CUBATURES FOR MEDIUM-SIZED PLUS ENERGY BUILDINGS

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INTRODUCTION

On the basis of dynamic building simulations within a maximal realistic framework, it may be useful with respect to the overall energy balance to dispense with pursuing a minimal surface/volume ratio of buildings—thus minimizing heat losses across the building shell—in favor of solar energy use. The specific use of the building (here: office or residential) plays a crucial role. Balancing the energy demand for heating and cooling and a possible photovoltaic yield, a surplus is possible in all cases under investigation. Long, low unobstructed buildings perform best due to large portions of roof area suitable for solar energy use. For tall buildings with less roof area, parts of the facades may be used for solar applications which makes them also perform better than compact designs. If the total energy demand including auxiliary energy for HVAC and especially electricity for the office and residential usages, respectively, is considered, compact cubatures of the size considered here (about 3500 m^2) are not capable of providing positive energy balances. Residential usage performs worse than office use. Investigations are performed for the climatic conditions of Berlin, Germany.

KEYWORDS:

building surfaces, power generation potential, building shape and energy demand, photovoltaic facades, solar energy, dynamic building simulations

BACKGROUND

The building sector is not only responsible for a large proportion of total energy consumption, but also affects the use of resources over a long period of time because of decades of useful life. It is therefore important to pursue the minimization of the building's energy demand during the planning phase. The influence of the building's shape on energy demand is significant. Keeping the ratio of surface area to volume as small as possible used to be a goal in order to avoid unnecessary heat transmission losses. However, a compact design provides less usable surfaces for solar electricity and/or heat generation. As part of the energy transition, building surfaces provide a power generation potential, which should be particularly utilized in an urban environment. To solve this optimization problem, i.e. compact design versus sufficient solar

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energy areas, simulations are conducted using TRNSYS (Klein et al. 2008) and the potential of photovoltaic electricity generation on these buildings is examined.

BUILDING MODEL FOR TRNSYS

The simulation is based on building segments that are numerically assembled to complete buildings with about 3,500 m^2 of residential or office space (see Figure 1). Each segment consists of two equally sized rooms with a window on each outer wall and an intermediate hallway part. The building shell is assumed to be in accordance with the German building code described in the so-called EnEV (see, e.g. in Tuschinski 2017) with heavy structures except for lightweight interior walls. The depth of the building is varied by the room size: 36 m^2 and 48 m^2. In this paper, however, only the results of the objects with smaller rooms are shown. The results for the larger rooms are similar and lead to the same conclusions. The analysis is done for the climatic conditions of Berlin, Germany. In a building, usage-dependent internal gains arise. In addition to the persons present, they include the waste heat of all electrical devices. In addition, sufficient ventilation must be ensured. Because these areas vary greatly depending on the type of building usage, two types of usage are the subject of investigation: office buildings and residential buildings. Offices are used by two persons on weekdays from 6 am to 6 pm or 0600 to 1800. For each person, 150 W (each 75 W of sensible and latent heat) for light, sedentary activity go into the calculation. Also, 140 W each for the use of electrical equipment is added. To illuminate the workspace, 10 W/m^2 are estimated in which artificial light is only switched on when there is less than 167 W/m^2 of horizontal solar radiation, so that an illuminance level of 500 lux is always guaranteed. The effect of orientation on the use of natural light is disregarded. For summer heat protection, the integration of solar shading is essential. Shading is activated when the direct solar radiation on the respective facade exceeds 200 W/m^2, limited to times outside of the heating period. The offices are heated to 19 °C, the hallway is unheated. The heating period is set so that the heater only operates when the average 72 hour outdoor temperature is less than 15 °C. At night and on weekends a temperature drop of not more than 3 K is permitted. During summer months, the offices are cooled. Here, the target temperature is set to 26 °C. If required, the cooling process runs during occupant presence times and during lunch breaks. To provide the necessary fresh air, a mechanical ventilation system with 80% heat recovery is included. An additional window ventilation is likely in use during summer, but is also not predictable which is why it is not considered. It is possible that as a result, the cooling demand will be overestimated, but this applies to all considered variations alike.

For the simulation of the residential building, the floor plan is kept unchanged as in the office building. Although this seems unrealistic, it is irrelevant concerning the selected lightweight construction of the interior walls. The number of residents is based on the average room size for Berlin of 38.4 m^2 per resident (IBB 2012) and adopted with one person per 36 m^2 room. In residential buildings, the occupancy times can be subject to strong fluctuations. The occupancy times assumed here reflect various day rhythms as shown in Figure 2.

