Impact of radiation exchange between buildings in urban street canyons on space cooling demands of buildings

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Abstract

There is worldwide a trend towards urbanization, and cities try to improve their sustainability by saving natural resources and energy, and to mitigate the impact of climate change. Therefore growing cities need to optimize the energy demand of their new and existing buildings. There are a large number of urban scale phenomena that influence the energy demand of buildings. One of the most important influencing phenomena is the shortwave solar and longwave radiation exchange within an urban environment. It was demonstrated that the influence of neighbouring buildings has to be considered in detail to predict correctly the building energy demand. In this study, space cooling demand of stand-alone buildings is compared with buildings in an urban street canyon configuration. Detailed radiation models for the solar and longwave radiation are used to determine the radiation exchange between the buildings. The results show a strong influence of neighbouring buildings on

the space cooling demands. This influence is strongly dependent on the shading device control strategy incorporated in the building energy management. Counterintuitively the space cooling demands are in some cases are higher for low values of solar irradiance, because the shading device control directs the devices to remain open during longer time periods when irradiance values are low, leading to higher total solar gains through the windows.

Keywords

Urban microclimate, Building energy simulation, Solar radiation, Shading device control, Space cooling, Energy demand

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1. Introduction

The part of the population living in urban areas is continuously increasing. During the past two decades globally the part of the population living in urban areas increased from 45 % to 54 % and will further increase to 67 % by 2050 (UN 2011). In more developed regions (Europe, Northern America, Australia/New Zealand and Japan) the urbanization is even more pronounced with currently 78 % of the population living in urban areas increasing to 86 % by 2050. Residential and commercial buildings consume together roughly 40 % of the final energy consumption in the EU (EU 2009). Almost 70 % of the residential energy consumption is consumed for heating and cooling. Therefore there is a great energy saving potential by minimizing the energy demand of buildings in urban areas. Buildings in urban areas are influenced by the local microclimate that differs significantly from the rural microclimate. The air temperatures are higher due to the urban heat island effect and the wind speeds are lower due to wind sheltering by buildings (Oke 1987, Santamouris 2001a). Measurements in London showed up to 7 K higher air temperatures at night-time in the city compared to measurements outside the city (Watkins et al. 2002). In Athens the urban heat island intensity ex-

ceeds 10 K, what may lead to a doubling of the space cooling loads and triplication of the peak electricity load for space cooling purposes (Santamouris et al. 2001b). The space cooling loads in urban areas is expected to further increase due to global warming and increasing urban heat island intensities caused by urbanisation (De Wilde and Coley 2011). The increase in the occurrence of heatwaves (Schär et al. 2004, Fischer and Schär 2009) will cause an even stronger increase of the peak cooling loads compared to the increasing annual loads.

Due to urbanization, the urban heat island effect and global warming, it is important to optimize buildings in terms of energy demand considering local urban microclimates. The commonly used building energy simulation (BES) models were developed for stand-alone buildings (Hensen and Lamberts 2011). Recent studies show that building energy demand simulations should take into account the influence of neighbouring buildings for the radiation and convective heat transfer as well as for the urban heat island intensity (e.g. Allegrini et al. 2012a, Bouyer et al. 2011). Neighbouring buildings may strongly influence the energy demand for space cooling and heating, and daylighting by shadowing and multiple reflections of the solar radiation. Stromann-Andersen and Sattrup 2011 found that the total energy consumption of buildings increases due to the fact that the urban density affects the daylight availability and passive solar gains. Solar gains have an important impact on the space cooling demands of buildings and are commonly minimized by using shading devices. There is a large energy saving potential for optimization of shading devices and their control strategies. Bellia et al 2013 showed that for an office building in Palermo 20 % of the global annual energy can be saved by using suitable shading devices. For buildings in urban areas, besides the shading devices, also neighbouring buildings influence the solar gains. Muhaisen and Gadi 2006 and Yasa and Ok 2014 compared the energy demand of courtyard buildings for different courtyard proportions. They concluded that self-shading has a significant impact on the building energy demand. Also a number of studies on the influence of shading device control strategies on the energy demand have been conducted. Tzempelikos and Athienitis 2007 studied amongst others the influ-

