

ZERO-ENERGY MASS CUSTOM HOME RESEARCH INITIATIVES

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Abstract

In response to today's growing global warming issues and drastic hike of energy prices, house-builders and housing manufacturers are becoming keener on the delivery of net zero-energy sustainable homes than ever. Nevertheless, their business operation still tends to follow routines and the close system mode of operation often hinders them from exploring or adopting unfamiliar innovative building materials and approaches. The application of innovations including renewable energy technologies is, however, the key to the production of such homes. Japanese housing manufacturers has been at the forefront of mass-producing net zero-energy-cost homes. Accordingly, in order to stimulate conventional homebuilders and housing manufacturers, as well as government officers and housing researchers around the globe, knowledge transfer study visits to Japanese housing manufacturers' production and sales facilities were organised in 2006. This educational event was later called 'Zero-energy Mass Custom Home Mission to Japan' resumed in 2007, 2008 and 2010. Consequently, 4 industry participants were transformed successfully from conventional housing suppliers to early adopters of net zero energy/carbon emission homebuilders in their local contexts. Moreover, to enhance the industry-academia education and collaboration, the related research network was also established. This study showcases the significance of the mission that was aimed at putting the theory of organisational buying behaviour into practice in order for homebuilding professionals and researchers to pave the way for their further exploration and delivery of zero-energy/emission mass custom homes (ZEMCHs) in global contexts.

1. Introduction

Housing is a system of energy and environment. Homes are responsible for a great deal of carbon dioxide (CO₂) emissions that encompass the enormous impact on global warming. For instance, housing accounts for 27% of the national carbon footprint in the United Kingdom (UK) to which each dwelling unit contributes on average 3 tons CO₂ per annum. How on earth can the CO₂ emissions in housing can be reduced or eliminated over the lifecycle? Undoubtedly, the mass production and marketing of net zero carbon emission housing is the key to resolving the societal pressure. In essence, zero-energy housing falls into two categories: self-sustainable or net. The former type is a standalone house whose operational energy relies solely on its own power generation and storage so that it is disconnected from the outside sources. The latter is the one whose energy use becomes net zero over a fixed period of time. Moreover, a house whose energy bill becomes net zero under the same conditions is termed net zero-energy-cost housing. In theory, homebuilders and housing manufactures are sensitive to societal needs and demands. Yet, in reality, traditional builders generally tend to follow routines in their way of doing business and cut down information search for determining whether or not to adopt unfamiliar design challenges and innovative building materials and systems. Nonetheless, to build zero-energy/emission mass custom homes (ZEMCHs) that aim to satisfy the wants and needs of individual consumers as well as society may be necessitated to employ some innovations. Then, how can such conventional house-builders and housing manufacturers be adapted to new business operations required for the delivery of ZEMCHs, whose design, production and marketing approaches may not be akin to those to which they are accustomed? In order for conventional homebuilders and housing manufacturers to grasp new business opportunities, the 'Zero-energy Mass Custom Home Mission to Japan' knowledge transfer event was organised in view of the factors relating to industrial buying behaviour.

The following sections firstly review the theoretical aspects of 'organisational buying behaviour' with the aim to grasp the nature of the homebuilding industry. Secondly, the contents of the Zero-energy Mass Custom Home Mission to Japan knowledge transfer event organised based on the factors relating to the industrial purchase behavioural theory reviewed will be identified. Thirdly, the participants' post-mission response will be reviewed to examine the impact.

2. Industrial Buying Decision-making Factors

Housing development involves the purchase of products and services. Hence, homebuilders can be considered as industrial (or organisational) buying decision-makers who determine whether or not to subcontract out to familiar or unfamiliar sub-contractors (i.e. suppliers) who actually execute housing

