INFLUENCE OF GLOBAL WARMING ON PRIMARY ENERGY CONSUMPTION FOR HEATING AND COOLING IN PUBLIC BUILDINGS

by

Dušan R. GORDIĆ**, *Jelena R. NIKOLIĆ, and Vladimir J. VUKAŠINOVIĆ

Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia

Original scientific paper
https://doi.org/10.2298/TSCI190527383G

The implications of global warming on energy uses for heating and cooling in buildings are analysed in the paper. The research methodology is based on monitoring data on average daily temperature variation during a certain period and expected future temperature variation of existing mean daily temperatures according to a certain climate model. Developed model also uses the current real energy consumption of public buildings at a location and envisaged variation of cooling and heating degree day influenced by global warming. Based on the model, authors examine the influence of global warming on primary energy consumption for heating and cooling in public buildings in a city of Kragujevac, Serbia. The results show that a consequence of global warming should be a significant reduction of total primary energy consumption for heating and cooling in the public buildings. Possible increase in mean annual temperature of 3.8 °C till the end of the century has an impact to the reduction of primary energy use for heating for 35.7% in public buildings in Kragujevac, while predicted consumption of primary energy for cooling will be almost five times higher than nowadays.

Key words: *global warming, heating degree days, space heating, cooling degree days, building energy use, space cooling*

Introduction

Buildings are great energy consumers that are responsible for nearly 30% of final energy use on a global level [1]. Space heating and cooling are responsible for a large fraction of European energy use. Heat is delivered to public buildings in Europe in different ways (district heating and individual boilers fuelled by fuel wood, coal, oil, gas or electricity) while cooling is currently delivered almost exclusively through electricity.

Although the consumption of heat in public buildings is lower than the consumption in residential buildings, its share is not insignificant. The total share of heat consumption in public buildings on a global level is 9% [2], in EU is 20.8% and 11.5% in Serbia [3]. Since 2000, cooling energy consumption in buildings has been increased by almost 100% (from 3.6 EJ to 7 EJ) which is the fastest growing end-use in buildings [2]. Space cooling energy is a fairly small share of total final energy use in public buildings, but cooled floor area constantly grows and cooling demand rises during the summer months.

Climate change influenced by global warming is evident. It is assumed that the increase of GHG emissions will have an additional influence on global warming, with a temperature increase of 0.3-4.8 °C for 2081-2100 compared to 1986-2005 [4]. This process has a significant

*Corresponding author, e-mail: gordic@kg.ac.rs

influence on energy systems, where milder winters decrease space heating demand and higher temperatures during summer increase space cooling demand [5].

There are several methods to analyse the implications of climate change and global warming to heating and cooling energy demand in buildings. For the projection of climate change *Morphing* algorithm with climate change projection and running simulation tools (TRNSYS, EnergyPlus, Tas Building Designer…) could be used [6-10]. Angeles *et al*. [11] investigated the impacts of climate change on building energy demands in the intra-Americas region using a method involving the utilization of historical reanalysis records and numerical models to project building energy demand per capita. Shibuya and Croxford [12] predicted the effect of climate change on office building according to the weather data from the Japan Meteorology Agency and Thermal Analysis Software. The implication of climate change to building energy consumption can be observed using different climate models, scenarios and heating and cooling degree days methods [13-18]. Heating degree days (HDD) and cooling degree days (CDD) are proxies for the energy demand needed to heat or cool a building. Relation between the meteorological parameters and the building energy demand are usually statistical analysis [10].

The results of all those researches show that global warming will cause a reduction of heat consumption but the increase of energy cooling demand. Depending on climate characteristics of a building location, percentages of heat consumption reduction and cooling energy increase differs. Nonetheless, the detailed research on the impact of future climate change on building energy performance in Serbia was not performed. Since results from the Energy efficiency program for the city of Kragujevac [19] show that public buildings consume the significant amount of the total final energy in the city of Kragujevac, the authors wish to examine the influence of global warming on primary energy consumption for heating and cooling in this building sector. For the analysis they propose the model which uses the current real energy consumption of public buildings at the location and envisaged variation of cooling and HDD influenced by global warming. The model is universal and can be applied to any other location worldwide.

