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Model Analysis of the Impact of Increased Time at Home on Household Energy Consumption: A Japanese Case Study during the COVID-19 Lockdown

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ABSTRACT

The emergence of the COVID-19 (coronavirus disease of 2019) pandemic in 2020 and the ensuing state of emergency issued by the Japanese government, which enforced from April 6 to May 25, 2020, changed our collective lifestyle dramatically. An increase in time spent at home resulted in a change in the structure of energy consumption. This study aimed to estimate the change in energy consumption at home during and after the state of emergency in Kobe, Japan. Six types of household energy consumption models were created based on the age of the head of household, the number of household members, and the usage time, and energy consumption of consumer durables were estimated for each model type. The results of the model analysis revealed that energy consumption during and after the state of emergency increased by 4.2% and 3.7%, respectively, compared to consumption before the state of emergency.

KEYWORDS

COVID-19, model analysis, household energy consumption, increased time at home, state of emergency, remote working

INTRODUCTION

COVID-19 (coronavirus disease of 2019) is a highly infectious virus that, in rare cases, causes serious respiratory illness. As of September 26, 2021, there had been 230.42 million confirmed cases of infection and 4.72 million deaths worldwide [1] . In Japan, there had been 1.69 million confirmed cases and 17,375 deaths [1]. The initial outbreak of COVID-19 in Japan followed the first confirmed case on January 14, 2020. The national government issued a state of emergency from April 7 to May 25, 2020 to slow The state of emergency was first issued locally, targeting specific areas with large numbers of infected people before gradually becoming a nationwide measure. During the state of emergency, non-essential activities were limited and city functions were shut down to achieve the national goal of "reducing persons' contact opportunities by 80%" [2]. Lifestyle changes were also proposed by the national

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government to prevent the spread of infection, such as avoiding the "three Cs" (crowded places, close-contact settings, and confined and enclosed spaces) [2]. Strong promotion of remote working and rotational shifts was required to achieve the national goal of " reducing the number of employees working physically at workplaces by 70%" [2]. Under these circumstances and thanks to the efforts of the government, businesses, and the public, the number of infected people has decreased. Finally, the state of emergency was lifted until May 25, 2020. The country experienced a second COVID-19 outbreak in August 2020 and a third wave of cases in November 2020, which was ongoing as of February 9, 2021, at the time of writing. The number of infected people is expected to gradually reduce while continuing to fluctuate incrementally.

The time spent at home increased significantly with the state of emergency, largely due to remote working. According to a questionnaire survey conducted by Values Inc. [3] in August 2020, approximately 70% of respondents answered that their time at home increased after the first COVID-19 outbreak when compared to their situation in February 2020. In another questionnaire survey conducted by Persol Research and Consulting Co. [4] in November 2020, many respondents answered that they continued to work remotely even after the end of the initial state of emergency. These reports suggest that the lifestyle changes brought about by the state of emergency persist even after its declared end. The remote working had been promoted by the national government as part of measures for climate change mitigation even before the COVID-19 pandemic. This is because the introduction of remote working might reduce electric power consumption by 14% per person [5]. However, working in an office setting was common in Japan and remote working was not widespread in most companies.

Remote working may increase not only working hours but also time spent conducting various home activities, e.g., cooking or watching television, due to the elimination of commuting time. These activities often involve the use of consumer durables including computers, televisions, and room lighting that results in an increase in energy consumption. Taking these factors into consideration, examining how increased time spent at home through remote working affects energy consumption is difficult unless changes to the population's home lifestyle are also taken into account. However, the aforementioned estimation by the Japan Ministry of the Environment [5] only estimates work-related power-consumption changes and does not consider changes in other home activities.

This study aims to clarify the impact of the increase in time spent at home on energy consumption at home as a result of the COVID-19 pandemic. This study takes Kobe city as a case study, estimating daily household energy consumption rates based on changes in lifestyle and daily routine before and after the initial state of emergency. Kobe's population was approximately 1.52 million in 2020 [6]. In Kobe city, there had been 26,725 confirmed cases and 607 deaths [7] as of September 26, 2021. The city's first state of emergency was enforced between April 7 and May 14. At the beginning of the state of emergency, there were about 68 confirmed cases, which the increase rate of confirmed cases was 21% [7]. Near the end of the state of emergency, the number of confirmed cases was close to 280, but the rate of increase in confirmed cases decreased up to 0.7% [7]. Ideally, data that directly measure household energy consumption, e.g., power consumption, would be useful for a study of this nature. However, given that sufficient actual measurement data were not available as of February 2021 when this paper was written, this study created household models considering the age of the head of household, the number of household members, the total floor area, the number of consumer durables possessed and their usage time to estimate the energy consumption.