projects initiated by the builders. Webster and Wind (1972) defined 'organisational buying behaviour' as: 'the decision-making process by which formal organizations establish the need for purchased products and services, and identify, evaluate, and choose among alternative brands and suppliers.' The term 'decision-making' used in this definition includes information acquisition and processing activities, as well as the development of goals and other multiple criteria to be used in choosing amongst the alternatives. The organisational buying process is complex and decisions are influenced essentially by task- and non task-related variables. 'Task-oriented' organisational buying decision models include those that emphasise task-related variables. Minimum price and lowest total cost models may well exemplify the task-oriented models with regard to monetary considerations. 'Non task-oriented' models are those that attempt to explain organisational buying behaviour based on a set of variables which have no direct bearing on the specific problem to be solved by the buying task. Non task-oriented models generally concern the emotional factors influencing organisational buying behaviour, thus disregarding the rational (or economic) factors as aforesaid. The task-oriented models may be most useful for investment justification; however, these models may suffer the disadvantages of incompleteness due to the absence of non task variables—e.g. 'perceived risk' (Schiffman and Kanuk, 1999). In general, the major types of risk that buyers somehow perceive when making a buying decision include performance risk, financial risk, psychosocial risk, and time risk.

Organisational buyers may adopt several strategies for reducing the amount of perceived risk. Firstly, the buyers may simply avoid a decision. Secondly, they may remain loyal to 'in' suppliers to maintain their 'routine' purchase. Thirdly, they may extensively gather and evaluate additional information in the search of new products or services. Fourthly, they may do business with well-known, reputable, established suppliers and this also reflects 'brand loyalty'—the term is used to describe consumers' consistent preference and/or purchase of the same brand in a specific product or service category. Webster and Wind (1972) introduced a unique approach to avoiding uncertainty in the course of the organisational buying action (i.e. 'split orders') and indicated that 'Another strategy used by organisational buyers to reduce risk is to split orders between two or more vendors, although single sourcing (especially from well-known suppliers) was found to be more common practice...' This approach may help buying organisations venture to apply more innovative products that meet their demand, whilst they can reduce risk by splitting the orders between two or more suppliers. In this case, buyers may be able to choose 'in' and 'out' suppliers not only for conventional products, but also for innovative products. The weight given to each of the suppliers for their products or services that will be purchased may vary according to the buying organisations' needs and demands for them.

A 'design charrette' approach being applied nowadays for the delivery of low to zero energy sustainable homes, which requires interdisciplinary collaborations on the design and construction decision-making (and problem-solving) activities involved, may somewhat reflect the means of alleviating organisational buying uncertainty (Onyango and Noguchi, 2009). The amount of uncertainty surrounding the purchase of a new product or service may be reduced through a series of problem-solving activities—the term 'problem solving' used in the field of consumer behaviour implies a general approach to understanding consumer decision making and it focuses on consumers' cognitive representation of the decision as a problem. Important aspects of the problem representation include consumers' end goals, sub-goals and relevant knowledge. Consumers construct a decision plan by integrating their knowledge within the constraints of problem representation (Peter and Olson, 1996). However, the type of problem solving adopted depends on the task at hand. In short, it is classified into two buying situations: programmed and non-programmed (Fig.1). A 'programmed' decision reflects a habitual (or routine) purchase, and it may lead almost immediately to a purchase, whilst a 'non-programmed' decision may require more time (which can be also considered as a cost relating to the search) for the acquisition and processing of information on a product to be purchased (Blythe, 1997). Information search usually comes from an internal search from memory and an external search from outside sources. The extent of the external search for information depends on a range of factors that are connected with the buyer's situation, the value and availability of the information, the nature of the decision being contemplated, and the nature of the individual.

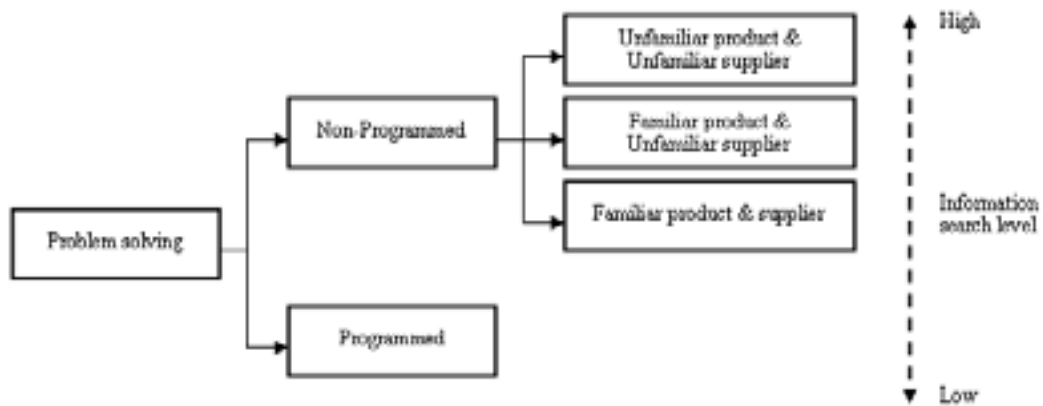


Fig. 1: Classification of problem solving (Noguchi 2008a)