Methodology

Heating and cooling degree days are applied for analysing the influence of temperature variation on the heating and cooling energy demand in a building during a certain time period. The HDD can be defined as the difference between reference comfort temperature (during a heating season) and the daily mean temperature when the latter is less than a certain threshold. The CDD can be defined as the difference between the daily mean temperature and the reference comfort temperature (during cooling season) when the former is bigger than a certain threshold. Therefore, annual heating (HDD) and CDD are calculated:

$$HDD = \sum_{i=1}^{n} HDD_i \quad \text{where} \quad HDD_i = \begin{cases} T_{rh} - T_m, & T_m < T_{bh} \\ 0 & T_m \geq T_{bh} \end{cases} \tag{1}$$

$$CDD = \sum_{i=1}^{n} CDD_i \quad \text{where} \quad CDD_i = \begin{cases} T_m - T_{rc}, & T_m > T_{rc} \\ 0 & T_m \leq T_{rc} \end{cases} \tag{2}$$

The values for reference comfort temperatures (T_{rh} = 20 °C and T_{rc} = 21 °C) and heating threshold temperature (T_{bh} = 12 °C) are valid for Kragujevac, Serbia. Those values vary across regions depending on human physiology, energy supply, the level of economic development, characteristics of temperature change [4].

Using HDD, the annual heating energy demand of a building Q_h [MWh] is calculated:

$$Q_h = 24 \cdot 10^{-6} \cdot q_h \cdot HDD \tag{3}$$

Since transmission and ventilation losses practically do not depend on HDD variation, based on eq. (3), the ratio of predicted and existing heating energy demand is:

$$\frac{Q_{h\,pr}}{Q_{h\,ex}} = \frac{HDD_{pr}}{HDD_{ex}} \tag{4}$$

Similarly, the variation of annual cooling energy demand can be calculated as:

$$\frac{Q_{c\,pr}}{Q_{c\,ex}} = \frac{CDD_{pr}}{CDD_{ex}} \tag{5}$$

Relations between annual heating, Q_h, cooling, Q_c energy demand and annual final energy for heating (cooling) are presented in eq. (6) and eq. (7):

$$\eta_h = \frac{Q_h}{Q_{hf}} \tag{6}$$

i.e.

$$\varepsilon_c = \frac{Q_c}{Q_{cf}} \tag{7}$$

The relationships between final (consumed) and primary energy are:

$$f_{con} = \frac{Q_{hp}}{Q_{hf}} \qquad f_{con} = \frac{Q_{cp}}{Q_{cf}} \tag{8}$$

Existing annual CDD and HDD for a certain location should be calculated using data on average daily temperature variation during a certain period. For the same period, average annual final energy consumption for heating *i.e.* cooling should be determined from energy bills during energy auditing. Future HDD and CDD values should be calculated based on expected temperature variation of existing mean daily temperatures according to a certain climate model.

Results and discussion

The city of Kragujevac is an administrative, industrial, cultural, educational and health care centre of central Serbia. Kragujevac has nearly 180000 residents which makes it the fourth largest city in Serbia. Kragujevac has a temperate continental climate with an average air temperature of 11.5 °C. The coldest month is January with an average temperature of 0.5 °C, while the hottest is July with an average temperature of 27 °C [19].

There are a relatively large number of public buildings with national and regional significance in Kragujevac. Public building in the city can be classified into six categories according to their purpose:

- Educational buildings – preschools and kindergartens, elementary and high schools.
- Buildings of cultural institutions – museums, libraries, houses of culture, theatres.
- Administrative buildings.
- Community health centres' buildings.
- Sport and recreation buildings.
- Buildings of public utility services and companies.

The majority of the buildings belong to administrative and educational buildings as shown in fig. 1. Also, the majority of the buildings were constructed between 1946 and 1980 which is the period of intensive construction but without or with weak thermal regulations [3].

