Encouraging Energy Conservation in Campus Dormitory via Monitoring and Policies

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ABSTRACT

Promoting and practicing energy conservation requires a cost-effective system for monitoring electricity usage and a well-designed incentive policy to induce energy-saving habits. In this paper, we describe our experiences in building a smart meter system in campus dormitories and the design of an incentive policy. The smart meter system captures different types of electricity usage in each dormitory room, and allows the students to see their usage and then to pay as necessary. The policy is to assign credit to students based on their long-term usage averages, and to make students pay if they go above that, but to rebate them for any unused balance. The system allows us to log the usage behavior on a continuous basis, and we can thereafter analyze the measurement data in order to report the effectiveness of such a scheme.

1. INTRODUCTION

Energy conservation is an important attitude to living that we try to promote and practice on our university campus. The challenge is how to set up a cost-effective way of monitoring energy usage and to design incentive systems to encourage energy-savings behaviors. The monitoring system measures and extracts energy usage patterns, which helps in designing effective policies to motivate lodgers to save energy. In this paper, we describe a practical system which we recently deployed in the student dormitories on our campus that allowed us to monitor and experiment with incentive policies. The results were positive and the experience is worth relating.

The Chinese University of Hong Kong [1] runs a College system. While academic study mostly happens in the faculties and departments, many other aspects of a student's life are supported by the College to which the student belongs. The Colleges provide the dormitories and dining halls for students, organize social and sporting activities, and offer various general education programs. The study reported here is based on a collaboration with Lee Woo Sing (LWS) College [3] for which "Green Life" is a motto. One of the projects at the College is to set up a smart meter system to encourage energy conservation.

The smart meter system includes the functionalities of: (a) electricity consumption measurement using smart sensors; (b) a prepayment system based on quota; (c) an interface for administrators to allocate quota; and (d) an interface for students to add payment. Electricity measurement is based on pulse counting. In each room in the dormitory, multiple smart units are deployed to separately collect the electricity consumption of Air Conditioner (AC), Power Socket, and Lighting & Fan. The collected values are periodically reported to a central server via TCP/IP. With the ability to monitor the electricity consumption of each dormitory room, the college designed and applied a pricing scheme for charging students as an incentive policy to conserve energy. The pricing scheme is progressive and it motivates students to save energy because it charges higher unit prices for more usage quotas and it refunds the unused quota balances.

Based on the measurement data exported from the smart meter system, we conducted a detailed analysis of the electricity consumption of the dormitory rooms as well as the quota value adding behavior of the students. The results validate the effectiveness of the pricing scheme on positively encouraging the students to conserve energy. Besides, we report some interesting observations in terms of energy usage, such as the influences from the gender factor and the weather factor. Other important findings include the potential policy adjustments to further encourage energy conservation, including modifying the current pricing scheme and encouraging energy conservation in the public areas of the dormitory.

The rest of this paper is organized as follows. In Section 2, we first briefly review the related work; this is followed by a description of the smart meter system in Section 3. In Section 4, we introduce the student dormitory setting and the incentive scheme design. In Section 5 and Section 6, we show our analysis of the measurement data and discuss its implications and our future plans. In Section 7, we draw our conclusions.

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2. RELATED WORK

In previous studies, there are various approaches for measuring and monitoring the electricity consumption in buildings. In some early studies [12, 8], the data of electricity consumption were collected manually and periodically. In [11], the authors presented an approach for selecting a set of sensors for capturing energy events in buildings. In our study, the electricity consumption is measured by deploying smart meters in dormitory rooms. Although our measurement approach is different, the experiences reported in the earlier studies suggested several good ideas, such as how to conserve energy in public areas.

There are some other studies concerning the design of effective policies to motivate energy conservation. Both [5] and [8] illustrate that feedback on electricity consumption may provide a tool for customers to better control their consumption and to thereby save energy. The authors of [5] have extracted the features of successful feedbacks and emphasized that successful feedback has to capture the attention of consumers. Their ideas suggest one direction for our future study: to develop interfaces for students to better compare their electricity consumption with that of others so as to further encourage energy conservation.

