A Study on the Actual Conditions of Residential Environment and a Solar Energy Applied House in the Tibetan Plateau

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Abstract
This study shows the results of field measurements of an apartment building located in Tibet's capital and in traditional houses in order to evaluate their levels concerning the living environment such as inside and outside temperature, humidity, illumination intensity, CO and CO2 concentration, intensity of solar radiation and the UV strength. The Tibetan plateau is characterized by high altitudes, low oxygen concentration, transparent atmosphere, wide diurnal range temperature, and special culture and life style, so UV and solar radiation, thermal environment and IAQ claim attention. Also a questionnaire survey was carried out for the consideration of improvements. We describe architecturally useful ways of utilizing the abundant solar energy in the Tibetan plateau of China and the solar potentials of various places are analyzed. Especially, the floor materials of the apartment houses and traditional residences in Lhasa city are examined and the living environment is improved using a direct heat gain system with simulation software. In addition, the condensation function of a solar cooker is used effectively in the local area, by selecting the most suitable materials. Also the power output performance of a solar cell using a compact portable sunlight concentrator proposes characteristic application methods for Tibetan residences.

Keywords: Tibetan plateau; living environment; field measurement; solar energy; sustainable development

1. Introduction
Tibet is located on a plateau that has an average elevation higher than 4,000 m and is often called the "roof of the world". The population of Tibet consists mainly of the indigenous Tibetan race (Photo 1.), who tend to follow Tibetan Buddhism. In recent years, the rapid modernization of urban areas has resulted in the construction of apartment houses, as well as increased use of automobiles and electrical appliances, etc. These factors have caused great changes in traditional Tibetan residential environments. Although lifestyle convenience is an important factor, it is believed that sustainable cultural-based elements should be passed on as well, and efforts to preserve regional characteristics are important. Oiwa Teruyuki has reported on Tibetan architectural planning since 19881, 2, and more recently, Tetsuo Yamaya investigated the lighting environment in Tibet3. However, the actual conditions in residential environments have not been clarified until now.

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The atmosphere in Tibet is extremely transparent; thus, UV and solar radiation can be expected to be high (Fig.1., Table 1., Photo 2.). In this study, we made measurements of solar radiation, UV strength, and illumination at an apartment building and traditional houses located in Lhasa (Photos 3., 4.). The climate is alpine and marked by a large diurnal range. The residential thermal environment and IAQ, including those of relatively well-sealed apartment houses and traditional houses using traditional fuels for cooking and heating, were investigated in cooperation with both Chinese and Japanese research groups.

2. Measurement Methods
The study was conducted under normal living conditions for an apartment building (Photo 5.) and traditional houses 1 and 2 (Photos. 6, 7) from August 9 to 13 and December 22 to 27, 2007. A very small data logger (TSDK-HT1•2) was used for collecting data in the living room and placed at 3 axes: 50 cm from the south window, in the center, 50 cm from the north wall and vertically 0.1 m above the floor, 1.1 m above the floor and 0.1 m below the ceiling. Vertical temperature measurements were taken at 1-minute intervals at a total of 9 points. Data loggers (T&D, TR-73U, RTR53 and TR-72S) were set outdoors and in living rooms at positions 10 cm and 60 cm above the floor in order to measure the temperatures at 1-minute intervals. The surface temperatures of the floor and ceiling were measured with an infrared radiation thermograph (Spot Thermometer HT-11D) at 1-hour intervals. CO concentrations were measured using an HOBO CO logger, CO₂ concentrations in the living rooms were measured using a CO₂ monitor (Telaire7001), automatically recorded at 1-minute intervals. All weather pyranometers (Eko. MS601), UV radiometers (Eko. MS212A, 212W) were placed on a level foundation and automatic measurements were taken at 1-minute intervals throughout the day. Figs. 2~5 show the placement of the instruments.

3. Results of Measurement
3.1 Thermal Measurement Results
As shown in Fig.6., the diurnal temperature ranges were respectively 19°C in the summer and 32°C during the winter, with a large annual range of about 30°C. Humidity was low during the winter, with an average of about 13%. Air pressure was 650 hPa, which is about 60% of the average level in Japan. The daily cumulative temperature in the living room is shown in Fig.7. Especially for the apartment building during the winter, the effect of solar radiation is significant as the windows are sealed and the high temperature region is larger than for the summer season (1.1 m above the floor). The value for the L₅₀ shows how the differences in the dwelling layout are reflected. For the apartment building, temperature distribution within the apartment was uniform during the summer. However, there was a 25°C

![Photo 5. Apartment](image1)
![Photos 6., 7. Traditional House 1, 2](image2)
difference along the south north axis during the winter. The maximum and minimum temperature differences for the living room were 3°C during the summer and 6°C in the winter. For the traditional houses as well as the apartment, the effects of solar radiation from the south and north sides as well as the vertical temperature differences must be taken into consideration.