3. Zero-energy Mass Custom Home Mission to Japan

There is a tendency for house-builders to rarely adopt or buy new products and services that to some extent interrupt their business operation that is often based on routine. However, the routine has been streamlined to a point at which homebuilders achieve great efficiency of their activities. Roberts (1970) emphasises that ‘working drawings’ are extremely simplified because craftsmen know how to carry out their task, based on traditional construction techniques and housing ‘specifications’ are also brief, because the designers know that craftsmen know how to fit materials together. In general, homebuilders tend to restrict their information search to the programmed decision, since the search for information for non-programmed decisions take too much time, money and effort (Noguchi, 2008a). Therefore, to open the gate for conventional homebuilders and housing manufacturers to consider the future production of their own net zero energy/emission sustainable houses, the ‘Zero-energy Mass Custom Home Mission to Japan’ was initiated by the first author of this paper. In Japan, a total of 1,093,485 houses were newly built in 2008 and amongst them, 154,271 homes, or 14.1%, were estimated to be prefabricated (JPA, 2010). Moreover, the housing manufacturers have been successful in commercialising their industrialised houses that are often equipped with renewable energy technologies, e.g. photovoltaic (PV) power generation and air-source heat pump systems, as standard features rather than options (Noguchi and Collins, 2008). This quality-oriented production approach reflects their high ‘cost-performance’ marketing strategy (Noguchi, 2003). Between 1994 and 2003, the number of domestic PV installations in Japan drastically increased from 539 to 52,863 houses. To alleviate the eccentric appearance of their contemporary PV solar homes, Japanese manufacturers tend to well integrate the cells into the roofing and façade materials (Fig.2).



Fig. 2: ‘Wa no Nagomi’ zero energy cost house in Japan (Source: SANYO Homes Corp.)

In 2005, CANMET Energy Technology Centre (called ‘CanmetENERGY’ today)—Varenes, Natural Resources Canada, appointed Dr. Masa Noguchi as the coordinator of the ‘Japan Solar Photovoltaic Manufactured Housing Technical Mission 2006.’ Later, Prof. Roger-Bruno Richard, the University of Montreal, was also invited to operate the Canadian mission which required English and French translation.

The knowledge transfer event was held from 20th to 23rd February, 2006, with the aim to provide Canadian homebuilders, housing manufacturers, building component suppliers, architects, academics, and government officers with opportunities to explore not only the state-of-the-art production facilities of the then four leading net zero-energy-cost housing manufacturers in Japan, i.e., Sekisui Chemical Co. Ltd., Misawa Homes Co. Ltd., PanaHome Corp., and SANYO Homes Corp., but also a sales centre that displays a variety of Japanese manufacturers' housing prototypes (Richard and Noguchi, 2006). Based on the past experience, from 3rd to 5th September, 2007, the educational event was reorganised by MEARU, Mackintosh School of Architecture, The Glasgow School of Art, in collaboration with the Centre for the Built Environment in the UK. Then, it was renamed to 'Zero-carbon Mass Custom Home Mission to Japan' and added a visit to Sekisui House Ltd. which had been committed to the development of a zero carbon emission house towards the exhibition during the G8 Hokkaido Toyako Summit that was expected to be held in the following year— N.B. the profiles of each company visited during the knowledge transfer event will be described in the following sections. In 2008, the title was again changed to 'Zero-energy Mass Custom Home Mission to Japan' and was held from 10th to 12th September. In the same year, the mission was organised as one of the Renewable Energy 2010 international conference's related educational events and was held successfully from 23rd to 25th June, 2010. In addition to the company visits, a post-mission strategic 'Zero-energy Housing' workshop was also executed within the conference programme, where 20 delegates from Australia, Brazil, Canada, Italy, Korea, Portugal, Sweden, UK and USA were invited as panellists to report the mission outcomes and discuss actual and potential issues arising in the delivery of ZEMCHs around the globe today. The workshop helped establish the forum of interactive discussion on design, production and marketing approaches to such homes and solidify diverse individual experiences into universal knowledge.