ence of control for shading devices on the energy demand of office spaces in Montreal (Canada). They concluded that with a shading pattern that has an optimal balance between solar gains and internal gains, the total annual energy demand can be reduced by 12 %. In a similar study Zhang and Lam 2011 analysed the impact of two window shading control strategies on thermal and lighting loads of office buildings for different climates in the United States. They showed a reduction of the total loads of 6.7 % for internal shading devices with an optimal control strategy (note that with external shading devices a stronger decrease of solar gains can be achieved). In reality the shading devices are often not used in an optimal way, because they are either not automated or overruled by the occupants. Correia da Silva et al. 2013 monitored the occupant's interaction with electric lighting and shading systems for offices in Porto (Portugal). The results showed that lighting and shading control were influenced more by occupational dynamics than by the environmental conditions. Most of the opening events for the shading devices occurred at the moment of the first arrival and most of the closing events at the moment of departure, only 37 % of the opening and closing events occurred in between.

Although the physics of radiation is well understood and can be described correctly, the radiation exchange in an urban environment is commonly not modelled in a detailed way in BES. The radiation exchange is commonly strongly simplified, due to the reason that when the geometry is complex, more advanced numerical methods are needed to determine view factors for estimating the exchange of longwave and diffuse shortwave radiation. Evins 2014 et al. concluded in their paper that there is no BES program that allows assessing the radiation exchange between buildings in a straightforward manner. They also showed the importance of considering longwave radiation exchange between buildings in sufficient detail.

In this study the impact of the radiation exchange between buildings in urban street canyons on space cooling demands is studied. Further the results for different shading device control strategies are compared, with a focus on the solar gains through windows by reflection with neighbouring

buildings. Additionally, the influence of different building orientations and ground surface covers are studied. BES with detailed radiation models for both short- and longwave radiation are conducted. The aim of this paper is to show how space cooling demand depends on the building surroundings and the control strategy of the shading devices. Results for three different shading device control strategies are compared. The control strategies used in this study are simplified models of actual shading device control strategies, since detailed information on the control strategy and their input parameters is often missing, and the implementation of the overruling of the control systems by the occupants is difficult (Correia da Silva et al. 2013). The focus of this study is therefor on the relative influence of the predicted space cooling demands on the used model for the control strategy, rather than wanting to analyse absolute values of the space cooling demands for different control models.

The structure of the paper is as follows. In Section 2 the numerical model and simulation methods are presented. The space cooling demands are analysed in Section 3.1. In Section 3.2 the shortwave irradiances on the façades for different cases are studied. In Section 3.3 and 3.4 the solar gains through windows for different the shading device control strategies are discussed. In Section 4, the obtained results are discussed critically and in Section 5 conclusions are drawn.

2. Numerical model and simulation method

For the Building Energy Simulation (BES), the program CitySim (Kämpf 2009, Haldi and Robinson 2011 and Robinson 2011) is used. A verification of CitySim was done using the BESTEST (Walter and Kämpf 2015). CitySim models the energy fluxes in a city, with size ranging from a small neighbourhood to an entire city. Detailed radiation models for solar and longwave radiation are implemented in CitySim, accounting for radiation exchange between neighbouring buildings, ground and environment. To compute hourly irradiance of short and longwave radiation on building surfaces, the Perez All Weather model (Perez et al. 1993) and a Simple Radiosity algorithm (Robin-

