A COP of 6-12: the Potential of Ground Source Heat Pumps

Clean Energy from Heat Under our Feet

JQR Editorial Staff   Photos: Tomoya Takai   Special thanks to: University of Yamanashi

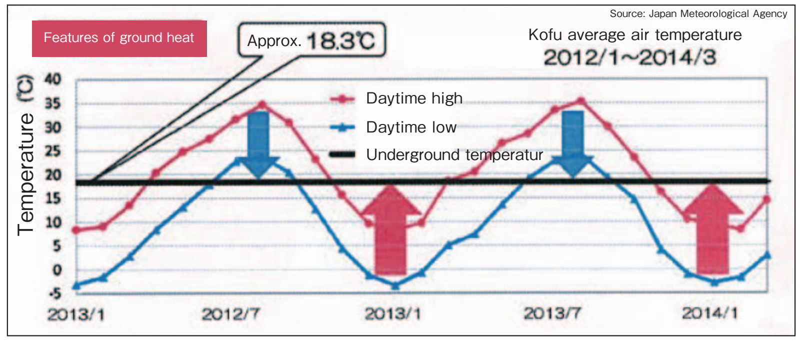
Finding clean energy sources that do not produce CO_2 emissions is one of the most urgent challenges facing humanity. The use of natural energy sources such as sunlight and wind continues to grow, but it is difficult to ensure a reliable supply of energy with these sources. University of Yamanashi professor of mechanical engineering Tetsuaki Takeda has turned his attention to ground source heat energy as a way to address this.

Energy is what makes machines work, and without it we could not sustain our modern lifestyles. However, the benefits of energy come at the cost of global warming, pushing our planet's environment into crisis.
In order to tackle this problem experiments are underway involving ground heat, which offers a reliability of supply that technologies such as solar energy and wind power do not. Ground source heat pumps are a highly efficient heating and cooling system capable of drawing energy from the ground right under our feet, making it possible to acquire ten units of energy for every one unit of electric power that is consumed.

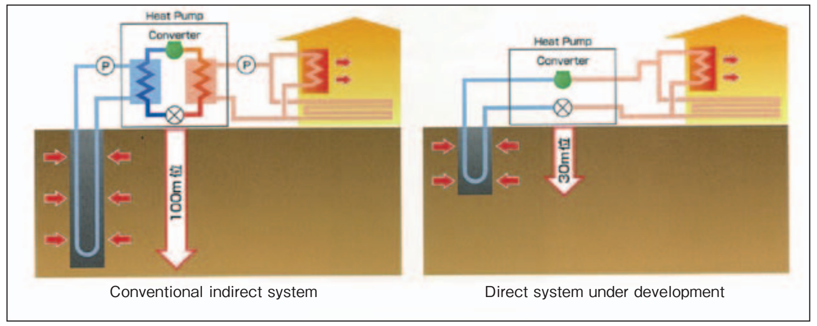
Stable Year-Round Heat in the Ground

Few of us know the temperature of the ground deep beneath our feet. The underground temperature at the University of Yamanashi's Kofu campus, for example, is about 18.3° C all year round. Underground temperatures are influenced by the sun's heat to a depth of about ten meters, but deeper down they remain largely constant day and night, and in all seasons. Meanwhile, the air temperature in Kofu fluctuates considerably – by around 40° C – throughout the year, from -4 to 35 degrees Celsius.
According to Professor Takeda, ground source heat pumps are an extraordinarily efficient way of utilizing this temperature difference.
The professor is focusing on the development and study of heat pumps that utilize ground heat, rather than heat from the air systems like those used in air-conditioners.
There are two types of ground source heat pump: indirect (the conventional system), and direct expansion, with conventional ground source heat pumps already operating at large, often public facilities such as Tokyo Skytree and the Kofu local government offices.
A Japanese Ministry of the Environment survey indicates that outside of Japan, uptake of ground source heat pumps is

