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Environmental Impact of Telework with Direct Uses of Geothermal Heat: A Case Study of Naruko Area

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ABSTRACT

Geothermal potential area in Japan has been depopulated recently, while most energy consumers living in urban areas and there have been distances between the geothermal potentials and the energy consumers. Since 2020, working from home (home-based telework) has spread rapidly due to the influence of the COVID-19. If some of the energy consumers work from a hot-spring area, which is high geothermal potential area, it would help to reduce the extra fossil fuel consumption, to reduce the environmental impact, and to save commuting costs and time. In this study, we quantitatively evaluated the advantages and feasibility of working from hot-spring area: Naruko area, Osaki City, Miyagi Prefecture, as a case study. The environmental effects were analyzed by using the annual CO_2 emissions and the costs, based on the life-cycle assessments with four scenario conditions ((a)base system, (b)home-based telework in a city, (c) (d) telework in a hot spring area using hot spring only for bathing and using hot spring for bathing and heating). Compared to the base system, the use of public baths in the hot springs can reduce CO_2 emissions by about 1/3, and the use of bathing and heating by hot springs can reduce CO_2 emissions by about 1/4. We expect that each of urban workers, companies, and onsen areas will change their awareness and take actions to be able to stay in the onsen area for a mid- to long-term.

1. INTRODUCTION

In Japan, the population of Japan has been concentrated in large cities, including Tokyo since 1970s, while other areas have declined the population. This population polarization may increase the risk of disasters and infectious diseases in urban areas and affects the maintenance and survival of local communities in rural areas. It would also have significant adverse effects on the utilization of geothermal resources. In the case of direct use of heat, which cannot be transported as far as electricity, the heat must be locally produced near the resource. However, the number of energy consumers living in areas with geothermal resources is decreasing in Japan, and they are losing the opportunity to use the geothermal resources directly as heat. Instead, in Iceland, for example, hot water is supplied to each household from nearby geothermal areas (transport distance is about 18 km for low temperature and 27 km for high temperature) in the capital city Reykjavik (Zuquim and Doorman, 2020), and about 90% of the energy used for heating in the country can be provided by geothermal resources (Shortall and Kharrazi, 2017). Since most of the electricity consumed by households is used as heat for heating and hot water supply, energy consumers can actively utilize geothermal resources by living and working in areas close to geothermal resources.

Since January 2020, the spread of the new coronavirus has triggered a rethinking of the conventional lifestyle of people living in densely populated cities. The term "work from home" or "telework" is a generic term for a variety of work styles, including work at home and work during traveling in various locations (Ministry of Internal Affairs and Communications, website). Telework has been promoted by various ministries and agencies since around 2013 in Japan, and as a countermeasure against the new coronavirus infection, meetings and classes have been moved online, and working without being restricted by one's place of residence has come to be accepted by society. If people who live in urban areas to work can stay in highly potential area for geothermal resources, such as hot springs, there is a possibility of increasing opportunities to directly use geothermal resources as heat. As a result, the utilization rate of geothermal resources can be increased, the electricity consumption used for heat supply can be reduced, the current excess fossil fuel consumption can be reduced, and the environmental load can be reduced.

Life cycle assessment (LCA) has been used in various fields as one of the evaluation methods to quantitatively analyze environmental impacts (Guinée et al., 2011; Finnveden et al., 2009). In the development of renewable energy, where sustainability is an advantage, the application of LCA can show the advantages over existing energy sources and the potential for deployment (Singh, 2013). For example, Ikegami et al. (2009) verified the CO_2 reduction effect and cost effect of hot spring wastewater heat utilization and proposed an effective introduction method of hot spring wastewater heat utilization. Fujiwara et al. (2011) estimated the CO_2 emissions and cost effectiveness of hot spring heating equipment using boilers and showed the possibility of introducing hot spring wastewater heat utilization to greenhouse cultivation. However, among these existing studies, the LCA for hot spring heat use was conducted for a hot spring business considering the introduction of hot spring heat use, and the CO_2 reduction effect and cost effect focusing on the lifestyle of energy consumers were not evaluated.