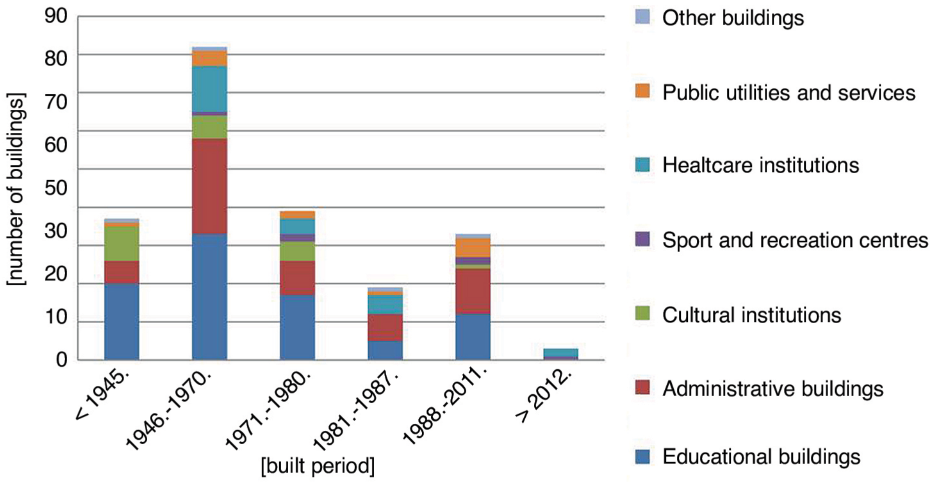

Figure 1. Public buildings in Kragujevac according to a year of construction
(*for colour image see journal web site*)

According to energy auditing of public buildings presented in Energy efficiency program of City of Kragujevac [19], average annual heating and cooling energy consumptions (final energy, energy costs, and primary energy) for 2014-2016 is presented in tab. 1. Values of conversion factors, building heating system efficiencies, and coefficient of performance of building cooling system for public buildings in Kragujevac are presented in tab. 2.

Annual cooling energy consumption is lower than expected because the majority of buildings (in terms of size and number) are educational buildings that have minimal operation during cooling season (summer holiday).

Table 1. Energy consumption for heating and cooling in public buildings in Kragujevac

Heating	$Q_{hf\,ex}$ [MWh]	Costs [€]	$Q_{hp\,ex}$ [toe]	$Q_{h\,ex}$ [MWh]
Electricity	201.81	19172	43.38	201.81
Natural gas	7708.96	277523	662.85	6938.06
Fuel oil	1032.48	96021	88.78	825.98
District heating	20567.79	2097.915	2758.88	20567.79
Coal and firewood	5224.20	99260	449.20	3656.94
Total heating	34735.23	2589.889	4003.09	32190.58
Cooling	$Q_{cf\,ex}$ [MWh]	Costs [€]	$Q_{cp\,ex}$ [toe]	$Q_{c\,ex}$ [MWh]
Electricity	219.29	20.833	47.14	460.51
Total cooling	219.29	20.833	47.14	460.51

The values of HDD_{ex} = 2425.6 and CDD_{ex} = 113.3, shown in fig. 2, were calculated using eqs. (1) and (2), and data on average daily temperature for 2014-2016 obtained from national hydro-meteorological service company (Republic Hydrometeorological Service of Serbia).

According to results of climate change projections obtained using the regional climate model EBU-POM for Serbia based on the A1B and A2 scenarios defined by IPCC (A1B 2001-2030, A1B 2071-2100, A2 2071-2100) annual average increase of temperature due to global warming is estimated in 0.8-3.8 °C range [20]. The annual value of mean temperature increase and corresponding mean temperature increase for each season (winter DJF: December, January, February; spring MAM: March, April, May; summer JJA: June, July, August; autumn SON: September, October, November) is presented in tab. 3.

Table 2. Values of conversion factors, building heating system efficiencies, and coefficient of performance of building cooling system

Heating	η_h [–]	f_{con} [–]
Electricity	1	2.5
Natural gas	0.9	1
Fuel oil	0.8	1
District heating	1	1.56
Coal and firewood	0.7	1
Cooling	η_c [–]	f_{con} [–]
Electricity	2.1	2.5

Using polynomial interpolation of data from tab. 3 and assuming that seasonal variation of temperature can be applied to the variation of daily mean temperature for each day of a seasonal month, HDD_{pr} and CDD_{pr} for different annual mean temperature increase were calculated. Absolute and relative variations of HDD and CDD were shown in tab. 4 and fig. 3.

