Refrigeration system using resources of the regional environment in the Oya area

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Abstract. The Oya area of Utsunomiya City in Tochigi Prefecture is now with far less vitality than before owing to the decline of the Oya-stone industry, which used to be the main industry in the area. This decline is caused by a rise in new construction materials and overseas production materials. Despite the lack of vitality, the area is now showing signs of recovery. The local government recently tackled the Oya area revitalization by utilizing the abundant underground water of the Oya-stone quarry, which was once a facility of the Oya-stone industry. The quarry groundwater has an average water temperature lower than that of the ordinal groundwater. Business projects utilizing the quarry groundwater as a heat source for the heat exchange system have recently been promoted by the local government. Therefore, this study aims to explore the possibility of region revitalization by utilizing the regional resources in the Oya area by evaluating the proposed cooling system that makes use of the quarry groundwater as a heat source of the heat exchange system from the viewpoint of cooling performance. A food refrigeration system that uses the quarry groundwater as the heat source is prepared herein for measurement. The food refrigeration business will trigger the creation of work places in the Oya area, where the stone industry has deteriorated. The heat exchange amount of each element in the cooling system is identified from the measured temperature and humidity. The cooling performance is simulated and evaluated for several models that use cold water by utilizing the measured temperature and humidity as well as the identified heat exchange amount. This study demonstrates the concept of a groundwater cooling system that could be a way for region revitalization.

1. Introduction

1.1. Background and aim of the study

1.1.1. Background The demand for Oya-stone is currently continuing to decrease. Over a hundred quarrying owners operated here before, but now, only seven of them are running operations. Uncountable abandoned sites have been left wild with stored water underground. The demand for Oya-stone may not recover; hence, we need a new industry to strive in this area.
1.1.2. Aim This study aims to utilize the regional environmental resources of the Oya area in a cooling system that uses stored water for stone-build warehouses, cold stores, and strawberry farms and greenhouses. Some projects using regional environmental resources are currently ongoing in the Oya area. As one of these projects, a cooling system that utilizes cold underground water and a heat pump system was installed last year in a cold store. The measurement procedures for different factors in this cooling system are still ongoing. First, we collected the amount of energy and aging to quantify the benefits of heat energy existing in the Oya area. Second, we simulated the possibilities of a large cold store or the renovation of old stone-build warehouses to a cold store to effectively use the stored water and stone-build warehouses. We also inspect the thermal environment inside these cold stores. Third, we inspect the cultivation of everbearing strawberries putting radiant heat, which we practically use herein. Using the data on the abovementioned everbearing strawberry cultivation and thermal and development environments, we have collected the benefits of heat energy in the Oya area.

1.2. Outline of the Oya area

The Oya area measures 4 and 6 km from east to west and north to south, respectively. It lies in the northwestern part of Utsunomiya City in Tochigi Prefecture. The Oya area’s ground bears farmlands and residential areas, whereas its underground has many quarry sites, with some parts accumulating cold water. The golden age of Oya as the Oya-stone producing area had passed in 40’s Showa (1965–1974). However, the quarrying industry in Oya has declined and continues to do because of new imported building materials. Vacant lands and abandoned houses are also increasing in number. Underground sites and cold energies, among others, are now being considered by the local government for the regional reconstruction of the Oya area by utilizing regional environmental resources such as abandoned houses. Quarry sites have been changed to tourist sites; hence, many sightseers are currently visiting.

And now, as a way to utilize abandoned farmlands and cold energy, the cultivation of strawberry is increasing as a way of utilizing abandoned farmlands and cold energy. As a result, the building of cold stores is considered (Figure 1, Table 1).

