SPATIUM
No. 39, June 2018, pp. 1-6

UDC 620.9:658.26]:69(497.11)
Original scientific paper
DOI: https://doi.org/10.2298/SPAT1839001G

SIMPLE ANALYSIS OF DAYLIGHT SAVING TIME EFFECTS IN BELGRADE CLIMATE AND LATITUDE

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Contemporary controversy about daylight saving time (DST) is mainly derived from different standpoints in studies investigating the positive and negative effects of the clock shift during summer period. From the standpoint of energy savings, most studies have consensus that the summertime clock shift in middle latitudes, with a large difference between winter and summer daylight hours, contributes to energy savings in buildings. Belgrade's mid-latitude, moderate-continental climate has a six-month long heating season and a three-month cooling season. The annual domination of the heating period assumes that the demand for heating energy also dominates in the annual energy breakdown for average office buildings. Since DST covers mainly summer time, the energy breakdown in office buildings during the DST period is dominated by the energy demand for lighting and cooling. The shift of time ahead of standard time during the DST period causes a shift in temperature, daylight availability and solar energy resources and thus a shift in the potential for the utilisation of the surrounding energy. This paper investigates how the application of DST in Belgrade's climate and latitude influences the change of climate parameters relevant for the cooling and lighting energy demand in office buildings.

***Key words*: daylight saving time, office buildings, daylight utilisation.**

INTRODUCTION

The first idea to implement clock shifting during the summer dates before the electrification era. It was introduced in order to prolong diurnal use of daylight during summer, either for enjoyment in nature or for prolonging workdays. During the Great Wars in the last century most countries imposed daylight saving time (DST) in order to save energy resources, but the losses in other areas of the economy increased due to arbitrary clock shifting in every country, county or state (Prerau, 2017). So, even today, when DST is legislated, there are *pro* and *contra* attitudes concerning its enforcement.

The effects of daylight saving time on energy savings have been studied since the 1970s. There are numerous studies that are divided in their conclusions – some conclude that the application of DST has positive effects on energy savings, while others conclude that there is an increased energy demand caused by the application of DST. A recent survey of the literature concerningthe effects of DST on energy demand (Havranek *et al.*, 2016) concluded that the design of a study has a crucial effect on its results. Reviewing 44 studies the authors concluded that "on average, the savings from DST amount to 0.34% of total energy consumption during the days when DST is applied" (Havranek *et al.*, 2016, p.3). The authors also concluded that the result of their main estimate of the effects of DST is within limits established in previous literature reviews (Reincke *et al.*, 1999) (Aries and Newsham, 2008 cited in Havranek *et al.*, 2016), which place their best estimate of the effect at between 0% and 0.5%.

There are not many studies about the effects of DST on energy savings in Belgrade. Most of the available studies are focused on improving either the building envelope or the built environment (Dimitrijević, 2013) (Đokić *et al.*, 2015), or investing in buildings (Ćetković *et al.*, 2010).

The potential for energy savings in buildings depends on a wide variety of factors, but mostly on a building's site and function, its architectural design and user behaviour. If there is an adequate positive change in the specific climate parameters that influence the energy utilisation in buildings, a well-organised building design and user behaviour should lead to energy savings in buildings.

Therefore, this analysis represents a simple study of the climate parameter shift during working time, as a result

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of the clock shift during the DST period, and the influence of the shift on the potential for energy utilisation in office buildings. Since DST is applied during the summer period, the heating period (and thus heating energy demand) was not considered in this analysis. During the summer period in Belgrade, the energy breakdown for office buildings is dominated by the cooling and lighting energy demand, so this analysis focuses only on the change of climate parameters that influence the energy utilisation for cooling and lighting. These parameters are: daylight hours during working time, direct insolation for four main orientations and the temperature boundary that causes cooling degree hours (*CDH*). The purpose of this analysis is not to evaluate the real conditions of environmental energy potential, but to compare the changes that happen when climate conditions change, and evaluate the positive or negative effects of the change. The analysis was carried out for typical Belgrade climate data (IWEC2 data file) (ASHRAE, 2011) using Ladybug (Sadeghipour Roudsari and Pak, 2013) software, anenvironmental plug-in for Rhino's (Robert McNeel & Associates, 2017) integrated 3-D modelling tool Grasshopper (Rutten, 2014). Ladybug is software specialising in detailed analysis of climate data. The results of the analysis were assessed for DST period only and for a period of one year.

