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Solar radiation and daylighting assessment using the Sky-View Factor (SVF) analysis as method to evaluate urban planning densification policies impacts

Cristina S. Polo López^{a,*}, Mariaemma Sala^b, Lavinia Ch. Tagliabue^c, Francesco Frontini^a,
Salim Bouziri^a

^aSUPSI, University of Applied Sciences and Arts of Southern Switzerland, Trevano CP 105, Canobbio CH-6952, Switzerland

^bPolitecnico di Milano, Via Ponzio 31, 20133 Milan, Italy

^cUniversity of Brescia, Via Branze 43, 25123 Brescia

Abstract

This study identifies and proposes simple methods to assess solar radiation, daylighting availability and Sky-View Factor (SVF) modification, in complex urban environment. Numerical methods and 3D simulation software are combined with photo processing methods using digital cameras with special mirrors to project the hemispherical environment onto a circular image. This methodology has been applied to a real case study in Switzerland that is undergoing a very fast urban densification process, where urban planning strategies will determine significantly the possibility to relish solar irradiation in buildings. This paper analyzed the particularities of different urban scenarios considering the effects of urban densification planning strategies on existing buildings, in particular historical protected buildings.

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* Cristina Silvia Polo López. Tel.: +41 (0) 586 666 314; fax: +41 (0)58 666 63 49
E-mail address: cristina.polo@supsi.ch

1. Introduction

Urban densification process could be a positive example of sustainability and as a parameter of an environmentally and socially sustainable development, nowadays it is a very common discussion topic and matter of research [1]. In Switzerland and other EU countries, this concept has been supported and emphasized through strategies and regulations at a national and federal level [2]. However, some aspects regarding solar rights [3] and especially the possible impacts to the cultural heritage existing in the area drastically modified by the densification process, has not been fully taken into account yet. Dense and compact urban settlements provide a complex environment, where solar access and daylight availability can become a scarce commodity with also implications in the urban microclimate. This is mainly related to the complex dynamic shadowing effects on building surfaces as a consequence of modifying the sky factor when high-rise buildings increase. The need to accurately quantifying these effects is a key factor for predicting reductions in solar availability or daylighting. In this development process, special cases are the cultural protected monuments, unchanged and immutable through time, protected by the regulatory plans and bound by preservation needs and constraints that cannot benefit from a rapid urban development. At this point it is necessary to wonder for the impact of this urban transformation and about the real influence on building energy aspects (especially historical heritage) and their surrounding micro-climate. Moreover the impact on solar energy availability on existing buildings (in particular historical buildings) during urban transformation is not yet well understood and is a matter of research. This reason also motivates the recent decision of the International Energy Agency (IEA Solar Heating and Cooling programme) to set up a working group on “Solar energy in urban planning” aimed at monitoring progresses in such issues, proving the innovation of our research. [4]

2. Purpose of the work

The starting point of this research is the analysis of a real case study in Ticino (Switzerland), in the Lugano Paradiso municipality, part of Lugano's settlement. It is a district that is currently undergoing a deep change towards densification of the urban environment, as defined in the new master plan regulations. Four protected heritage buildings were identified in the area (Fig.1): 1. Palace Riva Paradiso (A4905); 2. Hotel Victoria (A4906); 3. Palace G. Guisan Street (A4907); 4. Posthotel Simplon (A4908).

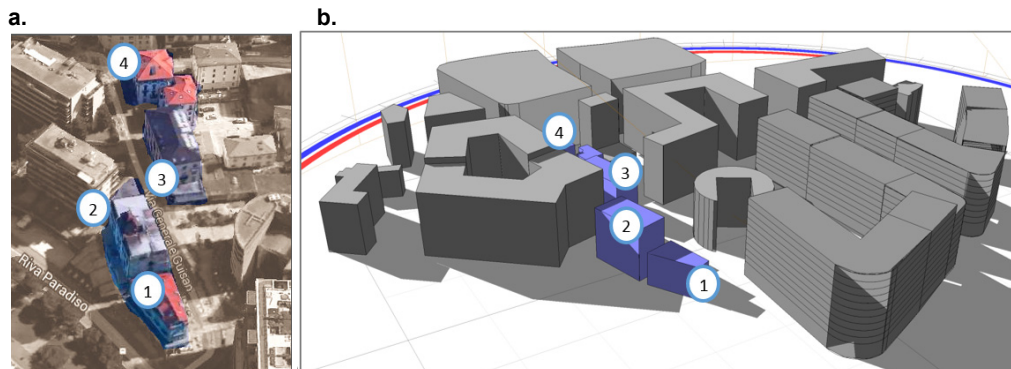


Fig. 1. Case Study: Paradiso, Lugano, (CH) urban transformation towards densification: (a) current status; (b) 3D simulation, future status when new master plan will be fully implemented. The blue buildings and numbers (1-4) are the existing cultural monuments protected in the area.