The switch-on times for artificial lighting are based on these assumptions, however, they cannot be directly linked to occupancy, since the room lighting is independent of the number of people. Morning and evening lighting peaks are assumed. As an internal load, an electrical power according to the so-called H0 Standard Power Profile (BDEW 2014) is added, distinguished between workdays and weekends. Assuming one to four person households in the residential buildings, an average consumption of 985.15 kWh/(person) is calculated. The composition of

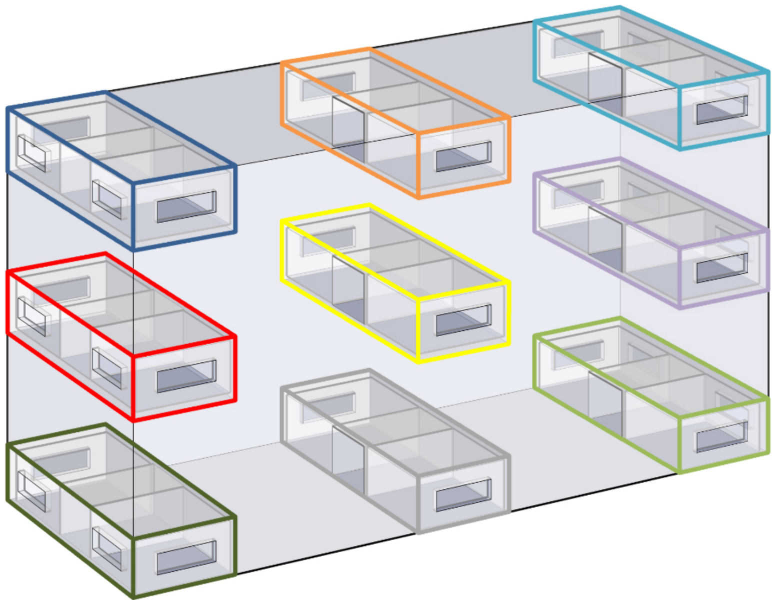
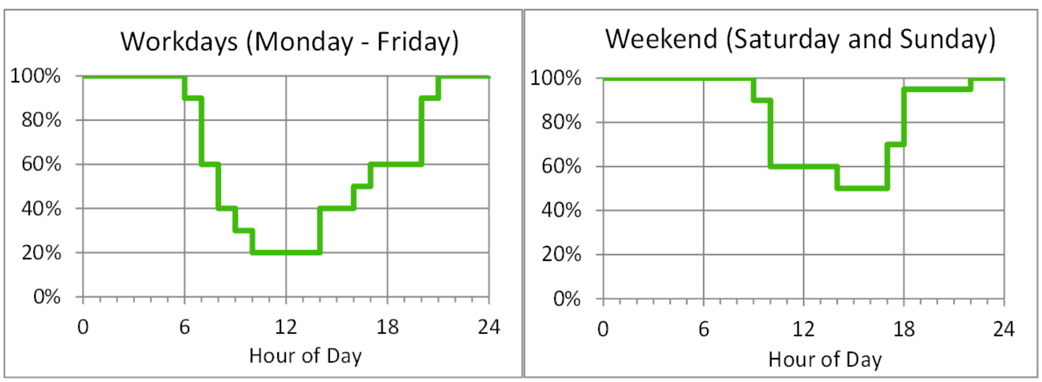


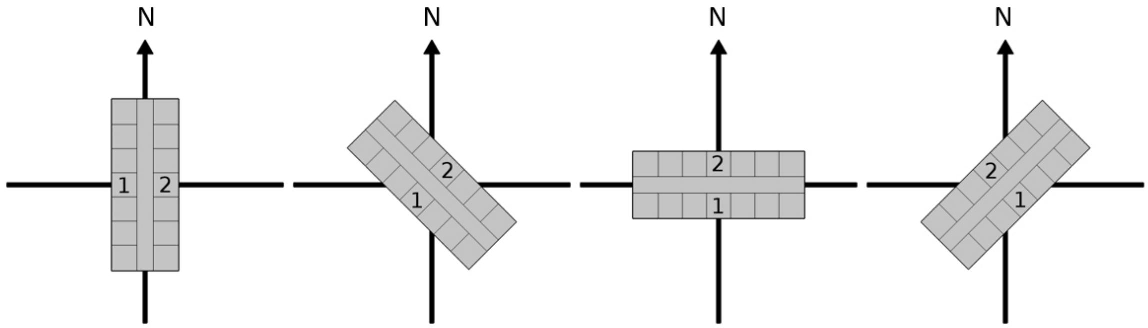
FIGURE 1. Arrangement of segments in the building. The colors are consistent with the representation of the results of the window variation shown later.

