Energy Savings Potential of the Summer Time Concept in Different Regions of Japan
From the Perspective of Household Lighting

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Abstract
Summer Time is a convention in which clocks are uniformly set one hour or more ahead of standard time to provide more daylight in the evenings during late spring, summer, and early fall. The main purpose of Summer Time is to make better use of daylight so that it more closely corresponds to our normal daily activities and thus saves energy. Japan is currently not observing Summer Time. This study thus investigated the feasibility of the energy saving potential of Summer Time/Double Summer Time from the perspective of household lighting in Japan and the optimum implementation period. The study found that both the Summer Time and Double Summer Time could reduce household lighting energy consumption, while the magnitude of energy saving potential of Double Summer Time is higher compared to Summer Time. It was also indicated that April-September is the optimum implementation period of Summer Time/Double Summer Time in Japan, from the perspective of household lighting. In terms of geographical location, under Double Summer Time, the household lighting energy saving ratio of the northern Japan regions is higher compared to the southern region. However, under Summer Time, the energy saving ratio of the southern Japan region is significantly higher.

Keywords: summer time; household lighting energy consumption; life schedule; sunrise and sunset times; geographical location

1. Introduction
With increasing concern on the escalating global energy demand and the awareness of the importance of energy saving, numerous researches on energy saving have been carried out in recent years and various energy saving measures have been implemented worldwide. One of these energy saving measures is Daylight Saving Time (the term used in the United States), or known as Summer Time in the Europe as well as Japan. This study was based on the case of Japan, thus hereinafter it shall be referred to as 'Summer Time' for a one-hour time switch and 'Double Summer Time' for a two-hour time switch.

Summer Time is a convention in which clocks are uniformly set one hour or more ahead of standard time to provide more daylight in the evenings during late spring, summer, and early fall. Currently there are more than 100 countries observing Summer Time/Daylight Saving Time. In most of these countries, clocks are usually set ahead one hour in March or April then set back one hour in September or October of each year.

The main purpose of Summer Time/Double Summer Time is to make better use of daylight so that it more closely corresponds to our normal daily activities and thus saves energy (Kandel and Metz, 2001). Energy used for lighting our homes is directly related to our lifestyles and life schedules, particularly in relation to the times we wake up in the morning, go to work/school, return home and go to bed. Summer Time/Double Summer Time 'makes' the sun 'set' one/two hours later and therefore reduces the period between sunset and bedtime (cf. Fig.1.). This means less energy is used for domestic lighting and appliances late in the day.

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Fig.1. Summer Time and Double Summer Time Concepts
In the field of research on energy saving, the present authors previously undertook a study on the future urban energy consumption trends using the System Dynamic Model (Fong et al., 2007a). The study concluded that household energy consumption and lifestyle are among the most significant factors dictating the future urban energy consumption trends. From these findings, further study has been carried out to investigate household energy consumption under different lifestyles, climates and geographical locations in Japan (Fong et al., 2007b). The study indicated that there are strong interrelationships among geographical locations, sunrise and sunset times, life schedules and household lighting energy consumptions. In view of these findings and the fact that currently Japan is not observing Summer Time, the authors then investigated the possible influences of the Summer Time/Double Summer Time concept on household lighting energy consumption in different regions of Japan (Fong et al., 2007c).

This study is a continuous work on the study of energy saving potentials of the Summer Time/Double Summer Time concept from the perspective of household lighting. The objectives of this study were to further update the previous study results with respect to the energy saving potential on household lighting if Summer Time/Double Summer Time were observed in Japan; to estimate the magnitude of potential energy savings in different regions of Japan; and to identify the optimum Summer Time/Double Summer Time period.

2. Method

In this study, the case study areas were divided into four cities in four different prefectures of Japan with various latitudes, as shown in Fig.2. The four case study cities, namely Sapporo, Saitama, Kagoshima and Naha, the capital cities of Hokkaido, Saitama Prefecture, Kagoshima Prefecture and Okinawa Prefecture respectively, are located at the north, central, south and most southern part of Japan, with latitude intervals of about 5° between each two cities.