3.2 IAQ Measurement Results

The change over time for CO concentrations in the kitchens is shown in Fig.8. For the apartment (Gas cooker), sudden high-level increases of CO during cooking in summer and winter were recorded. The results were compared to the China National Standard (GB below) 60, and the 10 ppm limit was exceeded. In contrast, for traditional house 1 (Cow dung stove), the kitchen faced the garden and was separated by an opened door. As ventilation was provided in traditional house 2 (Cow dung stove), the CO concentration remained relatively stable and no distinct changes in concentration were observed.

The changes with time for CO₂ concentration for the living rooms are shown in Fig.9. The CO₂ concentration in the observed apartment during meals and social periods exceeded the GB Standard of 1,000 ppm60 while the CO₂ levels in the traditional houses 1 and 2 were stable and were well within the standard.

3.3 Illumination Measurement Results

The illumination analysis results are shown in Figs.10.~12. for the living rooms at a height of 0.6 m. These calculated values showed a similar trend to the measured values. For the closed or drawn status of the curtains during the daytime, the apartment's curtains were usually fully opened while the situation differed at times for traditional house 1. The curtains were half drawn in traditional house 2.

If the daylight ratio for the living rooms of the dwellings were to be compared to the Japanese standard value of 0.7%, the apartment and traditional house 2 meet the illumination standard while traditional house 1 came close to meeting it. Traditional house 1 was darker than the other dwellings, while the lighting in the apartment building and traditional house 2 were almost at the same level.

3.4 Solar and UV Radiation Measurement Results

Fig.13. shows the solar radiation results. Fig.14. shows the results of UV-A radiation, while Fig.15. shows the UV-B radiation results for the same periods. The maximum values recorded during the summer were very high for solar radiation at 1283 W/m², UV-A 68.1 W/m² and UV-B 2.3 W/m².
UV-B, which is considered to be a cause of skin cancer, cataracts and other human illnesses, can be converted into the UV index using equation [1]\(^2\):

\[
\text{UVI}=1.074\times\text{UVB}^{0.2}+4.248\times\text{UVB}
\]

From Fig.16., during the winter UVI is about 4 during the peak hours, and its effects are thought to be minor unless long periods of time are spent outdoors. In summer, maximum values exceed 15 and the extremely strong time period is also longer, from 12:00 to 15:00. Discomfort can be expected to be high and there are also concerns regarding health issues. Additionally, the individual awareness regarding ultraviolet radiation results are shown in Fig.17., Photo 8.

4. Solar Energy Applied House

While taking into consideration the plateau climate and the architectural style prevalent in Tibet, we performed a 3-dimensional thermo-fluid simulation (using Stream ver. 6) on an apartment building (Fig.18.) and a traditional house (Fig.19.) in Lhasa. In each simulation, actual measurement data were entered for basic analysis conditions, such as inflow temperature (variable every hour), wind velocity and inside surface initial temperature (Tables 2., 3.). Then, we analyzed possible improvements to the 24-hour thermal environment.

Effects of solar shading in summer, with respect to Traditional houses 1 and 2 and the housing complex, surface temperatures during the summer were surveyed under five conditions: no solar shading, awning use, a 10% greening ratio, 50% greening ratio and rooftop greening. The effectiveness of awnings during winter was studied by calculating the wall surface temperatures of Traditional house 1 with and without an awning. The wall and roof surface temperatures examined were measured using Thermo Render Pro3 (A&A Co. Ltd.) (Table 4.).

We created a parasol-shaped sunlight concentrator, similar to the solar cookers commonly used on the Tibetan Plateau using a selected reflective material, and performed an experiment to evaluate its ability to augment solar cell power generation (Photos 9., 10., 11.).

4.1 Results of Solar Heating Simulations

Since actual measurements showed that the indoor temperature was lowest at around 10:00 (Beijing time), the floor surface temperature in the center of the living room was simulated from 10:00 to the same time 24 hours later in the target houses. Figs.20. and 21. show the simulation results for the apartment building and the traditional house, respectively. The flooring material currently used in the housing complex clearly exhibited a steep temperature gradient and a steep decay gradient, suggesting that it heats easily but has poor thermal storage capability. Granite, on the other hand, recorded its highest temperature seven hours after it began receiving heat, and the heat gradually dissipated over a period lasting into the following day. Thus, the direct heat gain effect is clear. The difference in surface temperature between the normal flooring material that had the lowest thermal storage capacity and granite, which showed the largest thermal capacity, was approximately 7°C.