son and Stone 2006) are used. Multiple iterations for the radiation calculations are performed to avoid numerical instabilities. The heat flow through the walls is determined with a model based on the analogy with an electrical circuit (resistor-capacitor network). Because the windows are not represented geometrically, no window surface temperature is determined separately, although heat conduction through the windows is considered. For the convective heat transfer coefficients, correlations by McAdams 1954 are used. More sophisticated approaches, considering results from CFD flow simulations (Allegrini et al. 2012b), are not considered in this model. To get individual surface temperatures for the individual façades and the roof of a building, each building is modelled as composed of several thermal zones, each consisting of exterior building walls (or roof) and the associated part of the building volume. CitySim also includes HVAC and energy conversion system models (Robinson 2011). In contrast to the standard CitySim version, in the version used here, a heat balance is solved for the ground surfaces between the buildings. This heat balance includes shortwave and longwave radiation and storage of heat as well as heat conduction to the soil. Evapotranspiration from green surfaces is not included. To model the heat storage and heat conduction in the ground, a number of ground layers are defined with thickness, heat conductivity and heat capacity as input parameters.

The simulations presented in this paper are conducted for stand-alone and buildings in a street canyon configuration (Figure 1) for the climate of Zürich (Switzerland). For the simulations a Typical Meteorological Year (TMY) from Meteonorm (Meteonorm 2014) is used. Two different ground surfaces are modelled around the buildings: grass and asphalt. For asphalt, the above described soil model is used. For grass the surface temperatures are obtained from Meteonorm (Meteonorm 2014), since evapotranspiration is not considered in CitySim. The solar reflectance for asphalt is 0.16, which is lower compared to grass (0.2).

All buildings are modelled as office buildings with standard occupancies and internal gains according to SIA (2006). Ventilation and infiltration are considered. The walls (with outer insulation) have

a U-value of $0.25 \text{ W/m}^2\text{K}$, the floors have a U-value of $0.3 \text{ W/m}^2\text{K}$ and the roofs have a U-value of $0.29 \text{ W/m}^2\text{K}$. The windows have a U-value of $1.1 \text{ W/m}^2\text{K}$ and a G-value of 0.7 and the glazing fraction of the buildings is 50 %. All façades have a solar reflectance of 0.5. External shading devices with different control strategies are used to protect the buildings from solar gains. The shading device control does not consider glare, since glare cannot be taken into account in CitySim. In buildings the controllers of shading devices would further take into account the occupancy of the buildings and daylighting. Taking all these effects into account is rather complex and often not done in building energy simulations (e.g. Wienold 2007), because detailed radiation simulations for the individual rooms of the buildings would be needed, which strongly increase the computational costs. The goal of this study is to find the sensitivity of the predicted cooling demand on the control strategies of the part of the controller that minimizes the solar gains. For control strategy 1 the shading devices close at shortwave irradiance on the façade of 100 W/m^2 , for strategy 2 at 150 W/m^2 and for strategy 3 at 200 W/m^2 . For all strategies the shading devices reopen at 50 W/m^2 . Control strategy 2 is the default strategy in CitySim and was also used by Wienold 2007. When the shading devices are closed, 0.15 of the incoming solar radiation is transmitted through the windows. The reflection of solar radiation on the shading devices (when they are closed) is neglected in CitySim. This case we refer to as the case ‘windows and walls’. To estimate the consequences of this simplification, additional simulations are conducted, where only one building with windows is simulated surrounded by buildings without windows (referred to as the case ‘only walls’). In this case, the neighbouring buildings have for the whole façades a solar reflectance of 0.5, what would be the case for closed shading devices that have the same reflectance of 0.5 as the walls. Because the shading devices are only closed during some time of the day, the real space cooling demand will be in between the two cases ‘only walls’ and ‘windows and walls’. Each building is modelled consisting of five thermal zones, each having an exterior building wall and/or roof and the associated part of the building volume. The buildings are split into different thermal zones to be able to model the individual walls separately and get their outside surface temperatures, but all zones have the same in-

side air temperatures. The room air temperatures are controlled to remain between 21 °C and 26 °C by heating and cooling. The electrical energy demand for artificial lighting is not considered, but the internal gains due to lighting are taken into account for the heat balance of the thermal zone. All buildings have a height (H) and a width of 10 m and length of 70 m (L). The width (D) of the street canyons is 10 m, leading to a canyon aspect ratio (H/D) of 1. The buildings are oriented in such a way that the main façades are either North - South or East - West façades. BES are conducted for a one-year period with an hourly timestep.