There are also some works which illustrate possible applications of the data collected in our smart meter system. For example, [10] evaluated the forecasting of household electricity demand by using three realistic datasets of geospatial and lifestyle diversity. Another example is the Grand Challenge of DEBS 2014 [6], which seeks the design of an event-based system to provide scalable, real-time analytics over high-volume sensor data. The dataset used is the recordings originating from smart plugs, which are deployed in private households to measure electricity consumption.

3. THE SMART METER SYSTEM

3.1 System Framework

Figure 1 shows the framework of the smart meter system. In each bedroom of the dormitory, we deployed a Single Room Unit (SRU) to measure the electricity consumption of the room in realtime. Each SRU periodically reports the measured values to the System Server via TCP/IP over the local Ethernet. Upon receiving a measured value, the System Server processes and stores it in a local database.

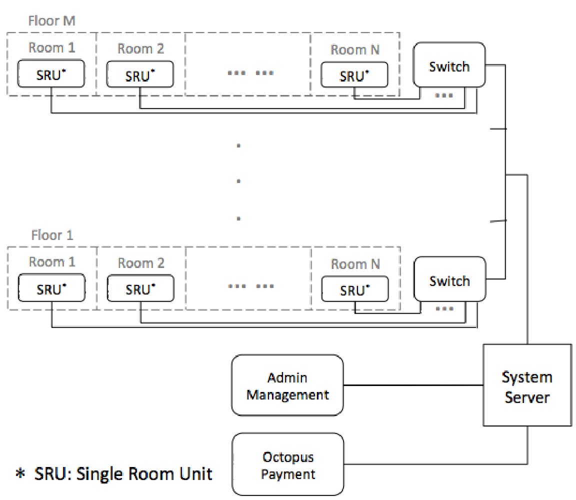

Figure 1: The Framework of Smart Meter System

Besides, the System Server is responsible for handling requests from the Admin Management Platform and the Octopus Payment System. These systems are provided for the college administrator and the students, respectively. The Admin Management Platform allows the dormitory administrator: (1) to check the electricity consumption of any room during a customized period; (2) to manage the usage quota for each room; and (3) to generate customized reports of electricity consumption and quota adding records. The Octopus Payment System provides the interface for students: (1) to check their quota adding history, and (2) to get additional quotas by payment when necessary.

3.2 Single Room Unit

The SRU is the core component of the smart meter system. Basically, it is responsible for measuring the electricity consumption from the different sources in a room. Meanwhile, it periodically sends the measured values to the System Server via TCP/IP for data aggregation. There are several components in the SRU: the Power Control Unit; the Network Panel; and the Power Calculating Circuit (PCC). Figure 2 illustrates the structure of the SRU.

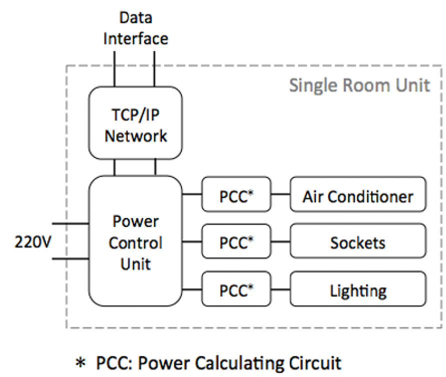

Figure 2: The Structure of Single Room Unit

The measurement of electricity consumption is based on pulse counting at the PCC. Pulses are generated at a rate proportional to the corresponding electricity consumption [7, 9]. Therefore, the frequency of such pulses indicates the power demand, while the number of pulses indicates the energy metered [13]. The number of pulses is convertible into the commonly used electricity consumption in kWh, and the conversion is given in the following formula.

$$Electricity\ Consumption\ in\ kWh = \frac{\#\ of\ Pulses}{3200}$$

At the beginning of each hour, the SRU reports the number of pulses counted in the previous hour. The reporting is done via the Network Panel. The Network Panel is an embedded system that is equipped with a TCP/IP connection for remote updating and monitoring. Through this connection, the measurement results are reported to the System Server in realtime. In the other direction, the configuration is downloadable to the panel for updating the equipments.

In the smart meter system, the electricity consumption of each dormitory room is divided into three parts: (1) Air Conditioner (AC); (2) Power Socket; and (3) Lighting & Fan. For each part, there exists a PCC for measuring the electricity consumption. Therefore, we can separately monitor the electricity consumption of each dormitory room in terms of AC, Power Socket, and Lighting & Fan. The Power Control Unit consists of several Solid State Relays, which cut off the power supply of the corresponding room when the quota balance reaches zero.

