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The benchmark analysis of office premises – potential energy saving opportunities in offices with 2nd generation and 3rd generation of energy management systems.

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Abstract

In our investigation we focus on the performance peaks and total volume of energy used in the offices premises and defining the potential energy saving potentials. We chose two types of office branches. In the first group we installed 2nd generation of energy management systems with ENERGRADE EMS [1] software to collect, analyse and report the energy consumptions and energy result periodically. In the other type besides the ENERGRADE energy management systems the automation process controllers and automation intervention in the daily energy consumptions has been installed. The benchmark database building (BDB) led us to the followings: in the same running and operational environment the energy volume is different; there are time periods when the energy saving potential is higher than 30%. By use of the 3rd generation energy management systems can add 10% more energy saving potential.

Keywords: *Energy saving, energy management, energy efficiency, office building energy savings, energy benchmark, energy monitoring.*

1. Introduction

Buildings are account for 40% of the total energy consumption in the European Union. According to the 2010/31/EU European Union directive [2] the sector including the private sector, commercial and industrial market segments – is continuously expanding which is bound to increase their energy consumption. The European Commission has founded the new vision about the global climate change in Paris, 2015 by collectively reducing the global emission by at least 60% below 2010 levels by 2050 [3].

The 2012/27/EU European Directive on energy efficiency fixed that besides the transportation, the production and the process, the buildings are the key figure for finding more energy efficiency potential and reducing the total volume of the energy consumption [4].

Our research's first goal was to build an energy management benchmark database to represent the difference and similarities in between the office buildings' energy consumption, secondly to prove the potential energy reduction and energy efficiency gap between the monitored and an automated system and thirdly to examine the correlation between the type of the energy management system and peak performance and fourthly to define and to prioritize the variant parameters effecting on energy efficiency. The research took 12 months long in Budapest, Hungary. In our previous research we found that energy efficiency can be raised due to automated system where the office premises' operational indoor temperature were hold in between the temperature zones given by the EN 15251 will lead lower peak performance tolerance and higher power efficiency [5].

2. Location and measurement enviroment

According to the research's program we chose 4 locations where the office's operational functions are the same, the working hours and non-working hours running in the same time period. The four locations have its own facility management. 3 of the 4 offices measured by such a monitoring system where for taking any operational command the office needs to intervene by hand and not real time in any cases. 1 of the offices has besides the monitoring system an automation process controlling and intervention system which ensures operational command accepting and sending the system installed in the office. The data collection from the local office's premises were collected by LAN system and forwarded by TCP/IP protocols. The office premises' peak power was in between 16,2 kW and 20,4 kW. The measurement's resolution was 15 minutes in electric power, 1 hour in gas energy carriers. The automation system in the BM4 model has its own automation command where the program for specifying the needs was programmed by the EN 15251 to keep the inner temperature in between the second classifications of the heating and cooling demand [5].

3. Energy management levels and its realisation

In our scope we defined the energy management systems in three different levels. The first level of energy management system (EMS) is just for representing the energy consumption data in real-time without any analysis and any interventions. The second level of energy management system stands for historical data collection and has analytical tools for making deeper analysis to ensure energy management decision making. The third level of EMSs takes into account both of the first and second level's EMS advantages and more over has the capability to intervene in real time to reduce and balance energy consumptions and raise the energy efficiency. [6]

We built 2nd generation energy management systems with the ability of transforming them easily into 3rd generation way in 3 offices up and a 3rd generation energy management system in the 4th office. The energy management systems main function was to measure, collect and analyze all the data collecting from the different office's running period and ensuring energy baseline for building up a benchmarking database to compare the different time periods and different operational intervals. All the office premises has been built with Programmable Logical Controllers (PLC), where a local intelligent "middle-ware" [7] was running and was responsible for local decision making according the local parameters. The 3rd generation EMSs systems run the middle-ware to be able to make local decision on cooling energy units (CEU) and heating units (HU).