The impact of the future buildings design on the historical heritage has been quantified to understand the change from different points of view: the solar access and the daylighting availability in the area in different scenarios. To assess solar irradiation changes and to analyze the different parameters that quantify energy impacts in an urban context not only solar simulation tools can be used, instead of this complex kind of analysis, there are also more simple methods, as photo image processing methods, to characterize the correct geometry of urban settlements.

3. Sky-View Factor (SVF) analysis

The urban canyon geometry is directly depended by the height, the length and spacing of the buildings itself and have a significant impact on the energy exchanges and on the urban areas temperatures. These energy exchanges that influence the local microclimate of an urban area directly linked with the street profile depend also on the orientation (N-S; E-W), the view factors and the building height: width (H:W) ratio. In this sense the sky-view factor (SVF) serves to analyses the incidence of urban canyon geometry. Some studies have also demonstrated the implication of the sky-view factor (SVF) on urban air temperature [5], [6]. The thermal properties in built-up areas and the lack of effective radiation due to obstructions affect the net radiation and consequently the temperature pattern in urban areas.

The sky-view factor represents the ratio of solar radiation received by a planar surface compared with that received from the entire hemispheric radiating environment. The sky can be covered with important reliefs or vegetation (which varies from season to season), from elements of street furniture and also by new buildings. The SVF can be used also to indicate the contribution / absence of solar radiation and natural light in the indoor environment due to obstructions and this therefore, affects the daylighting with implication also on human comfort because the perception and vision of the sky and the natural lighting has directly benefits on human health.

For this project this parameter has been analyzed by different methods using either analytical or photographic methods. Analytical methods use equations as function of the geometry of the site by knowing azimuth angles (α) and the associated elevation (in connection with produced shadow) angles (β) of each elements of the hemispheric environment (surrounding buildings). In this case it possible to assume that the sky-view can be calculated by the equation (1). In this equation (Johnson and Watson, 1987) [7], γ_1 and γ_2 are the azimuth angles of the walls determined by point of interest.

$$\psi_w = \frac{1}{2\pi} \{(\gamma_1 - \gamma_2) + \cos\beta[\tan^{-1}(\cos\beta \tan\gamma_1) - \tan^{-1}(\cos\beta \tan\gamma_2)]\} \quad (1)$$

Furthermore, sky-view factor (SVF) could be studied using digital cameras with fisheye lens [8], [9], or as in our case special mirrors to project the hemispherical environment onto a circular image plane (HORICatcher device¹). With a digital camera and a horizon mirror (spherical convex mirror) it is possible to register the horizon in the field quickly and efficiently in order to calculate limitations of the sunshine duration and irradiation due to obstacles and serves to obtain three-dimensional projections of the space projected in the mirror dome. Specific software calculates the sun's orbit, which is put in relation with the horizon and the images obtained with the digital camera can be exported and represented in a Sun-Path diagram. The horizon file recorded can be imported also to other tools like Meteororm² in order to precisely calculate solar irradiation. Thanks to these instruments, a comprehensive study of the urban area of the City Center of Paradiso has been made.

Then by processing the images it is possible to analyses the incidence of urban canyon geometry [10]. Specific processing image software (ImageJ software³) allowed the analyses of the incidence of urban canyon geometry. The program analyzes the image turned into a HDR (high dynamic range) with highest dynamic range of colors and shades and allows analyzing the brightness value of the pixel in question by measuring the precise figure of the value SVF analyzed.

Results obtained by using photographic methods for the urban current status have been then compared with the analysis made using 3D Ecotect⁴ polar sun-path diagrams for the future buildings configuration. Sun-path chart or Sun-path diagram are simple graphical methods to present Sun's apparent movement. The analysis has been performed for the buildings considered as a part of the changing urban tissue and an example of the sky-factor assessment for the building n. 3: Palace G. Guisan street (A4907) shown in Fig. 2.