To date, there have been several studies on COVID-19 and energy consumption. Bahmanyar et al. [8] indicates that different lockdown measures in European countries and their effects on population activities have considerably changed the consumption profiles. Javier and Sungmin [9] indicates that the cumulative decline in electricity consumption within the 5 months following the stay-home orders ranges between 3% and 12% in the most affected EU countries and USA states, except Florida. Kawka and Cetin [10] indicated that increased electricity use during periods that occupants would usually be away from home by the COVID-19 pandemic in the United States. Abdeen et al. [11] indicated that average household daily electricity consumption increased by about 12% in 2020 relative to 2019 in Ottawa, Canada. Rouleau and Gosselin [12] confirmed that overall household energy consumption increased according to the COVID-19 lockdown measures in Quebec City, Canada. Wang et al. [13] conducted simulation approach to investigate electricity consumption according to the COVID-19 outbreak in China. Kang et al. [14] indicated that the energy consumption in most facilities has tended to decrease while energy consumption in residential facilities increased during COVID-19 in South Korea. Jiang et al. [15]discusses that the pandemic situation offers five energy opportunities for better future development related energy: enhancement of digitalisation, new lifestyles with lower energy usage, resilience enhancement with Circular Economy, opportunities for renewables and energy storage, and fighting infectious diseases and saving energy. Beyer et al. [16] also discusses that without effectively reducing the risk of a COVID-19 infection, voluntary reductions of mobility will hence prevent a return to full economic potential even when restrictions are relaxed. Santiago et al. [17] conducted a detailed analysis of how confinement measures for the COVID-19 have modified the electricity consumption in Spain. Bienvenido-Huertas [18] also analyses the effectiveness of unemployment benefits and social measures for unemployed according to serious economic crisis induced by the COVID-19 in Spain. Mokhatari and Jahangir [19] built a model of a university building that minimizes population density (energy consumption) and the infection risk of COVID-19. Jiang et al. [15] provided an overview of changes in energy supply and demand around the world due to the COVID-19 pandemic and proposed how energy should be utilized after its conclusion. Cihan [20] examines how the lockdowns during the COVID-19 pandemic affected the amount of electricity and natural gas consumption in four organized industrial zones in the Turkey. Hartono et al. [21] assesses how the COVID-19 and its stimulus policy will affect the macroeconomic indicator, energy consumption, and emissions at the national and regional levels in Indonesia using a computable general equilibrium model. The present study focused on a smaller scale, estimating the impacts of changes in working and lifestyle behaviors at home associated with COVID-19 on energy consumption. This study provides a novel perspective by clarifying the impacts of COVID-19-related measures such as remote working on household energy consumption

METHODS

Figure 1 shows the steps used in this study to estimate the household energy consumption. First, six types of household models were created by relating the number of consumer durables to the age group of the head of household, household floor area, and number of individuals. Second, an estimation of daily household energy consumption for each household model type was obtained using estimated daily routine time at home and, with it, estimated usage time of consumer durables, both before and after the state of emergency. Finally, the daily household energy consumption of Kobe was estimated as a whole.