DESIGN FRAME OF THE STUDY

The hundred-year old idea about clock shifting, in order to exploit more daylight during summer and thus save energy, seems quite contemporary when considering office buildings. Office work hours usually last during the daytime period. The beginning of working hours in each country depends on local customs and legislation. In Serbia, most administrative public or private businesses, courts and government departments start work at 7:30 am or 8:00 am. Only a small number of companies have work hours between 9:00 am and 5:00 pm. The eight-hour workday covers the majority of daytime, so any clock shift assumes a change in energy resources on the site of a building, and thus a change its utilisation.

The annual working time profile, usually known as the occupancy profile, adopted in this analysis lasts 10 hours a day, from 7:00 to 17:00, including weekends and public holydays. Since the simulation software only counts full hours, the real start of working time at 7:30 in Serbia was adopted as 8 o'clock. A ten-hour working time was adopted in order to include: net work hours (eight hours), time before the net work hours start (an hour when users are arriving at work) and time after work hours (an hour when users are leaving their work posts). Also, this time frame allows for a flexible beginning of working time in Serbia (working time from 9 am to 5 pm).Weekly patterns of working time (week days and weekends) and holidays were not included, since their occurrences in the calendar change every year and this analysis needs to include every possible typical climate parameter throughout one year. So, the adopted working time annually lasts 3650 hours, which represents an unrealistic annual working time. This kind of annual occupancy profile is usually used for comparative analysis (Reinhart *et al.*, 2013).

In European countries, daylight saving time was gradually adopted during the 1970s, but in Serbia it was first introduced by government regulation in 1983. This regulation was applied until 2005, when it was officially legislated and harmonised with EU legislation. Today in Serbia, daylight saving time is applied as in other European countries: from the last Sunday of March until the last Sunday of October. For this analysis, the period of DST was selected according to existing legislation in Serbia. The dates of DST in this analysis were set according to the DST dates for the year 2017.

Belgrade is located in the European continental region, at a latitude of 44^0 north. Its climate is moderate-continental with four distinguishable seasons, with warm and humid summer weather conditions and a relatively mild winter period with precipitation (RHMS, n.d.). Belgrade's climate is heating dominated. The heating season starts from the middle of October and lasts for six months, until the middle of April. Extremely low temperatures are limited to December and January, when cloudy weather prevails. At the beginning and end of the DST period are months which require only occasional and moderate heating. May and September are months when no heating or cooling is required. There is only a requirement for cooling during June, July and August (for outside temperatures above 26^{0}C), which can sometimes be very intensive. Low cloud coverage and clear sky conditions prevail in August, causing high outdoor temperatures and a high intensity of solar radiation.

ANALYSIS

According to Europe's average office building energy breakdown, the use of lighting energy accounts for about 14% of the total final energy use in office buildings (EC 2017 cited in Halonen *et al.*, 2010, fig.2-5, p.23), with a high tendency to increase even more. If we also consider the fact that office buildings in Europe have the highest energy consumption in the commercial building sector (BPIE, 2011), the need for daylight utilisation, and thus lighting energy savings, becomes more and more evident. Today there are many technical solutions that minimise lighting energy consumption, like LED lamps and various control systems, but the cheapest solution with the best long-term performance is the utilisation of natural daylight. Also, human beings through evolution have adapted to the natural light spectra, so the best work performance in offices can be expected if the work environment is adequately daylit.