On the other hand, Morimoto et al. (2009) evaluated the effect of teleconferencing on reducing the environmental impact of telework. They compared teleconferencing with conventional long-distance travel and found that teleconferencing resulted in higher CO_2. In addition, Muto et al. (2018) estimated the environmental load reduction effect of teleworking in summer in summer resort areas, showing the effectiveness of telework utilization depending on the season. However, no studies have been reported on these LCAs related to telework for the thermal use of hot spring heat.

In this study, we focused on the new lifestyle of workers, "telework in hot spring area", as a new possibility to promote the direct use of geothermal resources and analyzed and evaluated the effect of telework in hot spring area on the environmental load by energy consumers. In this paper, we conducted a life cycle assessment (LCA) of the Naruko area in Osaki City, Miyagi Prefecture, as a study case of a hot spring area, and evaluated the quantitative CO_2 reduction effect and cost effect. In addition, a new way of staying in the hot spring area for energy consumers was discussed from the viewpoint of environmental load. The significance of this study is that it provides an opportunity for consumers to make conscious choices about environmental and social sustainability.

2. EVALUATION METHOD

2.1 Setting of the system to be evaluated

In this study, we compared four systems, focusing on transportation, bathing, and air conditioning, which are expected to change as a result of telework in the hot spring area. The comparison of the four systems is shown in Figure 1.

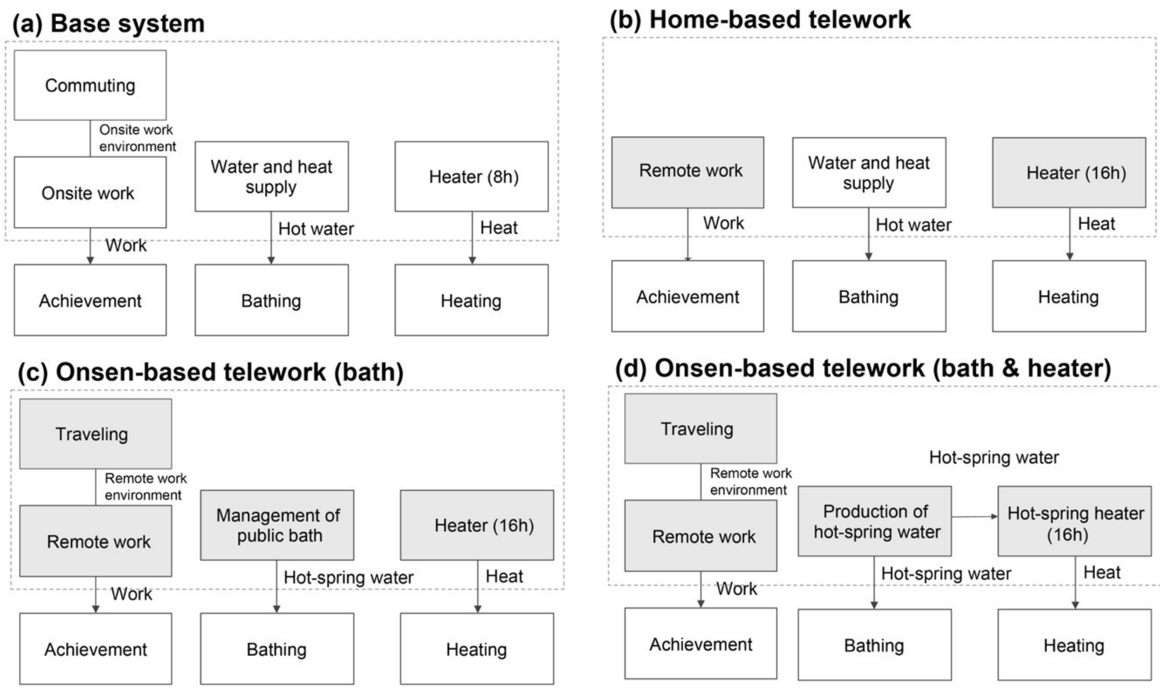

Fig. 1 System comparison. The items colored in gray indicate ones that differ from the basic system.