Average air temperature in Kofu

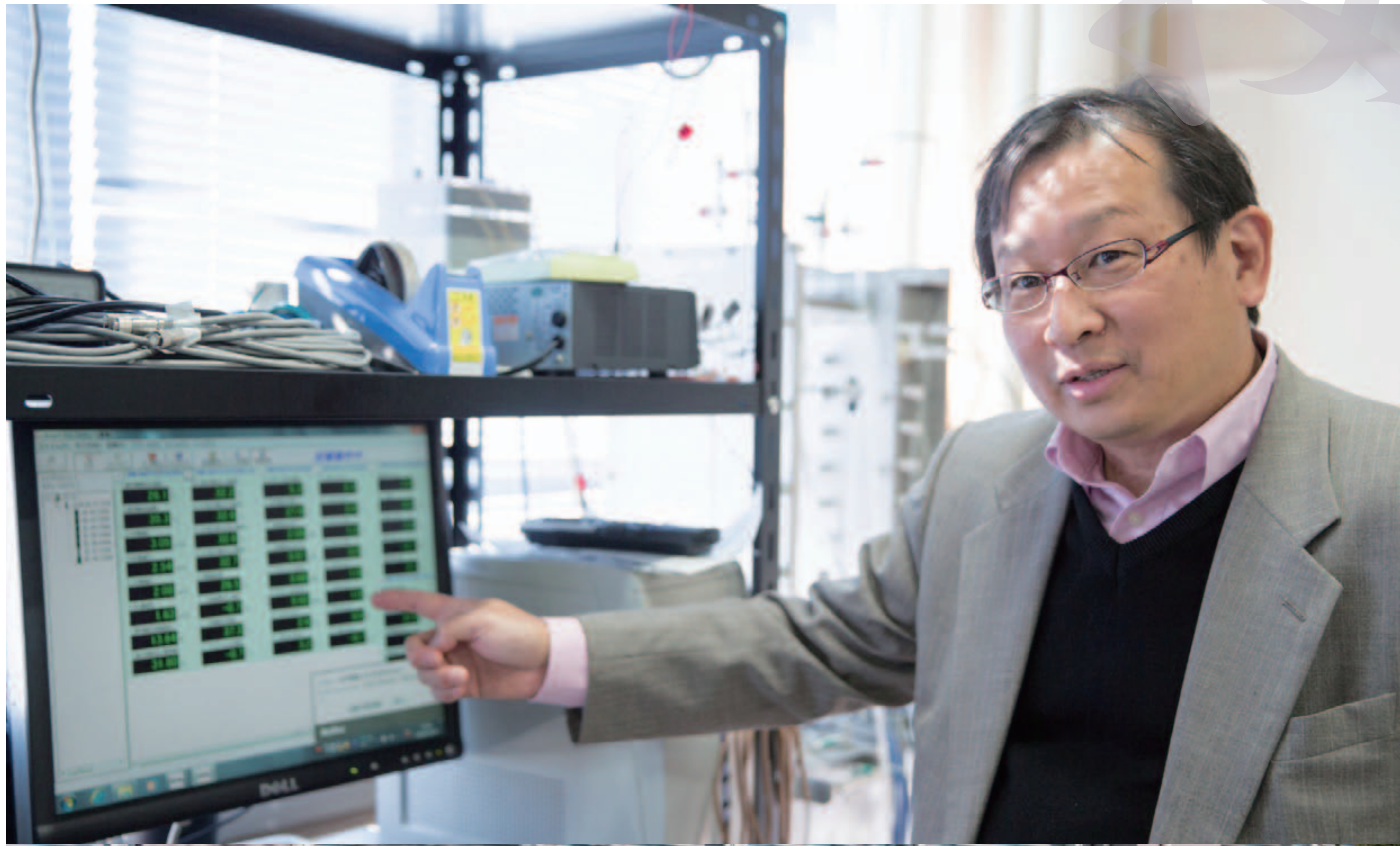


Two ground source heat pump types



Terminology 1

"Ground heat" is easily confused with "geothermal heat" but the two are not identical. Geothermal heat is a general term for heat held inside the Earth, while ground heat refers specifically to a heat source of lower temperature (about 15-20° C) found up to about 100m below ground and largely constant all year round.



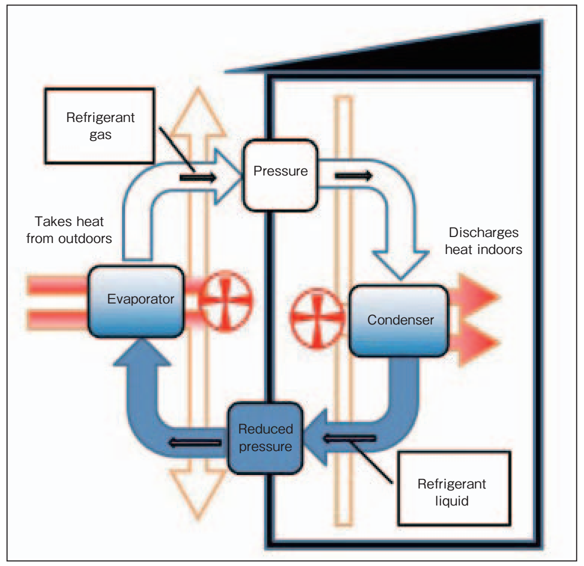
(Top photo) Professor Takeda explains ground heat data. (Bottom photo) Ground source heat pump installed next to the laboratory and actually used for air conditioning.

growing significantly, mainly in western countries, with a million 12kWt-capacity household units (12GWt) already operating in the United States. In Japan the combined annual figure is much lower, at 62MWt.