FIGURE 2. Occupancy percentage of residents on weekdays and weekends.



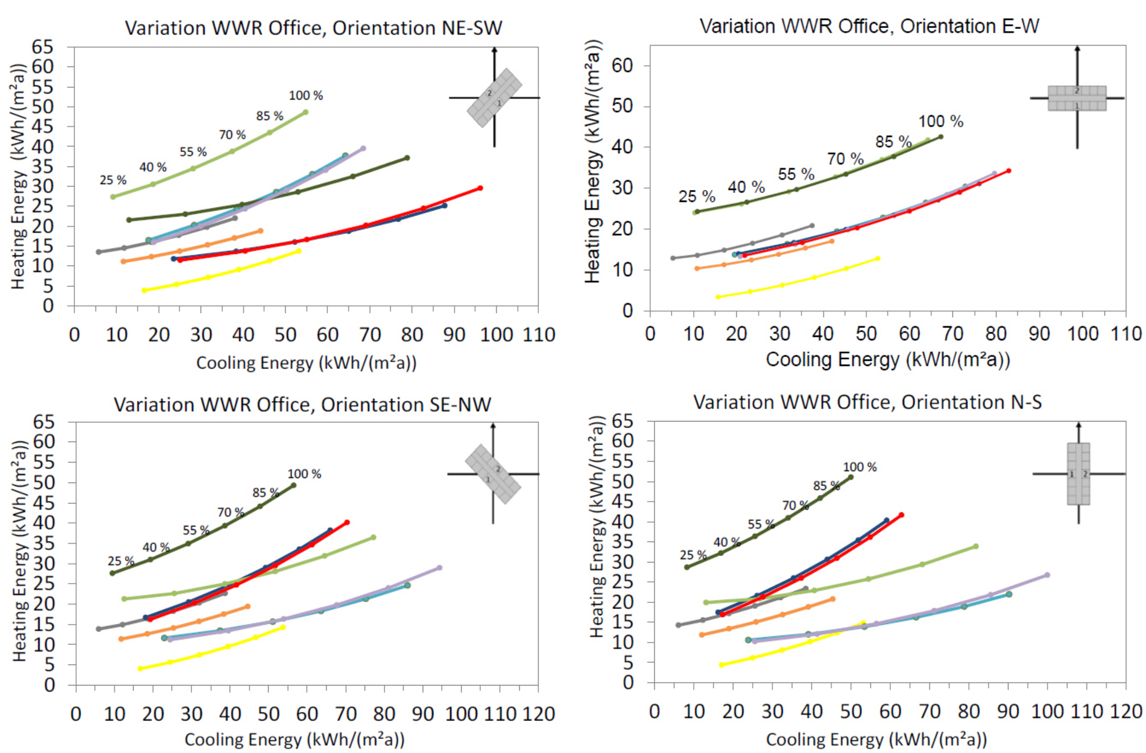
household sizes is equal to the average of 1.8 persons per dwelling that was mentioned in the housing market report 2012 for Berlin (IBB 2012). Although cooling in residential buildings is not typical in Berlin, Germany, it is maintained the same way as in the office building. Likewise, a ventilation system with heat recovery is provided. An air exchange rate of 30 m^3/h/person is scheduled according to the presence of people. For simplification, the timetables for the presence, light and ventilation are assumed consistent throughout the year and fluctuate only in case of dependency on external conditions. Generally, it may be assumed that there is a fairly high shading of window surfaces by sun protection elements for residential buildings on hot summer days, because it is common to keep curtains or blinds closed all day. However, exact numbers are not known. Therefore, the control rules for sun protection are set as in the case of the office building. Solar gains have a significant impact on the energy demand of a building. While they ensure valuable heating demand lowering solar gains on sun-facing facades in the winter, the insolation has an unfavorable effect on the cooling energy demand during summer, since the building is heated up to uncomfortable temperatures. To investigate this effect, four different orientations are considered.

