

Transfer of energy efficient building concepts to subtropical climate– The first MINERGIE P® based building in Japan

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SUMMARY:

While there are solid experience values for energy efficient buildings in moderate climate in Europe, the transfer of these concepts to differing climate and socio cultural conditions is a field of experimentation in building physics. Started as a cooperation project between Switzerland and Japan and now continued by including Sweden as a partner, the first Japanese residential building based on the MINERGIE P® standard has recently be realized in central Japan.

This presentation will offer a summary of the applied concept for the building envelope and housing services. The focus will be on measures to deal with the high humidity loads in subtropical industrialized country with related demand for comfort conditions and regular earthquakes straining the construction and the measures to achieve the MINERGIE P® targets in Japanese climate.

1. Introduction

With regard to the resource depletion and the global climate change, it is widely recognized that the construction industry is playing a key role for the rational use of resources and the realization of a more sustainable society (CIB 1999). On a global scale, the construction industry is contributing to about 50% of the manmade greenhouse gas emissions and to about 40% of the resource consumption (UNEP 2003). Energy consumption in buildings is of key importance in this regards and in order to improve the energy efficiency of buildings, several design protocols for building envelope and equipment have been proposed and implemented, though mainly in cold/mild climate regions. As a successful example the MINERGIE® Building Association of Switzerland has established an energy certification method labelling buildings to MINERGIE® and MINERGIE-P® standard. Due to the promotion driven by subsidies from local governments in Switzerland and the general perception that such labeled buildings are worth more in economic terms, more than 10,000 housings have been certified by this energy label in Switzerland so far. The Passivhaus Institute from Germany established similar energy labeling methods for buildings in Germany and other countries, mainly in Europe. A recent study has shown that the actual energy performance of certified Passivhaus buildings match the calculated energy demand (Passivhaus Institute) with the best exactness achieved again in cold and mild climates. These two examples show that the implementation of energy efficient building technologies accompanied by a labeling system can contribute to the further enhancement of the sustainability of the construction industry.

In order to address the energy performance of buildings on the global level, the implementation of such design protocols has been promoted recently. The key for a working concept as well as local acceptance is considering the local frame conditions when a certain technology is deployed in a certain place. Especially the climatic, craftsman skills and user behavioral difference may result in a serious damage in building components and/or inhabitants' health if not properly taken into account.

Within a series of research projects that started as a cooperation project between Switzerland and Japan and are now continued by including Sweden as a partner, the authors have developed an innovative vapor-open wooden building envelope system for subtropical regions. In June 2013, a test house, whose concept was based on MINERGIE[®], was realized in central Japan. This paper introduces the concept of the construction system, introduces the framework of the adoption of MINERGIE[®] certification, reports the designing and construction processes of this test house and presents the preliminary results of the measurement of the indoor climate and the temperature and humidity inside the envelope.

2. Energy efficient building concepts for subtropical regions

2.1 Subtropical climate

Energy consumption by buildings is of growing concern in subtropical regions because of the high growth rate in urbanizing areas in these regions (CIB & UNEP-IETC 2002). FIG 1 shows the subtropical regions defined by Köppen-Geiger climate classification. The major difference between cold/mild regions and subtropical regions is the long and hot-humid summer. This causes significant energy consumption for cooling and dehumidifying in addition to the heating load in winter. From the view point of building physics, such a climatic condition is very challenging because it results in both heating and cooling demands in buildings. Consequently the direction of the moisture flux - due to the gradient of vapor pressure between exterior and interior - reverses throughout the year. In summer the moisture transfer happens from outside to inside and in winter vice versa. Inappropriate design of the building envelope, which fails to deal with the moisture flux in the exterior wall, may result in the interstitial condensation in the exterior walls.

One way to deal with this would be sealing both sides of the wall with water vapor tight layers. In order to create a robust solution the desirable way however is making the envelope vapor-open, especially in earthquake-prone regions where rifts in barriers can never be completely prevented. Directly implementing the conventional designing method for cold regions introduced above does not solve the fundamental problems in subtropical regions, but rather introducing a novel envelope system for subtropical regions has been required.