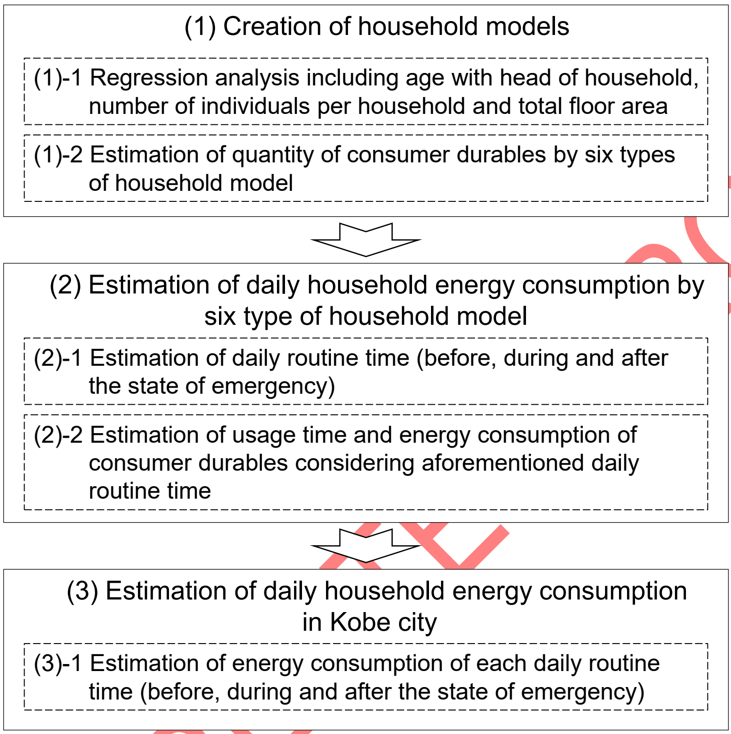

Figure 1. Study methodology

Household models

This study assumed that factors for the household models consisted of the number of individuals per household, the age of the head of household, and the total floor area. These factors contribute to estimations of the number of consumer durables possessed by each household model and their usage time that are necessary for estimating household energy consumption. The number of individuals per household, considering the age group of heads of household and total floor area, were adopted from the data listed in the national statistics [22]. This study classified the household models into six types based on the age of the head of household (24 years and under, 25–34 years, 35–44 years, 45–54 years, 55–64 years, and 65 years and over). A regression analysis was conducted to estimate the number of consumer durables possessed by each household model. Then the total floor area was set as the objective variable. The age and number of individuals per household, along with the age of each head of household, were set as explanatory variables.

Table 1 targets consumer durables. This table contains 35 different types of consumer durable products that were selected based on Inaba et al. [23]. The quantity of the consumer durables possessed by total floor area was also estimated based on results from the questionnaire on energy use conducted by Inaba et al. [23].

Table 1. Target consumer durables

Household equipment (10 types)	Induction heat (IH) cooking heater, toilet with warm flushing water, floor heater (electric, electric hot water, and gas hot water), electric water boiler, gas water boiler, oil water boiler, central heating and cooling, built-in stovetop
Household durables (18 types)	Microwave oven, rice cooker, refrigerator (<300 L and ≥300 L), clothes washer (combination washer/dryer, drum type, automatic, twin tub, etc.), vacuum cleaner, dishwasher, air conditioner (<21.9 m^2 and ≥21.9 m^2), heater (electric, city gas, liquid petroleum gas (LPG), oil burning, etc.), *kotatsu* (under-the-table heater), air purifier, central air conditioner
Indoor devices and decorative items (4 types)	Fluorescent lighting, light-emitting diode (LED) ceiling lighting, incandescent lighting, fluorescent light bulb
Educational and recreational durables (3 types)	Television, personal computer, video recorder

Household energy consumption by each household model

The daily household energy consumption of the six types of household models was estimated using the following formula:

$$E = \sum_{x} (C_x \times P_x \times U_x \times J_x) \quad (1)$$

where E is household energy consumption per household [MJ/household], C is the unit of energy consumption of the consumer durables [kWh/unit, L/h/unit], P is the quantity of consumer durables [unit/household], U is the usage time of the consumer durables per household [h/unit], J is the secondary energy conversion [MJ], and x is the type of consumer durable.

The unit of energy consumption of consumer durables was adopted from the results of Inaba et al. [23]. The amount of time spent at home before and after the state of emergency was specified as follows:

Daily routine time before the state of emergency. The amount of time spent at home for each age group before the state of emergency was adopted from a NHK Broadcasting Culture Research Institute [24] survey report. This questionnaire survey divided one day into 15-minute intervals, categorized how each time interval was spent into one of 28 categories, and measured the findings against respondents' age groups.

Daily routine time during the state of emergency. The rate of change of daily routine time at home before and during the state of emergency was calculated based on a questionnaire survey conducted by the Japan Ministry of Land, Infrastructure, Transport and Tourism [25] in August 2020, as shown in Table 2

. This survey asked respondents about changes in their daily routine time that occurred as the state of emergency came into effect. Respondents into remote workers and non-workers were also classified. The total daily routine time did not reach 24 hours because some daily routines, such as going outside, were excluded. The daily routine time under the state of emergency was calculated by multiplying the daily routine time before the state of emergency by the rate of change indicated in Table 2.