FIGURE 3. Building orientations used in the simulation.



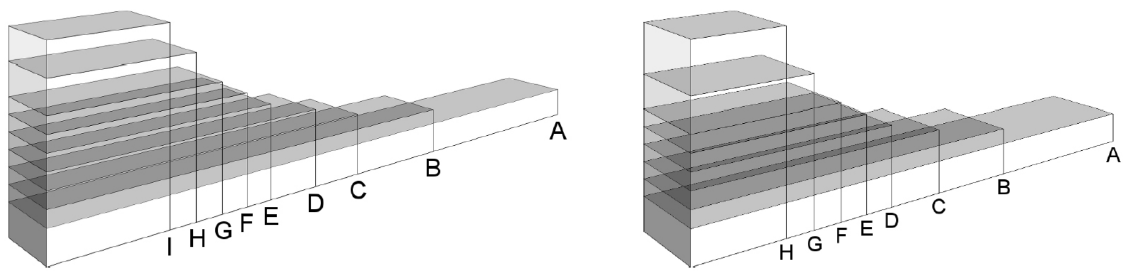
To optimize the window size, simulations were performed. For each façade, the Window-to-Wall-Ratio (WWR) was varied in six steps from 25% to 100%. The facades were considered independently so that the effect of the window orientation could be examined. Due to the abundance of data, however, only the results with windows of the same size on all facades are shown here. Increasing the amount of glass always causes an increase of energy demand. Here, the orientation determines how much the cooling and the heating energy are affected. These results confirm earlier investigations by Sick and Schade (2009). In addition, due to large windows, the area for a possible PV system on the facade decreases. It is clearly visible from Figure 4 that large windows especially raise the cooling energy requirements. For the examined

FIGURE 4. Cooling and heating energy of the individual segments, depending on the orientation of the building and the Window-to-Wall-Ratio (WWR). The side marked "1" corresponds to the visible facade in Figure 1. The color coding corresponds to that of Figure 1.



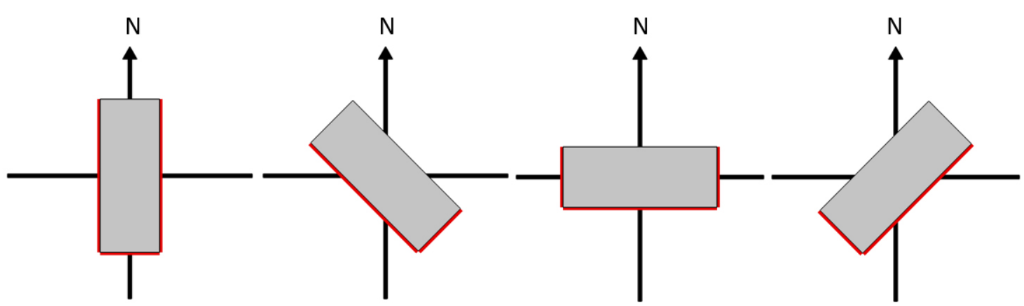
results, the case with 40% glass content on the facade surface is considered, which is adequately dimensioned for daylight use. The size of the buildings composed of the segments is set to about 3500 m^2 living or office space. Due to the modular design of the simulation, the surface fluctuates around this value. The slight fluctuation is permissible because only the specific values are compared. The building shape varies from elongated (variant A) with two stories up to the high-rise building with 12 stories (see Figure 5). With regard to the depth of the building, two variants are distinguished: 17 m and 21 m.

FIGURE 5. Variation of the building shape, left: narrow building, right: wider building.



The living or office space, respectively, is considered as the reference area. The use of solar energy is restricted to photovoltaics, without limiting the generality of the study. Unshaded roofs without superstructures are considered and the size of a possible system is determined using the program PV*SOL (Valentin 2014). The installation of the system is carried out in an East-West orientation with 10° inclination to achieve the best use of space and a more evenly distributed performance throughout the day. For the diagonal building orientations (NE-SW and SE-NW), the installation takes place in rows along the roof. For the dimensioning of the facade system it is important from which height such a facility is useful. For Berlin, the traditional eaves height of 22 m and the minimum distance on the property from the surrounding buildings that is to be maintained according to the Berlin Building Code is assumed. Under these conditions, shading analyses are performed.

