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Cost-Benefit Comparison of a Time-of-Use Tariff and Real-Time Pricing of Electricity Associated with Automated HVAC Load Management Strategies in Banks Across Mainland Portugal

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Abstract. The gradual liberalization of the Portuguese energy market opens up new pathways in which further progress on demand response programs can be achieved. In light of this, the main objective of this paper is to evaluate the cost-benefit of introducing a Real-Time-Pricing (RTP) rate over the prevailing Time-Of-Use (TOU) tariff structure in 26 Normal Low Voltage (NLV) bank branches dispersed across Mainland Portugal. Additionally, the further impact of the association of RTP with Automated RTP-Responsive HVAC Load Management Strategies (ALMS) on cost savings is also examined. This study grouped the bank branches in 8 bioclimatic zones, to assess the influence exerted by geographic location on these results. Analyses were conducted using real granular electricity usage data from 2015, which were collected using an integrated power optimization software platform entitled *Kiplo Smart Engine*. Simulations reveal that the introduction of RTP reflects an annual electricity cost reduction of approximately 34% against the TOU tariff. Furthermore, the association of RTP with the proposed ALMS raised the annual electricity cost savings to up to 47%. In conclusion, it is expected that the unique nature of exploration of this study will foment discussions around the regulation of RTP programs to NLV consumers in Mainland Portugal.

Key words

Real Time Pricing, Automated Load Management, Demand Response, Energy Cost Optimization, Energy Regulation

1. Introduction

The restructuring of the global electricity supply sector and, particularly, the gradual liberalization of the Portuguese energy market, open up new pathways in which further progress on energy efficiency and energy security can be achieved, especially with the introduction of RTP of electricity and demand-response load control strategies [1]. Within the RTP scenario, consumers are able to perform real-time adjustments in their electricity consumption, as a reflection of dynamic price signals in the wholesale electricity market [1]. This dynamic pricing strategy is most effective when consumers are able to actively manage their energy use [3]. Nonetheless, banks offer little flexibility over price responsiveness measures, mainly due to strict thermal comfort level requirements in acclimatized spaces. With that said, Section 2 of this paper defines TOU and RTP rate design structures, besides showcasing their month-by-month cost-variation performance for the year of 2015. Section 3, in turn, defines the concept of demand response and explains its importance in the context of liberalized electricity markets. A list of ALMS to be simulated follows, which are centered around *Kiplo Smart Engine*, an integrated power optimization software platform. Then, Section 4 groups the 26 NLV bank branches dispersed across Mainland Portugal in 8 distinct bioclimatic zones, following the premises set by the Portuguese legislation on this matter, in order to verify the influences exerted by geographic location on the ALMS abovementioned. Subsequently, Section 5 performs a cost-benefit analysis of an assumed RTP rate over the prevailing TOU tariff structure for each of the 8 distinct bioclimatic zones. Additionally, the further impact of the association of RTP with ALMS on electricity cost savings is also examined in Section 5.

This study represents a fraction of the scope of a joint project between Virtual Power Solutions (i.e., an innovative market leader in the design and operation of dynamic connected platforms), Simples Energia (i.e., a regional electricity retailer) and a major Spanish Bank with activities in Portugal. Finally, this paper concludes with a discussion on the principal results derived from these analyses.

2. Time-Of-Use Tariff versus Real-Time-Pricing of Electricity

TOU tariffs are related to electricity rates per unit consumption (€/KWh) that vary along the day, week or season in blocks of time, depending on the billing cycle, in an attempt to reflect plausible changes in electricity conditions [2]. Nonetheless, these prices are entirely defined in advance, thus do not reflecting present electricity conditions [1]. Billing cycles are structured by the Energy Services Regulatory Authority (i.e., ERSE) and divided in two: daily billing cycle and weekly billing cycle. The former refers to costs of kilowatt-hour that vary by time of day and season, whereas the latter refers to kilowatt-hour costs that vary by time of day, season and day of week [1]. The price of electricity for each scheduling period is also set by the ERSE.

In the case study analyzed in this paper, the 26 NLV bank branches were subjected to a 3-period TOU rate on electricity under a daily cycle. The electricity retailer was a local utility named Simples Energia. For the year of 2015, the daily billing cycle structure is presented in Table 1 and the electricity price is given in Table 2. Distribution costs were neglected in this study for either analyses (i.e., RTP and TOU rates), therefore electricity prices do not account for this variable.