The first is a lifestyle in which people are based in urban areas and commute to their workplaces, which is referred to as the basic system. Figure 1a shows the basic system. A single person living in a rented house in an urban area, commuting to the place of work, and working at the place of work is assumed. For bathing, a shower heated by gas is used, and air conditioning is provided by an air conditioner. On the other hand, the case in which a worker stays in a hot spring area instead of living in an urban area and teleworks in the hot spring area is called "hot spring telework". By staying in the hot spring area, the heat needed for bathing and heating can be supplied by the hot spring heat. At present, there are no rental houses in hot spring areas that are equipped with hot spring heaters. Therefore, in order to telework in the hot spring area using the existing facilities, we considered the possibility of two types of stay. One is the case where a single person stays in a rented house and uses a public bathhouse for bathing, and the other is the case where a person stays at a hot spring inn. The former is called "Hot-Spring Telework (Bathing)", and the latter is called "Hot-spring Telework (Bathing & Heating)". These systems are shown in Figure 1c and Figure 1d. For the sake of comparison, we assume that the teleworker lives in an urban area, but does not commute, and works at home. The system of home telework is shown in Figure 1b. In this case, the commuting included in the basic system is eliminated.

For all systems, the period covered is one year, and the subjects were per single person, working five days a week on weekdays. In the case of telework in the hot spring area, the travel from the urban area to the hot spring area is taken into account, and the round trip to the hot spring area at the beginning and end of the year is included. The impact during the construction of the equipment is uniformly distributed over the operational period of the equipment, i.e., the useful life of the equipment (20 years) as assumed by the operator.

We assume that the daily time allocation is working time for 8 hours, sleeping time for 8 hours, and other activities for 8 hours per day. The air-conditioning system is used during other activities (8 hours) in the case of the basic system. In the other cases, heater is used for 16 hours, including working hours and other activities. Bathing is assumed to be once a day. The conventional commuting time is not taken into account. In reality, it is thought that the commuting time reduces the amount of time for sleep and other activities.

2.2 Selection of the model area

It is necessary to obtain energy demand and cost data from the owners of facilities equipped with geothermal facilities for bathing and heating. In this study, Naruko area in Miyagi Prefecture was selected as a model area from among several candidate areas, where cooperation was obtained for this study.

Naruko area is located in Osaki City, Miyagi Prefecture and consists of five hot springs: Naruko Onsen, Higashi-Naruko Onsen, Kawatabi Onsen, Nakayamadaira Onsen, and Onikobe Onsen. The Naruko area is characterized by a wide variety of spring qualities (7 out of 10 listed springs), a large number of spring wells (about 370 wells in total), and an abundant amount of spring water (about 2,600 L/min) (Ministry of the Environment, 2016). There are active volcanoes of the Naruko Volcano Group, and there are many steam springs with temperatures exceeding 100 °C, resulting in a high geothermal reserve. There are a number of public bathhouses, public facilities with heating systems (Nakayamadaira Community Center), and ryokan (Japanese style inns) that use hot spring heat. They use hot springs not only for tourism (bathing) but also by residents on a daily basis.

There are four JR stations in the Naruko area, and the area is highly convenient for transportation in the Tohoku region, so it is expected to be a suitable place for telework and work vacation. As demonstration experiments have already been conducted, interest in telework in hot spring areas is increasing in the Naruko area, and it is considered to be a good model area for this study.

In this study, the Naruko area was selected as the hot spring area, and information on the input to and output from each process was collected from field surveys. In addition, we selected the Tokyo metropolitan area as the urban area and used published average data.

2.3 Input and output data of each process

The following table shows the details of the input and output information for each process that constitutes the four systems used in this study. The CO_2 emission intensity of each process is summarized in Table 1.

2.3.1 Work

The daily working hours were set to 8 hours in all cases so that the results produced by the base system conventional type and telework would be similar. In addition, it was assumed that the PC and lighting would be used even when working at the work site. The power consumption of the PC was set to 0.1 kWh (THIRDWAVE CORP., 2016), and the PC was assumed to be used 8 hours a day, 5 days a week. The power consumption of lighting was assumed to be 0.075 kWh, assuming an 8-mat room (PR TIMES, 2000). CO_2 emissions were calculated using the CO_2 emissions intensity of electricity. The electricity price was calculated by multiplying the unit price of the electricity volume charge and the unit price of the renewable energy power generation promotion levy by the amount of electricity used.