. In this survey, workers and students were classified as remote workers and homemakers were classified as non-workers.

Table 2. Daily routine time at home before and during the state of emergency

	Remote workers			Non-workers (homemakers, etc.)		
	(1) Before the state of emergency [h]	(2) During the state of emergency [h]	Rate of change ((2)/(1)) [–]	(3) Before the state of emergency [h]	(4) During the state of emergency [h]	Rate of change ((4)/(3)) [–]
Sleep	7.5	7.9	1.05	8	8.2	1.02
Eating	1.3	1.6	1.24	1.6	1.8	1.07
Work and education	3.1	6.6	2.12	0.4	0.6	1.48
Cooking, cleaning, etc.	1.6	1.9	1.16	3.5	3.7	1.05
Relaxing	3.2	4.2	1.29	7.8	8.4	1.08
Miscellaneous	0.15	0.20	1.27	0.280	0.282	1.01
Total	16.9	22.3	1.32	21.6	22.9	1.06

Source: [15]

Next, the consumer durables used for each routine were classified and daily usage time for each consumer durables was specified based on the daily routine time. For example, the routine "work and education" was set for remote working and online lessons with PCs and lighting listed as consumer durables. This study assumed that no remote working and online lessons were conducted at home before the state of emergency, setting the usage time as 0 hours. This study assumed that daily routine time for working and education determined the usage time of the PCs. In the case of a multi-person household, this study was assumed that there were several PCs present with a PC used by one parent for remote working and by one child for online lessons.

This study assumed that no heating equipment was used during the emergency. This is because the average daily temperature in Kobe city during this period never fell below 10°C and the number of days heating was used was set to 0 days. Based on this assumption, this study also assumed that no heating was used both before and after the state of emergency.

Household energy consumption in Kobe city

The daily household energy consumption in Kobe as a whole was estimated by multiplying the daily household energy consumption in each household model by the number of households in Kobe city. Table 3 shows the number of households in Kobe city, segregated by the age of the head of household. The households were divided into remote-working households and non-remote-working households, considering that not all households work remotely. The daily routine time before the state of emergency was applied for the remote-working households and the daily routine time during the state of emergency was applied for the non-remote-working households. Criteria for remote-working and non-remote-working households were obtained from the results of a Persol Research Institute [4] survey. According to this survey, the national average remote working implementation rate was 27.9% in April and 24.7% in November 2020. The November rate was considered in the estimation of household energy consumption after the state of emergency. This study assumed that heating was not used after the state of emergency.

Table 3. Number of households

Age group of head of household	Number of households	Age group of head of household	Number of households
24 years or under	32,364	45–54 years	113,841
25–34 years	70,324	55–64 years	111,113
35–44 years	108,207	65 years and above	253,818

Source: [6]

RESULTS AND DISCUSSION

The following equation was obtained by the multiple regression analysis:

$$Y = 0.967x_1 + 20.416x_2 - 21.0958 \quad (2)$$

where Y is the total floor area [m^2], x_1 is the age of the household head [years], and x_2 is the number of individuals per household [persons].

The modified multiple correlation coefficient, which represents how well objective variable can be predicted the equation, was 0.997, and the modified coefficient of determination, which objective variable is predictable from explanatory variables, was 0.994. The Durbin-Watson statistic, which is an indicator for whether the error term has autocorrelation, was 2.247. If this index is close to 2, the result is judged to have no autocorrelation. This result indicated that there was no autocorrelation. The t-value, which measures the size of the difference relative to the variation, was 2 or more for all variables, which was a significant result. Significance was observed at a level of 5% with p-values, which investigate the result of hypothesis testing, of less than 0.05 for all variables. The tolerance, which is an index for detecting multicollinearity between explanatory variables, was 0.1 or more. This result indicated that there was no multicollinearity between explanatory variables. Based on the above results, the regression equation was considered to be valid. Table 4 shows the six household model types that were created. The number of individuals per household was rounded to the nearest whole number. As there was, on average, only one person present where the head of household was aged 24 years or under, this type was set as a single-person household. As there were, on average, two people present for those aged 25–34 years, 55–64 years, and 65 years and above, these types were set as two-person households consisting of a couple, both the same age. Households with heads of households aged 35–44 years and 45–54 years had three members, with these types set as three-person households consisting of a couple of the same age and a teenaged child. The number of consumer durables possessed and their usage time in each household model were estimated.