3. Results

3.1 Space cooling demands

First, the yearly space cooling demand for the stand-alone building and building in a street canyon configuration is compared. Table 1 gives the cooling demands for the stand alone building surrounded with grass for different orientations and shading control strategy. Comparing the highest and lowest cooling demands there is about a factor of 3 to 5 difference for East-West and North-South orientation respectively (see Table 1). As expected, the space cooling demands increase, when the threshold value controlling the closing of the shading devices is set to a higher value allowing higher solar gains. The stand-alone buildings with main façades oriented to the East and West show a higher space cooling demand than the same building with main façades oriented to the North and South. The reason for the higher space cooling demand for East-West orientation is the larger total daily shortwave irradiance on East-West façades compared to North-South façades.

In Figure 2 the normalised space cooling demand is given for different ground surfaces (asphalt and grass) and different buildings located in the street canyon (red building). The two cases of different façade properties of neighbouring buildings (case of ‘walls and windows’ and ‘only walls’) are considered. The results are given for the control strategy 2 (default values in CitySim) and are normalised by the results of the stand-alone building with grass (see Table 1). This building energy demand was chosen for normalisation, because it represents a common stand-alone building.

For both orientations the cooling demand is higher for buildings surrounded by asphalt compared to the case of grass, which is caused by the higher ground surface temperatures for asphalt. For the cases with the main façades oriented to the East and West, the cooling demands for the building in the street canyon are lower compared to the stand-alone buildings. Reason is the lower solar gains for the buildings in a street canyon configuration, as will be discussed in point 3.3. Comparing the different buildings in a street canyon for the same orientation, the highest demands can be found for the most easterly and westerly buildings at the sides, because they have the highest solar gains due to less shadowing. The two middle buildings show the same cooling demands, because all their properties and their direct surrounding neighbourhood are the same.

For the cases with the main façades to the North and South, the buildings in a street canyon configuration have higher space cooling demands compared to the stand-alone buildings. This is due to the higher solar gains through the windows of the street canyon buildings, because the shading devices will close less often on the north façades in a street canyon configuration. The closing and opening of shading devices and the related solar gains are discussed in detail below. For the same orientation the lowest cooling demands can be found for the most northerly building, because it receives the lowest solar irradiance on its south façade due to shadowing and lower solar gains on the North façade. The most southerly building has the highest cooling demand, because there is no shadowing on the South façade and there are higher solar gains on the North façade.

We now compare the space cooling demands for buildings inside the street canyons for the case where the neighbouring buildings have no windows (case ‘only walls’) to the case where the buildings have windows (case ‘windows and walls’). In the case ‘only walls’ all surrounding walls have a high reflection coefficient ($\rho=0.5$), while in the case ‘windows and walls’ the windows have a low reflection coefficient ($\rho=0$). In the case ‘only walls’ we expect a higher irradiation on the considered building by the reflection of the solar radiation from the surrounding buildings with high reflection coefficient. Intuitively, we also expect higher cooling loads for the case ‘only wall’ in com-

parison with the case ‘walls and windows’. However, figure 2 shows the opposite trend. The case ‘only walls’ shows lower cooling loads, which is attributed to solar shading devices which close during longer time of the day, leading to smaller total solar gains to the inside of the building. The longer closing time is caused by the higher irradiation on the considered surface due to the reflected irradiation received from neighbouring façades. This will be discussed further in detail in parts 3.2 and 3.3.