¹ <http://www.meteotest.ch/en/footer/navi/solar_energy/horicatcher/>

² Meteororm software contains worldwide weather data for energetic analysis that can be import to building simulation software. <

³ ImageJ software is an open source image processing program designed for analyze multidimensional images.<<http://imagej.net/Welcome>>

⁴ Autodesk Ecotect is a modelling design tool that allows to simulate building performances <<http://usa.autodesk.com/ecotect-analysis/>>

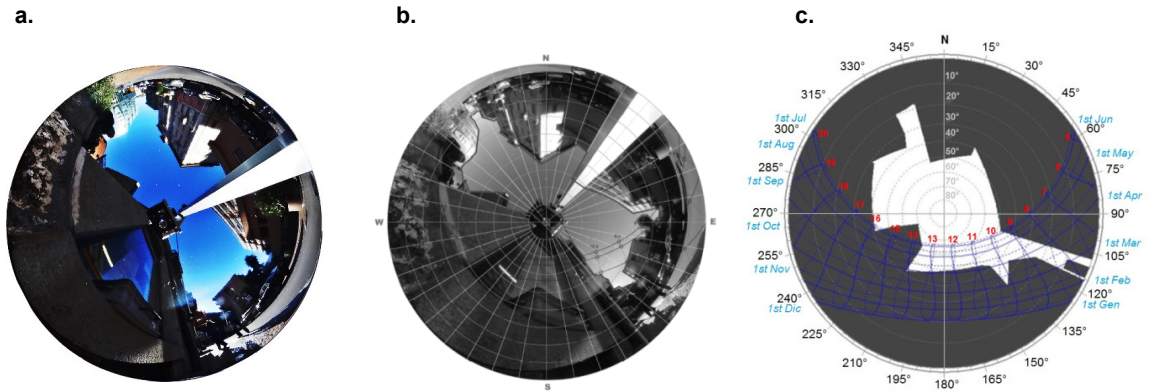


Fig. 2. Sky-factor assessment for building n. 3. Palace G. Guisan street (A4907) through photographic method, different steps in the image processing: (a) Image modification in HDR format; (b) Image for the actual situation; (c) and software simulation for a possible design scenario.

The comparison among the different evaluation methods had the objective to verify whether substantial differences exist between them due to the different complexity degree for each assessment, while a photographic method, for example, can be more useful and simple in the evaluation of this particular aspect.

3.1. SVF analysis results

A site inspection for data collection was carried out (see Fig. 3), covering the significant points of the urban area and taking as reference the studied historical buildings. This direct survey in the urban area of Paradiso city center have been made with the aim to state the differences, in percentage, of SVF measured and calculated between the previous-existing status and the future configuration when the new master plan will be implemented.

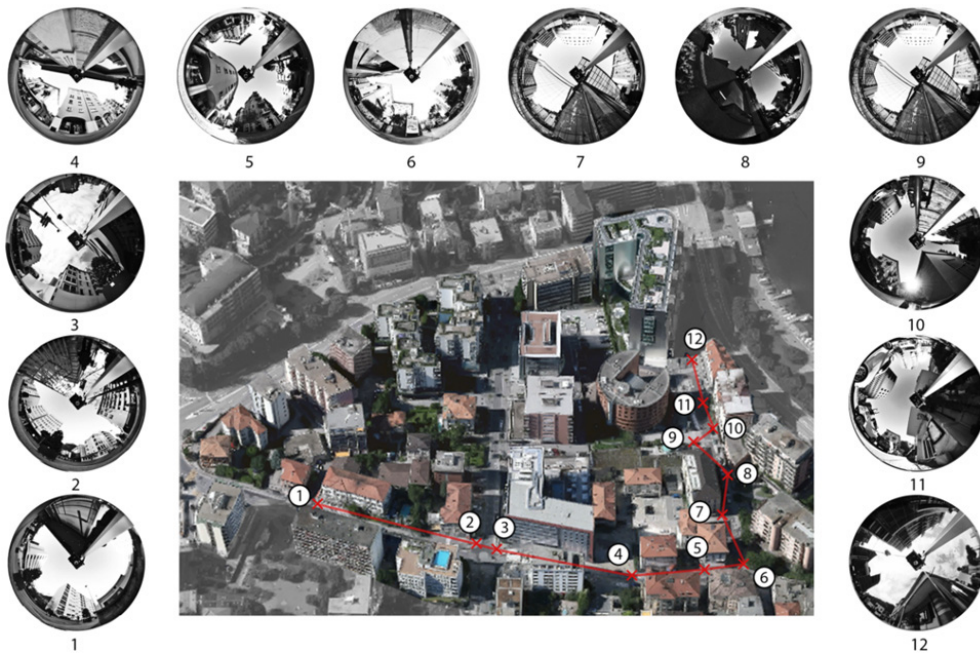


Fig. 3. Sky-view factors have been determined from analysis of hemispherical images collected and taken on site with digital camera and spherical convex mirror.