Table 5 shows an example of the results regarding the quantity and usage time of the main consumer durables. The usage time of PCs during the state of emergency was considerably long, reflecting an increase in remote working and online lessons.

Table 4. The six types of household models

Age group of head of household	Number of individuals per household	Total floor area [m^2]
24 years or under	1	27.01
25–34 years	2	50.05
35–44 years	3	77.11
45–54 years	3	83.91
55–64 years	2	87.44
65 years and above	2	86.34

Table 5. Quantity and usage time of main consumer durables

			Electric water boiler	Vacuum cleaner	Television	Personal computer
Rated power consumption [W]			3,422	550	90	16.84
24 years or under	Quantity (mean) [items]		0.33	1.12	1.10	1.33
	Daily usage time	Before the state of emergency	22min	1min	1hr37min	0min
		During the state of emergency	25min	1min	2hr5min	6hr1min
25–34 years	Quantity (mean) [items]		0.26	1.32	1.57	1.69
	Daily usage time	Before the state of emergency	51min	4min	2hr11min	0min
		During the state of emergency	58min	4min	2hr48min	11hr41min
35–44 years	Quantity (mean) [items]		0.22	1.36	1.73	1.90
	Daily usage time	Before the state of emergency	1hr17min	11min	2hr37min	0min
		During the state of emergency	1hr28min	12min	3hr22min	17hr39min
45–54 years	Quantity (mean) [items]		0.34	1.41	1.90	1.80
	Daily usage time	Before the state of emergency	1hr17min	16min	3hr	0min
		During the state of emergency	1hr28min	18min	3hr52min	17hr34min
55–64 years	Quantity (mean) [items]		0.34	1.41	1.90	1.80
	Daily usage time	Before the state of emergency	1hr17min	16min	3hr	0min
		During the state of emergency	1hr28min	18min	3hr52min	17hr34min
65 years and above	Quantity (mean) [items]		0.34	1.41	1.90	1.80
	Daily usage time	Before the state of emergency	47min	20min	4hr21min	0min
		During the state of emergency	54min	23min	5hr36min	5hr27min

Table 6 and Figure 2 show the results of daily household energy consumption for each household model. This graph expresses the rate of change after the state of emergency, with consumption before the state of emergency set at 100%. The results revealed that daily household energy consumption increased with changes in daily routine time for all age groups. According to the results, the age groups with a larger number of individuals per household consumed more energy, excepting the result of 25–34 years. The lowest rate of change for 24 years or under age group is presumed that they have only one resident and spend less time using PC and lighting. The highest rate of change for 25–34 years age group is presumed that they have two residents using PCs and lights for extended periods of time for teleworking. The rate of change in the 65-and-above age group was slightly lower than that of the 55–64 group. This may be because residents in the former age group are likely to be retired and thus may have had a higher level of home activity before the state of emergency than other age groups. However, aforementioned rate of change in daily household energy consumption between before the state of emergency and during the state of emergency was 14 to 17% in all age groups, which was not a big change. The reason for this result is the assumption that there is no energy consumption of cooling or heating because the declaration of first state of emergency was implemented in the spring season. The second and subsequent emergency declarations had implemented in the winter and summer seasons, and to analyse the impact of stay homes in these seasons is the future task.

Table 6. Daily household energy consumption by each household model

Age group of head of household	Before the state of emergency [MJ/household]	During the state of emergency [MJ/household]	Rate of change
24 years or under	1	27.01	110.8 %
25–34 years	2	50.05	118.0 %
35–44 years	3	77.11	116.7 %
45–54 years	3	83.91	115.9 %
55–64 years	2	87.44	115.9 %
65 years and above	2	86.34	115.5 %