![Regional environmental resources in Oya](image)

**Table 1. The list of regional environmental resources in Oya**

| Building type            | Number of building | Total floor space (㎡) |
|--------------------------|--------------------|-----------------------|
| Hotel                    | 8                  | 1,025                 |
| Factory                  | 9                  | 18,507                |
| Oya-stone-build warehouse| 8                  | 16,236                |
| Shop                     | 3                  | 3,859                 |

| Type of use             | contents                        |
|-------------------------|---------------------------------|
| Tourism Resources       | Oya history Museum, Underground lake cruise |
| Warehousing business    | Winery, Ham ripening facility   |
| Agriculture            | Ever-bearing Strawberry house   |
| Renovation Abandoned house | Restaurant                     |
1.3. Utilization of unused energy

Unused energy exists everywhere, and is widely and shallowly distributed but not yet popularized. It relies on timeframe; hence, it significantly changes the types and amount of heat to spread in a region. Several requirements must be met to spread unused energy. A good collection method for temperature or an agency must be selected to fit the heat source for each region or facility use. A relevant auxiliary heat source must also be selected (Figure 2). In comparison with fossil fuel, unused energy can restrain carbon emission. Unused energy does not heat the atmosphere significantly because of low waste heat. Consequently, we can expect a reduction in the heat island. The cooling costs in summer are increasing in many industries because of the environmental change. The Oya area is close to the Tokyo Metropolitan area. We think that the effective utilization of cold water in the Oya area as a heat source will have effects on the regional revitalization and reduction of environmental impact.

1.4. Cooling method and temperature distribution inside a room

Recovered heat can be utilized as room air-conditioners in several ways, including the convection of refrigerated air and radiation cooling from refrigerated wall or floor by cold water, among others. A convection system can quickly cool but it makes an air current and reduces the humidity inside the room. A radiation cooling system can control air current and humidity but it produces condensation. Figure 3 shows that each room usage and each storage target have their own suitable temperature and humidity. A low temperature and highly humid environment are desirable for most foodstuffs to prevent degradation caused by drying. The temperature and humidity range of a comfortable air-conditioned human living space and that inside a refrigerator are narrower than those of the data center, wherein cooling equipment or cold storage for vegetables is required.

| Regional environmental resources | Used |
|--------------------------------|------|
| Snow and ice heat source | Snow and ice heat source |
| Ground water in Oya 8℃ | Ground water in Oya 8℃ |
| River water | River water |
| Sea water | Sea water |
| Underground | Underground |
| River water | River water |
| Water | Water |

Fig. 2 Heat source temperature and used temperature

Fig. 3 Temperature distribution in room

2. Actual measurement of the system that uses water stored underground

2.1. Outline of the actual measurement

We chose a cold store that uses a cooling system utilizing stored water underground as a model. In this model, we measured the system for converting heat sources into available forms and indoor environment under this system’s influence.

We simulated the two following buildings to find a method of utilizing regional environmental resources based on the actual measured values:

- A 1000 m² cold store with a radiation cooling system and fan coil unit (FCU).
- Renovated buildings as a cold store or a living space from the Oya stone-build warehouses.

The facility had two sections: front chamber for control and cold store for preservation (Figures 4 and 5). This cryogenic energy system recovers heat in the heat exchanger through the stored water.
underground (Figure 6). We cooled down all the equipment in this cold store to prevent air convection inside the store and to simulate the temperature and humidity environment of the Oya-stone quarry sites. Accordingly, we set a FCU in the front chamber and constructed a radiation cooling system using pipes on the floor and the walls in the cold store. We aim to understand and organize the effects and challenges of energy reduction after studying the performance evaluation of the heat exchanger and FCU, among others.

2.2. Actual measurement result
Figure 7 shows the temperature change in the front chamber and cold store as well as the change in the amount of heat in each cooling equipment. Thin insulating materials and outside air intrusion were considered for the front chamber by opening and shutting the door. The temperature change was large, and the heat exchanger duty of the FCU was large as well. In this year, Water, what have been cooled down to lower temperature in the heat exchanger duty of the FCU was larger than that of last year. We added insulting materials on the cold store last autumn. This summer, it caused a reduction in the heat exchanger duty inside the cold store. We modified the system setting to increase the cooling capacity last September; hence, the heat exchanger duty also increased.