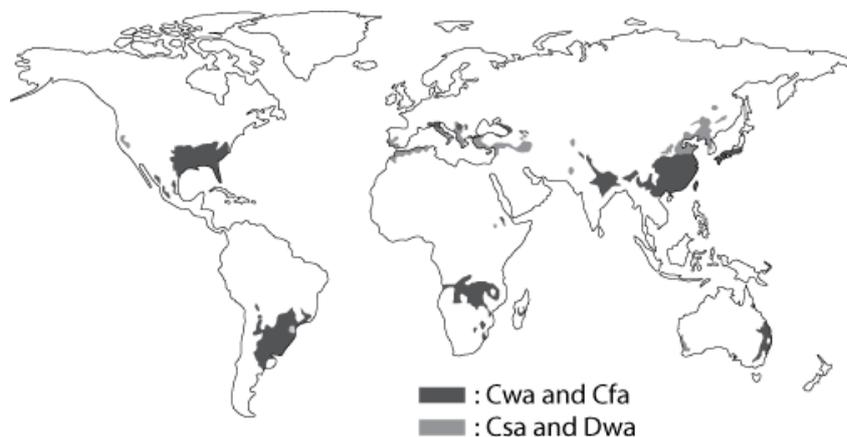


FIG 1. Subtropical regions according to Köppen-Geiger climate classification

2.2 Vapor-open envelope system for subtropical regions

A new building envelope system was developed within the research team led by the authors. This envelope system mainly consists of layers based on renewable, hygroscopic and vapor permeable materials, namely the external insulation layer made of wood fiber board, the structural layer made of

cross laminated wooden panel and the interior finishing layer made of a pre-dried composite of wood and clay. The illustration of the envelope system and the materials for each layer is shown in FIG 2. This system allows the moisture flux to move through the wall in both directions. By defining the appropriate thickness to each layer, it is possible to avoid moisture related problems inside the wall. Besides the building physical considerations, the design philosophy of the envelope also comprises ecological, economic and social aspects. The components are based on renewable materials, and so it may be produced using local resources, which contributes to the less transportation for each component. Local production also promotes the local economy creating local value chain. The local design conditions, namely local climatic conditions and socio cultural aspect such as user behaviors (preferred room temperature/humidity, heating/cooling strategies and so on) can be taken into account. Flexibility and adaptability to specific local conditions is assured by the layered structure of the envelope. This system enables the material of each layer and its thickness to be selected independently for its primary function alone. Therefore the thickness of the insulation layer, which gives not only the thermal resistance but also the moisture sorption capacity, can be determined according to the local climatic condition without interrupting the other components such as the structural element. By this flexibility, an actual wall make-up can be determined considering the local conditions of both sides of the wall easily.

By one dimensional transient heat and moisture transfer simulation program, hygrothermal property test and full scale testing with a climate chamber, the performance of the wall was verified (Goto et al. 2011). Then, the whole building heat and moisture balance simulation method for buildings with this system was also developed in order to predict the indoor climate and heating and cooling demand (Goto et al. 2012a). Combining these methods and Life Cycle Assessment (LCA) and Life Cycle Cost Assessment (LCCA), the authors proposed the optimization method for the thickness of the insulation layer within the Japanese economic and climatic conditions (Goto et al. 2012b).

