energy demand

Like in the previous simulations, the lighting energy demand in the case of north-facing windows decreases significantly by increasing the window-to-wall ratio from 0% upwards. So by increasing the size of north-facing windows, the lighting energy demand of office buildings decreases. Beyond a window-to-wall ratio of 20 to 30%,the lighting energy consumption is very low. A further increase in window area will not contribute substantially to a further decrease in the lighting energy demand.

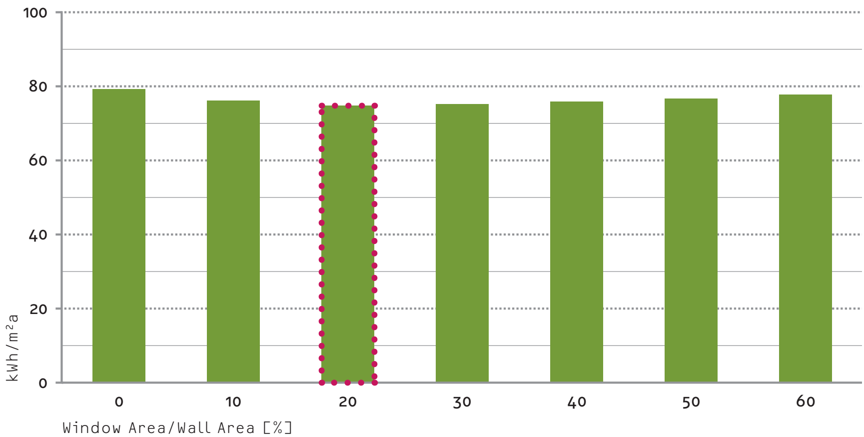

Fig. 17: Total energy demand of office building with different north-facing window-to-wall ratios (kWh/m²a)

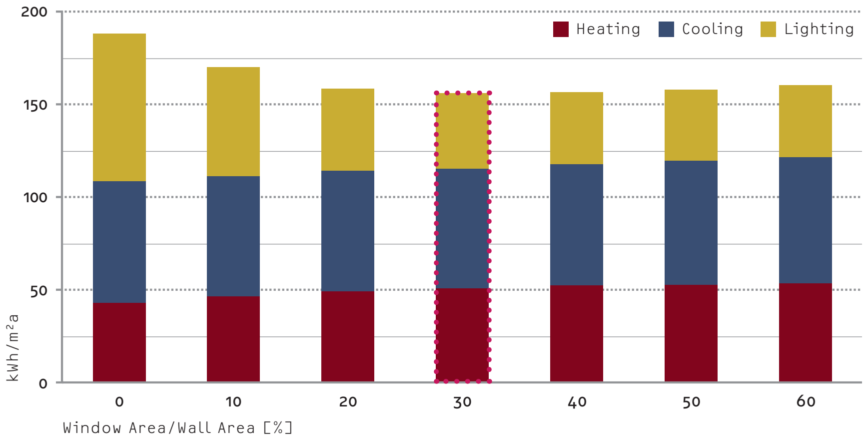

Fig. 18: Primary energy demand of office building with different north-facing window-to-wall ratios (kWh/m²a)

Total Energy demand

The total energy demand in office buildings decreases to its minimum by increasing the north-facing window-to-wall ratio from 0 to 20%. If the north-facing window area is raised beyond a 20% ratio, the total energy demand of office buildings increases. This shows that the optimum window area for a north-facing façade is a ratio between 20% and 30% (see Fig. 17).

Primary energy demand

Like the total energy demand, the primary energy demand decreases by increasing the window-to-wall ratio above 0%, which is due to the lighting energy demand's performance. This effect is intensified by the relatively high primary energy factor of electricity. The minimum primary energy demand is met at a 30% window-to-wall ratio(see Fig. 18).

Window-to-wall ratio on east and west façade (north 20%; south 60%)

In order to determine the most suitable window-to-wall ratio for both the east and west façade, the office building is simulated with a south-facing window-to-wall ratio of 60% and a north-facing window-to-wall ratio of 20%.