2.3.2 Commuting

This refers to the round trip from home to work in the conventional base system. We focused on commuting, and used 239 weekday commuting days in 2019. We selected 11 locations in the Tokyo metropolitan area: Toride City, Saitama City, Tokorozawa City, Chiba City, Matsudo City, the 23 wards of Tokyo, Ome City, Inagi City, Yokohama City, Kawasaki City, and Odawara City, and multiplied the average commuting distance and the ratio of commuting modes (train, bus, car, and motorcycle) in each city (Ministry of Land, Infrastructure, Transport and Tourism, website) to calculate the CO_2 emissions. The cost of commuting was calculated based on the distance of JR East's standard passenger fare, assuming that the mode of transportation was the train (JR East, website).

2.3.3 Round trip between urban area and hot spring area

This refers to the round trip between the urban area (Tokyo metropolitan area) and the hot spring area (Naruko area). The distance is assumed to be from JR Tokyo Station to JR Naruko Onsen Station; the distance from JR Tokyo Station to JR Furukawa Station is assumed to be by Shinkansen, and the distance from JR Furukawa Station to JR Naruko Onsen Station is assumed to be by train. The CO_2 emission was calculated from the CO_2 emission unit of JR East. The fare for the trip was calculated based on the distance from JR East's normal passenger fare (JR East, website).

2.3.4 Air conditioning

For the power consumption of air conditioners, Ono et al. (2017) statistically analyzed the relationship between temperature and power consumption of air conditioners in large multi-dwelling units, and in this study, using Ono et al. (2017) as a reference from the data, the following approximate equation (1) was roughly calculated from the plot of daily average temperature T and measured daily power consumption E

$$E = 0.0004T^4 - 0.016T^3 + 0.2695T^2 - 4.3563T + 40.352 \tag{1}$$

If E is less than or equal to zero in the above equation, then $E = 0$ was used. This equation takes into account the effects of both cooling and heating. In the analytical analysis, data for urban areas were used to represent temperatures in Tokyo, as published by the Japan

Meteorological Agency. As for the hot spring area, we calculated the monthly electricity consumption by substituting the monthly average temperature (Japan Meteorological Agency, website) of Kawatabi, which represents the Naruko area.

In the case of teleworks, the total time for air conditioning and heating use was 16 hours, including working hours and other activities. Therefore, the amount of electricity consumed by air conditioning and heating in telework was calculated by doubling the amount of electricity.

The data for hot spring inns were calculated based on an interview survey with "Ryokan Sugawara", which uses hot spring heaters. Ryokan Sugawara has its own 140 °C hot spring. In order to operate the hot spring heaters, electricity is required for the pumps that circulate the hot water in the building and for the radiators that supply the heat-exchanged air to the rooms. From the results of the interview survey, it was assumed that the power consumption standard of the heating pump was 5.5 kW, the power consumption standard of the radiator was 11 W per unit, and the number of units in the building was 30. The pump is used from November to March, and it is assumed that the pump is used for 16 hours per day as in urban telework. The direct and indirect CO_2 emissions associated with the manufacturing and operation of the hot spring thermal heating equipment were estimated for the equipment of "Ryokan Sugawara" by referring to the cost information of Owani Town (2011) and the Industrial Promotion Bureau of the Hokkaido Economic Department (2017). Specifically, we assumed that the equipment manufacturing cost was 60 million yen, the annual electricity cost was 700,000 yen, and the annual maintenance cost was 1.2 million yen (including the maintenance of the entire hot spring facility). Using this cost information, we estimated the direct and indirect CO_2 emissions per unit of production value as described in the Environmental Impact Intensity Data Book of the Input-Output Table prepared by the National Institute for Environmental Studies (website). CO_2 emissions from electricity use were estimated separately using the emission intensity of Tohoku Electric Power Company in order to reflect regional characteristics. These estimated annual emissions were divided by the annual number of customers (7,000) to obtain the annual per capita electricity consumption for heating. The monthly average temperature of the Naruko area was substituted into equation (1) to account for the use of air conditioners during the summer as well as to align the base system with the conventional system, and the CO_2 emissions and electricity charges for cooling were also added.