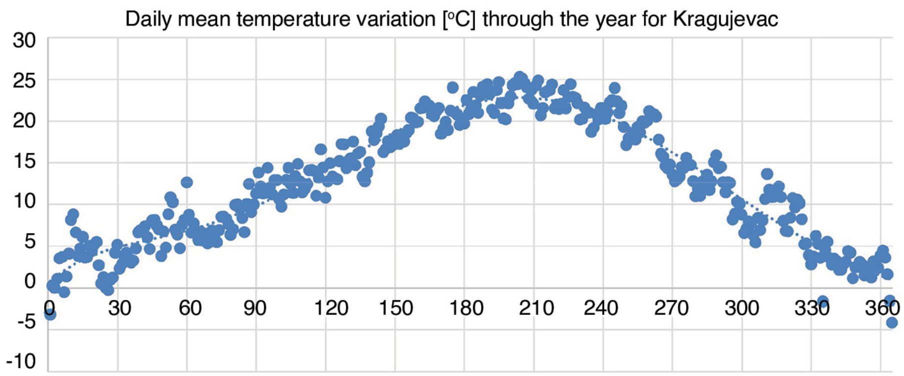

Figure 2. Daily mean temperature variation through the year for Kragujevac - average data for 2014-2016

Table 3. Seasonal variation of temperature in Serbia influenced by global warming [20]

Annual [°C]	Winter DJF [°C]	Spring MAM [°C]	Summer [°C]	Autumn SON [°C]
0.8	0.5	1	1.2	0.5
1.1	1	1.2	1.4	0.9
2.4	1.8	2.4	3.2	1.8
2.8	2.2	2.8	3.6	2.2
3.4	2.6	3.6	4.2	2.6
3.8	3.6	4	4.6	3.2

The estimated decreases of HDD as a result of future climate change are somewhat larger than the estimated increases of CDD in absolute terms. However, in relative terms, an increase of CDD is significantly bigger than a decrease of HDD. The change in consumption of primary energy for heating and cooling of public buildings in Kragujevac caused by temperature increase is shown in tab. 5. Significant reduction of total primary energy for heating and cooling in the public sector buildings in Kragujevac will be a consequence of global warming. It can be seen that the temperature increase of 3.8 °C can reduce primary energy consumption for heating

Table 4. Influence of annual temperature increase on HDD and CDD

Annual temperature increase [°C]	*HDD* [K]	*CDD* [K]	ΔHDD [K] $\Delta HDD = HDD_{pr}\text{-}HDD_{ex}$	ΔCDD [K] $\Delta CDD = CDD_{pr}\text{-}CDD_{ex}$
0.0	2425.6	113.3	–	–
0.8	2237.3	205.2	– 188.3	91.9
1.0	2164.4	214.2	– 261.1	100.9
1.2	2134.1	234.8	– 291.4	121.5
1.5	2105.2	276.2	– 320.4	162.8
2.0	1980.8	346.7	– 444.8	233.4
2.5	1863.0	405.8	– 562.6	292.5
3.0	1771.8	463.4	– 653.8	350.1
3.5	1704.9	529.6	– 720.7	416.2
3.8	1559.0	566.0	– 866.6	452.6

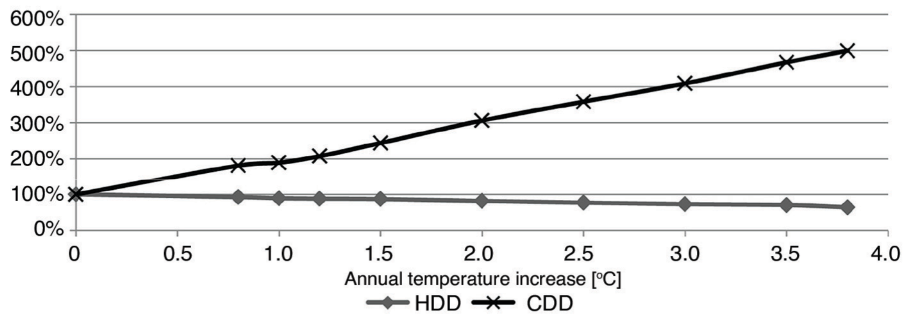

Figure 3. Influence of annual temperature increase on relative variation of HDD and CDD value