With the measurement results, we can infer the electricity usage profile for different consumption sources. For example, Figure 3 illustrates the hourly electricity consumption of AC, Power Socket, and Lighting & Fan in the same room during one week (2014/09/01 to 2014/09/07). Apparently, different consumption sources show great differences in terms of usage pattern.

Figure 3(a) shows the strong daily usage pattern of AC during weekdays: the student usually use AC from midnight to noon as well as for several hours in the afternoon. However, he or she might leave their room during the weekend as there is no electricity consumption of AC after midday on Saturday. Compared to AC, Power Socket consumes a relatively lower amount of power, but the consumption is continuous over time. While for Lighting & Fan, most of the electricity consumption is generated during the night, and zero values over the weekend are consistent with the usage of AC.

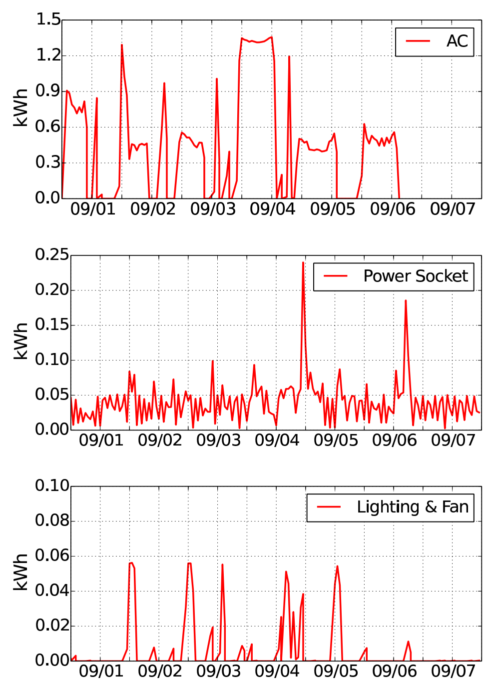

Figure 3: Hourly Electricity Consumption of AC, Power Socket, and Lighting & Fan in a Room during One Week

4. SYSTEM OPERATION

4.1 Overview

LWS College is a new and medium-sized college of the Chinese University of Hong Kong, which was founded in 2006. It promotes green life among students in order to raise their concerns about the environment, and to help develop a sustainable campus. The smart meter system was built into LWS College's new dormitory buildings when they were being constructed more than two years ago, so there were no retrofitting costs. Actually, the system is the first deployment of such a system in Hong Kong.

The dormitory building of LWS College has two blocks: North Block and South Block. Both of them have 155 dormitory rooms for students. Table 1 lists the detailed information of the college dormitory, including the number of rooms, the gender of the lodgers, and the room type.

We deployed a SRU in each of the total 310 rooms and connected all SRUs to the central System Server. Meanwhile, the System Server runs as a server of TeamViewer so that the college administrator can remotely access the Admin Management Platform via TeamViewer.

Block	Floor	Room #	Gender	Room Type
North	G	10	M	Triple
	01	22	F	Double
	02	21	F	
	03	22	F	
	04	21	F	
	05	22	M	
	06	21	M	
	07	16	M	Mixed
South	03	22	F	Double
	04	22	M	
	05	21	M	
	06	22	M	
	07	21	M	
	08	12	F	Mixed
	09	12	F	
	10	12	F	
	11	11	F	

Table 1: Detailed Information of Dormitory Rooms in LWS College

4.2 The Pricing Scheme

The pricing scheme for the students is semester-based. For a normal semester, at a fixed date in each month, the college administrator manually allocates some free quotas for all rooms. The amount value is calculated by referencing the average electricity consumption of the previous year and it varies for different room types: 95 units for a single room; 105 units for a double room; and 115 units for a triple room.

Whenever a room runs out of its quotas in the middle of a semester, its lodgers have to buy additional quotas. Otherwise, the power supply in that room will be unavailable till the next free quota releasing date. The lodgers get warning signals well before power supply is cut off. Between two consecutive free quota releasing dates, the unit price of the additional quota follows the rule in Table 2. Such rule is progressive and it means the more additional quotas are bought, the more expensive is the unit price.