Table 1 Results of the analysis for SVF values by using image processing methods.

	SVF [%] _ ImageJ method		
	Old Master Plan	New Master Plan	Deviation
Building B.1	60.5	59.1	2.3
Building B.2	23.0	18.9	17.7
Building B.3	21.1	9.9	53.1
Building B.4	24.0	10.8	54.9

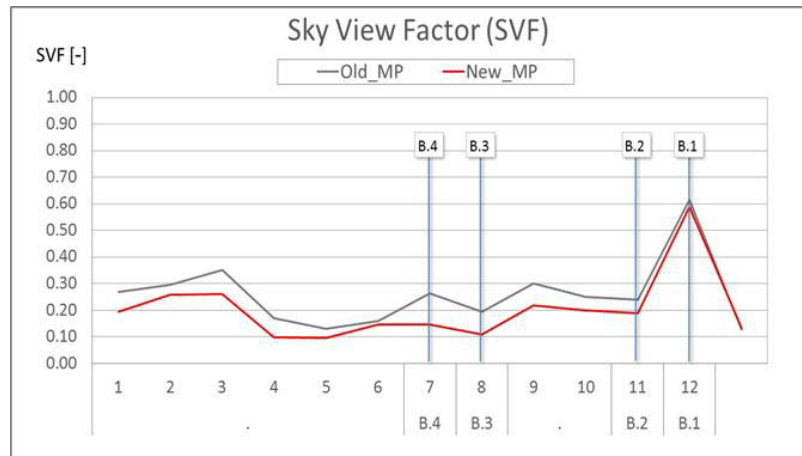


Fig. 4. Sky-view factors have been determined from analysis of hemispherical images collected and taken on site with digital camera and spherical convex mirror. The graph referred SVF results to the different points covered during the tour. B.1, B.2, B.3, and B.4 indicates the position of cultural heritage buildings in the route.

The SVF is a dimensionless value between 0 and 1, where a value of 0 (complete obstruction) means that all outgoing radiation will be intercepted by obstacles and a value of 1 (no obstruction) means that all radiation will propagate freely to the sky. Results have shown (Table 1 and Fig. 4) that a significant alteration of the SVF values throughout the urban area studied occurs. This result is most significant in regard to buildings 3 and 4. In this particular case, the percentage of the sky view factor value decreases of up to more than 50%, from about 21-24% to 9.0-10.8% respectively, over the previous value that corresponds to the current situation. However, it should be noted that in the present situation the SVF values are not already relevant, thus accentuating the situation dramatically when the new regulatory plan will be into action.

4. Daylighting analysis

The extraordinary urban modification which will take place in the area will not only affect parameters related to solar radiation or the indoor and outdoor comfort, as we have seen so far, but also will have an impact on issues related to the daylighting and visual comfort in the interior spaces, besides the visual impact that new constructions will generate in the urban environment. The pictures below (Fig. 5) show the visual effects of the new volumes built near the protected buildings (picture “b”), and a mask with the new ones that will be built in future (pictures “a, c, d”).

Urban densification effects consequently lead to a reduction in daylighting availability and in this case, the use of simulation tools becomes necessary. Daylighting factors (DF) and illuminance levels will be assessed by using Daysim Radiance-based daylighting analysis that models the annual amount of daylight in and around buildings and serves for performing lighting simulation (see Fig. 6). The use of these simulation tools, 3D models and advanced tools for the calculation of solar energy potential in this case, has proven to be an effective system to predict the dynamic effects of surface overshadowing at an urban scale [11],[12],[13]. This kind of analysis allow to improve

existing model design in order to conduct the process of the project from the initial (preliminary phase) to the late design simulation phases, letting to test different design solutions, to solve the conflict with existing buildings and existing public areas and to check effects on the surrounding and go back to test a new one scenario with an iterative process [14],[15],[16].