FIGURE 6. Display of photovoltaic facades depending on the building orientation.



Based on these results, a facade PV system is integrated for all buildings beginning at and upwards of the sixth full storey. Here, the size depends on the maximum, hypothetically usable and available space, i.e. facade surface minus the window surface. No surrounding shading is assumed for these heights. Photovoltaic facades are allocated on all facades facing South, East and West (see Figure 6). Thus, the installed capacities differ in part considerably depending on the building orientation.

RESULTS

Heating demand is lowest in compact buildings with medium building height with the fluctuation being less than 5 kWh/(m^2·a). The cooling energy demand increases with increasing height of the building and determines, due to significantly higher values, the sum of both energy demand shares. Comparing the building orientation, the East-West orientation always performs best. Figure 7 for residential use and Figure 8 for office use illustrate these observations.

FIGURE 7. Energy demand (heating and cooling) of the residential building and the heating requirements contained therein.

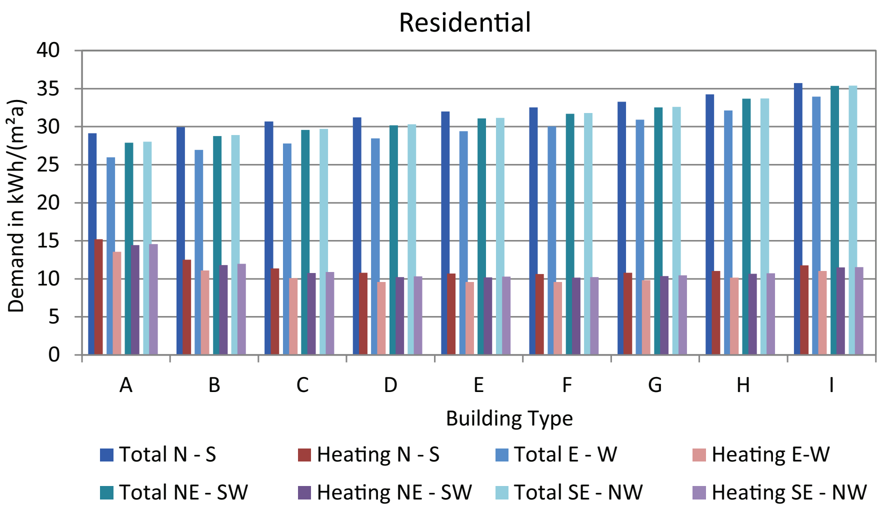


FIGURE 8. Energy demand (heating and cooling) of the office building and the heating requirements contained therein

