学位論文内容の要旨

This research work is about the *Modeling*, *Simulation* and *Optimization* of Domestic-Size Renewable Energy Systems with special emphasis in Cold Climate Regions. The interest in domestic-size systems was borne out of the fact that more than half of the total energy consumptions in very cold regions emanate from space heating of residential buildings during the cold seasons. Recent researches indicate that the consumption of energy for room heating per person in Hokkaido is more than 3.5 times greater than the average consumption in Japan, and that almost all energy sources (more than 90%) for room heating is oil. As a result, in Kitami city for instance, more than 50% of annual anthropogenic CO_2 emission originates in the residential sector, compared to other sectors such as the transportations and industries. It is therefore desirable that efficient domestic-size renewable energy systems be realized in order to reduce or completely eliminate the dependence on heating oil for room heating and thereby significantly reduce the CO_2 emissions from the residential sector in cold regions like Hokkaido.

A basic domestic-size renewable energy system was proposed and analyzed numerically, and five other configurations and improvements of the basic system were considered in order to clarify the best system configuration for cold climate regions, with Kitami City as a case study. In all the system configurations, the solar energy collected with an array of photovoltaic (PV) panels or PV/thermal collectors (26m^2) as well as underground geothermal energy drawn with a ground-source geothermal heat pump (GHP) were used as the primary renewable energy sources, and all the systems were tailored to a residential household of four persons. Hot water is drawn directly from a storage tank for hot water supplies and thermal energy is also drawn from the tank for room heating through a heat exchanger. The thermal sources of the tank are the thermal energy from the hybrid solar panel and/or the GHP and a 10kW auxiliary boiler. The electric energy produced by the hybrid solar panel or the PV cell can be sold to an electric company via an inverter.

Since annual estimations are very crucial for system evaluations and in order to objectively evaluate the cost merit and the feasibility of any renewable energy system, it is necessary to devise a simplified method for estimating the annual performances and energy balances of the system, as opposed to continuous daily simulations (365 days) throughout a whole year. The accuracies of five simplified meteorological data models were examined by comparison with the results of detailed real-time continuous simulations using actually measured data during a selected period (May 2002). Based on error analyses, it emerged that a *Double Grade 1 Meteorological Model* is adequate for estimating seasonal energy balances, from which annual energy balances can be made. In this meteorological data model, system simulations are made using only two representative days (*Clearest* and *Cloudiest*) during each season of the year, and the daily results (in each season) are multiplied with clear and cloudy day ratios to arrive at the seasonal sums. Annual results are then obtained as the sum of the seasonal results.

Detailed numerical studies revealed that the hybrid solar panel is insufficient for the production of thermal energy during very cold seasons because of excessive low ambient temperatures resulting in high heat losses from the solar collector. The percentage of the thermal energy produced by the hybrid solar collector to the total thermal supplies for room heating and hot water consumption, was less than 7% during the winter season even in the improved systems. More than 90% of the desired thermal energy for household use, could be supplied using the GHP. For most of the system configurations considered, the system running cost and the CO_2 emissions were drastically reduced (below 40% and 16% respectively) compared to an equivalent conventional, non-renewable energy system. Numerical studies also revealed that a compact system configuration, with two small storage tanks, each for hot water supplies and room heating respectively, lead to higher system efficiency compared to systems with a single, large storage tank that supplies thermal energy for both hot water and room heating. In this compact and optimized system, the use of the auxiliary oil boiler was completely eliminated and all the room heating was achieved using the GHP.

An actual renewable energy house located in Kitami City was also studied and analyzed using numerical simulation studies and actual monitoring/measurements. The house is equipped with a floor heating system which is powered using only a GHP throughout the year. Actual monitoring and continuous measurements for a period of one

year showed that even during very cold seasons, the GHP can supply all the thermal energy for room heating and there is no need for any other auxiliary heaters, which are the same conclusions that were reached using detailed numerical system studies. Annual energy demand for room heating was well predicted within several percent of error. Simulation studies also indicated that the use of only the GHP in the actual renewable energy house reduces the system running cost and CO_2 emissions to 47% and 49% respectively, compared to an equivalent conventional system (a system without the GHP).

Initial cost considerations were also done for GHP-only powered renewable energy system. Presently, one demerit of renewable energy systems is their very high initial costs. A detailed cost analysis revealed that if the cost of heating fuel keeps increasing (a reasonable assumption) up to ¥120/*L*, then the payback period for a GHP-powered renewable energy system is about 14 years. If 30% of the initial cost of the GHP renewable energy system is funded by the government or some other agencies, this payback period reduces to about 10 years.

論文審査結果の要旨

本研究は北見のような寒冷地において、太陽エネルギーと地中熱ヒートポンプ（以下GHPと略記）の複合自然エネルギーシステムによって戸建住宅の冬期暖房をまかなう技術の実用性を創出することを目的とする。先ず通年の自然エネルギーシステムのエネルギー収支を簡便に予測するプログラムコードを開発し、5種類の方式の中から最も精度に優れた簡易モデル（1年を8日分の計算で済ませる）を提案した。次にこれを新規に開発した家屋モデルと組み合わせて年間エネルギー収支を計算した結果、適切な自然エネルギーシステムを選ぶことによって寒冷地の冬期熱需要をまかなうことができることを示した。また太陽電池（PV）、太陽熱集熱器およびGHPを組み合わせた6種類のシステムについてシステム効率の改善および二酸化炭素（CO_2）の低減に取り組んだ結果、太陽熱集熱器では寒冷地の場合冬季の熱需要の7%程度しかまかなえず、また太陽集熱器を排除してもGHPのみで熱需要を満たせることを明示した。PVパネルを併用した場合、灯油ストーブ＋灯油ボイラを備える在来型システムに比してCO_2排出量とランニングコストを共に約1/3に低減できることが明らかになった。PVパネルを備えない場合でも双方の大きな低減効果があり、GHPシステムの普及を強く訴求する結論に達した。さらに本予測手法は2004年北見市に建設されたGHPシステムを備える戸建モデル住宅に適用を試み、2005年の通年熱需要予測誤差は実測値に対し約７％であった。

以上を要するに、申請者は寒冷地におけるGHPシステムの実用性を明示すると共に、実現のための技術要件をも明らかにしたものであり、工学の発展ばかりでなく寒冷地向けの自然エネルギーシステムの実用化と普及に著しく貢献するものである。よって申請者は北見工大博士（工学）の学位を授与される資格があるものと認める。