Table 1: Daily billing cycle structure (2015)

Daily billing cycle structure	Winter period (Jan 01, 2015 to Mar 31, 2015/Oct 01, 2015 to Dec 31, 2015)	Summer period (Apr 01, 2015 to Sep 30, 2015)
On-peak	09:00am-10:30am	10:30am-01:00pm
	06:00pm-08:30pm	07:30pm-09:00pm
Mid-peak	08:00am-09:00am	08:00am-10:30am
	10:30am-06:00pm	01:00pm-07:30pm
	08:30pm-10:00pm	09:00pm-10:00pm
Off-peak	12:00am-08:00am	12:00am-08:00am
	10:00pm-12:00am	10:00pm-12:00am

Table 2: Electricity prices of each scheduling period per kilowatt-hour unit under a 3-period TOU rate structure (2015)

	Scheduling period	Price (€/KWh)
3-period TOU rate	On-peak	0.0945
	Mid-peak	0.0836
	Off-peak	0.0693

Within RTP programs, electricity prices change hourly as a reflection of dynamic price signals in the wholesale electricity market, which are usually known to customers on a day- or hour-ahead basis [3]. In the case of Portugal, the electricity spot market refers to the Iberian Electricity Market (i.e., MIBEL) [1]. These programs naturally carry within more risks to consumers, given the unpredictability of electricity price volatility; however, that being so, electricity prices are free of risk costs associated with any fixed rate on electricity [3].

For the purposes of this study, the conditions of the RTP contract entitled *Termo Indexado Plano Flex Max Online*, offered by Simples Energia in 2015, are studied. It targeted NLV customers (i.e., customers with contracted power between 3.45 kVA and 41.4kVA) under 3 scheduling periods (i.e., on-peak, mid-peak and off-peak periods). Simples Energia´s equation to calculate the electricity price at each scheduling period is given below:

$$\mathrm{PE}\hbar_{(i)} = (PMOMIE(\hbar)_{(i)} + CGS_{(i)}) \times (1 + Losses_{(i)}) + PTAR_{(i)} + K$$

Where:

1) *(i):* scheduling period (i.e., on-peak, mid-peak or off-peak periods);
2) *PMOMIE*($\hbar$): hourly electricity market price that is being transacted at MIBEL (€/KWh);
3) *CGS*: system manager cost (0.0013€/KWh);
4) *Losses*: loss coefficients published by the ERSE for each scheduling period (%);
5) *PTAR:* distribution costs published by the ERSE for each scheduling period (€/KWh);
6) *K:* fixed price associated with the operational costs of the electricity retailer (€/KWh), which are given in Table 3.

Table 3: K values corresponding to 3 distinct scheduling periods (€/KWh) (2015)

K value	Scheduling period		
	On-peak	Mid-peak	Off-peak
Price (€/KWh)	0.005	0.007	0.012

Going further in the analysis, Figure 1 provides a month-by-month comparison between the volatility of the average monthly electricity prices per kilowatt-hour unit under a TOU rate and the applicable RTP rate over an one-year period (i.e., 2015). These prices were calculated using the abovementioned real tariff design structures from Simples Energia. Given that distribution costs remain unchanged for both rates, its value was neglected in the monthly totals.

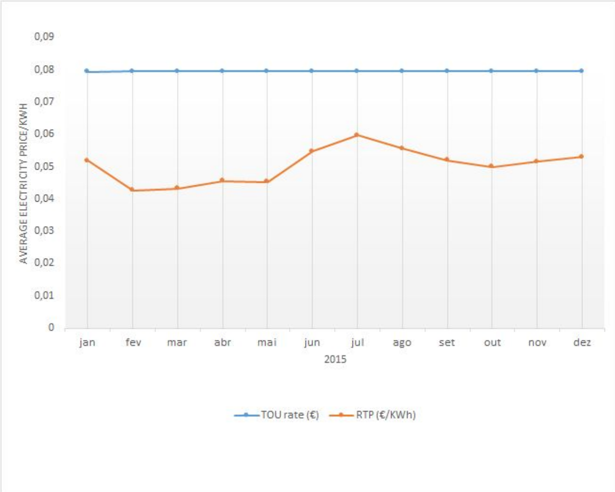

Figure 1: Month-by-month variation of average electricity prices under RTP and TOU rates (2015)

The yearly RTP price-variation performance seen in Figure 1 showcases the volatility of electricity prices per kilowatt-hour unit in the electricity spot market and the difficulty to design any TOU rate model that faithfully represents real-time electricity prices. The analysis of Figure 1 also clearly indicates that the bulk of actual total cost under RTP occurred at much lower prices per kilowatt-hour unit when compared to the results for the TOU rate, reaching up to 46% difference in the most extreme case (i.e., February 2015). Aggregated across 2015, the total energy price per kilowatt-hour unit under the applicable RTP are about 37% less expensive than with the TOU rate.