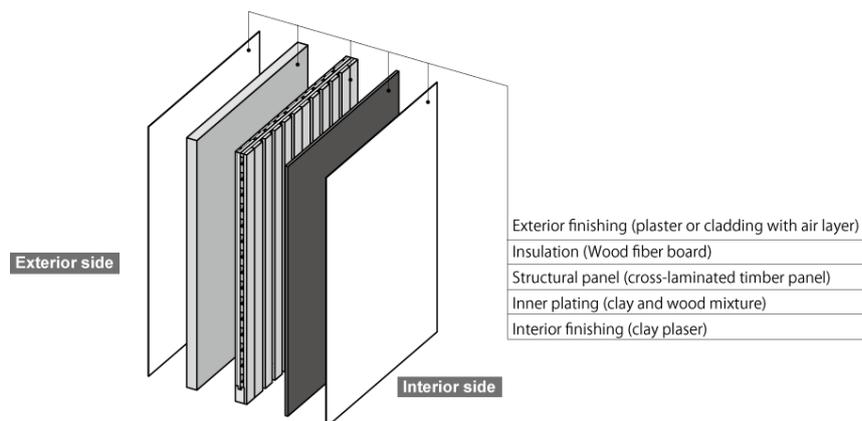


FIG 2. Layered make-up of the vapor-open envelope system

3. Adaptation of MINERGIE® to subtropical conditions

MINERGIE® is an energy label for new and refurbished buildings. It is mutually supported by the Swiss Confederation, the Swiss Cantons along with trade and industry. Assuring comfortable living environment is the origin of MINERGIE®. A wholesome level of comfort is argued to be made possible by high-grade building envelopes and the controlled ventilation. In Switzerland the MINERGIE® Standard is widely accepted and recent studies have found that on the free market labeled houses achieve a 6% higher sales price than non-labeled ones of similar performance (Salvi et al 2008). This shows the potential of such labels to be also perceived as a quality proof. By now, the building sector has developed a wide range of products and services for MINERGIE® buildings. Suppliers include architects and engineers as well as manufacturers of materials, components and systems. The diversity and competition of this market furthers quality and lowers costs.

Specific energy consumption is used as the main indicator to quantify the required building quality. Only the final energy consumption is relevant. The measures applied to achieve the goal are in many aspects not pre-described and the label follows the idea of naming the goal but not the way. This makes the label very flexible in regards to transferring it to different climate conditions as long as the target numbers are achievable. The experience with about 10.000 labeled buildings in Switzerland allows the association to identify the most cost competitive ways to achieve the standard (Mosteiro et al. 2014). These are listed in the figure below, being compared with the ones chosen for the building in Japan. In addition to the general criteria, it was decided to restrict the relative humidity in the exterior walls not to exceed 80%RH throughout the year in order to assure the longevity of the house in the case of prototype house.

TABLE 1. Comparison of MINERGIE P[®] in Switzerland and Japan

	MINERGIE P [®] (Switzerland)	Prototype house in Japan
Energy demand	Weighted energy index accounting for heating, ventilation, hot water, and air conditioning of 30 kWh/m ² taking losses for extraction, transportation and distribution into account	Target as in Switzerland, based on a monthly calculation as well as dynamic modelling (29,2 kWh/m ² a)
Renewable energy	Prerequisite	PV (4.18 kWp) and solar thermal
Heating and cooling demand	<60% of legally allowed annual heat demand for new homes (SIA 380/1:2009 limit) or <15 kWh/m ² , max. 10 W/m ² for air heating	Not applicable
Controlled outdoor air ventilation and indoor air quality	Controlled outdoor air ventilation prerequisite. Heat recovery required. Proof of thermal comfort during summer necessary	Enthalpy exchanger,
Air intrusion	<0.6 h ⁻¹ air exchange rate at 50 Pa pressure difference	Measured according to Swiss standards to be
Opaque walls Glazing	20–35 cm (U-value: <0.15 W/(m ² K)) Triple panes (U-value for glazing: <0.6 W/(m ² K))	18 cm, lambda 0,04 0,7 to 1,0 W/(m ² K)
Costs	Should not exceed construction costs of a conventional building by more than 15%	In range of upper class Japanese houses

Based on LCA, LCCA and hygrothermal analysis considering the specific design conditions as well as the MINERGIE P[®] criteria, the insulation thickness was decided to be 18 cm. For the openings airtight and triple glazing windows (0.7 W/m²K) were installed. PV panels cover the south roof (4.18 kWp) combined with solar water heater panels for domestic hot water. The building orientation and the shading of the openings were carefully decided considering the balance of solar gain in summer and winter. As for HVAC system, radiators for heating and cooling-dehumidification and mechanical ventilation with heat exchanger were employed. The façade consists of cladding with venting layer.