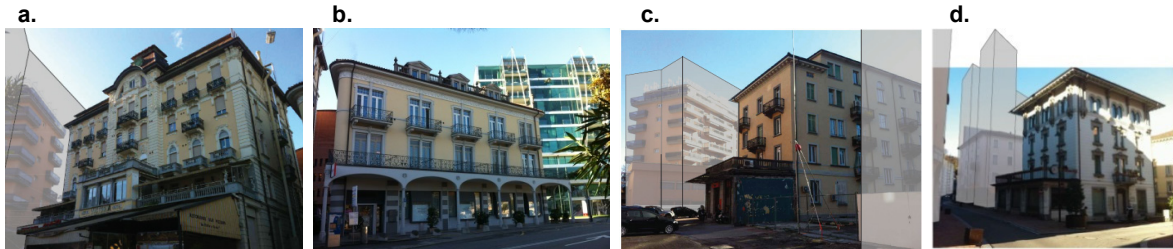


Fig. 5. Transformation scenarios of New Paradiso Master Plan, impacts on protected cultural monuments: (a) Building 1: Palace Riva Paradiso (A4905); (b) Building 2: Hotel Victoria (A4906); (A4906); (c) Palace Via Geretta (A4907) and adjoining square; (d) Posthotel Simplon (A4908). Pictures scenarios by Cristina Polo, December 2014.

The three dimensional model of the urban area have been used in order to calculate and predict the total solar radiation and luminance levels incident on the protected building envelopes studied, taking into account the dynamic effects of adjacent buildings in the urban area, in terms of shadows, mutual reflections and albedo, an example is shown in the following figures (Fig.6).

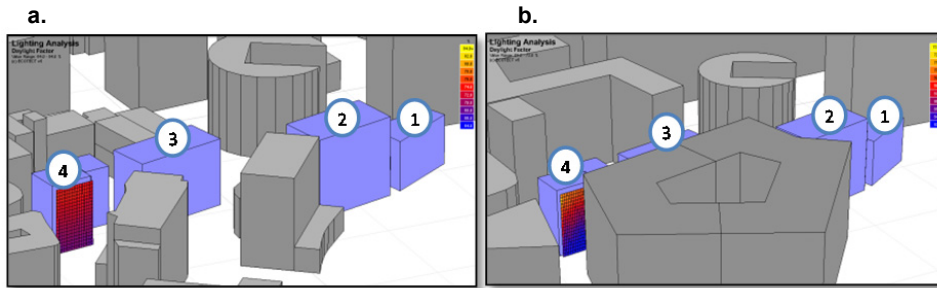


Fig. 6. Example of lighting analysis visualization in Ecotect. Colour coded cumulative luminance levels (cd/m2) on the urban current status on the assessed building envelop, façade Est of building 4. Palace Geretta (A4908).

4.1. DF analysis results

The analysis show, as reported in Table 2, that major impacts at annual level occur in Building 3 (Palace Via Geretta A4907) and Building 4 (Palace Via Geretta A4908) where differences are more than 10% in the first case and more than 6% in the second case. As seen in previous studies general conditions also in the current case are not very good regarding daylighting availability, as buildings in the neighborhood are already high and there are so many obstructions. In any case the future situation will clearly worsen the current situation in this sense.

Table 2. Daylighting factor (DF) results in terms of percentage of DF losses considering the current scenario (Old Master Plan) and the future (New Master Plan).

	DF max. losses [%] _ Ecotect simulation		
	Old Master Plan	New Master Plan	Deviation
Building B.1	88.6	88.7	0.0
Building B.2	92.9	89.3	3.8
Building B.3	90.7	80.8	10.9
Building B.4	85.4	79.7	6.6