3.1. Company Profiles

During the Zero-energy Mass Custom Home Mission to Japan event, the participants were given opportunities to scrutinise innovative design, production, and marketing techniques being applied to the commercialisation of low to zero energy sustainable homes in Japan. In addition to the five ZEMCH manufacturers, as described above, the 2010 mission also extended the scope and arranged another visit to the showroom of a building material and sanitary system manufacturer. The company profiles will be summarised in the following sections so as to highlight their distinguishing features.

INAX Corp.: Since 1924, INAX has pioneered a number of industry innovations including the first Japanese shower toilet and the world's first self-powered, automatic water faucet. The company is based in Tokyo, Japan, employing 15,861 workers (as of March 31, 2009). INAX manufactures and supplies building materials, tiling and sanitary fixtures applied for residential, commercial and public buildings and facilities. The company is considered as a practitioner of 'mass customisation' when designing their modularised bathroom unit in compliance with customers' choices of the standard decorative and functional components given. Miniature bathroom models accompanied by a set of the options are utilised to mass-customise the unit with the aim to accommodate the user demands, requirements and expectations (Fig.3). Most clients visit their showroom a few times to understand the value of product quality and decide a particular bathroom style available for their further design arrangements. However, once the style is determined, the bathroom unit design can be completed within 2 hours using the relevant mass-customisable miniature model.



Fig. 3: Miniature bathroom unit model for ceramic wall tile and bathtub selections (Source: INAX Corp.)

Sekisui Chemical Co. Ltd.: Locally, the company is called 'Sekisui Heim' that derives from the name of Japan's first modular house that they built in 1971. Sekisui Chemical is aiming to develop business that

focuses on the production of high performance and value-added housing products where their modular construction system technologies are brought into effect. In general, modular housing systems ensure a high level of in-factory completeness of housing components. The company claims that nearly 80% of housing components used for building a house can be assembled at their factory. Today, Sekisui Heim possesses 8 factories nationwide which have the capacity for producing wood- and/or steel-frame modular homes through their highly mechanised assembly lines (Fig.4). Moreover, given the cumulative sales of over 85,000 solar homes to date, the company is also recognised widely as the largest modular manufacturer of net zero-utility-cost housing in Japan.



Fig. 4: Sekisui Heim production line (Source: Sekisui Chemical CO. Ltd.)

Misawa Homes Co. Ltd.: Founded in 1967, the company is headquartered in Tokyo, Japan. Misawa Homes, together with its subsidiaries, engages in the development, construction, and marketing of prefabricated mass custom homes and housing materials. Their house is also constructed based on 3-dimensional modules consisting of rigid steel frames. Yet, their homes are characterised by the use of large-sized non-structural ‘precast autoclaved lightweight concrete’ (PALC) panels that the company produces (Fig.5). Misawa Homes started business operations upon acquisition of the housing industry’s first certification from the then Ministry of Construction in 1962. The company spread a ‘Home Core’ design concept by building the demonstration homes in Abu Dhabi, UAE in 1968. Afterwards, Misawa Homes put 1-million JPY Home Core houses on the local market in 1969 and the concept was well exhibited at Expo ‘70 in Osaka. In 1980, the company commenced with research on the development of its own zero-energy housing prototype and in 1998, it successfully commercialised Japan’s first zero energy homes.



Fig. 5: Precast autoclaved lightweight concrete panels (Source: Misawa Homes Co. Ltd.)

PanaHome Corp.: Since 1963, PanaHome, formerly called ‘National House industrial Co. Ltd.’, has been operating as a housing company within Panasonic Group. Yet, the group’s housing business itself actually

dates back to the introduction of its first house prototype called ‘Matsushita Type-One Housing Units’ in 1961. Then, the Koto Plant (present Head Plant) also opened in Shiga Prefecture. Today, PanaHome produces steel-frame panels applied to their industrialised mass custom homes through highly automated production lines. In line with their state-of-the-art automation system, the company has also been at the forefront of solar community developments. In fact, the PanaHome City Seishin Minami housing estate in Hyogo Prefecture was selected as one of 100 excellent regional projects that introduced new types of energy hosted by the Ministry of Economy, Trade and Industry, and the New Energy and Industrial Technology Development Organization (Fig.6). Afterwards, their proposal was also adopted in a scheme, which was led by the Ministry of Land, Infrastructure, Transport and Tourism, and entitled ‘Initiative Model Project for Developing Long-Life Houses.’