Three main differences can be identified when transferring the standard:

1. Any kind of solar technology (PV, solar thermic) is cost competitive to passive measures (insulation) at a much earlier stage. From a cost viewpoint there will be a focus on active technologies when limiting the assessment to an annual balance.
2. The envelope is affected by both energetic as hygro-thermal conditions in its design to a much higher extend than in Europe. In this case the minimal insulation thickness was 14cm out of hygro-sorptive reasons and 18cm was chosen because the customer wanted some safety and at the same time felt to set an example for better insulated houses. 18cm of insulation results in the better environmental LCA result while in terms of an economic LCC a lower insulation combined with more PV would have performed better.
3. Controlled ventilation is mandatory simply to achieve comfort in summer within the set conditions. To avoid excessive de-humidification an enthalpy exchanger is an attractive option.

4. Construction of a test house

4.1 Planning

It was decided that a building with the envelope system would be realized in Ohmihachiman (central Japan) which has a typical subtropical climate with hot-humid summer and cold-dry winter. The general design of the building was done by local architects and the technical supervision was done by the research team. The building is a detached residential building where two to four persons (two adults and up to two children) are supposed to reside. The surface of the insulation was designed to be covered with vapor-open water-tight membrane. Air-tight membrane is employed between the insulation and the structural panel. The concrete foundation was designed to have a flat surface and to be covered with asphalt sheet so that the control of heat and moisture transfer through it becomes the least intricate. The roof was based on the conventional design with air venting layer. FIG 3 shows the plan and elevation of the test house.

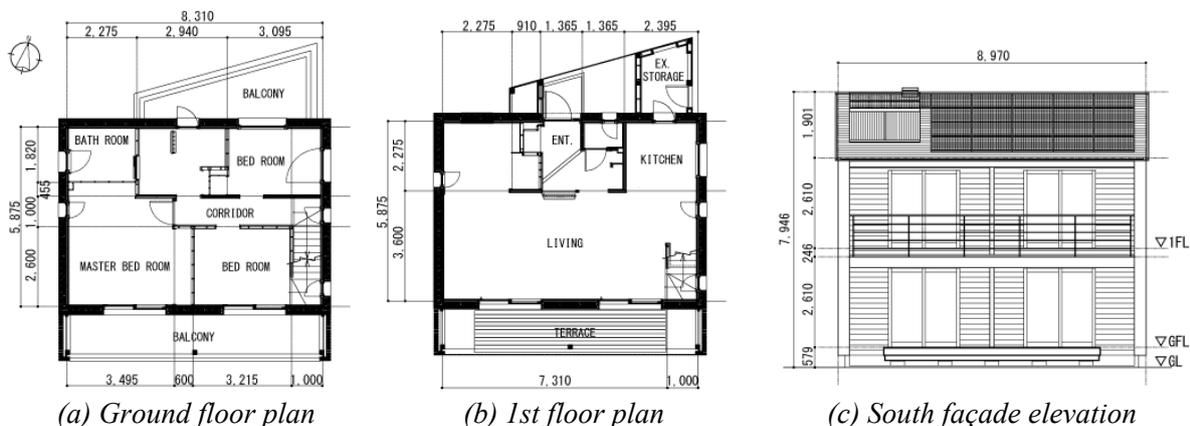


FIG 3. Plan and elevation of the test house

4.2 Construction

The structural panels were pre-cut and pre-assembled so that the work at the building site could be minimized. The assembled panels were carried in the building site on the 5th March 2013, and the building frame (floors, walls and roof) was constructed in three days. Subsequently, windows, plumbing, electric cables, insulation, housing services, façade, roofing and others were installed. FIG 4 shows the construction processes. The construction processes were carefully supervised by the research team so that no faulty works were to be done until the insulation and the water-tight membrane was completed. Because of the lack of experience with this construction system, several

significant faults were observed and modified (e.g. insufficient air-tightness at the bottom of the exterior walls between the structural panel and the insulation which would result in the direct flux of ambient air into the inside of the wall and eventually in moisture condensation).