The following graphs show how the building's energy demands change with different east- and west-facing window-to-wall ratios.

Heating Energy demand

The building's heating energy demand decreases only slightly by increasing the east and west-facing window areas. This decrease is due to the increasing solar heat gains in winter. However, a greater window area also means greater heat loss in winter. Heat loss and solar heat gain almost cancel each other out. It cannot generally be stated that the size of the east and west-facing windows has a significant positive influence on the building's heating energy demand.

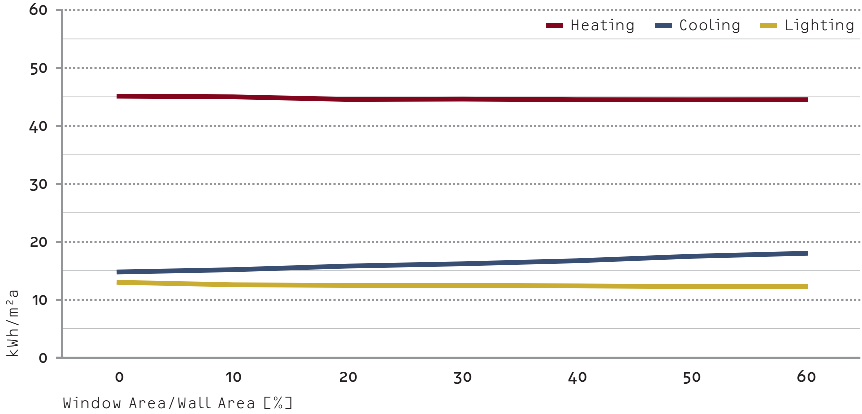

Fig. 19: Energy demands of office building with different east and west-facing window-to-wall ratios (kWh/m²a)

Cooling Energy demand

The building's cooling energy demand rises by increasing the east and west facing window area. This is due to the relatively high solar radiation in the east and west during summer, and thus the greater solar heat gains though larger windows.

Lighting Energy demand

An increase in window area on the east and west façades is cause for a decrease in lighting energy demand. However, the effect is very slight and almost non-existent because the building already receives sufficient daylight through the north-facing and especially through the south-facing windows.

Total Energy demand

By increasing the window-to-wall ratio on the east and west façade, the building's overall energy demand increases. This is due to the fact that the solar heat gains through the east and west-facing windows is higher in summer than in winter and the increase in cooling load is greater than the decrease of heating load. East and west-facing windows in buildings with south-facing windows are, therefore, a weak point regarding energy efficiency. If an office building has no south-facing windows, the east and west-facing windows will have a positive effect in reducing the total energy demand. Although these simulations actually suggest a window-to-wall ratio of 0 to 10%on the east and west side of the building to minimize the total energy demand, the window-to-wall ratio is nevertheless set at 10% due to the importance of daylight.

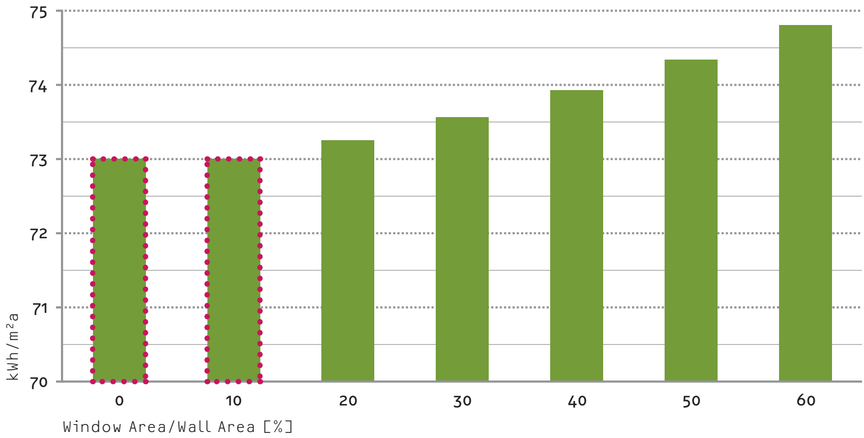

Fig. 20: Total energy demand of office building with different east and west-facing window-to-wall ratios (kWh/m²a)

Primary Energy demand
The analysis of the primary energy demand offers no new insights than the total energy demand. It also shows a minimum demand with no windows on the east and west sides.