This leads to the conclusion that the façade properties of the neighbouring building can strongly influence the space cooling demands of the studied building since they influence the time the shading devices are open and closed. Besides the properties of the walls also the properties and control of the shading devices are important, because they change the solar reflectivity for the time periods the shading devices are closed.

Figure 3 shows the cooling demands for the three shading device control strategies as defined in the previous section. The results are normalised by the corresponding values for the stand-alone buildings with grass given in Table 1. The normalised space cooling demands for the street canyon buildings with shading device control strategy 1 are lower than for control strategy 2, while control strategy 3 shows the highest cooling demands. Reason for this observation is that for control strategy 1 the shading devices are closed during longer time compared to control strategy 3 leading to lower solar gains.

For the East – West orientation, the cooling demands for buildings in the street canyon are lower compared to the stand alone building. This is due to the lower irradiance, and solar gains for buildings in street canyons. For the buildings with main façades oriented to the North and South, the results are not similar. For example, for shading strategy 3, the cooling demand is higher for buildings in a street canyon configuration compared to stand alone buildings. This is caused by an increase of solar gains through the windows, caused by the larger number of hours the shading devices are open for buildings in a street canyon compared to the stand-alone building.

We again find a lower space cooling demands for the case of ‘only walls’ compared to the case ‘windows and walls’. The reason is again that more solar irradiance is received on the wall due to the higher reflected solar radiation from neighbouring façades, what leads to the shading devices to be closed during longer time resulting in lower solar gains.

The results of this section show how sensitive the space cooling demands are to changes in the reflected radiation from the surrounding buildings. Not only the shading device control strategy of the building itself is important, but also the control strategy of the shading devices of the neighbouring buildings. Therefore, depending on the design of the shading devices, it is important to consider the reflectance values of the closed (open) shading devices.

When modelling the shading device control, it is important to consider possible overruling of the control systems by the occupants. As Correia da Silva et al. (2013) showed, this would lead to much fewer opening and closing events compared to the prediction from a BES. We did not consider influence of human behaviour in this paper.

3.2 Shortwave irradiance

As shown in the previous section, the cooling demand of buildings is highly influenced by the period the shading devices are closed or open determining the solar gains in the building. The opening and closing is determined by the solar irradiation, direct and reflected, received on the building façade. Small differences in the irradiance due to reflections can cause the shading devices are closed or open resulting in high differences in solar gains inside and the cooling demand. Therefore we study in detail the solar shortwave irradiance. Figure 4 shows the shortwave radiation stand-alone and street canyon buildings during a typical day. The shortwave irradiance is lower for buildings in a street canyon compared to stand-alone buildings due to the higher shadowing effect in street canyons. The differences are highest for the East façade in the morning and the West façade in the evening. For the North and the South façades the difference is less pronounced, because the shadowing effect is less important due to larger solar angles at the time, when the South façade is sunlit.

On the North façades the differences are rather small and constant over the day, because there is no direct solar radiation on the North façades. We remark that when the irradiation value is near the threshold value for closing the shading device, large differences may occur in solar gains into the buildings since the shading device can be closed or open during different periods.

For all stand-alone and street canyon buildings the irradiance is for all façades slightly higher for a grass cover than for an asphalt cover, because the solar reflectance of grass is higher (0.2) than asphalt (0.16).

For the case ‘only walls’ the reflections of solar radiation from the neighbouring walls are higher leading to irradiance values somewhat higher during the hours that the neighbouring façades are sunlit. This effect can be observed mainly for the North façade.

3.3 Solar gains

Table 2 shows that the solar gains for a stand-alone building with grass around the buildings for three different shading device control strategies and two orientations. The solar gains are higher for the East-West orientation compared to the North-South orientation, and the gains increase when the shading devices are closed at higher threshold value.