Fig. 6: PanaHome City Seishin Minami housing estate in Hyogo Prefecture (Source: PanaHome Corp.)

SANYO Homes Corp.: The forerunner of SANYO Homes Corp. is ‘Kubota House Co. Ltd.’ which was established in 1969 and won the first place for ‘the 1st Pilothouse Technique Invention Competition’ held in 1972 by the then Ministry of Construction in Japan. In 2002, the company was renamed to ‘SANYO Homes’ as it became owned by SANYO Electric Co. Ltd. Today, SANYO Homes emphasises that housing should be gentle to people and the earth, stemming from the company’s business concept of an ‘Eco & Safety’ life that aims to enhance their housing performance as to local power generation, energy-efficiency, earthquake resistance and emergency measures. In 2004, SANYO Homes received a ‘Good Design’ award with their housing prototype called ‘Logia-Type E’ which had a simple cubical exterior appearance designed based on a minimalism concept for space use efficiency. The company is thriving in their mass custom homes’ architectural integration with SANYO HIT solar cells that have the world’s highest energy conversion efficiency of 23% (Fig.2). The company also introduces solar water heating panels to their homes equipped with an air-source heat pump, which aims to control and secure the supply of domestic hot water according to weather conditions.

Sekisui House Ltd.: In 1960, the company incorporated with the capital stock of 100 million JPY, stemming from the housing division of Sekisui Chemical Co. Ltd. Today, Sekisui House is recognized as the largest housing manufacturer in Japan given the cumulative sales of 2,001,722 homes estimated as of 31st January 2010. The company is committed to taking the initiative in developing zero CO₂ emission housing based on the company’s ‘Action Plan 20’ that aimed to introduce a variety of energy-efficient housing measures (Ishida 2008). In conjunction with the G8 Hokkaido Toyako Summit held from 7th to 9th July, 2008, Sekisui House announced their so-called ‘Zero Emission House.’ The house was a single-storey steel structure prefabricated house with a total floor area of approximately 200m², featured particularly by a 14.5kWp capacity photovoltaic power generation system, energy efficient lighting, a household fuel cell, and energy saving domestic appliances. Moreover, in order to assist clients in understanding the value of their products, Sekisui House opens the home amenities experience studio, called ‘Nattoku Kobo,’ to the general public. The studio provides a variety of information on housing functions and performances such as lifetime barrier

free design, home security, earthquake and typhoon resistance, energy and space use efficiency, and local power generation (Fig.7).



Fig. 7: 'Nattoku Kobo' home amenities experience studio (Source: Sekisui House, Ltd.)

The housing manufacturers' communication approaches derived from their cultural context where 'customer satisfaction' is of utmost concern. Prior to entering into a contract with their clients, the manufacturers offer an extensive amount of information in order to motivate consumers to learn more about the company's products and services during the buying decision-making process. Today, in response to the market demands for design customisability of housing and the societal needs for sustainable development, Japanese manufacturers tend to produce high cost-performance homes (Noguchi and Collins, 2008). In order to enhance clients' motivation for purchase of high cost-performance housing, the manufacturers have been practicing three principal communication approaches to dealing with homebuyers: (1) advertisement, (2) Education, and (3) Value assurance (Noguchi and Friedman, 2002). Their communication approaches applied to each stage of their marketing efforts are proven to be influential in the enhancement of customer satisfaction. The JPA (2008) unveiled an annual survey of consumer preferences in the purchase of industrialised housing in Japan. The survey indicates that the perceived high quality of industrialised housing was the utmost significant factor that attracts potential buyers (Table 1). In fact, 22% of the purchasers that replied to this survey said that their primary factor influencing their buying decision was the 'reliability' of the large-scale housing company which somewhat reflects the 'brand name' effect on the sales. 18% of the buyers preferred to live in an industrialised house due to the higher levels of housing performance. Ranking next to them, 17% of the homeowners responded that they purchased an industrialised house because it was designed to be earthquake-resistant. 15% of the buyers preferred the factory-built home since they were well convinced of the sales staff's explanation as to the product features and the company's services offered to their clients before and after occupancy. These results suggest that homebuyers in Japan tend to consider the quality of housing to be the top priority, whilst the selling price is less of a consideration. Only 2% of the buyers regarded the total price of industrialised housing as relatively low. In other words, Japanese consumers venture to purchase an innovative industrialised house, whose price is higher than the site-built one, if convinced of the superior housing quality.