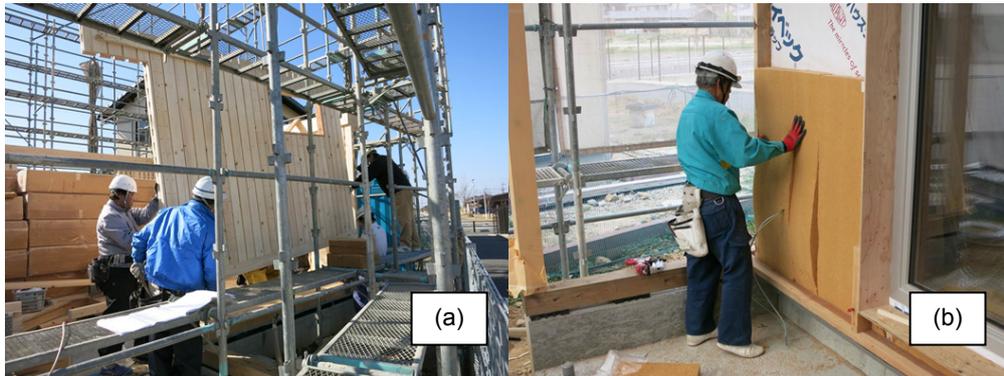


FIG 4. The processes of the construction ((a): the erection of the load bearing element (b): the installing of wood fiber insulation)

4.3 Completion and measurement set-up

The construction was completed on the 26th June 2013. FIG 5 shows the finished house.

In order to measure the indoor climate and the conditions inside the external walls, 21 temperature and humidity sensors were installed. FIG 6 shows the sensor and sensor node. The measuring points are; northern side wall on the ground floor (5 points across the wall from the living room to the exterior), living room, kitchen, northern side wall on the 1st floor (5 points from the bathroom to the exterior), west side wall on the 1st floor (5 points from the master bedroom to the exterior), northern side roof (4 points from the attic to the exterior). Figure 1(b) shows a sensor installed inside the insulation layer. The measured results are available online simultaneously. The measurement started in September 2013.



FIG 5. The completed house ((a): east side façade, (b): living room on the ground floor)

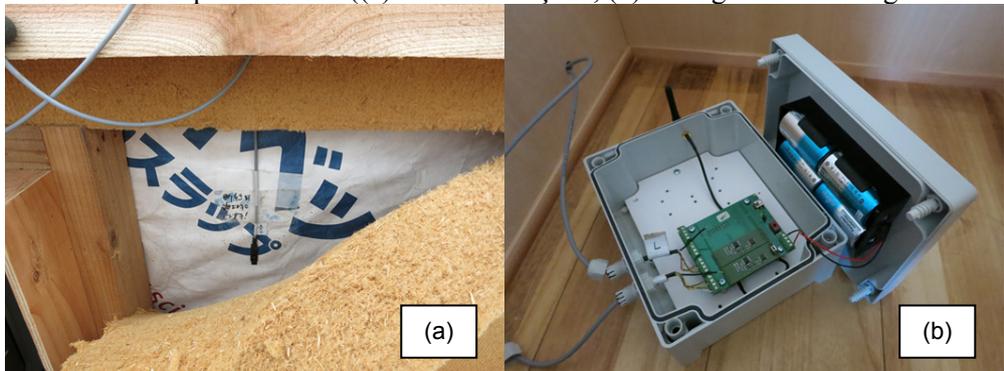


FIG 6. The installation of sensors. ((a) sensor inserted between air-tight membrane and insulation, (b) a sensor node box))

5. Result and discussion

The planning and the construction of the test house were successfully completed. Currently the monitoring is running. FIG 7 shows the temperature and humidity of the five points across the west side wall of the master bedroom (in ambient air in venting layer of the façade, inside insulation layer (80mm deep from the exterior side surface), between insulation and air-tight membrane, between structural panel and clay board and in master bed room).

Performance of the system is currently in line with the expectations but no final statement can be given yet as no full annual cycle has been recorded.