In Figure 5 the normalised solar gains through the windows are given for all shading device control strategies, different ground surfaces, building orientations and reflective façade properties. The values are normalised by the solar gains of the stand-alone building with grass (see Table 2). The observed trend is very similar to the trend for the space cooling demands in Figure 3. This shows that the solar gains through windows are the main reason for the trends in cooling demands. In the following section we analyse the relation between solar gains, cooling demand and shading device behaviour.

3.4 Shading device behaviour

In Figure 4 it was shown that solar irradiance on façades is smaller for buildings in street canyons compared to stand-alone buildings. Counterintuitively these lower irradiance values lead to higher solar gains through the windows, which was explained by the shorter times the shading devices remain closed. In this section we study the time that the shading devices are closed for the different cases.

Table 3 shows the hours that the shading devices are closed during the cooling season for stand-alone buildings with grass around the building, for three different shading device control strategies and two orientations. In general, the devices remain closed during longer times for strategies with a low radiation threshold values (e.g. strategy 1), as expected. Façade orientation and control strategy have also an important effect: the shading devices on a North oriented façade are only closed for 295 hours for strategy 3, which is much smaller compared to strategy 1 where the devices are closed for 1298 hours. North façades only receive small amounts of irradiation in the range of thresholds for opening and closing shading devices, and are as a consequence sensitive to the control strategy. For other orientations, the number of hours that shading devices are closed is less sensitive to the control strategy.

Figure 6 shows the normalized number of hours that the shading devices are closed during the cooling season for stand-alone buildings and buildings in street canyons with different ground surfaces (asphalt and grass). Compared to stand-alone building, the shading devices of buildings in a street canyon representation remain longer open. On North façades the shading devices are longer open in time for street canyon buildings compared to stand-alone buildings. Depending on the control strategy the shading devices inside the street canyon are only 10 % - 50 % closed of the time the shading devices for the stand-alone buildings are closed. For the other three façades this decrease is much less pronounced.

For the case ‘only walls’, where the neighbouring buildings show a higher reflectivity and irradiation on the specific façade is higher due to reflections, the shading devices are for a longer time

closed, leading to lower solar gains and space cooling demands compared to the ‘windows and wall’ case.

3.5 Influence of street canyon width on space cooling demands

The results above were given for street canyons with an aspect ratio of 1. In this section results for the space cooling demands for street canyons with different widths are discussed. Figure 7 shows the normalized space cooling demands as a function of the street canyon widths. The space cooling demands are normalized by the demand of a stand-alone building with grass (Table 1). There is a wide range of space cooling demands depending on the orientation of the buildings, the aspect ratio of the street canyons, the location of the buildings within the building cluster and the shading devices control strategy. For both orientations a large influence of the neighbouring buildings can be found up to $D/H = 3.5$. The results for the buildings with the main façades to the East and West show similar trends. For the control strategies 2 and 3 the normalized space cooling demands almost coincide, while for control strategy 1 they are lower. For buildings with façades to East and West the space cooling demands are increasing with increasing distance between the buildings, which is mainly attributed to the higher solar gains with increasing width of the street canyon.

For buildings with main façades oriented to the North and South, the trend of the space cooling demands with distance between the buildings is more complex. For instance, for shading device control strategy 1 the space cooling demand for the most southerly building is decreasing with increasing distance between the buildings, while for the most northerly building the space cooling demand shows the opposite trend, or is increasing with increasing distance between the buildings. For control strategy 2, there is first an increase of space cooling demands, followed by a decrease of space cooling demands for the two middle buildings and the most southerly buildings. Finally for control strategy 3, an increase of the space cooling demands with increasing distance between the buildings can be observed. The reason for these different behaviours is two contradicting phenomena. As long as the time when shading devices are closed does not change, increasing the distance between the

buildings lowers the shadowing effect leading to higher solar gains and cooling demands. As soon as the time when the shading devices open or close changes, the solar irradiance due to shadowing will change. For example, in the case of North – South façade orientation, shading device control strategy 1, and most southerly building, the shading devices are closed during longer time for increasing distance between the buildings, resulting in lower solar gains through the windows and lower space cooling demands.