Air-Conditioners Require Heat Exchange with the Outside Air

A ground source heat pump essentially works the same way as the ubiquitous household air conditioner. To heat a space, an air conditioning system takes in heat from the outside air through its outdoor unit, and this heat causes refrigerant to evaporate, i.e., turn into gas. This gas (refrigerant) is compressed and sent to an indoor heat exchanger. There the gas condenses, becoming liquid, and the heat discharged at that point is used to heat the space. For cooling, the circuit is reversed to circulate refrigerant the other way.

Heat exchange in air-conditioners



Terminology 2

The coefficient of performance (COP) is used to rate the energy efficiency of air conditioning systems and other appliances. COP is calculated by dividing output by power consumption in kilowatts (kW), and indicates heating and cooling capacity per kW of electricity consumed.

Air conditioner	Indirect	Direct expansion
Catalog value is COP 4-5 Average is around 3	COP4 ~ 5	COP6 ~ 12

In other words, when cooling a space, an air conditioner transfers heat into the outside air, and when heating, it does the opposite, taking in heat. Thus air conditioners cannot heat a space in Hokkaido winters, when the outside air temperature falls below freezing point, because they cannot take heat from outside.

“Heat,” notes Professor Takeda, “is like water: it will only flow from a high place to a low place. When the air temperature reaches 35° C, air conditioning systems cannot reduce the heat below 35° C.” This means that in order to discard heat into outside air of 35° C, the air conditioner has to raise the temperature of the refrigerant above that. The air conditioner utilizes the rise in temperature caused by compressing the refrigerant. This is why the outdoor unit blasts out warm air when cooling, contributing to the urban heat island phenomenon.

While ground source heat pumps work in a similar fashion to air conditioners, heat intake and discharge takes place underground. Obviously, no hot air is blown out.

How a Ground Source Heat Pump Works

As mentioned earlier, there are two different types of ground source heat pump. The indirect type exchanges the heat of the refrigerant for anti-freeze in a heat exchanger, and circulates this anti-freeze through pipes in the ground, exchanging heat with the ground. An established technology, it is referred to as indirect due to the intervention of a heat exchanger. Unfortunately, heat exchangers have only limited efficiency. The other technology is direct expansion, the subject of Professor Takeda's development work.

“This circulates an alternative CFC called A-401A directly through pipes in the ground. Because the thermal exchange between refrigerant and ground takes place directly, no heat exchanger is required. It's a very simple and efficient method.”

Ground heat is a non-resource-depleting clean energy source with no CO2 emissions. Heat is also discharged into the ground, rather than warming up city streets. In Hokkaido, air-conditioning systems cannot be used in winter, but with a ground source heat pump, because it is warm under the ground even when the air temperature dips below zero, that heat can be extracted and used for heating. So here we have energy use with many positives. If uptake is to increase, however, it needs to be more cost-effective.

Introduction Costs and Thermal Efficiency Performance

Professor Takeda agrees that cost is a problem.

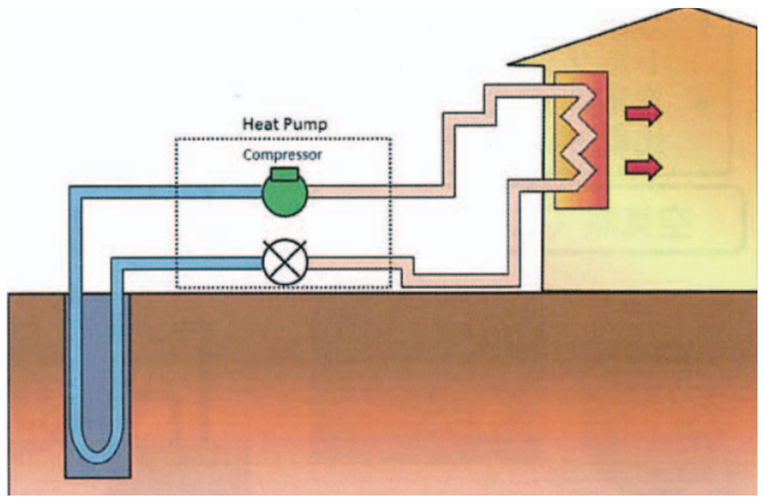
According to the professor, the initial cost of introducing a ground source heat pump system is 2.7 times that of