Fig.3 presents the overall framework of the study methodology. Lighting required for various domestic activities is very much dependent upon the sunrise and sunset times. The 2006 daily sunrise and sunset times of each case study city were obtained from the data published by the National Astronomical Observation of Japan (NAOJ, 2007). Due to the large north-south geographical extension of Japan, these four case study cities have distinctive differences in sunrise and sunset times. For example, sunrise and sunset times in Sapporo were 03:54–07:06 hours and 16:09–19:16 hours respectively, while in Naha, the sunrise time was between 05:36–07:18 hours and the sunset was...
18:06~19:19 hours. Fig. 4. shows the 2006 sunrise and sunset times of these four case study cities.

In order to estimate the daily lighting needs, it is necessary to relate the sunrise and sunset times with the life schedules of the people. The typical life schedules of various employment status groups (working group, retirees, housewives and students) were summarized from the Life Schedule Survey Report (NHK, 2006), which was compiled based on the life schedule survey of 12,600 respondents throughout Japan in 2005. The life schedule data used in this study was identified from the detailed breakdown of daily activities of different employment groups in 15-min. intervals for weekdays, Saturdays and Sundays. The extracted data includes waking-up time, going to work/school, returning home and bedtime. Table 1. presents the summary of life schedules adopted in this study.

Table 1. Typical Life Schedules of the Different Employment Status Groups in Japan (NHK, 2006)

| Day      | Wakeup | Go to work/school | Return home | Bedtime |
|----------|--------|-------------------|-------------|---------|
| Working Group: |
| Weekday  | 06:45  | 08:00             | 18:15       | 23:00   |
| Saturday | 07:00  | 08:45             | 17:15       | 23:00   |
| Sunday   | 08:00  | 08:45             | 17:15       | 23:00   |
| retirees: |
| Weekday  | 06:30  | -                 | -           | 22:00   |
| Saturday | 06:30  | -                 | -           | 22:00   |
| Sunday   | 06:45  | -                 | -           | 22:00   |
| Housewives: |
| Weekday  | 06:15  | -                 | -           | 23:00   |
| Saturday | 06:30  | -                 | -           | 23:00   |
| Sunday   | 06:45  | -                 | -           | 23:00   |
| Students: |
| Weekday  | 07:00  | 07:45             | 18:00       | 23:00   |
| Saturday | 08:30  | 10:00             | 17:20       | 23:00   |
| Sunday   | 08:30  | 12:00             | 17:30       | 23:00   |

From the above sunrise/sunset and life schedule data, durations of daily household lighting needs were calculated for (1) different employment status groups, (2) weekdays, Saturday and Sunday, and (3) each case study city. The main assumption was that lighting was only required between sunset and sunrise times, excluding sleeping time. Other intangible personal lifestyles such as personal preferences on brightness, type of lighting, and energy saving consciousness were not included in this stage of the study. However, it must be noted that the average household lighting energy consumption rates used were based on the on-site monitoring of 80 houses in various regions of Japan carried out by the Architectural Institute of Japan (AIJ, 2006), the data thus has included the actual lifestyles, building designs and weather factors throughout the monitoring periods.

The daily lighting durations were then multiplied by the typical household lighting energy consumption rates to obtain the daily and annual household lighting energy consumptions. As mentioned above, the household lighting energy consumption rates were calculated from the data published by AIJ (AIJ, 2006). The typical consumption rates applied in this study were averaged at about 2.3 MJ per hour, with some adjustments for different household sizes.

The above calculations yielded the annual household lighting energy consumptions under Standard Time. Using the same procedures, annual household lighting energy consumptions under Summer Time (1 hour time switch) and Double Summer Time (2 hours time switch) were calculated. In this respect, in order to identify the Summer Time period (both the number of time switch hours and the implementation months) with highest energy saving potential, separated calculations were undertaken for Summer Time and Double Summer Time under the periods from the first Sunday of each of the following starting months to the first Sunday of each ending months: (1) March to September, (2) March to October, (3) March to November, (4) April to September, (5) April to October, (6) April to November. For instance, in Case (4) April-September, the time switches were made on the first Sunday of April and the first Sunday of September. These results were then integrated with the 2005 population data (Japan National Institute of Population and Social Security Research, 2003) of Hokkaido, Saitama Prefecture, Kagoshima Prefecture and Okinawa Prefecture to produce the prefectural annual household lighting energy consumption under various Summer Time and Double Summer Time periods (note: this calculation only took into account the specific predetermined typical household patterns as explained in the latter section).