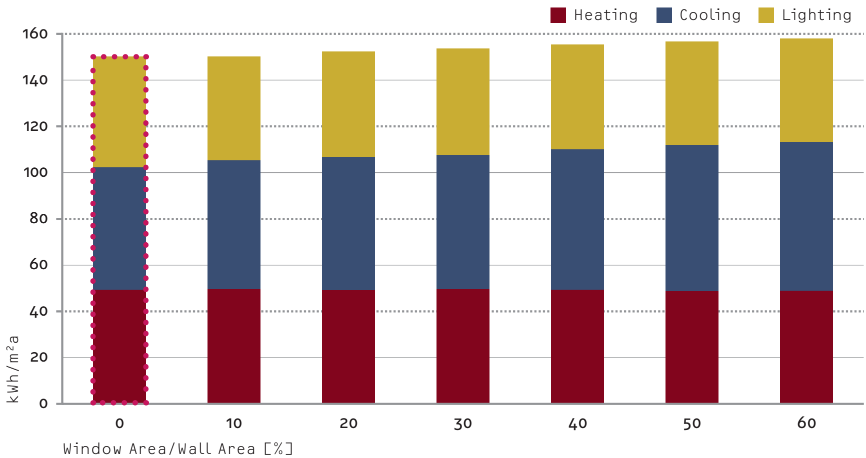

Fig. 21: Primary energy demand of office building with different east and west-facing window-to-wall ratios (kWh/m²a)

Conclusion

Various simulations have been performed to determine the ideal window-to-wall ratios for office buildings in regard of energy efficiency. Buildings with the same basic characteristics and the same climatic, structural and architectural conditions were simulated with varying window-to-wall ratios on

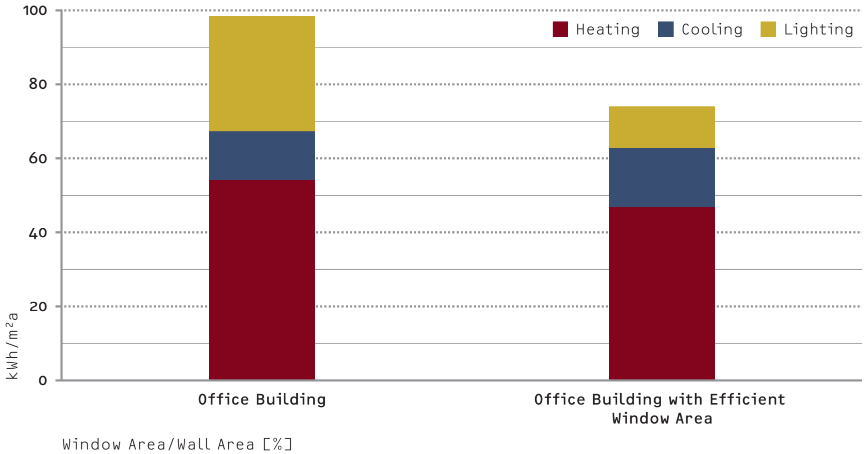

Fig. 22: Energy demand of two office buildings with different window area (kWh/m^2a)

all façades and were compared in terms of their heating, cooling, lighting, total and primary energy demands.

According to the results, the cardinal direction of a particular window area can significantly affect the energy demand. The window-to-wall ratio is, therefore, one of the most important architectural features to increase the building's energy efficiency. Optimizing a building's window area does not require any special building materials or techniques, nor does it increase the investment costs. It does, however, decrease the life-cycle costs significantly by reducing the building's energy demand.