Ground heat characteristics and the efficacy of ground source heat pumps

- Underground temperatures are virtually constant all year round
- This technology can be used anywhere, irrespective of climatic or regional variations
- Employing energy-saving systems helps reduce consumption of non-renewable energy and CO2 emissions
- Waste heat produced during cooling operations is not discharged into the air, thus alleviating the heat island phenomenon
- High-performance systems reduce running costs

Direct Expansion Ground Source Heat Pumps in Brief

A feature of direct expansion systems is their ability to minimize condensing pressure and maximize evaporation pressure, because no discrepancy in temperature with a secondary medium is required. This removes the need for a pump, heat exchanger, expansion tank, etc., reducing the total number of components in the system. It also eliminates the need for electricity to run these components, making for more efficient operation than indirect systems. Eliminating brine piping work also simplifies installation, for further cost reductions.



Comparison of initial and running costs

	Air source heat pump (air conditioner)	Ground source heat pump (conventional) (Note)	Ground source heat pump (direct expansion type)
Initial cost ratio	100 (base)	270	200 Initial cost approx. 2X air conditioner
Running cost ratio	100 (base)	75	30 ~ 40 Running cost approx. 1/3X air-conditioner

Note Source: Hiito Panpu to Sono Oyo “Heat Pumps and their Applications” (March 2011 No. 81)

installing air-conditioning. The mechanism itself is simple, but excavations for the pipework are a significant expense.

Once installed, the cost of heating and cooling will obviously be lower. Rough calculations suggest that the cost of operating a conventional ground source heat pump is 70-80 percent that of running an ordinary air conditioning system, while a direct expansion system slashes the cost to about 30 percent of air conditioning.

“Direct expansion was actually trialed over 30 years ago, but failed due to inadequate performance by the refrigerant and machinery. Apparently the refrigerant would not circulate from 50m below ground. So direct expansion systems came to be seen as impractical, and were not adopted for buildings even when suggested.”

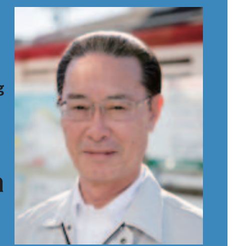
For Professor Takeda, who is working on direct expansion technology, the winds of change began to blow about two years ago with the results of an experiment he conducted. At the time the outside air temperature in Kofu was 38° C. However, because heat was discarded underground, both the cooling capacity and electricity consumption were the same as when it was cool outside. This proved that the COP was fixed, that is, even using direct expansion, a ground source heat pump system is unaffected by the outside air.

Professor Takeda notes with some pride that, “The technical issues have mainly been solved.” The next step is to collect the data required to work toward practical implementation of the technology, such as investigating the effects of heat discarded into the ground. At the same time, the professor intends to promote the certification of products, and develop maintenance checks.

Under our feet lies an infinite source of clean energy, and ground source heat pumps allow us to extract that energy and use it in day-to-day living. Professor Takeda continues to research ways to maximize efficiency, with a view to making this dream-come-true technology into a reality.

Ground Heat: a Promising Energy Source

Hagiwara Boring Co. Ltd President
Toshiki Hagiwara



“In the wake of the March 2011 earthquake and tsunami in northern Honshu, I pondered what might be the most stable form of energy, and decided upon ground source heat. We then began to look into its practical application. The problem is that the more you go down the environmentally-friendly route, the more the initial costs become a sticking point. We are working with the University of Yamanashi to build systems that boost the efficiency of ground source heat technology. Personally, I believe ground source heat pumps, with their superlative stability, are the energy-saving system with the greatest long-term potential. We are currently undertaking an exciting program of development as part of the MEXT Regional Innovation Strategy Support Program, which involves collaboration between industry, academia, government and finance.”

University of Yamanashi, Department of Research Interdisciplinary Graduate School of Medicine and Engineering Takeda Laboratory

Conducts research into direct expansion ground source heat pumps, binary power generation and thermoelectric generation using hot spring water, and the development of integrated systems.
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