3. Automated RTP-Responsive HVAC Load Management Strategies

Presently, within the liberalized Portuguese electricity market, demand response (DR) programs gain progressive emphasis given ever-increasing concerns for energy efficiency and energy security. DR refers to deliberated changes in electricity consumption by end-users as a reflection to changes in the electricity price over a given period [2]. Additionally, it also refers to financial incentives that lead to lower electricity consumption when electricity price is high in the spot market [1]. Because of that, DR strategies reduce electricity costs, electricity price volatility and increases system reliability [2]. These benefits can be maximized with the introduction of softwares and tools that operate such strategies.

With that said, this paper presents *Kiplo Smart Engine*, an integrated power optimization simulator developed by Virtual Power Solutions that performs several decision-making processes related to DR strategies in distributed networks, through the analysis of granular real-time data and advanced forecast algorithms. Aligned with the purposes of this study, *Kiplo Smart Engine* is able to remotely control individual circuits based on electricity price forecasting models, thus furthering the impact of the implementation of RTP.

For the case study presented in this paper, the HVAC system was responsible for approximately 39% of the annual active energy consumption in 2015. In light of this, 6 distinct automated RTP-responsive HVAC load management strategies were selected for a second cost-benefit analysis, which are detailed in Table 4. Their identification required considerable experimentation and were chosen with the sole purpose to expand costs saving opportunities with minimal impact on the bank branches' functional conditions and on the thermal comfort of occupants.

Table 4: List of proposed automated RTP-responsive HVAC load management strategies

Strategy	Description
1	The HVAC system could only operate between 8:00am and 5:50pm (bank branches´ working time)
2	The HVAC system was shut off in moments when the electricity cost spiked to peak levels, exceeding an established baseline of 95% of the daily highest electricity cost
3	The HVAC system could not be off for over 1 hour
4	During summer (04:38pm June 21, 2015 to 08:21am August 23, 2015), between 11am and 4pm, the HVAC system could not be off for over 30 minutes
5	During winter (04:48am December 22, 2015 to 10:45pm March 23, 2015), between 8am and 1pm, the HVAC system could not be off for over 30 minutes
6	When turned on, the HVAC system had to operate for a minimum of 30 minutes

The obtained results from the impact of these particular strategies on the bank branches´ electricity bill over the year of 2015 is described in Section 5, which shows the adequacy and relevance of the proposed methodology.

4. Bioclimatic Zones in Mainland Portugal

According to Decree-Law no. 118/2013 of August 20, Mainland Portugal is divided in three winter bioclimatic zones (i.e., I1, I2 and I3) and three summer bioclimatic zones (i.e., V1, V2 and V3) [4]. The Decree-Law characterizes winter bioclimatic zones by its number of heating degree-days, which correspond to how many degrees and for how many days outside air temperature was lower than the established base temperature (i.e., 18 ºC) [4]. In the other hand, summer bioclimatic zones are characterized by its number of cooling degree-days, which correspond to how many degrees and for how many days outside air temperature was higher than the established base temperature [4]. The bioclimatic zoning of Mainland Portugal was defined in order to address the variable thermal behavior characteristics of buildings across the country and its respective bioclimatic strategies.

This study took into consideration such regional specificities, in order to verify the influences exerted by geographic location on the automated electricity cost optimization strategies abovementioned. Therefore, following the premises defined by the Portuguese legislation on this matter, the 26 NLV bank branches encompassed in the scope of this study were segmented by its respective bioclimatic zones, as detailed in Table 5.