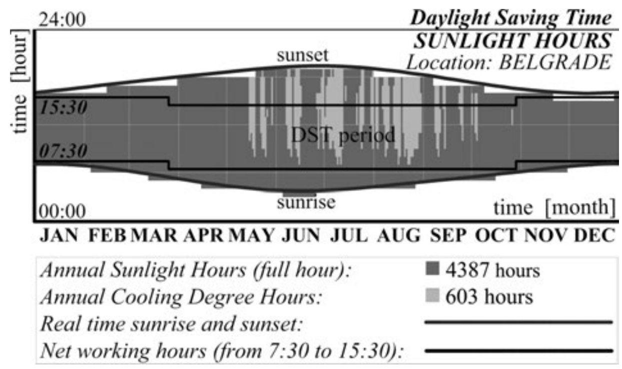

Figure 1. Full hour annual sunlight hours, sunlight hours with cooling degree hours and real time sunrise and sunset during the annual profile of net working time (from 7:30 to 15:30) in Serbia

In this analysis, a sunlight hour is considered to be an hour when the Sun is above the horizon. The total annual sunlight hours for Belgrade were calculated for an unobstructed horizontal surface (Fig. 1). A sun exposure hour or insolation hour is considered to be an hour when the surface is directly exposed to the Sun. Insolation hours depend on the surface orientation. In the real world, insolation hours do not necessarily express the presence of full direct radiation on the surface (or facade). Cloud cover can significantly reduce the insolation time or the intensity of solar radiation, but these factors were ignored in this analysis. A Cooling Degree Hour (CHD) is considered to be an hour when the average ambient outside air temperature is above the previously established base temperature for cooling (in this analysis, established as 26^{0}C) (Sadeghipour Roudsari, 2015).

If only full hours are considered, Belgrade has 4387 sunlight hours annually on a horizontal surface (Fig. 1). In standard time annual mode (Fig. 2 – A1), the selected occupancy profile for office buildings (3650 work hours annually) is 95.4% of the time within the sunlight hours range. Only the last hours of working time are outside the daylight availability, from mid-October to mid-February. In standard time mode, during the DST period only, 99% of working time is within the sunlight hours range. If DST mode is applied (Fig. 2 – A2), these percentages improve by only up to 1% (Tab. 1). As small as it is, the improvement in the sunlight hours during working time, caused by DST clock shift, might influence the energy demand in office buildings. It is important to stress that no further increase in sunlight hours during the DST period is possible, since work hours during the DST period are 100% within the sunlight hours range. At Belgrade's latitude, a very high percentage of annual working time during daytime, as high as 96% with DST annual mode, ensures environmental daylight conditions that can provide a very high probability for the utilisation of daylight in office buildings. However, the level of daylight utilisation will greatly depend on the insolation hours of the facade.

It should be stressed that the selected occupancy profile for an office building with ten work hours a day and a full hour count represents the worst case scenario. If we consider the net working time in Serbia, eight hours a day from 7:30 am to 3:30 pm, and the real time sunrise and sunset, even in standard time annual mode, work hours are 100% within the sunlight hours range for Belgrade (Fig.1).

The average cooling energy demand in office buildings in Europe is relatively small, around 4% of the total final energy demand in office buildings (EC 2017 cited in Halonen *et al.*, 2010, fig.2-5, p.23). The energy demand for cooling in office buildings in Serbia is similar. The annual cooling degree hours (*CDH*) profile for Belgrade in Figure 2 predicts the hours of energy demand for cooling buildings from mid-May to October. The need for cooling therefore exists only during the DST period of the year. In the annual mode with standard time, the calculation of *CDH* for the selected office occupancy period resulted in 534 hours annually when cooling is needed (Fig. 2 – A1) (Tab. 1). This result represents 24.6% of the working time during the DST period. With the application of the clock shift, during the DST period, the number of hours which require cooling is reduced to 486 hours, or to 22% of working time during the DST period. So, with the application of DST, there is only a 2.6% reduction in the number of cooling hours (for the DST period). However, a relative reduction from 534 to 468 hours is around