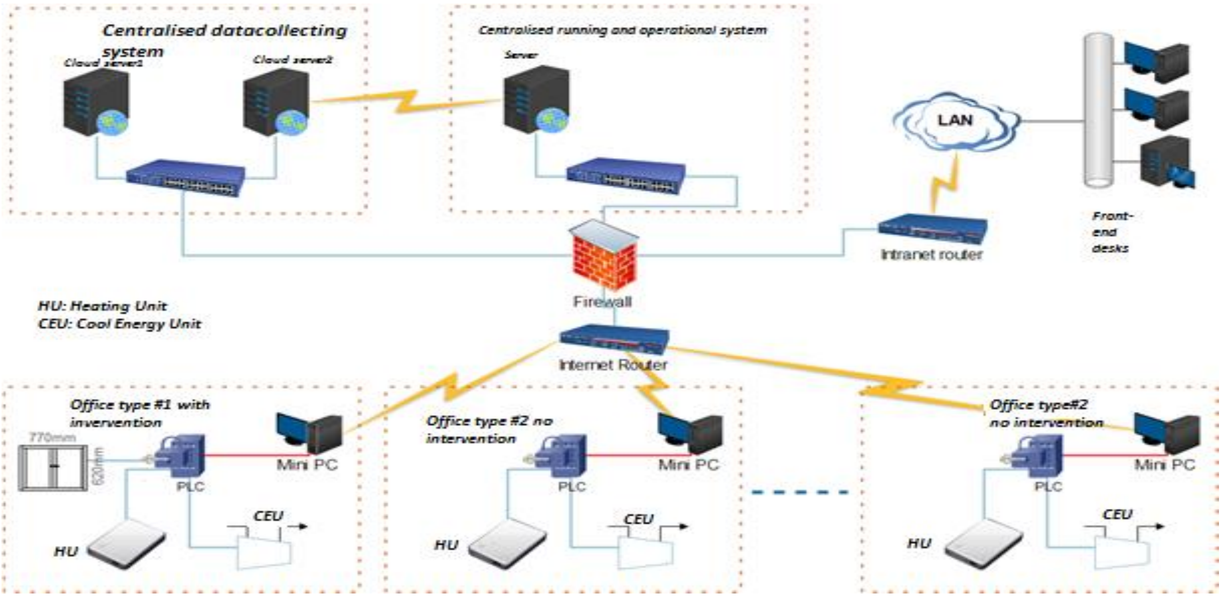


Fig. 1.: 2nd and 3rd generation EMSs integration and topology

The office premises' energy consumption data collection was built on a platform independent software system, on ENERGRADE energy management information system (EMIS).

4. Benchmarking database building (BMB)

Our office selection for the program was built on the following parameters: main function of the office premises, operational characteristic of the office premises, the mixture of the user of the office, duration of the renting, energy efficiency classification of the office premise and according to the minimum requirements for energy efficiency benchmarking according to the EN 16231:2011 standard [8].

The benchmarking model has four pillars where the different time periods and their energy consumptions can be compared according to pair-to-pair methods known as pairwise method [9,10]. The EMIS system ensured the following comparison methods see in Fig2.

Comparison method	**Compared to**	**Comparison method**	**3rd generation EMS is compared to the 2nd generation EMS system**
Day-to-day (DTD)	*The office's energy consumption is to compare to another office's energy consumption on the same day;*	*Day-by-day (DyD)*	*The office's energy consumption is to compare to another office's energy consumption on the same day;*
Week-to-week (WTW)	*The office's energy consumption is to compare to another office's energy consumption on the same week;*	*Week-by-week (WyW)*	*The office's energy consumption is to compare to another office's energy consumption on the same week; Sum of the Day-to-day differences.*
Month-to-month (MTM)	*The office's energy consumption is to compare to another office's energy consumption on the same month;*	*Month-by-month (MyM)*	*The office's energy consumption is to compare to another office's energy consumption on the same month; Sum of the week-to-week differences.*
Season-to-Season (STS)	*not in the scope in our investigation*	*Season-by-Season (SyS)*	*not in the scope in our investigation*

Fig2.: Benchmarking comparison methods

Under our investigation and after the data collection we made the pair-to-pair comparison in between the offices built with 2nd generation EMS to represent the similarities and differences. We examined the followings see in Fig3.

Abbreviation	***Meaning***	***Calculation***
MID	*Minimum of the differences*	*The minimum of the difference in between energy consumption on the same time period.*
MAD	*Maximum of the differences*	*The maximum of the difference in between energy consumption on the same time period.*
RANGE	*Difference of MAD and MIN*	*The difference of the maximum and minimum in between energy consumption on the same time period*
AVG	*Average of the differences*	*The average of the difference in between energy consumption on the same time period.*
CUSUMxy (from till)	*Cumulated Sum of differences*	*The total amount of the difference in between energy consumption aggregated day by day on the wishes time period.*

Fig 3. Benchmarking calculation

5. The benchmarking time-to-time matrix

To define the baseline in between the different but compatible office premises according to the EN 16231:2011 standard we run the pairwise analyses under ENERGRADE EMIS.