Payment ($)	First 50	Next 50	Next 50	Next 50+
Unit Price	$0.92	$1.61	$2.07	$2.87

Table 2: Progressive Pricing Scheme of Additional Usage Quota in LWS College

At the end of a semester, the balance of unused quotas of a room can be refunded to the corresponding lodgers of that room. Therefore, the charge of electricity consumption is directly linked to student consumption levels, and this motivates students to save energy.

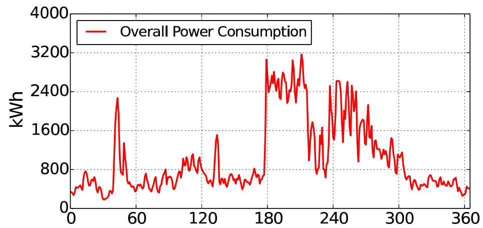

Figure 4: Daily Overall Electricity Consumption of All Dormitory Rooms in 2014

5. MEASUREMENT DATA ANALYSIS

5.1 Electricity Consumption

Figure 4 gives the daily overall electricity consumption of all dormitory rooms in 2014. As we explained in Section 3.2, the electricity consumption of each dormitory room is divided into three components: AC; Power Socket; and Lighting & Fan. Figure 5 shows the daily overall electricity consumption of each component during the whole of 2014. There exist great disparities in consumption amount and usage pattern between the three components.

According to Figure 5, the electricity consumption of

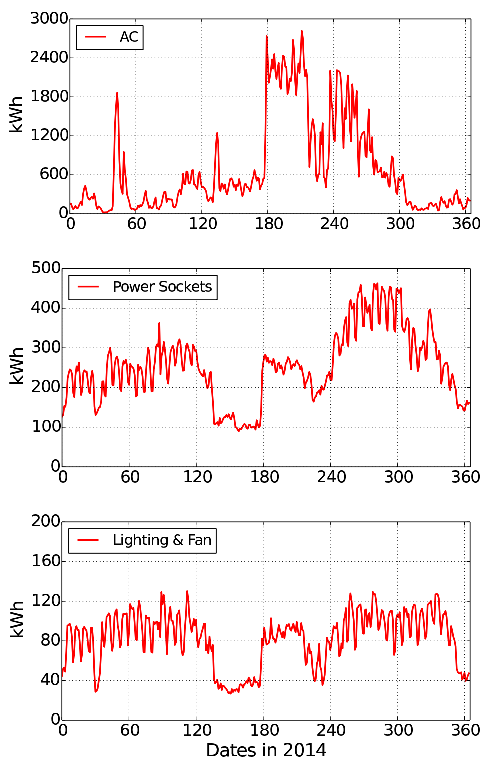

Figure 5: Daily Overall Electricity Consumption of All Rooms for AC, Power Socket, and Lighting & Fan in 2014

AC represents the largest portion of overall consumption, and the usage pattern of AC is highly related to time. The electricity consumption of Power Socket and that of Lighting & Fan share similar usage patterns and distribute more uniformly over time, even the usage amounts are not comparable. Table 3 shows the absolute electricity consumption value and the corresponding percentage of the three components, which suggests that the primary target of energy saving is AC.

Component	Consumption Value	Percentage
AC	251429 kWh	67.24%
Power Socket	92419 kWh	24.72%
Lighting & Fan	30053 kWh	8.04%

Table 3: Overall Electricity Consumption of AC, Power Socket, and Lighting & Fan in 2014

5.2 The Effect of Pricing Scheme

For LWS College, the motivation for deploying the smart meter system and setting up the pricing scheme is to encourage the students to be responsible for their own electricity consumption, thereby promoting a reduction in energy waste. Actually, the pricing scheme described in Section 4.2 is applied only to dormitory rooms during the normal semesters. There is no separate charge for electricity consumption when the rooms are rented to guests during summer holidays. Therefore, we can compare the electricity consumption during a normal semester with that during a summer holiday to validate the effect of the pricing scheme.