Japanese housing manufacturers produce marketable and reproducible low to zero energy mass custom homes that aim to meet the wants and needs of individuals as well as society. The 'mass custom design' approach may theoretically achieve a high level of standardisation of housing components that homebuyers can directly select in planning their new home, whilst the user choices of the mass-producible standard components paradoxically increases the level of design customisability (Noguchi and Hadjri, 2009). Thus, it contributes to reducing design and production costs by achieving the economies of scope, whilst helping to customise a house in consideration of the buyer's economic constraint (Noguchi and Hernández, 2005). Yet, Japanese housing manufacturers may use the money, which could be saved from lowering design and production costs through mass customisation, for equipping homes with luxurious standard equipment; thus, this, in turn, upgrades housing quality and distinguishes their products from conventionally built houses. In fact, the manufacturers today tend to install a variety of amenities including PV and air-source heat pump systems as standard features rather than options and emphasise that they have been producing better-quality homes for about the same price as conventional ones (Noguchi and Collins, 2008).

Tab. 1: Buyers' motivation to purchase industrialised housing in Japan

MOTIVATION FACTORS SELECTED	YEAR 2008
Reliability of the large-scale company	22 %
Superior product quality and performance	18
Earthquake resistance	17
Convinced by the sales persons' explanation	15
Good post-purchase services	2
Good design	4
Customisation according to needs and demands	5
Reliable safety measures	0
Short construction time	2
Wide variety of equipment selections	1
Confirmed by visiting housing exhibitions	1
Consideration of environmental issues	1
Recommendation from acquaintance	3
Relatively low price	2

4. Post-mission Industry Response

As per the post-mission feedback, most delegates who participated in the past 'Zero-energy Mass Custom Home Mission to Japan' educational events expressed their positive impression on Japanese manufacturers' systematic and innovative way of commercialising low to zero energy prefabricated homes (Richard and Noguchi, 2006). A number of the participants admitted that Japanese housing manufacturers, which they visited, were all large-scale enterprises and might be able to invest heavily in developing their own design, production and marketing approaches to their industrialized homes equipped with luxurious renewable energy technologies. The feedback led to an argument that small- or medium-sized homebuilders and housing manufacturers, such as mission industry delegates, hardly spend extra time, money and effort for R&D or apply Japanese manufacturers' approaches to mass-producing ZEMCHs without scaling down the extent. Notwithstanding remaining concerns over innovations including the applicability of costly renewable technologies, four companies (i.e. Alouette Homes, Tenants First Housing Co-operative, ROBERTRYAN Homes, and NRGStyle) who attended the knowledge transfer event held in 2006, 2007, 2008, and 2010 raised motivation and took the initiative to deliver ZEMCHs in their local contexts. The following sections will describe the companies' challenges, aspirations and achievements.

4.1. Alouette Homes: The ÉcoTerra House

Alouette Homes is a panelised and modular housing manufacturer based in Quebec, Canada. The company attended the first mission held in 2006. Immediately after the factory visits in Japan, the company considered the actual production of PV solar housing in Canadian contexts. In fact, receiving support from external zero energy housing experts including Dr. Masa Noguchi as the housing design lead and Prof. Andreas Athienitis as the engineering lead, the manufacturer developed its own near net zero energy house prototype, later called 'ÉcoTerra house' (Fig. 8). The house is a single detached home built on a 1.1 hectare rural lot of a new mass housing development in Eastman, Quebec (Noguchi, 2008b). The floor area of this house is 141m² and 2 bedrooms are located on the first floor and semi-private spaces, such as a kitchen, dining room, and sunspace family room/lounge, are on the ground floor. A semi-basement was introduced to this project, serving as a multifunctional space and machine room. The total heated floor area of the house was estimated at 234m³ and the heated volume at 671m³ including the basement. The house was constructed by making use of Alouette Homes' pre-engineered modular housing system that helped eliminate or reduce on-site construction nuisances, such as bad weather, theft and vandalism. A closed garage is located on the north side of the house being attached to the façade; thus, it somewhat functions as an air buffer space that reduces