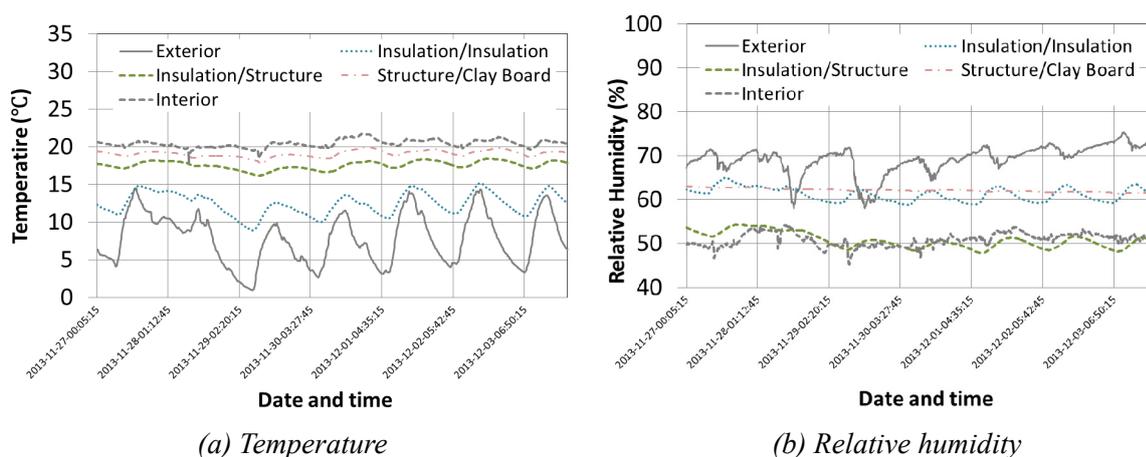


FIG 7. Sensor data for temperature (a) and relative humidity (b) for the complete wall make-up

6. Conclusions

This paper reports the designing and the construction processes of a test house in central Japan with a novel vapor-open wooden building envelope system and based on the Swiss energy label MINERGIE P®. Throughout the designing and the construction process, it was found that close communications among the designers, the constructors and the client is essential in order to realize a building with new features as it is designed. Unless the construction work is carefully supervised, the measurement of the house in the use phase might not meet what is supposed to be measured.

The MINERGIE P® label in general was found to be of sufficient flexibility to allow for feasible solutions in the Japanese climate. In order to assess whether the frame conditions of the label finally lead to cost efficient solutions that are in line with the solutions that are optimal from an environmental viewpoint the market for such concepts first has to grow in Japan.

The energetic and hygrothermal performance of the building must be validated with the measured data once sufficient data becomes available.

7. Acknowledgements

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References

- CIB. 1999. Agenda 21 on sustainable construction. Available at online <http://www.cibworld.nl/site/home/index.html> (accessed on 12/12/2013)
- CIB & UNEP-IETC. 2002. Agenda 21 for sustainable construction in developing countries. Available at online <http://www.cibworld.nl/site/home/index.html> (accessed on 12/12/2013)
- Goto Y. & Ghazi Wakili K. & Ostermeyer Y. & Frank T. & Ando N. & Wallbaum H.. 2011. Preliminary investigation of a vapor-open envelope tailored for subtropical climate. *Building and Environment*, 46(3). pp719-728.
- Goto Y. & Ghazi Wakili K. & Frank T. & Stahl T. & Ostermeyer Y. & Ando N. & Wallbaum H.. 2012a. Heat and moisture balance simulations of a building with vapor-open envelope system for subtropical regions. *Building simulation* 5(4). pp301-314.
- Goto Y. & Ostermeyer Y. & Ghazi Wakili K. & Wallbaum H.. 2012b. Economic, ecological and thermo-hygic optimization of a vapor-open envelope for subtropical climate. *Energy and Buildings* 55. pp799-809.
- Mosteiro-Romero, M. & Krogmann, U. & Wallbaum, H. & Ostermeyer, Y. & Senick, J. S. & Andrews, C.J. 2014. Relative importance of electricity sources and construction practices in residential buildings: A Swiss-US comparison of energy related life-cycle impacts. *Energy and Buildings*. 68. pp620–631.
- Passivhaus Institute. <http://www.passiv.de/> (accessed on 12/12/2013)
- Salvi, M., Horejájová, A. and Müri, R. (2008) *Minergie macht sich bezahlt*, Centre for Corporate Responsibility and Sustainability (CCRS) and Zürcher Kantonalbank, Zürich, Switzerland.
- UNEP. 2003. Sustainable building construction. *Industry and Environment*, Vol.26 No.2-3.