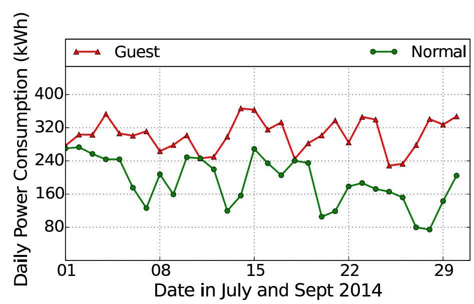

Figure 6: Effect of Pricing Scheme on Electricity Consumption

We selected the daily total electricity consumption of the same floor (6th) in two different months for comparison: July 2014, and September 2014. During July, the lodgers were visitors and there is no pricing scheme of electricity consumption for them. The pricing scheme was, however, applied to students during September. We chose September for comparison to minimize the influence of the weather; this is because the weather in Hong Kong in July and in September is similar both in temperature and humidity.

Figure 6 illustrates the comparison results. Apparently, the consumption under the pricing scheme is smaller than that without usage limitation. The overall electricity consumption in September is only around 63% of that in July. Therefore, the pricing scheme shows a positive effect on motivating students to save energy.

On the other hand, Figure 6 proves the different energy usage patterns for visitors and students. For example, compared with weekdays, students usually spend less time in their dormitory room during weekends. The visitors, however, have the opposite behavior: that is, they spend more time in their room during the weekends.

5.3 Value Adding Behavior

As we described in Section 4.2, students are allowed to buy additional usage quotas, and the pricing scheme follows the rule in Table 2. The behavior of value adding helps us to understand the usage pattern of students so as to enhance the pricing scheme.

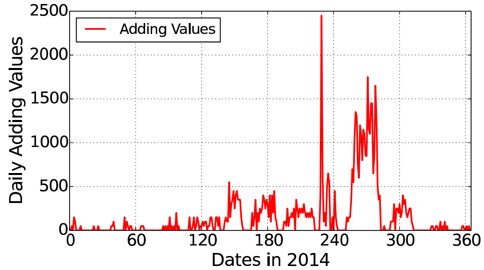

Figure 7: Daily Overall Adding Amounts in 2014

The daily value adding amount of 2014 is shown in Figure 7. Apparently, the majority of value adding occurs from August to October, which is consistent with the results shown in Figure 4. There are only two amount options for students to select when paying additional quotas: 50HKD, and 100HKD. Therefore, we can infer the amount of value adding behavior of a student from the history records of his or her value adding amount.

According to the daily electricity consumption shown in Figure 4, the demands placed on the power supply are distributed in a non-uniform way. The pricing scheme formulated by the College determines that the free quotas are assigned uniformly for each month. Students have to buy additional quotas once their quota balance runs out. Even though the unused quotas are refundable at the end of each semester, the unit price of an additional quota is much higher than the refund price.

5.4 Other Observations

5.4.1 Gender Effect

Another interesting observation which we made from the measurement results is the influence of gender on electricity consumption. The College assigns the dormitory rooms to male or female students based on floor. We chose two adjacent floors to extract the gender effect. Both floors have 21 rooms with the same room type. We compared the electricity consumption of the two floors during the same period.

Figure 8 illustrates the daily electricity consumption in September for both floors. Basically, male students and female students share similar consumption patterns, while the female students on average consume less energy than the male students. For this reason, the college administrator might consider normalizing the free usage quota for the male students and the female students separately.

5.4.2 Weather Effect

According to Figure 5(a), the usage pattern of AC is highly related to time. A possible explanation is the influence of the weather. The hourly measurement of AC usage

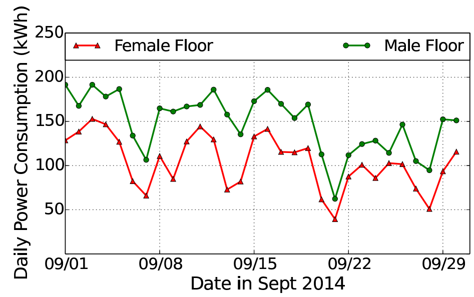

Figure 8: Electricity Consumption Comparison Between Male and Female Students in September 2014

for dormitory rooms allows us to study the correlation between the weather and the AC usage. We retrieved the daily average temperature of Hong Kong in 2014 from [2] and then calculated the Pearson correlation coefficient between the daily temperature and the daily AC usage (electricity consumption) of overall rooms. The coefficient value is 0.5867, and it proves the strong positive correlation between the weather and the AC usage.