From the above, optimum Summer Time/Double Summer Time months were identified. Based on the optimum Summer Time months, detailed calculations were made to estimate the annual household lighting energy consumption (per household) and energy savings potential under the Summer Time and Double Summer Time concepts, for each predetermined typical household pattern (household size and composition), i.e. (1) single-person households of the 'working group' and 'retiree group', (2) 2-person households of 'both working', 'working husband and housewife' and 'both retirees' groups, and (3) 3-person households of 'working parent and school child', 'working husband, housewife and school child' and 'retired parent and working child' groups. In this study, children below school age were omitted as the influence of this age group on the overall household energy consumption is negligible, as found in the previous study (Fong et al., 2007b). For the household pattern, based on the projection by the Japan National Institute of Population and Social Security Research (2003), it was predicted that by the year 2025, about 79.5% of the total families in Japan would be in the categories of single-person
family, husband-wife family (i.e. 2-person family) and husband-wife-child family (i.e. 3-person family). Fig.5. shows the projection of growth trends for different family patterns in Japan, from 2000 to 2025. As such, for the estimate of household energy consumption, this study only focused on these three family groups.

Finally, using the above calculation results and the official household projection data published by the Japan National Institute of Population and Social Security Research (2003), projections of prefectural household lighting energy consumption were carried out for each prefecture of the case study areas i.e. Hokkaido, Saitama Prefecture, Kagoshima Prefecture and Okinawa Prefecture, based on the standard energy consumption rates of Sapporo, Saitama, Kagoshima and Naha respectively.

3. Results and Discussion

3.1 Summer Time Period

As mentioned above, the first stage of the analysis was to identify the optimum Summer Time/Double Summer Time period (both the number of time switch hours and the implementation months), from the perspective of household lighting energy saving potential in Japan. For this purpose, prefectural annual household lighting energy consumptions under Summer Time and Double Summer Time were calculated for Hokkaido, Saitama Prefecture, Kagoshima Prefecture and Okinawa Prefecture, based on the 2006 sunrise/sunset data and 2005 population data (official 2006 population data was not available during the time of the study), as shown in Fig.6.

In terms of the number of hours of time switch, from the results shown in Fig.6., it can be concluded that both Summer Time and Double Summer Time could reduce household lighting energy consumption, while the magnitude of energy saving potential of Double Summer Time is higher.

With respect to the implementation period (i.e. 'months' in this case) of Summer Time/Double Summer Time, the results showed that under Summer Time, the most effective period for Hokkaido and Saitama Prefecture is March-November, while for Kagoshima Prefecture and Okinawa Prefecture it is April-September. For the case of Double Summer Time, April-September is the most effective period in all the case study areas. The conclusion is summarized in Table 2. From Table 2., it can be concluded that April-September is the optimum implementation period of Summer Time/Double Summer Time. Although for the case of Summer Time, in Hokkaido and Saitama Prefecture, the lowest energy consumptions were achieved during the March-November period, its differences compared to the April-September period were rather small; about 0.07-0.08 PJ/year.
This finding has clarified the question raised in the previous study (Fong et al., 2007c) that the optimum Summer Time period of Japan could be distinctive from other countries because of the unique life schedules of the Japanese population, who tend to wake up early in the morning and return home from work late in the evening.

Referring to the sunrise and sunset times in Fig.4., it is obvious that April to September is the period with the earliest sunrise (generally before 0600 hours) and the latest sunset (generally after 1800 hours). Implementation of Summer Time during the period when the sunrise time is later than 0600 hours and the sunset time earlier than 1800 hours (in March, October and November) would not have much impact on lighting needs, as the typical wakeup time of housewives is about 0615 hours and the returning home time among the working group is 1900 hours (cf. Table 1.). This is because the 'delayed' sunrise under Summer Time would result in an increased lighting need in the morning, and the 'delayed' sunset up to 1900 hours will not yield any benefit to the working group who returns home at about 1900 hours in the evening.