the fabric heat loss. The south wall is fitted with generous south-glazing. The window area of the south, west, east and north walls were estimated at 20.90m², 5.20m², 6.67 m² and 0.65 m², respectively. The south-glazing to floor ratio is 9.1%. The glazing areas allocated to the exterior walls of this house were designed to ensure the comfortable level of natural day-lighting and reduce the total amount of electricity required for artificial lighting. In the ÉcoTerra house, a 3kWp building integrated photovoltaic thermal (BIPV/T) system was installed. The PV array of the BIPV/T system is comprised of 22 amorphous silicon 136W laminates placed on the 55m² (5.8m x 9.5m) south-facing metal rooftop. The potential annual electricity production was estimated initially at approximately 3,420kWh when the roof faces is sloped at 30.3°. The air under the PV panels is heated by solar radiation, drawn into the lower portion of the house from the roof ridge ducted. The BIPV/T system introduced to the ÉcoTerra house contributes to the drastic reduction of energy consumption for heating the space and water in addition to the alleviation or elimination of an electric clothes tumble dryer use. With due consideration of the utilisation of the advanced renewable energy technologies combined with passive solar techniques applied to the ÉcoTerra house, the annual space energy consumption would become as low as 1,130kWh. The electricity used for domestic hot water reduced from 3,353kWh to 553kWh as a result of the contributions of the heat pump desuperheater, BIPV/Thermal system and drain-water heat recovery unit. As for the energy consumption of indoor lighting, appliances and exterior use electrical equipment, it was decreased from 3,975kWh to 3,275kWh with the reduced energy load for an electric dryer. Subtracting the expected PV electricity generation of 3,420kWh from the sum of these figures, the annual energy consumption of the ÉcoTerra house can be re-estimated at 2,155kWh.



Fig. 8: The ÉcoTerra house by Alouette Homes

In 2006, Alouette Homes entered the house in the ‘Equilibrium’ sustainable housing competition that had been run by the Canada and Mortgage and Housing Corporation (CMHC). On 13th February, 2007, the Canadian government unveiled the finalists of the competition (CMHC, 2007). In total, 12 homebuilder teams were originally selected out of 72 entries and the Alouette Homes’ ÉcoTerra house was also included in the list of the winning projects. On 9th November, 2007, the grand opening of the ÉcoTerra house was held at the construction site in Eastman, Quebec, where the Honorable Christian Paradis, who was the then

Secretary of State, made the inaugural address and congratulated Alouette Homes on the successful completion of Canada's first near net zero energy home built and commercialised through the federal government's EQuilibrium sustainable housing initiative.

4.2. Tenants First Housing Co-operative: ZEMCH Donside Urban Village

In 2000, Tenants First Housing Co-operative was formed through the amalgamation of 6 separate Housing Co-operatives, based in Aberdeen, Scotland. The original co-operatives were set up in response to the Housing Act 1988. Today, it possesses over 1,300 properties being recognised as the largest Fully Mutual Housing Co-op in the UK. Tenants First Housing Co-operative attended the Zero-energy Mass Custom Home Mission to Japan in 2007 and 2008. Following the success of the 2006 mission delegate's ÉcoTerra house project, the company decided to construct low to zero emission affordable homes in consideration of social, economic and environmental sustainability in Scottish housing. Accordingly, the three-year R&D project was developed launched on 27th May, 2009. Since then, this £1.5million eco-housing project has been carried out in partnership with MEARU, Mackintosh School of Architecture, The Glasgow School of Art, and supported partially by the UK government through the Knowledge Transfer Partnership program. The first design workshop for determination of the site plan was held on 23rd November, 2010, and the charrette for development of the intermediate housing unit design was organised on 18th and 19th May, 2011. The project documents are currently reviewed by local authorities to secure the construction in 2012.