Figure 8 shows the temperature and the humidity inside the front chamber and heat source temperature. The temperature inside the front chamber was still undergoing outside influences but the environment inside the cold store was kept under 15 °C near 80% humidity.

The average humidity outside changed to 50%–60%, especially in winter from December to March. On the contrary, the humidity inside the cold store remained near 80%. The temperature inside the cold store from November to March was as low as approximately 5°C. From autumn to winter, lower humidity seasons, we can use cold air for heat exchange; hence, we can reduce the system operation time. In summer, dehumidification is required if humidity is above 80%. In this case, humidity must be controlled to a certain degree using a cooling dehumidification system and not a reheating dehumidification system, from the viewpoint of saving energy. The heat source temperature is constant throughout the year.
3. Simulation conditions and results

3.1. Simulation contents
On the assumption that this cooling system is used in practice, we set some conditions based on the results of the actual measured value. We then simulated two buildings that had below 1000 m² width. The cold store had a radiation cooling system and a FCU. The renovated buildings were the cold store or living space from the Oya stone-build warehouses. The results of the actual measurement and simulation were almost consistent in terms of temperature, humidity, and temperature of the wall surface.

3.2. Cold store with a radiation cooling system

3.2.1. Model condition  The food inside the cold store was stacked on a pallet. In this case, we basically used only the floor cooling system. We combined the wall cooling systems and the FCUs in this cold store. We performed some comparative experiments on temperature, humidity, and convection by changing the conditions of the wall cooling system, FCUs, and their number by changing the cooling capacity and the cooling area. Table 2 lists the simulation conditions, and Figure 9 presents the interior view inside the cold store.

Table.2 conditions of the simulation

| Total floor space (㎡) | 1,000 ㎡ |
|-----------------------|----------|
| Height of Building    | 7m       |
| Use                   | cold store C-class |
| Insulation            | Polystyrene foam(A) |
| Cooling method        | Floor cooling |
|                       | Wall cooling |
|                       | air conditioning |
|                       | Partition wall |
| Directions            | Northeast | South | West |
| Outside temperature (℃) | 41 | 42 | 42 |
| Roof Temperature (℃) | 66 | 66 | 66 |
| Software              | FlowDesigner2017 |
| Minimum size          | Width: 7m, Height: 6.8m |
| Thermal insulation specifications | Polyurethane foam/A |
| Part                   | cold | side |
| Dimension (mm)        | 260 | 202 |

3.2.2 Simulation result  Figures 10 and 11 show the comparisons between two conditions: 1) using only the floor cooling system and 2) using both the floor cooling system and the air conditioning system. The two patterns are:
• Pattern 1) The temperature and humidity are moving vertically when only the air conditioner is used.
• Pattern 2) The change curves of temperature and humidity intersect in the middle of the graph when only the radiant cooling system without an air conditioner is used. Both curves drew an X shape on the graph.

This shows the difference between the convection and radiation characteristics. The characteristic curve of radiation for the convection system was difficult to draw. Moreover, for radiation, drawing parallel lines like those in the convection system was difficult. Each characteristic was required for suitable conditions. As mentioned earlier, Pattern 2 was more suitable than Pattern 1 for a cold store. Using only the radiant cooling system caused a temperature difference between the floor and ceiling.

Figure 11 shows the temperature distribution inside the cold store. We considered cooling the upper-half surface of the wall to reduce the temperature difference (Figures 12 and 13).

This system had several other benefits. It can set a temperature difference to the floor and wall to divide the water supply system to the floor and wall, respectively. It also yielded an easier condensation measurement. We considered the partition wall as another cooling method.

Figure 14 shows a movable cooling wall system. Pipes with flowing cold water were pasted on a curtain-like film. This cooling wall can separate the room to required parts and cool only the required
area. The partition cooling wall supplies the requisite minimum cooling and reduces the time for remodeling and expansion of a cold store.