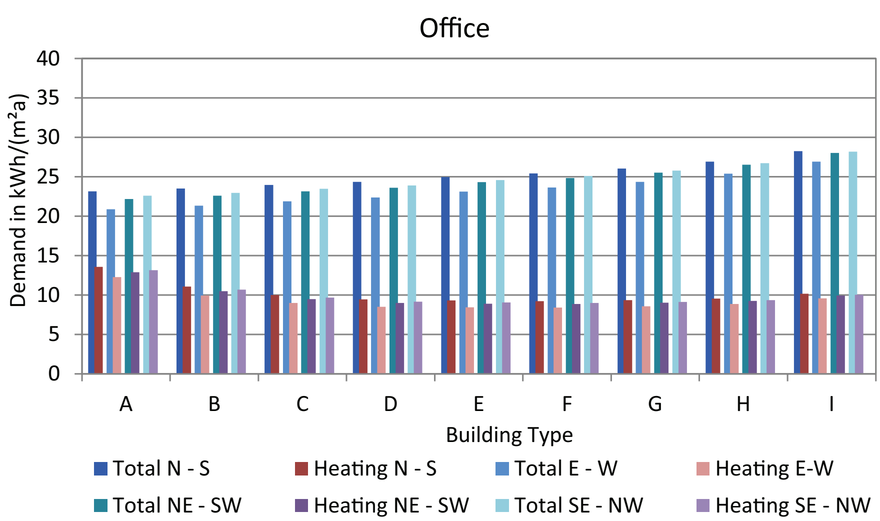
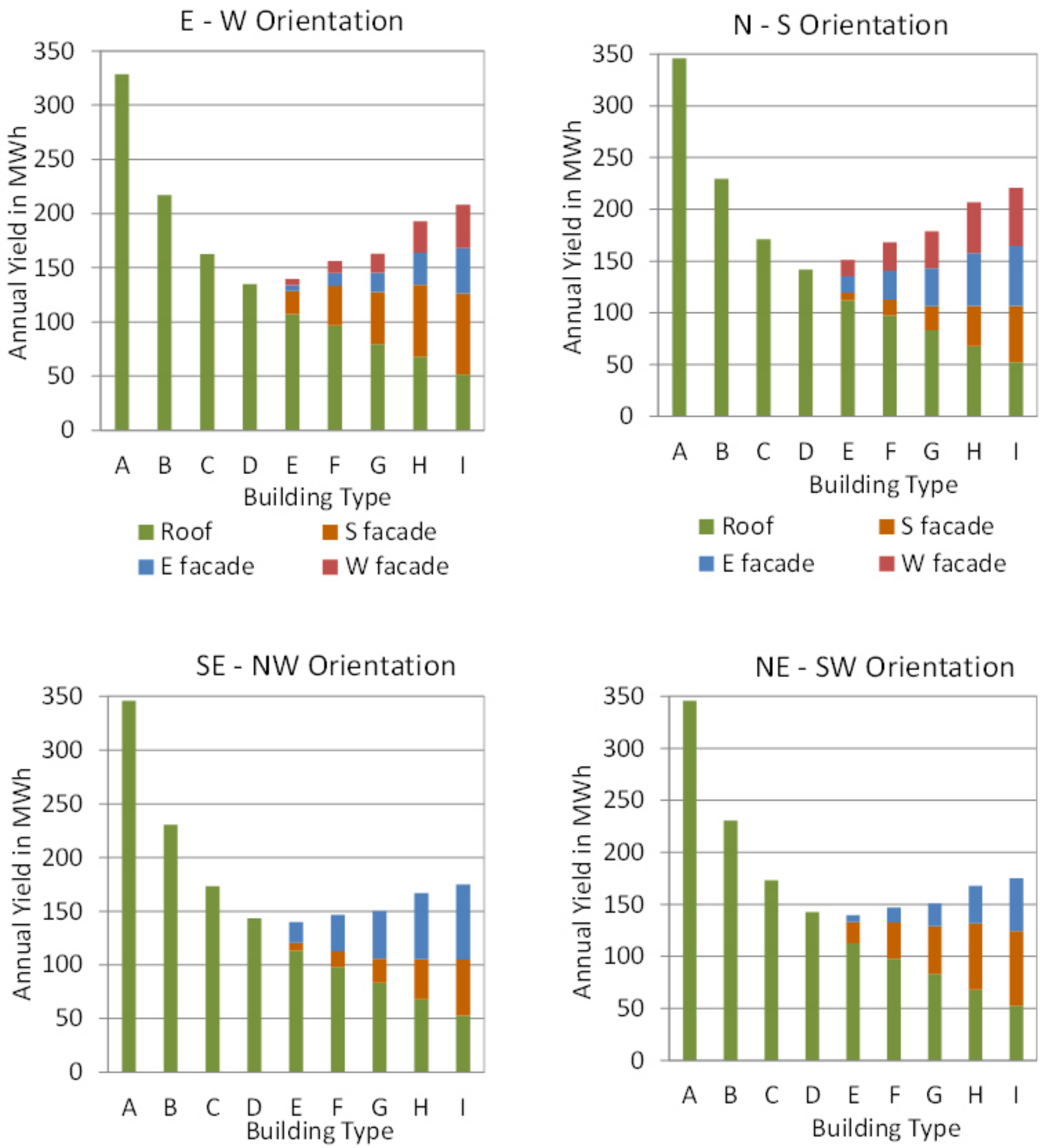


FIGURE 9. Simulated annual photovoltaic yields.



The solar electricity yields (Figure 9) are highest on a large roof area, decrease with compact buildings, and increase again for high-rise buildings due to the additional energetic use of the facades.

In a simple annual balance, the partial results—heating and cooling energy demand and photovoltaic power—are compared simply on the basis of kWh. Figure 10 contains the results for the office building, while Figure 11 shows the residential case. In this theoretical balance, all buildings achieve surpluses. The flat, elongated buildings (A) perform best, but a non-shadowed roof on very low buildings must usually be considered unrealistic.