Table 5. Changes in primary energy demand

Annual temperature increase [°C]	$Q_{hp\,pr}$ [toe]	$Q_{cp\,pr}$ [toe]	$Q_{hp\,pr}+Q_{cp\,pr}$ [toe]
(1)	(2)	(3)	(4) = (2)+(3)
0	4003.09	47.14	4050.23
0.8	3692.34	85.35	3777.69
1	3572.10	89.09	3661.19
1.2	3522.11	97.67	3619.78
1.5	3474.33	114.86	3589.19
2	3269.00	144.20	3413.20
2.5	3074.59	168.80	3243.40
3	2924.10	192.75	3116.84
3.5	2813.68	220.26	3033.94
3.8	2572.85	235.41	2808.26

by 35.7%, while predicted consumption of primary energy for cooling will be almost five times higher than existed. In this scenario, energy consumption for cooling will be 4.7% of the total share of total primary energy for cooling and heating. The estimated increases in the cooling demand may further exacerbate peaks in electricity demand in the summer which can provoke additional energy costs.

If someone supposes that there are no changes in energy prices, the reduction of energy costs will be somewhat higher compared to the reduction of primary energy consumption as shown in tab. 6. This is the opposite of expected since district

Table 6. Reduction of total energy and costs

Annual temperature increase [°C]	Reduction of energy demand for heating/cooling [%]	Reduction of primary energy use [%]	Reduction of the total energy costs [%]
0	0.0	0.0	0.0
0.8	6.5	6.7	7.1
1	9.4	9.6	10.0
1.2	10.3	10.6	11.1
1.5	11.0	11.4	12.0
2	15.2	15.7	16.5
2.5	19.2	19.9	20.9
3	22.2	23.0	24.3
3.5	24.1	25.1	26.5
3.8	29.6	30.7	32.3

heating provides nearly 65% of necessary final energy for heating of public buildings in Kragujevac and district heating price (10.2 c€/kWh average price for public buildings in Kragujevac) is big comparing to the electricity price (9.5 c€/kWh average price).

Conclusions

Global warming is making the European climate significantly warmer, which effects on building energy consumption. Public building heating presents significant constituent of European energy use, so a decrease in its use has the potential to lead to a substantial decrease in total energy use. On the other hand, temperature increase influenced by global heating caused a substantial increase in the space cooling energy, which can lead to problems in secure electricity supplying in warmest summer days.

Such estimations of the influence of global warming on primary energy consumption for heating and cooling in public buildings can be very important in preparing long-term future energy plans and projections on national, regional or municipal level.

Acknowledgment

This research was a part of the research project III 42013, which is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

Nomenclature

CDD – annual cooling degree day, [K]
CDD_{ex} – known annual cooling degree day, [K]
CDD_{pr} – future (predicted) annual cooling degree day, [K]
f_{con} – conversion factor (primary to final energy), [–]
HDD – annual heating degree day, [K]
HDD_{ex} – known annual heating degree day, [K]
HDD_{pr} – future annual heating degree day, [K]
n – number of days in a year (365 or 366), [-]
$Q_{c\,ex}$ – known (existing) annual cooling energy demand, [MWh]
$Q_{c\,pr}$ – future (predicted) annual cooling energy demand, [MWh]
q_h – specific heat loss rate of a building (which depends on transmission and ventilation heat losses), [WK^{-1}]
$Q_{h\,ex}$ – known (existing) annual heating energy demand, [MWh]
$Q_{h\,pr}$ – future (predicted) annual heating energy demand, [MWh]
Q_{hf}, Q_{cf} – annual final energy consumption for heating *i.e.* cooling, [MWh]
Q_{hp}, Q_{cp} – annual primary energy consumption for heating *i.e.* cooling, [MWh]
T_{bh} – heating threshold temperature [K]
T_m – daily mean temperature, [K]
T_{rc} – reference comfort temperature during cooling season, [K]
T_{rh} – reference comfort temperature during heating season, [K]

Greek symbols

ε_c – coefficient of performance of building cooling system, [–]
η_h – building heating system efficiency, [–]