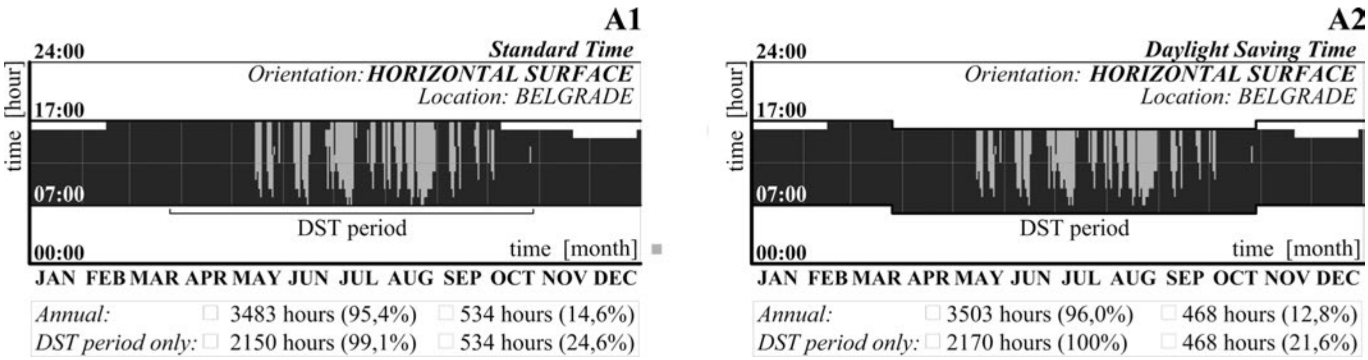

Figure 2.The annual profiles of sunlight hours and sunlight hours with cooling degree hours, for the standard time annual mode (diagram A1 -left) and for the annual mode with daylight saving time (diagram A2 - right), during the selected occupancy profile for office buildings in Belgrade's latitude and climate

Table 1. Sunlight hours and sunlight hours with cooling degree hours, for standard time annual mode and for annual mode with daylight saving time, during the selected occupancy profile of office buildings in Belgrade's latitude and climate

	Occupancy Hours*		**Sunlight Hours (during occupancy hours)**				**Sunlight Hours with Cooling Degree Hours (during occupancy hours)**			
	annual	DST period (26. 03. - 28. 10.)	annual		DST period (26. 03. - 28. 10.)		annual		DST period (26. 03. - 28. 10.)	
time mode	[hours]	[hours]	[hours]	[%]	[hours]	[%]	[hours]	[%]	[hours]	[%]
STANDARD TIME (without DST)	**3650**	**2170**	**3483**	95.4%	**2150**	99%	**534**	14.6%	**534**	24.6%
DAYLIGHT SAVING TIME (DST)	**3650**	**2170**	**3503**	96%	**2170**	100%	**468**	13%	**468**	22%

* Occupancy hours - every day during one year, ten hours a day, from 7:00 to 17:00