Figure 15 shows the temperature distribution while using partition cooling walls. The partition cooling walls separated the inside of a cold store into three parts. This system separated not only the space to three but also the temperature zone to three. The partition cooling walls can freely control the arrangement and temperature zone of a large-sized cold store depending on the type and amount of stocks. We considered a suitable draining system for the movable partition cooling wall. It was not a fixed pipe but a combination of movable trays and pipes that drain waste water to the outside through a pump.

3.3. Utilization of cold for strawberry cultivation

We constructed a cooling system in the Oya area using stored water for strawberry cultivation. We also observed the growth environment of strawberries.

Of course we have to collect more data, but we can say several things in our data in present.

Figure 16 shows the growth environment of strawberries in a usual system known as the “crown cooling system.” Figure 18 shows the radiation cooling system. The crown cooling system used heat transfer and was run by a cooling pipe, wherein cold water flowed, on the plant foot treatment. The radiant cooling system used radiation. The proposed system is a combination of the crown and radiant cooling. The increased heat transfer area cooled not only the plant foot treatment but also the seedings and the leaves by radiation.
Figure 18 shows the thermal situation inside the strawberry greenhouse in summer. The thermal storage of ground came from the solar energy in day time. The thermal storage remained for a long time after the sunset. Our cooling system was a thermal cascade system. First, cold stored water was drawn from the underground of the Oya area to cool the heat-dissipation circuit. Second, the cold stored water was used as the heat source of heat pump. Third, it cooled the pipes of crown cooling system inside the greenhouse before it returned to the quarry site underground. The output quantity of the heat pumps reduced the amount of heat required and the power consumption in the summer to 1/3. This system represented the effect after sunset and cooled the water such that it cooled the inside of the greenhouse. Under this system, the temperature difference between day and night was larger than that in the usual crown cooling system.

Figure 19 shows two conditions of the control experiment. Two greenhouses were built side-by-side. One was under the usual crown cooling system, while the other was under the proposed system, and a difference in quality was found. The average height of the strawberry seedlings was approximately 3 and 5 cm under the usual system and the proposed system, respectively.

One strawberry producer said: “By our cooling system the production has increased 7%, quality is also better, value is rise, sales has increased 20%.”

A correlation to the growth and temperature environment of strawberries was observed. After the end of August, the absorption rate of the nutrient solution was reduced under the usual crown cooling system but did not under the proposed system. The difference between the production volumes appeared after this time.
Figure 20 shows a comparison of the temperature of the culture medium between the usual crown cooling system and the proposed system. The temperature on the culture medium of the proposed system was 2°C lower than that of the usual crown cooling system. Figure 21 shows the amount of low-grade heat source. The maximum value of the entered quantity of heat in 12:00 corresponded to 49.2 kW. The average quantity in day time (10:00–15:00) was 37.2 kW.

The proposed system was able to supply heat-only passive mode driving (transport power control).
4. Conclusion

The results obtained herein are as follows:

- We continued the actual measurement of the system what we are pitting in action, using cold energy in a cold store, stone-build warehouse, and strawberry greenhouse. Effects and challenges were acquired.
- Under our cooling system, the cold store has maintained 15°C temperature and 80% humidity throughout the year.
- The simulation of the radiation cooling system provided a simple and suitable cold store for each kind of food.

Herein, we constructed a better cooling system than a usual crown cooling system. Furthermore, we confirmed the importance of the thermal efficiency in a plastic greenhouse heavily affected by the outside temperature. Some of the challenges are:

- The demand of cold will increase in future summer seasons. However, in winter, the worm water, which have been heated as refrigerant for summer, it has some possibilities. It will be put in use as the source for heating system in winter. The demand of water supply equipment, among others have not yet been considered. We have to consider heat pumps and waste heat utilization, among others for winter and summer.
- More measurements are necessary for the cultivation of everbearing strawberries.

This study acquired a possible heat flow system based on regional environment sources with very little environmental impact. The most suitable heat source and recovering method can be constructed with auxiliary heat pumps if necessary. Heat energy can also be converted for easy use in the temperature zone for each application and region.

This system has a feasibility similar to existing refrigerators but it runs almost without waste heat, greenhouse gas, or heat island effects.

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