2.3.5 Bathing

The frequency, shower time, and shower flow rate were calculated based on the questionnaire results of Hirose and Iio (2013), and the average shower time per family member living together was calculated. The average flow rate of the shower was calculated as follows. The average flow rate of the shower was assumed to be the optimal flow rate of 9.91 L/min (Negishi et al., 2014). The amount of water consumed by the bathing process was calculated by multiplying the average flow rate of the shower by the showering time. The calorific value of city gas was calculated as 10,750 kcal/m^3, and assuming that 90% of the energy of the gas is used to raise the temperature and prepare hot water at 45 °C, it was calculated as (45 - temperature) × water consumption × 90% / calorific value. The temperature was calculated as (45 - temperature) × water consumption × 90% ÷ calorific value, using the monthly average temperatures of Tokyo for urban areas and of Kawatabi, Miyagi Prefecture or Sendai City for hot spring areas (Japan Meteorological Agency, website). The CO_2 emissions were calculated from the CO_2 emission intensity of water supply and gas, respectively. For water supply, the amount of water consumption was multiplied by the taxable amount of metered charges.

The public baths were obtained by conducting an interview survey at the Kawatabi Public Bath in the Naruko area. The temperature of the source water at the Kawatabi Public Bath is 52.6 °C, and it is used without adding water. The annual electricity, water, and sewage charges for management and the number of users were investigated, and the annual per capita electricity and water charges were calculated. The amount of electricity used, the amount of water used, and the amount of sewage used were calculated backwards from the electricity and water rates, respectively, and the amount of CO_2 emissions was calculated from the CO_2 emission intensity of electricity, water, and sewage.

In the "Ryokan Sugawara", hot water supply, including that for showers, can be provided by the same system as that for hot spring heaters. Therefore, the amount of electricity used for management is included in the hot spring water heating system. The amount of sewerage used was the amount of sewerage used per person as calculated for the public baths.

2.3.6 Others

The cost of facilities related to buildings was recorded by including the average rent of rental housing in Tokyo, and the Naruko area. The average rent in the metropolitan area was set at 59,085 yen for a single person in 11 locations in the metropolitan area, and 25,000 yen in the Naruko area, based on the results of interviews. For hot spring inns, we assumed that the accommodation cost per night was 5,000 yen. In the case of teleworkers in the hot spring area, we assumed that the rental housing in the city would be cancelled, so we did not record the rent for the rental housing in the city but recorded the annual rent for the rental housing in the Naruko area or the accommodation cost at the hot spring ryokan as equipment costs.

3. RESULTS AND DISCUSSION

3.1 Annual CO_2 Emissions and Costs

Figure 2 shows the total annual CO_2 emissions and the associated costs for each system. In Figure 2a, in the basic system, the proportion of CO_2 emissions from the commuting process is high. The work process and bathing process have about the same CO_2 emissions. In the bathing process, 8.2 kg/year of CO_2 emissions are associated with water consumption and 155.3 kg/year of CO_2 emissions are associated with gas consumption, indicating that gas use emits a lot of CO_2. On the other hand, the CO_2 emissions from the air conditioning process were not so large compared to the other processes. It should be noted that the CO_2 emissions from the air conditioning process would be higher if we assume that oil stoves or electric stoves with high electricity consumption are used.