Table 5: Grouping of the 26 NLV bank branches by Bioclimatic Zone (BZ) and description of each BZ

BZ	County	Area (m2)	Description
I1 V1	Águeda	365	The most moderated BZ in Mainland Portugal, which reflects in lower thermal comfort requirements. In summer, due to the maritime influence, there are lower daily thermal amplitudes
	Aveiro (Lourenço Peixinho)	292	
	Caldas da Rainha	189	
	Figueira da Foz	200	
I1 V2	Albufeira	262	In summer, due to the maritime influence, there are lower daily thermal amplitudes; nonetheless, summer requires more attention to thermal comfort requirements than winter
	Lisboa (Campo de Ourique)	280	
	Loulé	162	
	Setúbal	181	
I1 V3	Almeirim	184	Summer is more demanding than winter. The continental influence reflects in a dry climate and high daily thermal amplitudes
	Montijo	269	
	Santarém	312	
	Vila Franca de Xira	200	
I2 V1	Espinho	150	In summer, due to the maritime influence, there are lower daily thermal amplitudes; thus, winter is more demanding than summer
	Esposende	173	
	Maia (Catassol)	178	
	Porto (Amial)	220	
I2 V2	Braga (Campo da Vinha)	230	In summer, daily thermal amplitudes have average values
	Fafe	166	
	Guimarães	130	
	Pombal	170	
I2 V3	Abrantes	180	Dry climate and high daily thermal amplitudes. Summer is more demanding than winter
	Portalegre	232	
	Tomar	192	
	Torres Novas	211	
I3 V1	Guarda	109	High latitude reflects in a more demanding winter
I3 V2	Chaves	244	Winter is more aggressive than summer. In summer there are lower daily thermal amplitudes
I3 V3	No representative	-	The most aggressive BZ in Mainland Portugal in both seasons. In summer, due to the continental influence, there are high daily thermal amplitudes

5. Cost Effectiveness Analysis and Results

This section presents and investigates the results from the Excel simulations that illustrate the capabilities of *Kiplo Smart Engine*.

As already presented in Section 4, the case study analyzed in this paper embraced 26 NLV bank branches dispersed across Mainland Portugal, which were grouped into 8 bioclimatic zones. Therefore, in total, 8 distinct scenarios were evaluated, combining the referred characteristics: I1V1, I1V2, I1V3, I2V1, I2V2, I2V3, I3V1 and I3V2 scenarios. This study used a 1-year horizon as reference period (i.e., January 1st, 2015 to December 31st, 2015). Granular real electricity consumption data harvested over this period was provided by *Kiplo Smart Engine*.

In a first analysis, the weighted average values of annual electricity cost reduction per square meter for each of the 8 distinct scenarios were conducted, considering a change from the current tariff structure (i.e., 3-period TOU tariff on electricity) to RTP, as presented in Table 6.

Table 6: Annual electricity cost reduction/m2 of a change from

the current TOU tariff to RTP, in percentage

Scenario	Electricity cost per m2 (€/m2) (2015)		
	TOU	RTP	Cost reduction
I1V1	9.45	6.19	35%
I1V2	10.04	6.59	34%
I1V3	10.60	6.97	34%
I2V1	11.79	7.69	35%
I2V2	13.13	8.66	34%
I2V3	11.62	7.68	34%
I3V1	17.33	11.39	34%
I3V2	20.88	13.86	34%

According to the results presented in Table 6, the change in electricity tariffs has the potential to drive, on average, annual electricity cost reductions of 34% per square meter in the considered scenarios.

Additionally, Table 2 presents the results from a secondary simulation, which associated RTP with the ALMS presented in Table 4. The cost reductions per square meter from this approach are given in Table 7.

Table 7: Annual electricity cost reduction/m2 of a change from the current TOU tariff to RTP associated with ALMS, in percentage

BZ	Electricity cost per m2 (€/m2) (2015)		
	TOU	RTP + optimization strategies	Cost reduction
I1V1	9.45	5.48	42%
I1V2	10.04	5.54	45%
I1V3	10.60	5.88	45%
I2V1	11.79	6.72	43%
I2V2	13.13	7.48	43%
I2V3	11.62	6.33	46%
I3V1	17.33	9.90	43%
I3V2	20.88	12.17	42%

From the results shown in Table 7, it is possible to conclude that different opportunities of higher profits arose with the implementation of the ALMS abovementioned, even in the case of banks that have low demand elasticity. Furthermore, it can also be drawn from the overall results presented in Table 7 that the I2V3 bioclimatic zone is the scenario with the most significant cost saving results, corresponding to a reduction of 46% of the total annual electricity cost per square meter.

Nonetheless, there is no strong evidence of correlation among area, geographic location and annual electricity cost reductions when only these three variable are analyzed. Other specificities (such as customer flow, building occupancy, variations in thermal comfort level requirements, building surroundings, building envelope, building orientation, to name a few) might impose different impacts on these results; however, they were not encompassed in the scope of this study.