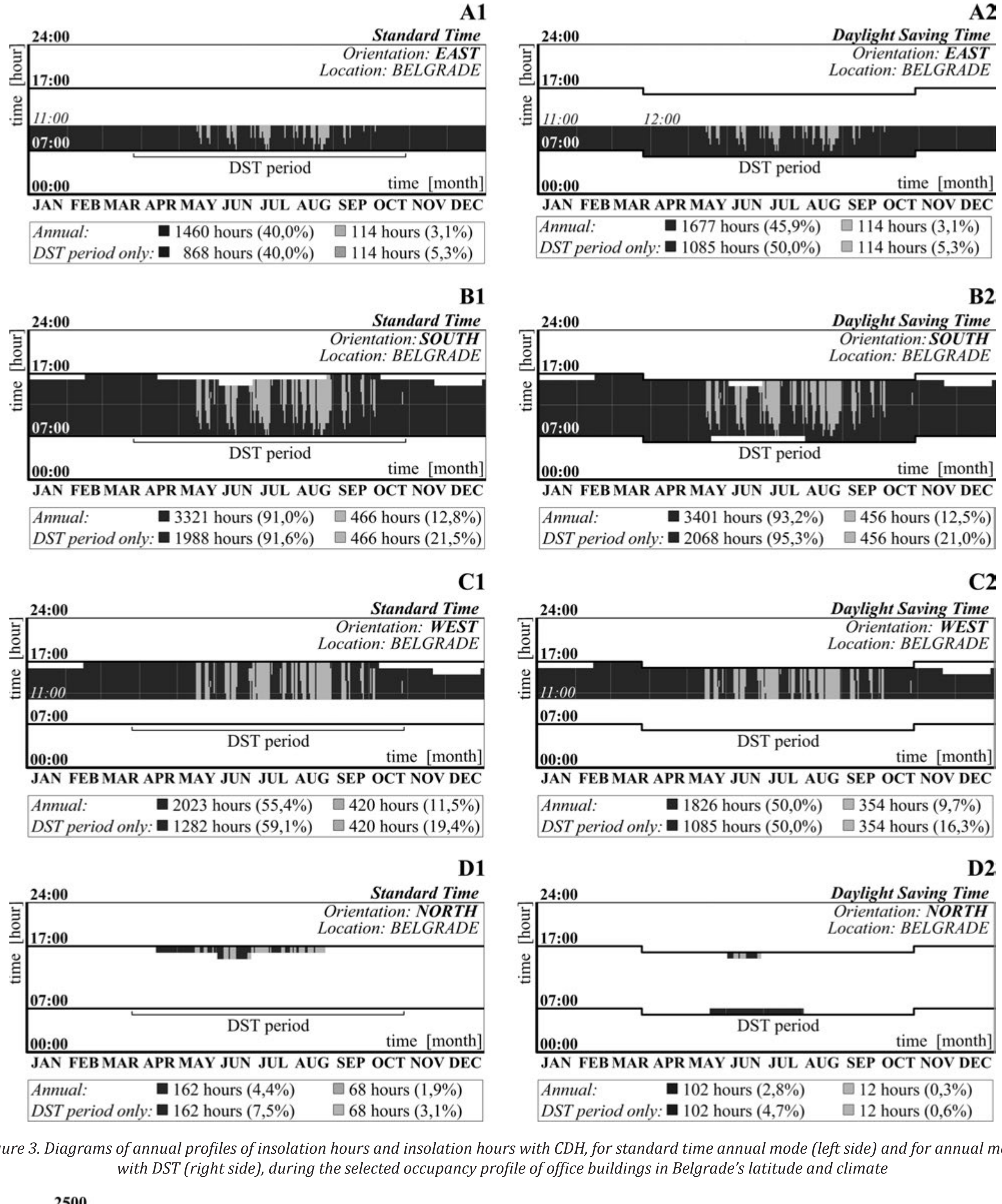

Figure 3. Diagrams of annual profiles of insolation hours and insolation hours with CDH, for standard time annual mode (left side) and for annual mode with DST (right side), during the selected occupancy profile of office buildings in Belgrade's latitude and climate

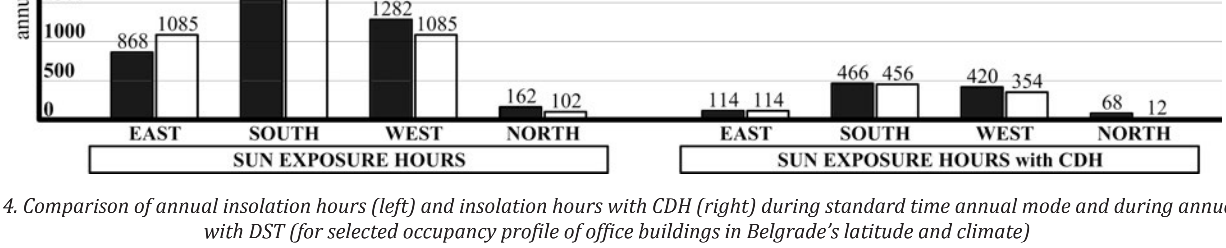

Figure 4. Comparison of annual insolation hours (left) and insolation hours with CDH (right) during standard time annual mode and during annual mode with DST (for selected occupancy profile of office buildings in Belgrade's latitude and climate)

12%, which represents a substantial contribution to the probability of cooling energy savings during the summer. With the application of DST, a reduction in the number of cooling hours during working time is caused by a one hour shift at the beginning of working time, when radiation and temperature intensity are lower and no cooling is needed (Fig. 2 – A2).

The daylight and energy performance of an office space is crucially influenced by its exposure to direct sunbeams. Direct sunbeams cause glare and thermal discomfort and substantially affect thermal gains in the office environment. In order to maintain a comfortable environment and to control thermal gains, it is necessary to apply strategies (like shading), which alter the utilisation of available daylight and thermal gains. Also, strategies designed for summer conditions, in order to prevent thermal gains, are not beneficial for the winter conditions in Belgrade, when solar thermal gains can make a substantial reduction in the heating energy demand.