The results in this section show that it is difficult to predict the trends in space cooling demands generally for different building configurations, because there is a wide number of parameters that influence the space cooling demand and, depending on the building configuration, can result in an increase or a decrease of the space cooling demands.

It is important to note that the energy demand not only covers the space cooling demand, but also the electricity demand for artificial lighting. This means that the closing/opening control of the shading devices can lead to a decrease of the space cooling demand, but at the same time to an increase of the electricity demand for artificial lighting.

4. Discussion

In this paper building energy simulations were conducted to study the influence of neighbouring buildings and ground surfaces on the space cooling demand of buildings in urban street canyons. Further the sensitivity of the space cooling demands on the shading device control strategy is investigated. The results show that a wide number of parameters can influence the space cooling demand of buildings in urban areas. However, this approach does not consider all or simplifies some parameters that effect the space cooling demand for buildings in urban areas. The limitations of the approach are given here:

- Air temperatures in urban areas can be higher than the ones in rural areas due to the urban heat island effect. In this study, the urban heat island effect was not considered and its influence on space cooling demand was not covered.
- When comparing stand-alone with street canyon buildings, different convective heat transfer coefficients at the walls of the buildings have to be used. Here only coefficients for stand-alone buildings were used, since the current version of CitySim did not allow to consider different relations for street canyon buildings.
- The energy demand due to artificial lighting might increase when shading devices are used to minimize the space cooling demands. Therefore the decrease of the total energy demand of the building might be less than the decrease in space cooling demands. This effect is not discussed in this paper.
- The BES model used in this study does not represent the windows geometrically and assumes one single surface temperature for a façade including the surface temperatures of the shading devices. However, considering different temperatures for façade and windows / shading device could be important. Especially, when the façade is sunlit the windows and shading devices will have higher surface temperatures than the walls, leading to a higher longwave radiation exchange between the buildings. When the shading devices are closed and sunlit, we use a lower solar reflectance value for shortwave exchange leading to an underestimation of the solar irradiance. The reflectance of shading devices is strongly dependent on their design and normally not modelled in a BES model. To account for the detailed radiation exchange of shading devices raytracing methods are needed.
- Simplified shading device control strategies were used for this study. The shortwave irradiance was used as a criterion for the closing and opening of the shading devices to minimize the solar gain. The simplified model does not consider glare, occupancy and daylighting

level, because it is rather complex to take into account these parameters in the control strategy. These parameters are also often not considered neither in real building shading control nor in building energy simulations. However, the simplified control models allow to demonstrate the relative sensitivity of the predicted space cooling demands on the model used for the shading device control and the chosen level to protect the buildings from solar gains.

- For the studied cases, the shortwave irradiation on the north facades is near the threshold value for closing the shading devices, causing a high sensitivity of the space cooling demands on this threshold value. However, when the neighbouring buildings have different material properties, or when the local microclimate is different, the shortwave irradiance could be further away from the threshold leading to different conclusions.
- Finally, due to the high sensitivity of the cooling demands to the shading device control, urban geometry and façade materials of neighbouring buildings it is difficult to draw very general conclusions. Additional simulations for different urban morphologies and building geometries should be conducted, including different materials for the neighbouring buildings.