Starting at four storeys, the tall buildings perform better in some cases. However, it depends on the orientation of the high-rise buildings: North–South or an East–West orientation is more advantageous than a diagonal arrangement, since three facades each are available for photovoltaics.

FIGURE 10. Simple energy balance of the office building containing only heating and cooling energy and photovoltaic yields.

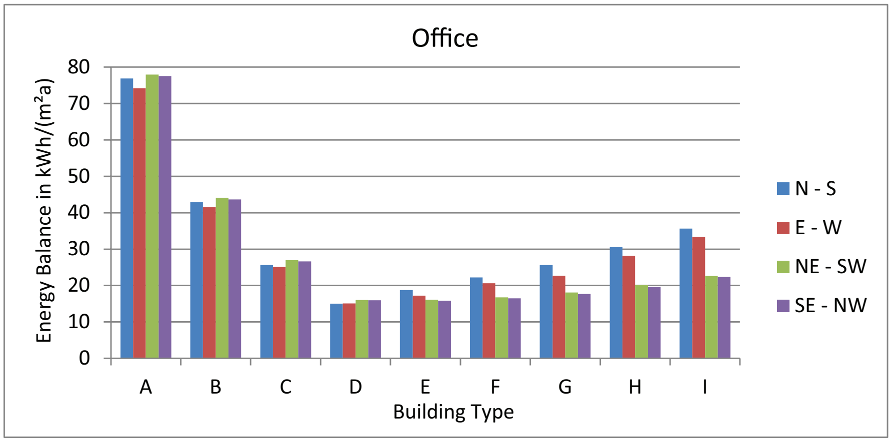
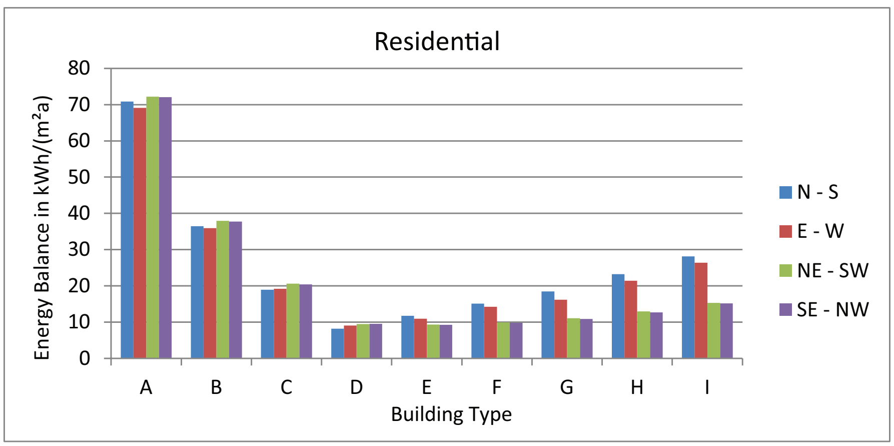


FIGURE 11. Simple energy balance of the residential building containing only heating and cooling energy and photovoltaic yields.



Finally, the building is analyzed in full operation using the example of a compression heat pump operation for heating energy production. Efficiencies, auxiliary power for pumps and vents, the user's power demand and domestic hot water (in the residential sector only) are included in the balance. The values for user's power as described above are used. Auxiliary power for HVAC components are set as follows:

TABLE 1. Factors defining auxiliary energy including heat pump operation.

Auxiliary energy ventilation	2.6 kWh/($m^2 \cdot a$)
Auxiliary energy storage	0.28 kWh/($m^2 \cdot a$)
Auxiliary energy distribution	0.88 kWh/($m^2 \cdot a$)
heat pump	seasonal performance factor 3.7
Auxiliary energy heat pump	1.09 kWh / ($m^2 \cdot a$)

Figure 12 and Figure 13 show the final results for the office building and the residential building, respectively. The compact building and diagonally aligned high rise buildings now show negative balances. Therefore they require more energy than they can produce. Thus, it is indeed worthwhile to dispense with pursuing a minimal surface/volume ratio of buildings in favor of solar energy use. Especially long and low buildings like Type A and B in the typology used here (compare Figure 5) show the potential of a significant energy surplus, provided the roof stays virtually unshaded. If three facades (South, East and West on the northern hemisphere) may be used for solar energy production, high rise buildings like Type I may also show slight positive balances, provided the WWR stays equal or below 40%.