As such, implementation of Double Summer Time during the period of April to September, when the sunrise is earlier than 0600 hours and the sunset is later than 1800 hours, can maximize the benefit of a time switch from the view point of home lighting needs. This is clearly shown in Table 3., which will be further elaborated in the later section of this paper. With Double Summer Time, the working group could enjoy at least one hour of extra daylight in the evening. Although there would also be an increase in lighting needs in the morning, the increased energy consumption in the morning is offset by the savings of energy in the evening. This is because in the evening, the intensity of energy consumption is higher when all the family members are at home. Also, it is very likely that people may plan for outdoor activities during the extra daylight hours in the evening, thus resulting in less household energy consumption.

3.2 Household Pattern

From the above result in which April-September is the optimum Summer Time/Double Summer Time period, the subsequent analyses were based on the fixed Summer Time/Double Summer Time period of April-September. This section investigates the interrelationships between household pattern (in terms of household size and composition) and household lighting energy consumption, as well as the energy savings potential of the Summer Time/Double Summer Time concept based on household pattern.

Table 2. Optimum Summer Time/Double Summer Time Period

| Prefectures       | Summer Time   | Double Summer Time |
|-------------------|---------------|--------------------|
| Hokkaido          | Mar-Nov       | Apr-Sep            |
| Saitama Prefecture| Mar-Nov       | Apr-Sep            |
| Kagoshima Prefecture| Apr-Sep   | Apr-Sep            |
| Okinawa Prefecture | Apr-Sep     | Apr-Sep            |

Fig.7. presents the annual per household lighting energy consumption under Standard Time (ST, present condition), Summer Time (ST1) and Double Summer Time (ST2), under the Summer Time/Double Summer Time period of April-September. The results indicated that there is no distinctive variation in terms of household lighting energy consumption among different household patterns. However, the results showed that the implementation of both Summer Time and Double Summer Time can reduce household lighting energy consumption in all household patterns, while Double Summer Time has a greater magnitude in terms of energy saving potential.

Fig.7. Annual Per Household Lighting Energy Consumption under Standard Time (ST), Summer Time (ST1) and Double Summer Time (ST2)

W: working, R: retired, WW: both working, WH: working husband & housewife, RR: both retired, WWS: working parent & school child, WHS: working husband, housewife & school child, RRW: retired parent & working child

Table 2. Optimum Summer Time/Double Summer Time Period
This finding is not in line with the previous study finding that the overall household energy consumption is distinctly higher in the larger households, also the retirees and housewife groups generally consume more household energy compared to the working and student groups (Fong et al., 2007b). The current results indicated that there is no obvious trend of higher lighting energy consumption under larger household size, and by the retirees and housewife groups.

In terms of the energy savings potential of Summer Time and Double Summer Time on household lighting needs, from the results shown in Fig.7., it is obvious that both Summer Time and Double Summer Time can achieve energy savings in household lighting. As mentioned above, compared to Standard Time whereby the energy consumption rate was 1.53-2.05 GJ/year/household, under Summer Time and Double Summer Time, the consumption rates were reduced to 1.03-1.88 GJ/year/household and 1.00-1.25 GJ/year/household respectively. Table 3. shows the magnitudes of potential annual household lighting energy savings for each typical household, if Summer Time or Double Summer Time were observed in Japan. It can be seen that in each typical household ST2 is more effective than ST1.

3.3 Geographical Location

In terms of the interrelationship between geographical location and household lighting energy savings potential of Summer Time/Double Summer Time, it is shown from Fig.7. that northern Japanese households generally have higher lighting energy consumptions. This is in line with the finding of the present authors’ previous study (Fong et al., 2007b). This is essentially because the earlier sunset hours in the northern regions, particularly during the winter season (cf. Fig.4.), results in higher lighting needs in the evening.

Referring to Fig.4., it can also be seen that during the period of mid-spring to mid-autumn, the northern regions have much earlier sunrise hours than the southern regions, while the sunset times are fairly similar compared to the southern regions. For this reason, the lighting energy saving potential of Double Summer Time is much higher in the northern region, as shown in Table 3. This is because of the early sunrise hours of about 0400 hours during summer in the northern regions, hence even with the application of Double Summer Time there will be a very minimal increase in the morning session lighting needs as the waking up times are generally not earlier than 0615 hours (cf. Table 1.). On the other hand, the two hours 'delay' of sunset times will significantly reduce evening session lighting needs.