The results show that:

- The energy demand of office buildings with different window areas varies significantly for buildings with and without shading devices.
- Buildings with the same window-to-wall ratio in all cardinal directions and without shading devices have their lowest total and primary energy demands at a window-to-wall ratio of 50% and 30% respectively.
- Buildings with the same window-to-wall ratio in all cardinal directions and with shading devices have their lowest total and primary energy demands at a window-to-wall ratio of 60%.
- South-facing windows have the greatest impact in reducing the total energy demand. Therefore, buildings require their largest window area with a 60% window-to-wall ratio on the south-facing façade.
- North-facing façades have their lowest total and primary energy demand with a window-to-wall ratio of 20 and 30% respectively.
- East and west-facing façades have their lowest total energy demand at a 0% to 10% window-to-wall ratio and their minimum primary energy demand at a 0% ratio.

4 Shading Devices

Shading devices are very effective elements for reducing the cooling energy demand where internal and, in particular, external heat gains are the cause for uncomfortable conditions inside the building. This is especially the case in climates with warm summers. Shading devices affect a building's energy balance by preventing some of the solar radiation from entering the building through glazed areas and thus contributing towards higher temperatures inside the building.

External shading devices are much more effective than internal ones and have a smaller shading coefficient. This is due to the fact that the external devices obstruct the solar radiation before it enters the building and is converted into heat. Adjustable shading devices, if controlled accurately and in accordance with the heating, cooling and lighting requirements, are more efficient than fixed ones. On the other hand, these require greater financial and technical input, and are dependent on the user behavior. Fixed shading devices reduce solar heat gain in winter too, which leads to a higher heating energy demand. Thus, each solution, fixed and adjustable, has its advantages and disadvantages and must be selected according to the specific needs of the opening.

Overhangs

In architecture, an overhang is usually a horizontal structural element protruding from the building above each window. The following section shows how an overhang can help to prevent some of the sunlight from entering the building. It also illustrates how the overhang's depth influences the effect of the shading device (see Fig.23).

Figure 24 shows the three main energy demands of an office building in relation to the overhang's depth. All windows, independent of the orientation, have the same overhang.

The diagram shows the following: By increasing the depth of the overhangs, the heating energy demand of the office building in the climate conditions of Hashtgerd increases, whereas the building's cooling energy demand decreases. These effects are due to the fact that the building's external heat gains are reduced in summer as well as in winter. The lighting energy demand increases slightly since the large overhangs lead to greater overshadowing.

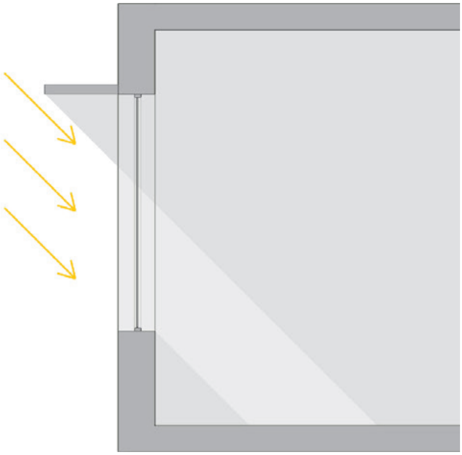

Fig. 23: Overhang

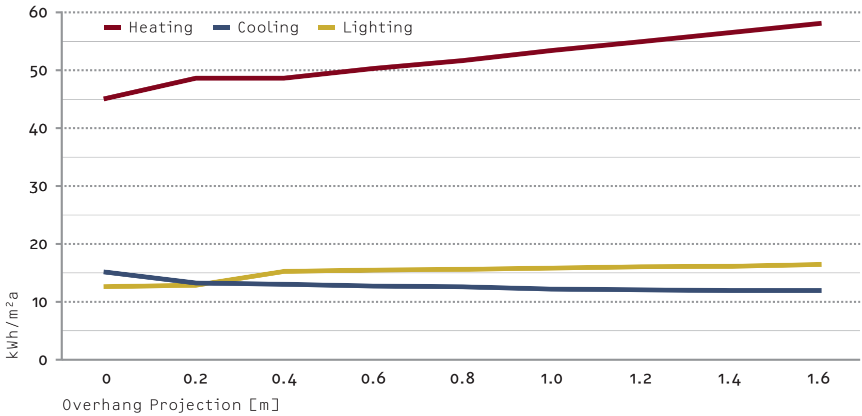

Fig. 24: Energy demands of office building with different overhang depths (kWh/m²a)

Because the increase of the heating and lighting energy demand is greater than the drop in the cooling energy demand, large overhangs ultimately increase the building's total final energy demand. Therefore, in order to determine the minimum total energy demand, it is not recommended to use overhangs at windows in all four cardinal directions.