In the case of the traditional house (Fig.21.), the initial temperature of the material was set at 5°C based
on actual measurements. The rise and decay curves showed similar tendencies to those of the housing complex, with some characteristics similar to those of an earth floor.

The change in surface temperature of the indoor structure caused by insolation was visualized by a simulation program, as shown in Figs.22., 23. Figs.22.a~20.c depict the temperature distribution at the maximum temperature in the case of granite or concrete flooring. Figs.22.d~20.f show the stored heat of each of these materials at 22:00.

While the temperature setting for the traditional house was lower than that for the housing complex, the simulation results indicated that Flooring (Fig.23.a) < Earth (Fig.23.b) < Granite (Fig.23.c) in terms of thermal storage capability, denoted the characteristics of the earth floor.

4.2 Improvement of External Thermal Environment of Residences

The outside surface temperature distributions at 11:00, 14:00 and 17:00 in Traditional houses 1, 2 and the Apartment building in Lhasa are shown in Figs.24. and 25. respectively. Hourly surface temperature changes are plotted in Figs.26. and 27. These data show that temperature changes are notable on the windows, external walls near the windows, and roof surfaces of the buildings, under the given conditions. On the external walls, a maximum temperature decline of 5.2°C was observed when an awning was used, while a maximum drop of 5.7°C was observed at a greening ratio of 50% (Table 5.). In particular, rooftop greening had a marked impact on the roof surface temperature. Each building type examined experienced a temperature drop of at least 21°C. In winter, the wall temperature of the living room of Traditional house 1 was 5°C lower than it was with an awning in place.

4.3 Results from the Experiment to Improve the Power Output of Solar Cells Using Solar Cooker

Regarding the rooftop thermal environments during the experiment period (Fig.28., Table 6.), temperatures ranged from 24.9 to 33.8°C and the humidity from 29 to 73%. The maximum amount of insolation was found to be 1,101 W/m² and was very unstable due to cloud cover. The surface temperature of the panel (Fig.29.) reached a maximum of 59°C when sunlight was concentrated, but was still within the optimum range, possibly due to the cooling effects of the wind (average wind velocity on August 25 was about 2 m/s). Fig.30. shows the I-P characteristics of the panel in standard use and with the use of the sunlight concentrator. The data were obtained by a variable resistor while solar radiation was stable (results from three representative tests). It was observed that the power output increased about 2.29-fold under optimal conditions. The diurnal measurements of the power output indicate that the output from the standard panel is consistent with changes in the amount of insolation received, while the output increases when it is sunny when the sunlight concentrator is used. More specifically, the sunlight
5. Conclusions

The results of actual conditions on the residential environment in the Tibetan plateau were as follows:

1. The temperature range is large in each residence between south and north rooms in winter.
2. The high CO concentration was observed in the apartment, especially the kitchen.
3. The lighting capability was good, though the overall balance was unfavorable.
4. The annual intensity of solar radiation and Summer UV was strong.
5. The utility of solar energy heating in Tibet was investigated.
6. The change in floor surface temperature caused by insolation depends on the floor material. Significant differences were identified among six different locally-available materials. When a material with low thermal capacity is used for indoor surfaces that can be reached by solar rays, the impact of weather and the amount of insolation on temperature variations becomes prominent. Therefore, the thermal environment can be improved by using appropriate, locally-available floor materials in places with sufficient sunlight, resulting in efficient heat gain. In particular, bricks and stone are abundantly available in Tibet, and they are deemed practical for such uses.
7. In summer months, the installation of awnings reduces the wall surface temperatures by 4.5-5.7°C.
8. If the greening ratio is raised to 50%, the cooling effect is more significant.
9. Rooftop greening plays a significant role in reducing roof temperatures.
10. In winter, the presence of awnings has a marked impact on the building surface temperatures. Thus, a flexible installation of awnings is recommended.

The use of a parasol-shaped sunlight concentrator, similar to solar cookers, proved effective in improving the power output performance of solar cells. While the power generation potential of concentrated sunlight is unstable in Japan because of the large number of cloudy days, in the Tibet Autonomous Region, where cloud cover is minimal, strong and stable solar radiation conditions indicate that application of solar power generation systems would be effective in the region. In the meantime, it is vital to construct comfortable spaces based on the effective utilization of natural energies, including photovoltaics, by incorporating additional solar and ultraviolet shaded areas, not only in houses but also in public spaces.

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Table 6. Performance of Solar Panel

| Parameter                  | Value     |
|----------------------------|-----------|
| Maximum electric power     | 5W        |
| Voltage                    | 21.6V     |
| Maximum output voltage     | 17.6V     |
| Short-circuit current      | 0.30A     |
| Maximum current            | 0.281A    |
| Optimum temperature        | -45~85°C  |
| Deviation                  | ±5%       |