From Table 3., it is also very obvious that in the northern regions (Sapporo and Saitama), the energy saving ratios of Summer Time are very low compared to Double Summer Time. This is due to the fact that the sunset hours of Sapporo and Saitama are about half an hour earlier than the southern regions (Kagoshima and Naha), during the periods of April and mid-August to mid-September, when Summer Time/Double Summer Time is observed. During these periods, sunset times of the northern regions are generally earlier than 1830 hours while the southern regions are about 1900 hours. Hence, during the times when the sunset hours are earlier than 1830 hours, the application of a one hour time switch under Summer Time will not yield much effect in term of household lighting energy saving as the typical time of returning home of the working group is about 1900 hours (cf. Table 1.).

Table 3. Household Lighting Energy Saving Potentials under Summer Time and Double Summer Time (per household)

| Household Pattern | Summer Time | Double Summer Time |
|-------------------|-------------|--------------------|
| Sapporo           |             |                    |
| W                 | 0.15        | 0.74               | 41.2%              |
| R                 | 0.18        | 0.79               | 42.4%              |
| WW                | 0.15        | 0.74               | 41.2%              |
| WH                | 0.16        | 0.80               | 39.3%              |
| RR                | 0.18        | 0.79               | 42.4%              |
| WWS               | 0.25        | 0.89               | 44.6%              |
| WHS               | 0.21        | 0.84               | 41.9%              |
| RRW               | 0.16        | 0.76               | 41.8%              |
| Saitama           |             |                    |
| W                 | 0.13        | 0.71               | 39.8%              |
| R                 | 0.18        | 0.75               | 41.5%              |
| WW                | 0.13        | 0.71               | 39.8%              |
| WH                | 0.16        | 0.76               | 37.9%              |
| RR                | 0.18        | 0.75               | 41.5%              |
| WWS               | 0.16        | 0.78               | 40.8%              |
| WHS               | 0.16        | 0.77               | 39.3%              |
| RRW               | 0.16        | 0.73               | 40.7%              |
| Kagoshima         |             |                    |
| W                 | 0.61        | 0.68               | 38.9%              |
| R                 | 0.58        | 0.60               | 37.3%              |
| WW                | 0.61        | 0.68               | 38.9%              |
| WH                | 0.64        | 0.68               | 37.5%              |
| RR                | 0.58        | 0.60               | 37.3%              |
| WWS               | 0.65        | 0.74               | 40.4%              |
| WHS               | 0.64        | 0.71               | 38.0%              |
| RRW               | 0.59        | 0.64               | 38.2%              |
| Naha              |             |                    |
| W                 | 0.56        | 0.66               | 37.9%              |
| R                 | 0.48        | 0.48               | 31.3%              |
| WW                | 0.56        | 0.66               | 37.9%              |
| WH                | 0.56        | 0.61               | 32.5%              |
| RR                | 0.48        | 0.48               | 31.3%              |
| WWS               | 0.59        | 0.68               | 37.6%              |
| WHS               | 0.57        | 0.64               | 35.0%              |
| RRW               | 0.52        | 0.57               | 34.8%              |

W: working, R: retired, WW: both working, WH: working husband & housewife, RR: both retired, WWS: working parent & school child, WHS: working husband, housewife & school child, RRW: retired parent & working child
that northern regions would have higher Summer Time energy saving potential. The present study has updated the results by application of the optimal Summer Time/Double Summer Time period of April-September, and the results showed that the northern regions would obviously have higher lighting energy saving potentials.

3.4 Future Projection
The above sections indicate that both Summer Time and Double Summer Time have the potential to reduce household lighting needs in all the case study areas in Japan. This section highlights the cumulative energy saving effects of Summer Time/Double Summer Time by projections of prefectural household lighting energy consumptions up to the year 2025.

Before looking into the projection results, it is necessary to have an overview of the household projections of the respective prefectures under study. Fig.8. shows the official household projections published by the Japan National Institute of Population and Social Security Research (2006). The projection showed that Saitama Prefecture has the largest number of households, followed by Hokkaido, Kagoshima Prefecture and Okinawa Prefecture. There will be a gradual decrease in household numbers in all the prefectures except Okinawa Prefecture.

Fig.9. depicts the present projection results of the prefectural household lighting energy consumptions. It must be noted that the projection only included the predetermined single-person, 2-person and 3-person household groups as explained in the previous Method section.