FIGURE 12. Complete energy balance of office building including user power and heat pump in kWh/(m^2 · a).

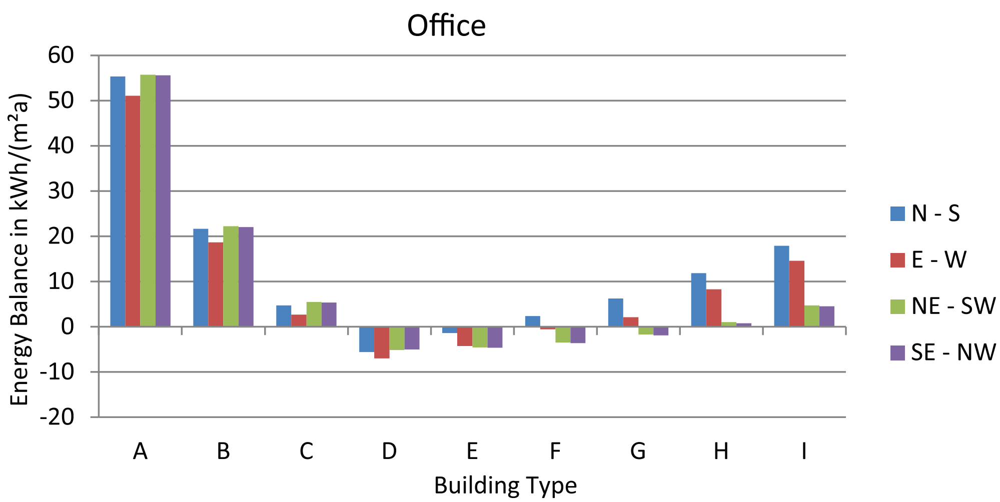
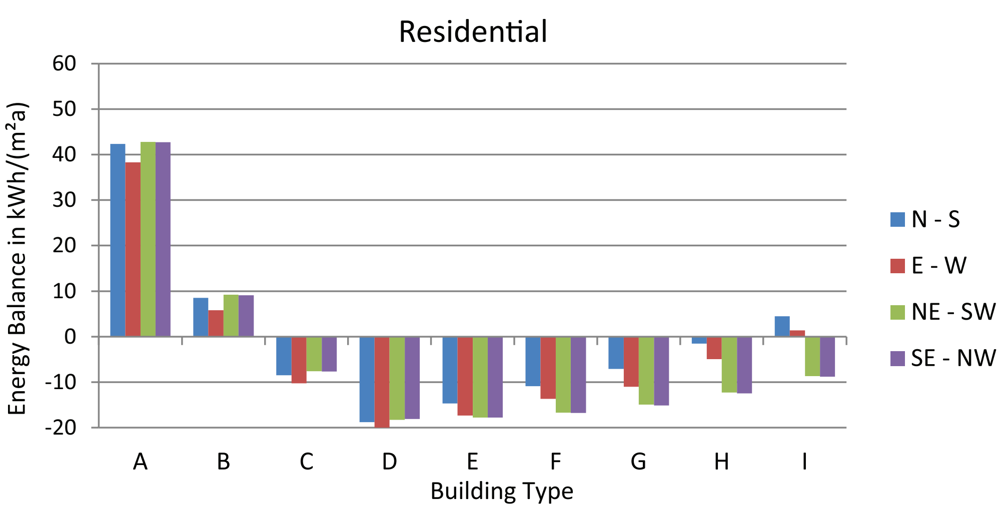


FIGURE 13. Complete energy balance of residential building including user power and heat pump in kWh/(m^2 · a).



CONCLUSION

The study shows that improvements in the overall balance can be achieved if a good coordination of architecture and energy concept are pursued from the beginning of design. With good heat insulation, it is advantageous to neglect the optimal surface/volume ratio in favor of possible solar energy yields. Therefore, even large buildings can achieve an energy surplus when at least considering the pure building operation but also in some cases where the total energy demand including the building's usage are taken as a basis. In reality, formal specifications often already restrict individual parameters. Nevertheless, the work carried out can provide assistance for optimizing energy use. Besides the purely energetic balancing that was conducted here, a combined economic and ecologic analysis would be a useful supplement. Furthermore, the inclusion of seasonal variations in the context of a self-consumption analysis including storage components would be of interest in order to achieve a maximum of grid independence.

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