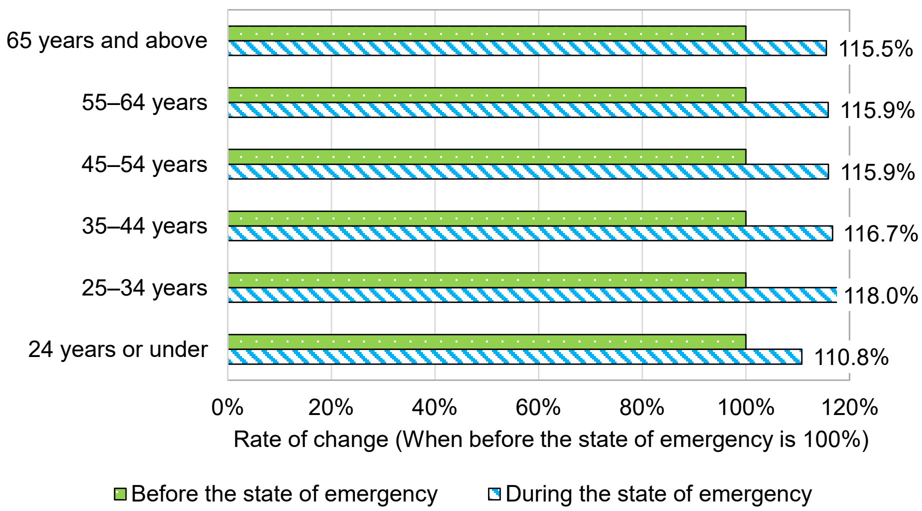

Figure 2. Daily household energy consumption by each household model

Figure 3 shows the results of the breakdown of daily household energy consumption by dividing it into domestic hot water, kitchen use, appliances, and lighting. In all age groups, the energy consumption associated with domestic hot water exceeded 80% of the total, with no significant change in this figure once the state of emergency was declared. The major changes in consumption were related to appliances and lighting, which may have been due to an increase in remote working. Another possible reason is that the excess time spent watching television and cleaning rooms using vacuum cleaners contributed to the increase in consumption.

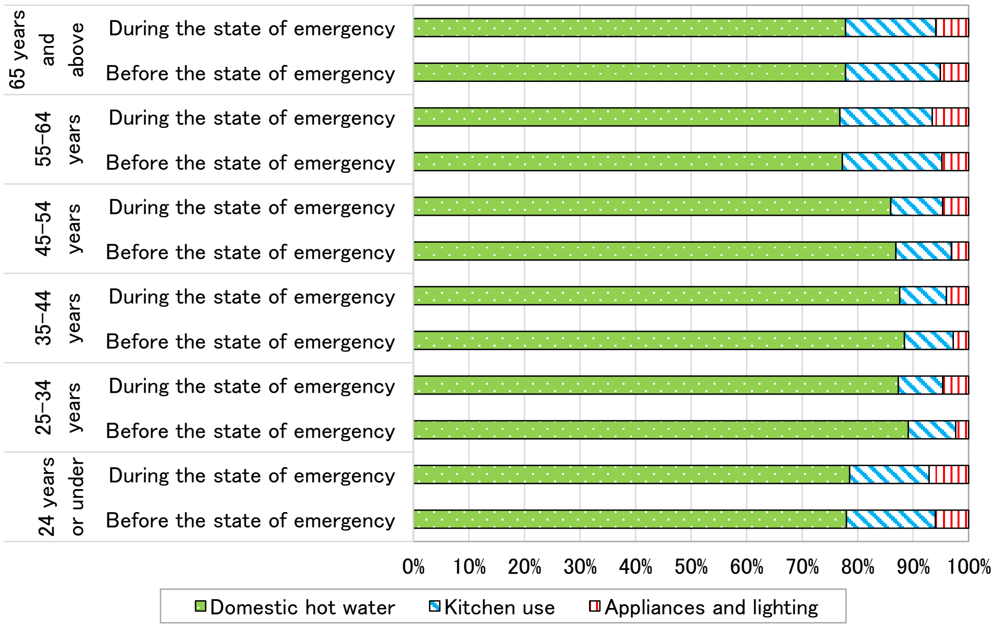

Figure 3. Breakdown of daily household energy consumption by household models

Figure 4 shows the results of the total daily household energy consumption in Kobe city using the household models. Considering that Kobe citizens keep the same activity during the different seasons, the results revealed that the total household energy consumption increased by 4.2% during the state of emergency when compared with consumption before the state of emergency. Even after the state of emergency had ended, the total household energy consumption still increased by 3.7% when compared with consumption prior to the state of emergency. The same results were obtained for each age group. Following the implementation of remote working, office use decreased; thus a decrease in energy consumption in offices would be expected. However, in reality, even though the number of office workers decreased, offices were not completely unused as some functions of the office could not completely shut down. Nakanishi [26] supposed that, during and after the state of emergency, office lighting and air conditioning were often left on, leading to only a small decrease in the energy consumption of the office basing on a results of survey for household energy consumption of teleworking. The results of this study also indicated that household energy consumption increased as a result of the lifestyle changes derived from more time spent at home. In addition to remote working, other activities may also have contributed to the increase in household energy consumption. In some cases, the implementation of remote working during the state of emergency might increase energy consumption in society as a whole.