6. POTENTIAL POLICIES

6.1 Free Quotas Allocation

According to the daily value adding amount shown in Figure 7, the values are somewhat different for the two semesters. For the spring semester (from January to May), there are only a few records of value adding, although there are many records of value adding in the autumn semester (from September to December). This is a reasonable observation because the average temperature is much higher in the autumn semester than in the spring semester, and this leads to heavy electricity consumption on AC in the autumn semester. This observation suggests that there should be a review of whether or not the uniform allocation of free quotas for each month is reasonable, given that the electricity consumption distributes non-uniformly over the year.

6.2 Continuous AC Usage

Another observation which we made from the measurement data relates to the AC usage pattern of the students. A large portion of AC usage is in a continuous mode. Table 4 gives the distribution of AC operating time for the AC usage in September 2014. More than half of the AC usage is with an operating time longer than three hours. A possible reason is that the AC used in the dormitory rooms of LWS College is Window-Mounted Air Conditioner (WM-AC), which is the most commonly used AC for single rooms. In this type of AC, all the components are enclosed in a single box, which is fitted into a slot made in the wall of the room, or more commonly onto a window sill [4].

Time	**1 Hour**	**2 Hours**	**3 Hours**	**> 3 Hours**
Percent	16.33%	19.28%	9.70%	54.69%

Table 4: Distribution of Continuous AC Usage Time

The WM-AC provides several control functions for its users; these functions are limited to the ON/OFF Switching, the Fan Speed, and the Cooling Level. Users can hardly control the operation of WM-AC is in a smart way, such as setting the auto-switching on and off at a preferred time. The continuous operating of AC might be easily neglected by users, especially during the night. According to the results in Section 5.1, AC use is the greatest part of overall electricity consumption, and hence it should be the primary target of energy conservation. Therefore, it should help conserve energy by fixing the problem of continuous AC usage.

The problem can be improved in two dimensions: (1) by encouraging students to switch AC to a lower Cooling Level for continuous operating; and (2) by developing additional features for the smart control of AC. Approach (1) strongly depends on the promotion and education by the College; this should result in increased efficiency. Whereas for approach (2), the deployment might only involve in software adjustments. As we introduced in Section 3, the existing Solid State Relay connected to AC helps in upgrading to more advanced control.

6.3 Energy Conservation in Public Areas

The smart meter system of LWS College monitors the electricity consumption of student bedrooms, but does not cover the public areas. However, according to the College's electricity consumption report, the electricity consumption of the public areas represents an even larger proportion than that of the students' bedrooms. Therefore, we are working on ways to encourage energy conservation in the public areas as part of our future study.

Actually, energy conservation in the public areas is considerably more difficult. Firstly, compared to the student bedrooms, the structure of the electricity transmission line in the public areas is quite complicated. It is challenging and costly to deploy smart meters for different components of electricity consumption. We are investigating how many meters need to be installed and at which locations so as to make the system cost-effective. Secondly, it is not clear who is responsible for the power usage in the public areas at any given time. In some cases, it makes sense to make all students responsible for the cost in the public areas, whereas in other cases (for example, at times when most students are not present), it makes more sense to use a system which identifies the student(s) responsible. In any case, we cannot simply apply the same pricing scheme in the public areas as in the student bedrooms.

Understanding the main challenges, we have started the work by using some commonly used approaches for energy conservation in the public areas. For example, we have done delamping for lightings in the public areas, especially in the corridors of the students' bedrooms. With regard to the usage of AC in the public areas, we plan to deploy a central system to control it.

7. CONCLUSIONS

In this paper, we reported our experience in deploying a smart meter system in a university campus for measuring and monitoring the electricity consumption in the dormitory rooms. Setting up such a system allows the College's administrators to adopt incentive policies to manage demand and to encourage energy-saving practices. We show that such policies are effective. From our study, it is also clear that there is much room for improvement. In particular, we discuss the need to implement incentive policies for public areas as well, and the challenges facing this problem.

Compared to other studies of electricity consumption in buildings, we focused on the consumption in campus dormitories. In such a scenario, the lodgement usually lasts for a short period, and this requires stronger incentives to encourage energy conservation. On the other hand, promoting energy conservation in campus dormitories is profound and it will influence students in their future lives. We believe that our experiences are useful for many similar efforts in campuses worldwide.

8. ACKNOWLEDGMENTS

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