Number [Benchmarking model number]	***Examined to [The object examined to]***	***Day to day (DTD) energy consumption differences cumulated***	***Week to week (WTW) energy consumption differences cumulated***	***Month to Month (MTM) energy consumption differences cumulated***
BM1	*In this model our energy breakdown was compared to the office1 where there is no automation*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*
BM2	*In this model our energy breakdown was compared to the office2 where there is no automation*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*
BM3	*In this model our energy breakdown was compared to the office3 where there is no automation*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Difference (CUSUM):*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*
BM4	*In this model our energy breakdown where there is automation was compared to the average of the 3 office premises (BM1,BM2,BM3)*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*	*Min of difference (MID):* *Max of difference (MAD):* *Average of differences (AVD):* *Cumulated Sum of Differences (CUSUM):*
Energy saving potential		*CUSUM calculated on the time period chosen.*		

Fig4.: Benchmarking database modelling and methods.

6. Time-to-time benchmarking

In the time-to-time benchmarking analysis there are the special days (e.g.: national celebration day, bank off days) had a marker to show the specialty of those days. The special days were taken from the calendar out for not being able to compare special and non-special days to each other. The EMIS program supported the pairwise analyze and handled the special and non-special days problem. The energy breakdown was calculated on kWh metric dimension both in electric (power) and caloric (gas) energy carriers. This led us to the following data. At the day-to-day and week-to-week comparison we gave the lowest and the highest MID and MAD values to represent the potential according to the sum of differences.

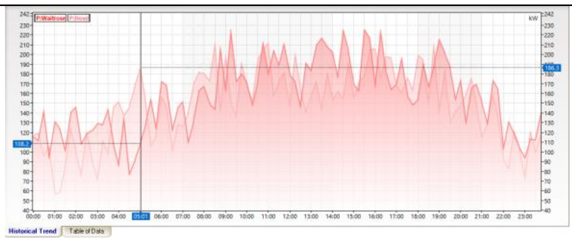
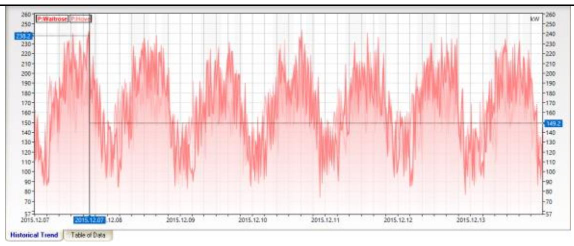
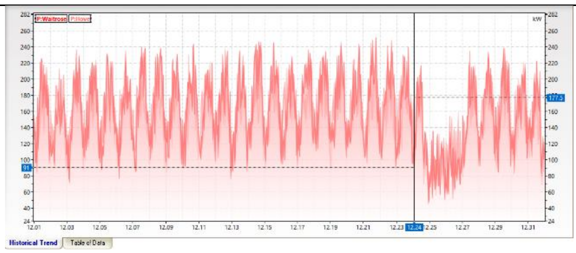
Benchmarking method	Representation of the benchmarking comparison	Benchmark factors
Day-to-day *similar operational running at office premises*		*In the pairwise comparison there are two of 2nd generation office premises to be compared to each other. In the day-to—day analysis the same day's operational data has been put together like Monday to Monday, Tuesday to Tuesday etc. We looked for the minimum and maximum difference in between the same days' energy consumptions.*
Week-to-week *similar operational running at office premises*		*In the pairwise comparison there are two of 2nd generation office premises to be compared to each other. In the week-to-week analysis the same week's operational data has been put together like 1st week to the 1st week. We looked for the minimum and maximum difference in between the same days' energy consumptions.*
Month-to-month *similar operational running at office premises*		*In the pairwise comparison there are two of 2nd generation office premises to be compared to each other. In the month-to-month analysis the same month's operational data has been put together like 1st month to the 1st month. We looked for the minimum and maximum difference in between the same days' energy consumptions.*

Fig5.: Benchmarking models and representations

7. Benchmarking models and analysis

In our investigation we run 4 different benchmarking models where the different but compatible office premises have been compared to each other. Each model has a name under BM1, BM2, BM3 and BM4. According to the model we built, we compared the energy consumption items pairwise to see the minimum and the maximum differences in between the time period's energy consumptions item by item. In the BM1 model all the other 2nd generation EMS's system was compared to the BM1 office premises' energy consumption so the BM1 was the defined energy baseline in the group of the compared office premises. In the BM2 model the BM2 was the energy baseline for comparison and in the BM3 model and in the other modelling the followings (BM3, BM4) were the energy baseline to compare.

To define the energy reduction and energy efficiency raising potential in the group of the office premises in the pairwise analysis we looked for the lowest and highest rates in between the same days' energy consumptions. By the use of the minimum of differences and maximum of differences we could calculate the total amount of the energy saving potential where the energy baseline consumption is compared to the other office premise's energy consumptions. There are MID values, where the minimums of the differences of two chosen office premises were added to compare, give the days where there are minimalized differences between the two selected office premises. At the MAD values we looked for maximums of the differences of two chosen office premises.