5. Conclusion

The impact of neighbouring buildings on the irradiation, solar gains and space cooling demand of a buildings in an urban street canyon was studied. Building energy simulations were conducted for different stand-alone and street canyon building configurations. A number of parameters were found to significantly influence the space cooling demands of buildings in urban areas. The properties of the soil around the buildings are important, because they determine the incoming shortwave radiation due to solar reflectance and the incoming longwave radiation resulting from the soil surface temperature. For example asphalt causes higher space cooling demands due to the higher sur-

face temperature, since it has a lower reflectance and higher absorptivity for solar radiation. Another important parameter is the orientation of the building, because it influences the amount of solar radiation absorbed on the façades. The aspect ratio of the street canyon is found to show a similar strong influence on the absorbed solar radiation due to shadowing effects. The surface properties of the neighbouring building are also found to determine the cooling demand. Mainly the solar reflectance is important, because it influences the irradiance on the studied buildings. A last important parameter identified in this study is the shading device control strategy. For well-insulated buildings the solar gains through the windows importantly contribute to the building energy load. As a consequence, the space cooling demand significantly depends on the number of hours the shading devices are closed during the day. In that context rather counterintuitive results were found in this study. Lower solar irradiance in street canyons on north façades can cause higher solar gains, because the shading devices are closed for fewer hours of the day, leading to higher space cooling demands.

This study shows the high sensitivity of the space cooling demand for a building to the urban surrounding, which does not allow to derive general conclusions. Especially the correct modelling of the shading device control has an important influence on the correct prediction of the space cooling demand of buildings in an urban environment.

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Figures

Figure 1: Studied buildings in stand-alone and street canyon configurations with grass and asphalt as ground surfaces.

Figure 2: Normalized space cooling demands for stand-alone buildings and buildings in street canyons with different ground surfaces (asphalt and grass) and neighbouring buildings with different façade properties (walls and windows or only walls) and two orientations. Results for shading device control strategy 2.

Figure 3: Normalized space cooling demands for stand-alone buildings and buildings in street canyons with different ground surfaces (asphalt and grass) and neighbouring buildings with different façade properties: ‘walls and windows’ case for the top figures and ‘only walls’ case for the bottom figures. The results are given for two orientations and all three shading device control strategies.

Figure 4: Shortwave irradiance (not absorption) for street canyons (neighbouring buildings with different façade properties: walls and windows or only walls) and stand-alone buildings.

Figure 5: Normalized solar gains during the cooling season for stand-alone buildings and buildings in street canyons with different ground surfaces (asphalt and grass) and neighbouring buildings with different façade properties: walls and windows for the top figures and only walls for the bottom figures. The results are given for two orientations and all three shading device control strategies.

Figure 6: Normalized number of hours that the shading devices are closed (during the cooling season) for stand-alone buildings and buildings in street canyons with different ground surfaces (asphalt and grass) and neighbouring buildings with different façade properties: walls with windows for the top figures and only walls without windows for the bottom figures. The results are given for two orientations and all three shading device control strategies.

Figure 7: Normalized space cooling demands as a function of the normalized distance between the buildings for buildings in street canyons with asphalt as ground surface and neighbouring buildings with windows and walls. The results are given for two orientations and all three shading device control strategies.

Tables

Orientation	Strategy 1	Strategy 2	Strategy 3
East-West	5.26 MJ/m ²	8.65 MJ/m ²	15.06 MJ/m ²
North-South	2.44 MJ/m ²	4.89 MJ/m ²	11.36 MJ/m ²

Table 1: Yearly space cooling demands for stand-alone buildings with grass around the buildings for three different shading device control strategies and two orientations.

Orientation	Strategy 1	Strategy 2	Strategy 3
East-West	68 MJ/m ²	81 MJ/m ²	99 MJ/m ²
North-South	59 MJ/m ²	74 MJ/m ²	95 MJ/m ²

Table 2: Solar gains during the cooling season for stand-alone buildings with grass around the buildings for three different shading device control strategies and two orientations.

Orientation		Strategy 1	Strategy 2	Strategy 3
East-West	East	1350 h	1217 h	1141 h
	West	1149 h	808 h	617 h
North-South	North	1298 h	723 h	295 h
	South	1247 h	1094 h	980 h

Table 3: Yearly hours that the shading devices are closed during the cooling season for stand-alone buildings with grass around the buildings for three different shading device control strategies and two orientations. The results are given separately for the different orientations of the main facades.