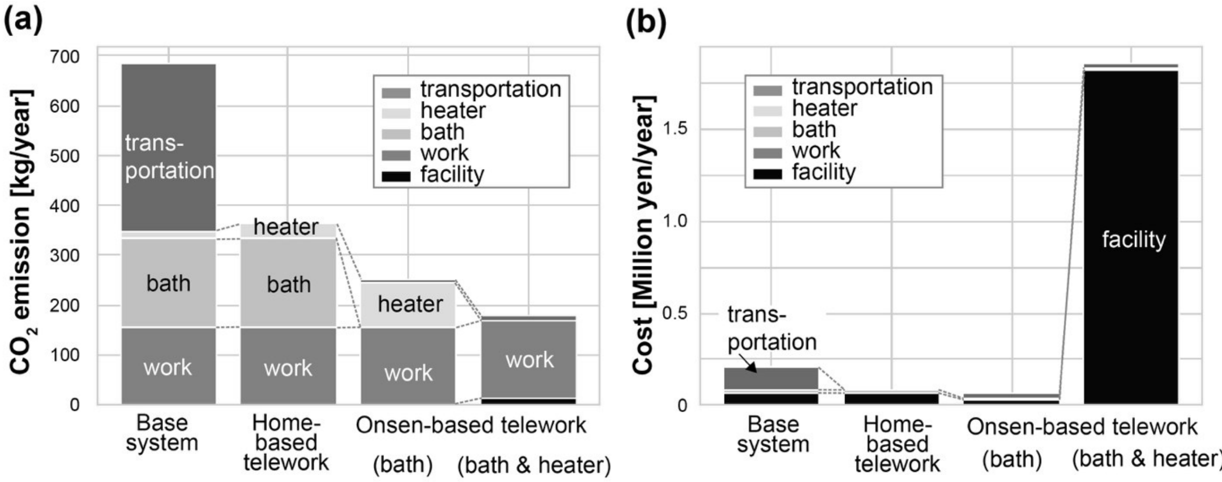

Fig. 2 Comparison of (a) Annual CO_2 emission and (b) costs with different systems.

Next, comparing conventional and urban telework, In Figure 2a, the CO_2 emissions associated with the bathing process and the work process remain unchanged, while the air-conditioning process increases slightly and the CO_2 emissions associated with the commuting process are significantly reduced. In the hot spring area telework (bathing), CO_2 emissions associated with the bathing process were lower than those in the conventional and urban telework. In addition, in the hot spring area telework (for bathing & heating), the CO_2 emissions associated with the air conditioning process can be further reduced, and the CO_2 emissions can be reduced to about 1/4 of the basic system.

As shown in Figure 2b, the cost of travel associated with the commuting process accounted for the largest proportion of the fees in the case of the basic system, accounting for 110,000 yen per year. The major difference between conventional and urban telework is the difference in the fees associated with the commuting process. In the hot spring area telework (bathing), the cost was set to stay in rented housing in the Naruko area, and the cost was the lowest because the rent in the Naruko area is lower than in urban areas. In the hot spring area telework (bathing & heating), the equipment cost accounted for a large proportion of the cost. This can be said to be due to the use of ryokan accommodation fees instead of rent, which resulted in higher costs.

It was found that teleworking in a hot spring resort area (bathing and heating) with a stay in a ryokan reduced CO_2 emissions the most, but the cost of staying in a ryokan was the highest. Hot spring area telework (bathing) staying in a rented house in a hot sp ring area was found to have the lowest cost and the second lowest CO_2 emissions because the rent was lower than in urban areas.

4. SUMMARY

In this study, we focused on the new lifestyle of workers, "telework in hot spring area", as a new possibility to promote the direct use of geothermal resources, and quantitatively analyzed and evaluated the effect of telework in hot spring area on the environmental burden of energy consumers. In order to quantitatively evaluate the superiority and feasibility of telework in hot spring areas, we analyzed the environmental effects using annual CO_2 emissions and costs as indicators, using the Naruko area in Osaki City, Miyagi Prefecture as a case study. The findings are as follows.

- In the basic system of work where employees commute to their workplaces, commuting CO_2 emissions and commuting costs account for a large proportion of the total.
- In the case of using air conditioners, the CO_2 emissions of air conditioning are small, and the gas consumption associated with bathing and the electricity consumption associated with work have a larger impact on CO_2 emissions.
- In the case of using public baths in the hot spring area, the annual CO_2 emissions are about 1/3 of those of the basic system, and in the case of using hot spring baths and heating, the annual CO_2 emissions are about 1/4 of those of the conventional system. Thus, by using hot spring heat in the bathing process and air conditioning process, CO_2 can be significantly reduced.
- In the case of teleworking in the Naruko area with renting a room and using a public bath for bathing, the reduction in CO_2 emissions can be expected and the cost can be kept to a minimum.

In this study, we were able to quantitatively show that telework in hot spring areas has a certain effect on reducing CO_2 emissions under certain conditions. It may provide an opportunity for consumers who are conscious of environmental and social sustainability to willingly adopt telework in the hot spring area.

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