The RANGE is calculated after the range between the maximum and minimum of the differences' values. The AVG is calculated by average of the total differences in a time period. As its name implies, CUSUM [11] involves the calculation of a cumulative sum (which is what makes it "sequential"). Samples from a process x_n are assigned weights w_n, and summed in Fig4.

$$S_0 = 0, S_{n+1} = \max(0, S_n + x_n - \omega_n)$$

Fig6.: CUSUM

In Fig7, Fig8, Fig9, Fig10 the calculations' result written. After the evaluation of the different comparisons we got the following results on the different types of benchmarking parameters.

BM1 – running method – energy consumptions	**MID [kWh]**	**MAD [kWh]**	**RANGE [kWh]**	**AVG [kWh]**	**CUSUM [kWh]**
Day-to-day	*-2,51 (low)*	*101,565 (high)*	*104,075*	*-7,81 (low)*	*-401,05 (High)*
Week-to-week	*-54,17 (low)*	*74,47 (high)*	*128,64*	*- 9,12 (low)*	*-1457,14 (High)*
Month-to-month	*-92,3 (low)*	*101,565 (high)*	*193,84*	*-96,88 (low)*	*-2679,48 (High)*
Season-to-season	*not in the scope of investigation*				

Fig7.: Benchmarking – BM1

BM2 – running method – energy consumptions	**MID [kWh]**	**MAD [kWh]**	**RANGE [kWh]**	**AVG [kWh]**	**CUSUM [kWh]**
Day-to-day	*-4,57 (low)*	*87,00 (high)*	*91,51*	*- 6,13 (low)*	*-423,21 (High)*
Week-to-week	*-46,70 (low)*	*94,41 (high)*	*139,11*	*- 8,02 (low)*	*-976,99 (High)*
Month-to-month	*-82,5 (low)*	*256,5 (high)*	*339,00*	*-135,92 (low)*	*-3971,25 (High)*
Season-to-season	*not in the scope of investigation*				

Fig8.: Benchmarking – BM2

BM3 – running method – energy consumptions	***MID [kWh]***	***MAD [kWh]***	***RANGE [kWh]***	***AVG [kWh]***	***CUSUM [kWh]***
Day-to-day	*-6,51 (low)*	*73,63 (high)*	*80,14*	*- 7,01 (low)*	*-378,25 (High)*
Week-to-week	*-42,74 (low)*	*131,01 (high)*	*173,75*	*- 9,12 (low)*	*-771,61 (High)*
Month-to-month	*-78,56 (low)*	*131,56 (high)*	*210,12*	*- 91,87 (low)*	*-3211,09 (High)*
Season-to-season	*not in the scope of investigation*				

Fig9.: Benchmarking – BM3

BM4 – running method – energy consumptions	MID [kWh]	MAD [kWh]	RANGE [kWh]	AVG [kWh]	CUSUM [kWh]
Day-to-day	-1,51 (low)	154,81 (high)	156,32	- 12,01 (low)	-384,44 (High)
Week-to-week	-82,74 (low)	165,32 (high)	248,06	- 23,12 (low)	-957,10 (High)
Month-to-month	-111,56 (low)	141,53 (high)	253,09	- 211,87 (low)	-4214,29 (High)
Season-to-season	not in the scope of investigation				

Fig10.: Benchmarking – BM4

The BM4 model shows the highest value in energy saving potential, where the CUSUM value is -4214,29 kWh which gives 38% more added energy saving compared to the 2nd generation EMS's systems. The maximum of differences is highest in the B4 model again, which ensures that there is a huge amount of energy saving potential in between the 2nd and 3rd generation operational EMS systems. This high energy saving potential is also represented in the range values and moreover the average values for energy saving have the highest value in the BM4 model again with 35% compared to the average of the month-to-month energy saving.

8. Conclusion

Our previous investigation focuses on the first and second classification energy management according to the EN 15251 where we saw that there is almost 40% performance efficiency saving potential in between the different operational temperature zones. In our investigation we built up a benchmarking database for a year-long period where electricity and gas energy consumption data monitored and one of the office premises had a process control to reduce the energy use. After the built of the database we realized that the minimum and maximum of the differences in between the office premise' energy consumption led us to the followings: The office building with benchmarking values has a 14% energy saving potentials and this rates can be higher if there is automation systems installed in the office premises. In this case the energy saving potential is little more than 35%, which almost three times higher energy reduction compared to the 2nd generation energy management system's energy saving potential.

Our conclusion is that the 3rd generation energy management systems has hidden energy potential which can be represented in numbers and the potential can be almost 40%.

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