For a more detailed study, the annual electricity cost variation per square meter in 2015 for the I2V3 bioclimatic zone is given in Figure 2, in relation to the change in electricity tariffs and the association of RTP with the automated RTP-responsive HVAC load management strategies.

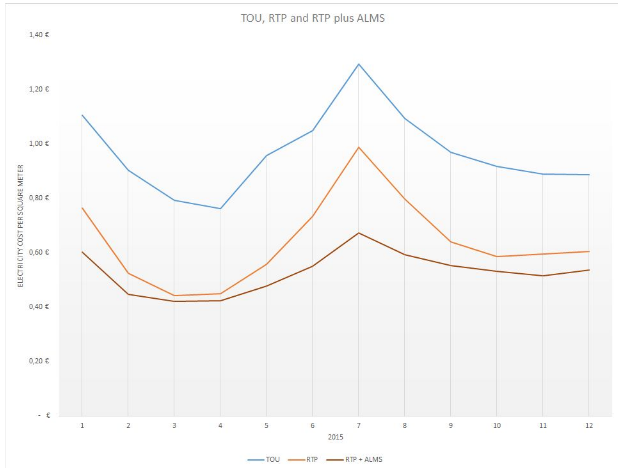

Figure 2: Annual electricity cost variation per square meter, corresponding to the 3-period TOU tariff, RTP and RTP plus ALMS

The analysis of Figure 2 led to the conclusion that, throughout the year of 2015, electricity costs per square meter under RTP presented large advantages when compared to electricity costs per square meter under the current 3-period TOU rate, reflecting in significant annual electricity cost savings for the bank. There was no single event where RTP exceed the price per square meter paid under the current tariff structure. Furthermore, the association of RTP with ALS achieved much greater electricity cost reductions throughout the year.

6. Conclusions

This paper compares the variability of electricity prices per square meter of the 26 NLV bank branches encompassed in this study under a 3-period TOU rate structure and under an assumed RTP rate. Furthermore, this study also analyzes the impact of the association of RTP with ALMS on annual electricity cost savings per square meter. This paper takes into account the effect of building area and geographic location on these results, grouping the 26 bank branches scattered across Mainland Portugal in 8 distinct bioclimatic zones. This paper attempts to simulate the performance of *Kiplo Smart Engine*, an automated demand-response control software that delivers optimal price-responsive strategies, among other features. Excel simulations for the year of 2015 reveal that, even though banks have virtually no flexibility to implement cost-responsive measures, the introduction of RTP reflects a reduction of approximately 34% on the annual cost of electricity per square meter against the prevailing tariff structure. The association of RTP with ALMS raised the annual electricity cost reductions per square meter to 46% in the most effective scenario and 42% in the less attractive scenario, providing solutions that not only reduce electricity prices per square, but also reduce price volatility and improve system reliability. Therefore, it can be concluded that, even though the future of RTP available to NLV consumers in Mainland Portugal is still unknown, due largely to impending deregulation, it is expected that the unique nature of exploration and extension of this study will foment discussions around the regulation of RTP programs to them. Finally, this paper goes further by suggesting that the automation of RTP-responsive HVAC load management strategies could largely augment cost savings, as it alleviates consumers from the need to constantly intervene in operations to implement price-responsive measures.

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References

[1] Saraiva, J. T., Fidalgo, J. N., Pinto, R. B., Soares, R., Afonso, J. S. and Pires, G. (2016). Implementation of dynamic tariffs in the Portuguese electricity system - preliminary results of a Cost-Benefit Analysis. 2016 13th International Conference on the European Energy Market (EEM), Porto, 2016, pp. 1-5. doi: 10.1109/EEM.2016.7521329.
[2] Spees, K. and Lave, L. B. (2008). Impacts of responsive load in PJM: load shifting and real time pricing. Energy Journal, 29, 2, 101-121. doi: 10.5547/ISSN0195-6574-EJ-Vol29-No2-6.
[3] P. Faria, Z. Vale. (2011). Demand response in electrical energy supply: an optimal Real Time Pricing approach. Energy, Elsevier, 2011, 36, 8, pp. 5374. doi: 10.1016/j.energy.2011.06.049.
[4] Despacho (extrato) no 15793-F/2013. Decreto-Lei no 118/2013 de 20 de Agosto. Diário da República: II série, No 234 (3 de Dezembro de 2013).