From the projection results, it can be seen that the impact of both Summer Time and Double Summer Time on household lighting energy consumption is very significant. In line with the earlier results in Sections 3.2 and 3.3, the magnitudes of household lighting energy saving potential of Double Summer Time are higher compared to Summer Time. For example, in the case of Saitama Prefecture, the annual energy saving potential under Summer Time and Double Summer Time are as high as 0.39 PJ/year (35%) and 1.73 PJ/year (40%) respectively.

4. Conclusions
In response to the increasing concerns on the escalating global energy consumption, particularly urban energy consumption, the present authors have been actively and continuously studying urban energy consumption trends with specific focus on the household sector. Several studies have been carried out to investigate the interrelationships among household energy consumption and factors such as lifestyle, household pattern, life schedule, age, gender, employment, geographical location, climate, etc.

Japan is currently not observing Summer Time, and very limited studies and publications exist regarding Japan in this field. Hence, as a continued investigation from the previous works (Fong et al. 2007a, 2007b, 2007c), the authors of this study investigated the energy savings potential of Summer Time/Double Summer Time from the perspective of household lighting. The following are the key findings of this study:

(1) Both Summer Time and Double Summer Time could reduce household lighting energy consumption, while the magnitude of the energy saving potential of Double Summer Time is higher compared to Summer Time.

(2) April-September is the optimum implementation period of Summer Time/Double Summer Time in Japan from the perspective of household lighting.

(3) In terms of geographical location, under Double Summer Time, the household lighting energy savings ratio of the northern Japan regions is higher compared to the southern region. However, under Summer Time, the energy saving ratio of the southern Japan region is significantly higher.

(4) There is no distinctive variation in terms of household lighting energy consumption among different household patterns.

Although this study has effectively highlighted the energy savings potential of the Summer Time concept, it must also be noted that there are some limitations in this study. In this study, fixed life schedules and household lighting consumption rates were applied in the calculations. Also, building design was generalized in this study. In terms of lifestyle, only life schedule
was taken into consideration, while other intangible personal lifestyles such as personal preferences on brightness, type of lighting and energy saving consciousness were not included in this stage of study. The above-mentioned limitations will be improved in the subsequent stages of study.

In most of the previous studies on household energy consumption, questionnaire surveys and long-term on-site monitoring methods were commonly used. Although those methods may produce better accuracy of data, the disadvantages are that they are costly and time consuming. Thus, this study sought to estimate household lighting energy consumption using the existing life schedule data, which is cost and time efficient. Also, in this study, the main purpose was to understand the energy consumption trend rather than to calculate the exact energy consumption rates. Hence, the results are deemed sufficient to illustrate possible trends in household lighting energy consumption should Summer Time/Double Summer Time be observed in Japan.

It must also be noted that this study focused solely on domestic lighting and did not include other impacts that might result from the time changes. Hence, this paper should not be used as a sole reference for evaluating the appropriateness of Summer Time implementation in Japan.

On the whole, despite many researchers arguing that Summer Time may result in health, social, economic and other issues as well as ineffectiveness in energy saving (some of the issues are discussed in Hecq et al. 1993, Rock 1997, and Lahti et al. 2006), the results of this study concluded that the implementation of Summer Time/Double Summer Time does have significant energy saving potential in terms of household lighting in Japan.

With increased awareness concerning environmental conservation, various efforts have been taken to ensure sustainable development and use of resources. In this respect, energy efficiency is one of the very important aspects being seriously taken into consideration in various aspects of modern life in order to ensure sustainable use of energy resources. Nowadays, various technologies and measures have been implemented to reduce energy consumption while maintaining the quality of life. However, the research and development of these energy saving technologies requires huge long-term capital investments. As an alternative, in the long term, change of lifestyle can also have significant effects on energy savings, as advocated in the authors' previous studies (Fong et al. 2007a, 2007b, 2007c). The important point is that change of lifestyle does not incur cost as compared to other measures such as technology development that require huge capital investments. Under the Summer Time concept, we 'change' our lifestyles by waking up 'earlier' and going to bed 'earlier' in accordance with the earlier sunrise and sunset times during the period of mid-spring to mid-autumn, in order to save energy. This study indicated that the Summer Time concept can significantly reduce household energy consumption, from the perspective of household lighting energy.

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