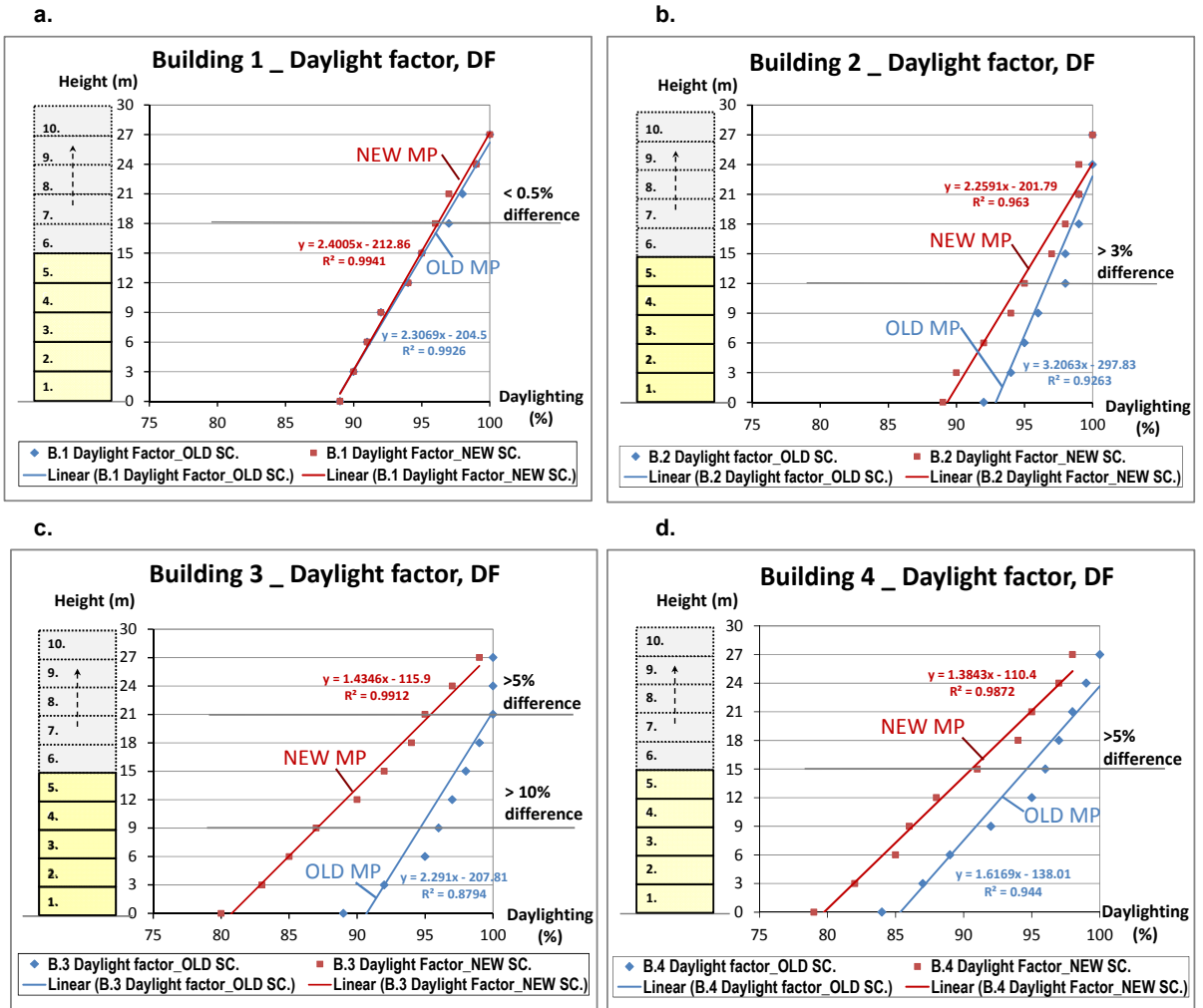


Fig. 7. Daylighting analysis performed with simulation tools, the figure shows variations in Daylight Factor (DF) at different height levels: (a) Building 1 (Palace A4905); (b) Building 2 (Hotel Victoria Palace A4906); (c) Building 3 (Palace A4908) and (d) Building 4 (Posthotel Simplon A4907).

Simulation results at different building height levels indicate (see Fig. 7), once again, that the greatest differences are shown especially in buildings 3 and 4 as large urban modifications will be expected in the surrounding area, while for building 1 and 2 some urban modifications have already been implemented according the new master plan. In building 2, from 12 meters height to zero (almost equivalent to 4 floors) the differences in daylighting availability, between the current situation and future, are greater than 3%. In building 3, from 21 meters height to zero (almost equivalent to 7 floors) the differences in daylighting availability is always greater than 5%, while from 9 meter height (3 floors) this parameter increases to more than 10%. In building 4, nevertheless, from 15 meters height to zero (5 floors) results show those differences are greater of 5%.

Results of these studies can be used to further investigate the impact of urban densification scenario on lighting energy consumption where daylighting can be strongly reduced. Moreover, these reductions especially for the first floors could be reflected into new possible use of these areas.

5. Conclusions

Comparison with simple methods using photographic and analytical techniques allows checking urban transformation and the impact on heritage buildings. Yield values for Sky-View Factors could be obtained by simple post-processing of digital images that are then compared using simulation software for the new urban master plan developments. Aspects like solar radiation and daylighting access can be investigated with a combination of methods considering the existing buildings, the surroundings and the public space using the current scenario of the real situation and the virtual simulation for new urban planning scenario. The study has proven that dense urban policies have a direct impact on energy efficiency measures in terms of solar radiation loss, solar gains decreasing, and provision of daylight availability.

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