Subscripts

c – cooling
ex – existed values
h – heating
pr – predicted values

References

[1] ***, Market Report Series: Energy Efficiency 2018, https://webstore.iea.org/market-report-series-energy-efficiency-2018
[2] ***, International Energy Agency, Buildings, https://www.iea.org/buildings/?utm_campaign=buffer&utm_content=buffer5582f&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer
[3] Gordić, D., *et al*., Benchmarking of Heat Energy Consumption in Public Buildings in the City of Kragujevac, *Proceedings*, 4th Virtual International Conference on Science, Technology and Management in Energy - eNergetics, Niš, Serbia, 2018, Vol. 1, pp. 139-146
[4] Shi, Y., *et al*., Changes of Heating and Cooling Degree Days over China in Response to Global Warming of 1.5 °C, 2 °C, 3 °C and 4 °C, *Advances in Climate Change Research*, *9* (2018), 3, pp. 192-200
[5] Hausl, S., *et al*., Effects of Climate Change on Regional Energy Systems Focussing on Space Heating and Cooling: A Case Study of Austria, *Thermal. Science*, *18* (2014), 3, pp. 771-786
[6] Chan, A. L. S., Developing Future Hourly Weather Files for Studying the Impact of Climate Change on Building Energy performance in Hong Kong, *Energy and Buildings*, *43* (2011), 10, pp. 2860-2868
[7] Shen, P., Impacts of Climate Change on U.S. Building Energy use by Using Downscaled Hourly Future Weather Data, *Energy and Buildings*., *134* (2017), Jan., pp. 61-70
[8] Jenkins, D., *et al*., Climatic and Internal Factors Affecting Future UK Office Heating and Cooling Energy Consumptions, *Energy and Buildings*, *40* (2008), 5, pp. 874-881
[9] Shen P., Lukes, J. R., Impact of Global Warming on Performance of Ground Source Heat Pumps in US Climate Zones, *Energy Conversion and Management*, *101* (2015), Sept., pp. 632-643
[10] Cellura, M., *et al*., Climate Change and the Building Sector: Modelling and Energy Implications to an Office Building in Southern Europe, Energy for Sustainable Development, *45* (2018), Aug., pp. 46-65
[11] Angeles, M. E., *et al*., Impacts of Climate Change on Building Energy Demands in the Intra-Americas Region, *Theoretical and Applied Climatology*, *133* (2018), 1-2, pp. 59-72
[12] Shibuya, T., Croxford, B., The Effect of Climate Change on Office Building Energy Consumption in Japan, *Energy and Buildings*, *117* (2016), Apr., pp. 149-159
[13] Gi, K., *et al*., A Global Analysis of Residential Heating and Cooling Service Demand and Cost-Effective Energy Consumption Under Different Climate Change Scenarios up to 2050, *Mitigation and Adaptation Strategies for Global Change*, *23* (2018), 1, pp. 51-79
[14] Zhai, Z. J., Helman, J. M., Implications of Climate Changes to Building Energy and Design, *Sustainable Cities and Society*, *44* (2014), Jan., pp. 511-519
[15] Amato, A. D., *et al*., Regional Energy Demand Responses to Climate Change: Methodology And Application To The Commonwealth Of Massachusetts, *Climate Change*, *71* (2005), 1-2, pp. 175-201
[16] Gonseth, C., *et al*., Impacts of Global Warming on Energy Use for Heating and Cooling with Full Rebound Effects in Switzerland, *Swiss Society of Economics and Statistics*, *153* (2017), 4, pp. 341-369
[17] Labriet, M., *et al*., Worldwide Impacts of Climate Change on Energy for Heating and Cooling, *Mitigation and Adaptation Strategies for Global Change*, *20* (2015), 7, pp. 1111-1136
[18] Olonscheck, M., *et al*., Heating and Cooling Energy Demand and Related Emissions of the German Residential Building Stock Under Climate Change, Energy Policy, *39* (2011), 9, pp. 4795-4806
[19] Gordić, D., *et al*., Program Energetske Efikasnosti Grada Kragujevca (2018-2020) (Energy efficiency program for the city of Kragujevac (2018-2020) (In Serbian), Kragujevac, Serbia, 2018, http://www.aarhus.org.rs/wpcontent/uploads/2018/11/Program_energetske_efikasnosti_grada_Kragujevca.pdf
[20] Prohaska, S., *et al*., Initial National Communication of the Republic of Serbia under the United Nations Framework Convention on Climate Change, The Ministry of Environment and Spatial Planning, Belgrade, Serbia, 2010., https://unfccc.int/resource/docs/natc/srbnc1.pdf

Paper submitted: May 27, 2019
Paper revised: September 2, 2019
Paper accepted: September 16, 2019