An office building with an overhang depth of 20 cm has a lower primary energy demand than a building without any overhangs. However, if the projection of the overhang is increased beyond 20 cm, the primary energy demand increases. Even though the building does not require an overhang to meet the minimum total energy demand, the building also reaches the minimum primary energy demand with an overhang of 20 cm. This is due to the fact that overhangs reduce the cooling energy demand (electricity), which has a higher primary energy factor.

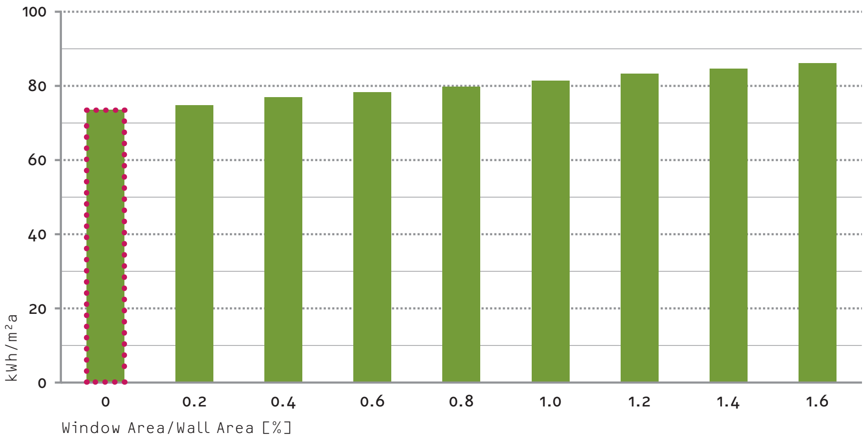

Fig. 25: Total energy demand of office building with different overhang depths (kWh/m²a)

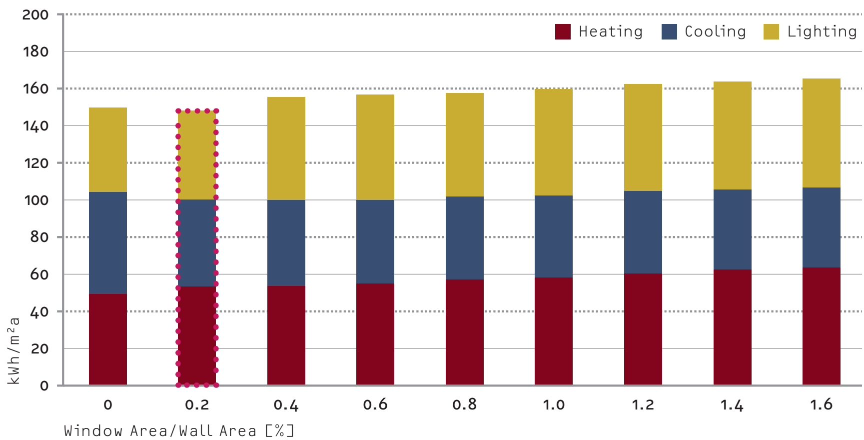

Fig. 26: Primary energy demand of office building with different overhang depths (kWh/m²a)

External Blinds

Since external adjustable shading devices affect a building's energy balance in different ways, for example depending on when it is being used, the question of whether it should be controlled automatically to optimize the positive impact must be considered. The following diagram shows that an external blind, placed in front of the window, does not have to be as static as an overhang. Its shading effect can be changed according to certain control strategies.