As mentioned before, hours with cooling energy demand for office buildings have a 12% relative reduction with the application of DST. This reduction is associated with spaces facing all orientations, since the reduction is caused by lower temperatures during early work hours. The worst case scenario for cooling energy performance in offices is the condition when temperatures are high and cause CDH and, at the same time, there is direct insolation present on the facade. The occurrence of this condition indicates how high the CDH might be. This condition was taken into account in the assessment of the cooling energy demand for each orientation. It should be emphasised that this cooling energy condition is interconnected with lighting energy use. When insolation is present on the facade, strategies to control thermal gains are reducing daylight availability and reducing the lighting energy demand.

The highest potential of direct sun exposure is in south oriented spaces (Fig. 3 and Fig. 4). In annual mode with standard time, south orientated spaces are exposed to direct sun rays 91% of the annual working time, which is almost double that of west oriented space (55.4%), and more than twice that of east oriented space (40% of working time). North oriented spaces are only exposed to direct sun 4.4% of the annual working time, only during summer time, at the end of working time (Fig. 3). For south and west oriented spaces, the number of insolation hours with CDH is also very high (12.8% and 11.5% of working time annually, respectively). It is an indicator that summer thermal gains are very high for these orientations of office space. East oriented spaces have a much smaller number of these critical hours (insolation hours with CDH), accounting for only 3.1% of annual working time. North oriented spaces have an almost negligible number of insolation hours with CDH (0.3% of annual working time), indicating that there is a high probability of diffuse daylight utilisation with low thermal gains.

With the application of DST, there is an increase in the insolation hours for east and south oriented spaces, but there is no increase in insolation hours with CDH (Fig. 4). The increase of insolation hours takes place in the early morning hours during summer, when the temperature is lower than the rest of the day and when no additional cooling is required. With the application of some kind of thermal gain control (like shading), in south and east oriented spaces there should be no increase in the cooling energy demand, but a prolonged period of work hours with protection from thermal gains would certainly lead to an increase in the lighting energy demand.

With the application of DST, there is a reduction in the number of insolation hours for west and north oriented spaces, along with a substantial relative reduction in the insolation hours with CDH. The reduction in insolation hours contributes to the utilisation of diffuse daylight, thus reducing the energy demand for lighting. The main characteristic for north oriented spaces is the low presence of direct sun. With the application of DST, low insolation hours are further reduced (from 4.4% to 2.8% of annual working time) (Fig. 3 - D2). The greatest benefit from the application of DST occurs for west oriented spaces. With a 15.4% relative reduction in the number of insolation hours during the DST period (which relates to a 9.7% annual relative reduction in the number of insolation hours) (Fig. 4) there is high probability for an increase in diffuse daylight utilisation and a reduction in the lighting energy demand. There is also a relative reduction in the number of insolation hours with CDH of 15.7% of working time. This reduction would certainly cause a reduction in the cooling demand for west oriented spaces.

CONCLUSION

Belgrade's latitude and climate provide high daylight availability. With the application of DST, the selected worst case occupancy profile is annually 96% during daytime.

With the application of DST, working time is shifted one hour ahead of standard time, which causes a12% relative reduction in the number of hours for which cooling is necessary and about a 1% relative increase in the number of sunlight hours for the selected occupancy profile during the DST period. The relative reduction of 12% would certainly influence the cooling energy demand and certainly lead to energy savings for cooling in office buildings. Since the cooling energy demand covers only a small percentageof the total final energy demand in office buildings, its influence upon the total final energy demand amounts to around a 1% reduction. As for daylighting, a 1% relative increase in sunlight hours with the application of DST during summer is negligibly small, but still might play a small part in reducing the energy demand for lighting. A reduction in the energy demand for cooling is likely to happen in all spatial orientations except east.

The greatest benefits in energy saving can be expected in west oriented spaces. Insolation hours and insolation hours with CDH are greatly reduced with the application of DST, which leads to lower thermal gains, less protection from thermal gains and better utilisation of daylight. In other orientations there is no significant change in the climate parameters that would lead to significant lighting or cooling energy demand changes.

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Received December 2017; accepted in revised form May 2018.