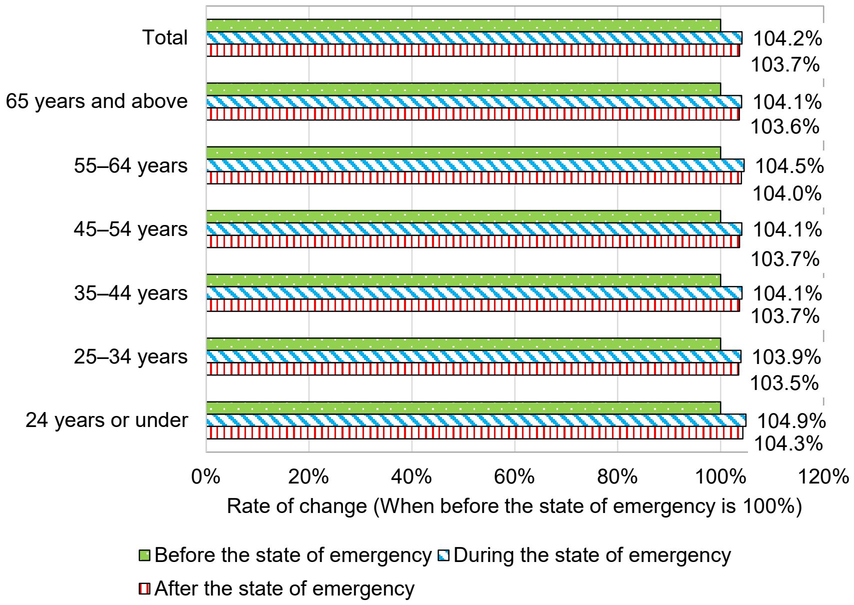

Figure 4. Daily household energy consumption by household models in Kobe city

The validity of the results was discussed. The daily household energy consumption of Kobe city [27] was 51.84 TJ in 2018. The result obtained from this study was 82.22 TJ, which is 1.6 times larger than the result of Kobe city. One of the reasons for this overestimation is that there are overlapping times in living time and usage time of consumer durables depending on the number of residents. The report for the amount of time spent at home for each age group that this study adopted, this time has overlapping time in the form of eating while watching TV. The time might be duplicated due to the simultaneous use of consumer durables and sharing within the home. And the calculation result might be become excessive. Another reason is that the household models created in this study simplifies the age group into 6 categories. However, the actual home structure is complicated, and the models might not fully express the actual structure. Improvement of the models is required. According to the results released by Jyukankyo Research Institute, Inc. [28] in November 2020, the national household energy consumption in the period from July to September 2020 increased by 3.7% compared with the previous year. Although overall household energy consumption was overestimate, increasing rate of household energy consumption of the present study was similar to the aforementioned report. Therefore, this study assumes that appropriate results can be obtained using household models.

CONCLUSION

This study clarified the impact of changes in lifestyle at home due to the state of emergency implemented against the COVID-19 outbreak on household energy consumption in Kobe city. The results revealed that household energy consumption increased by 4.2% due to increases in daily household routines, including remote working, cooking, and relaxing. This study also revealed that household energy consumption did not return to a normal level even after the state of emergency had ended.

The national government had issued three state of emergency in the target area including Kobe City after the first state of emergency as of September 26, 2021. The national government has been planning subsidies to promote remote working as part of measures against COVID-19 [29]. These measures make remote working mandatory for not only large companies but also small and medium-sized companies. However, such subsidies only guarantee the introduction of Internet communication technology equipment. This study does not assume a reduction in energy consumption in offices and homes through remote working. Continuing to live in an environment influenced by COVID-19 might require long-term efforts, not only to prevent the spread of infection but also to control energy consumption in offices and homes.

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