In order to study the effect of external blinds (and their control strategy) on a building's energy demands in the climate conditions of Hashtgerd, an office building without any shading devices and one with external blinds using different control strategies are simulated. The following diagram compares the heating, cooling, lighting and total energy demands of the office building with and without external blinds. The results show clearly that the external blinds and control strategy affect the heating, cooling, lighting and total energy demand of office buildings quite significantly.

Heating energy demand

The heating energy demand of an office building changes according to the control strategy of the external blinds. In the case of each strategy, the blinds are controlled according to the solar radiation, inside or outside air temperature, the need for daylight or solar radiation or within a set time period. An (inside or outside) air temperature setpoint, solar setpoint or a time schedule must be determined for each strategy according to which the blinds are closed or opened.

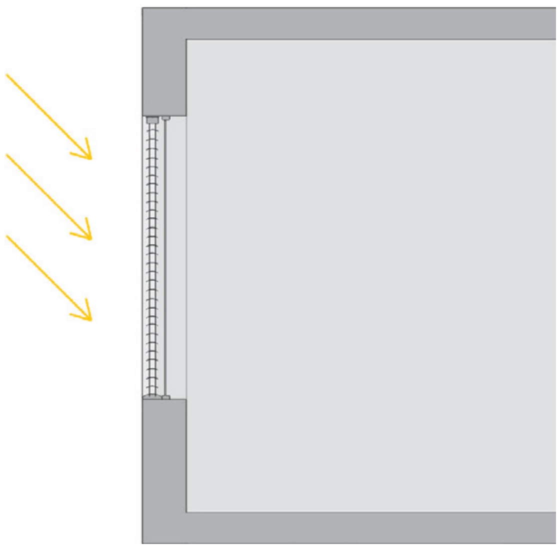

Fig. 27: External Blind

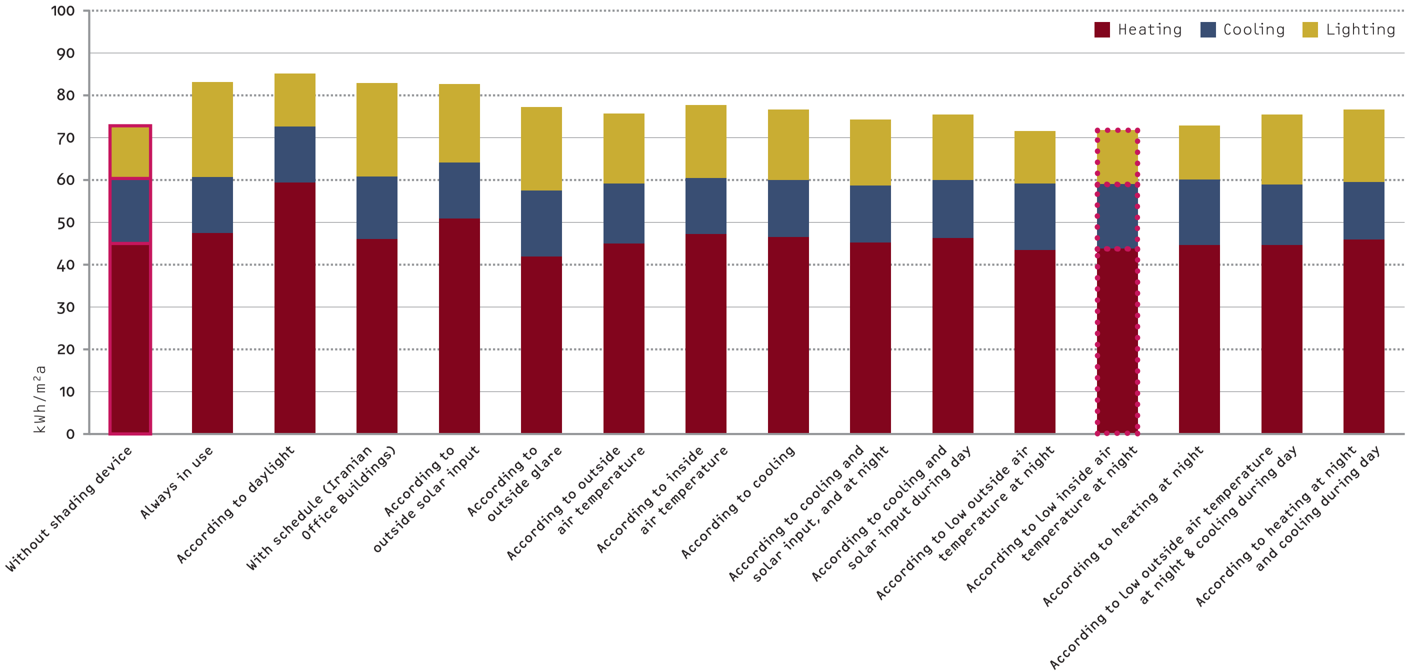

Fig. 28: Energy demand of office building with different external blind control strategies (kWh/m²a)

External blinds reduce the heating energy consumption of a building in comparison to not having any blinds, if they are controlled according to the following strategies:
- outside air temperature
- cooling and solar radiation during the day, and at night,
- low outside air temperature at night
- low inside air temperature at night
- heating at night
- low outside air temperature at night and cooling during the day

Five of the six above-mentioned strategies to reduce the heating energy demand are based on circumstances at night. This is due to the fact that opening the blind (closing the windows with the blind) in the winter nights reduces heat loss through long wave radiation from the warm inside surfaces to the cold outside atmosphere.

Cooling energy demand
Most of the control strategies concerning external blinds decrease the cooling energy demand of office buildings. They only increase the cooling energy demand marginally, if they are controlled according to:
- outside air temperature
- low outside air temperature at night
- heating at night
- low inside air temperature at night

These mentioned strategies are therefore not recommended if the cooling energy demand is the main concern.

Lighting Energy demand
All control strategies concerning external blinds increase the energy demand for lighting except the following four:
- daylight
- low outside air temperature at night
- heating at night
- low inside air temperature at night

Total energy demand
Only a few of the mentioned external blind control strategies reduce the sum of energy demands for heating, cooling and lighting in the office building. These are:
- low outside air temperature at night
- heating at night
- low inside air temperature at night

If the external blinds are controlled according to these strategies, both the heating and lighting energy demand decrease; the cooling energy demand, on the other hand, increases slightly. This does not generally suit the initial task of a shading device, but it shows that shading devices, especially adjustable ones, can affect the heating and lighting energy demand too. It also illustrates that the use of blinds to minimize the total energy demand is actually a complex process. The perfect operation of shading devices depends on different factors including the time of year, time of day, outside air temperature, amount of solar radiation, solar altitude, solar azimuth, etc.

Primary energy demand

The primary energy demand of an office building using different shading control strategies is similar to the performance of the total energy demand. As is the case for the total energy demand, only a few control strategies for external blinds have the potential to lower the primary energy demand. These are:

- low outside air temperature at night
- heating at night

Conclusion

The effect of external blinds on the total energy demand of an office building is generally very slight. The high solar altitudes in Hashtgerd New Town, especially in summer, short working hours in office buildings in Iran (and Hashtgerd New Town) and a large proportion of work being performed before noon are the main reasons for the little impact shading devices make on the energy demand of office buildings in this climate.

The simulations illustrating the effect of different-sized overhangs and external blinds on the energy demands also show that the use of overhangs as well as external blinds can even increase the office building's total energy demand in some cases. Nevertheless, the simulations are proof that an office building with external blinds requires less energy than an office building without any blinds, but that this is only the case if the blinds controlled effectively. The use of automatic control mechanisms with menu options, such as "low outside air temperature at night", "heating at night" or "low inside air temperature at night", is essential to exploit the blinds' full potential. Adjustable external blinds require specialized materials and techniques, all of which are available in Iran. Wind and dust can pose problems for external blinds and are a challenge in terms of technical and planning aspects.

On the one hand, the application of adjustable external blinds increases the investment costs, on the other hand, the energy costs and therefore the life cycle costs of a building decrease. These results show that it is economically viable to apply sun shading devices in office buildings.

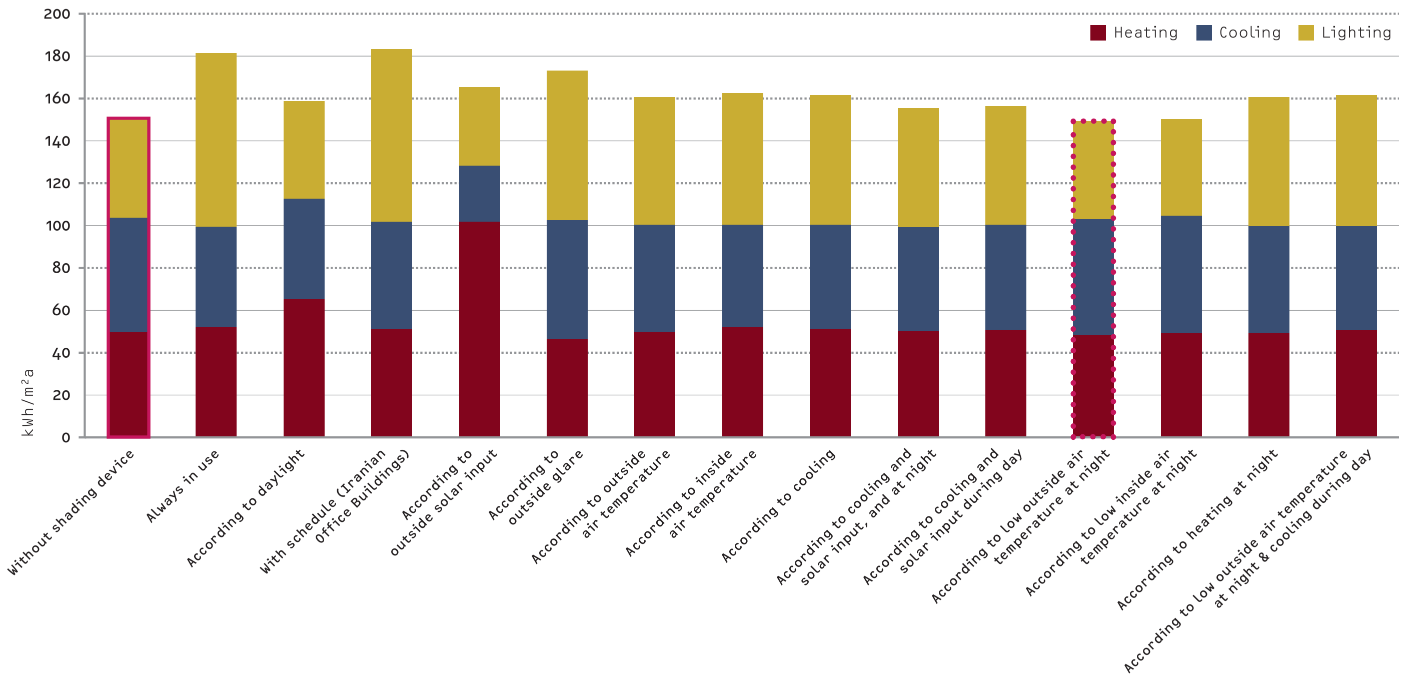

Fig. 29: Primary energy demand of office building with different external blinds control strategies

Imprint

Design/Typesetting büro-d | Communication Design Berlin

Publisher
Universitätsverlag der TU Berlin
Universitätsbibliothek
Fasanenstr. 88
10623 Berlin | Germany

www.univerlag.tu-berlin.de

ISSN 2196–517X (Print)
ISBN 978-3-7983-2552-4 (Print)
ISBN 978-3-7983-2553-1(Online)

Simultaneously published online on the Digital Repository of the Technische Universität Berlin
URL http://opus.kobv.de/tuberlin/volltexte/2013/3972/
URN urn:nbn:de:kobv:83-opus-39729
[http://nbn-resolving.de/urn:nbn:de:kobv:83-opus-39729]

All texts are based on scientific research performed within the Young Cities Project. All pictures, tables and graphics are courtesy of the respective article's authors, unless otherwise mentioned.