4.3. ROBERTRYAN Homes: Z-en House

ROBERTRYAN Homes is the marketing name for Ayrshire based RDK Construction and RobertRyan Timber Engineering. RDK Construction Ltd. was founded in 1992 and today, it is recognised as one of the National House-Building Council registered builders in the UK. The company is owned by Scottish brothers, Billy and Robert Kirkwood, and both attended the Zero-carbon Mass Custom Home Mission to Japan held in 2007. Afterwards, the former became one of the ardent industry advocates of zero carbon homes through the Scottish Building Federation, where he was serving as the President in 2007. In 2010, ROBERTRYAN Homes unveiled their attempt to construct their net zero energy housing prototype called 'Z-en house' (Fig.9). The research has been undertaken in partnership with MEARU, Mackintosh School of Architecture. The house will be designed to optimise passive solar gains, yet heated mechanically using energy sources characterised by low CO₂ emissions. The performance of a solar photovoltaic thermal mechanical ventilation heat recovery (PV/T MVHR) system has been studied in collaboration with Prof. Mitsuhiro Udagawa, Kogakuin University, Japan. The PV/T MVHR system is relatively new to the UK housing industry and it will be applied to the Z-en house in order to lower the energy load for heating the habitable space and to generate electricity at the same time.



Fig. 9: The Z-en house, ROBERTRYAN Homes (Source: MEARU Mackintosh School of Architecture)

4.4. NRGStyle: ZEMCH Prestwick

NRGStyle is a newly established consulting company where one of the co-directors attended the Zero-carbon Mass Custom Home Mission to Japan held in 2010. The company is currently aiming to build a zero-emission end-terraced housing extension in Prestwick, which will be featured by the installation of wind turbines and a PV/T MVHR system (Fig.10). In partnership with MEARU, Mackintosh School of

Architecture, the conceptual design was developed and the project documents are currently reviewed by local authorities for acquisition of the planning permission. As an industry partner of ‘ZEMCH Network’ that will be identified in the following section, this project will serve as one of the network’s demonstration houses, where the post occupancy evaluation of the domestic energy consumption will be carried out in collaboration with ZEMCH Network academic partners including Dr. Hasim Altan, BEAU, the University of Sheffield.



Fig. 10: ZEMCH Prestwick, NRGStyle (Source: NRGStyle)

5. Post-mission Academic Response

Albeit increasing market demands for achievement of social, economic and environmental sustainability in housing, conventional homebuilders and housing manufacturers particularly in Europe and North America still tend to follow routines in their business operation for the reason described above; thus, they tend to be reluctant to spending extra time, money and effort for information gathering of innovations. In fact, some of the industry delegates, who attended the Zero-energy Mass Custom Home Mission to Japan, also criticised the tendency during the post-mission strategic meetings, as described above. Accordingly, in view of the feedback, the ‘ZEMCH Network’ was established immediately after the execution of the 2010 mission. As the founding partners, the network initially comprised the academic mission delegates, aimed at serving as a source for promotion of the ZEMCH research, practice and demonstration, stimulation of the industry-academia information exchange, and collaboration on publications. Currently, the network is in the process of organising the ZEMCH 2012 international conference that will be held at The Glasgow School of Art in September 2012. Then, as the technical tour, the conference attendees will be invited to visit some of the aforementioned ZEMCH building sites. In addition to the conference organisation, the network is also developing the 2013 ZEMCH edition of the ‘Open House International’ journal in collaboration with national experts of the International Energy Agency’s jointly implementing programmes: Solar Heating and Cooling (SHC) Task 40/Energy Conservation in Buildings and Community Systems (ECBCS) Annex 52. Moreover, the Mackintosh School of Architecture recently validated a new ZEMCH postgraduate course that aims to engage with ZEMCH Network’s interdisciplinary research and educational activities.

6. Conclusions

Given the theoretical issues of industrial buying behaviour, conventional housing suppliers seem to be unwilling to pay for information and to restrict their information search to the programmed decisions. That is because the search for information needed for the non-programmed decisions of whether or not to purchase unfamiliar innovative design and construction systems takes too much time, money and effort. Nonetheless, the application of innovations including renewable energy technologies nowadays has the potential to help them deliver zero energy/emission mass custom homes (ZEMCHs) that correspond with the global market demands—i.e. social, economic, and environmental sustainability in housing. Therefore, to change their perception to such innovations, housing suppliers should be given educational opportunities that help them comprehend not only the excellence in technicalities but also the profitability. To open the gate for them to grasp the new business opportunities, the ‘Zero-energy Mass Custom Home Mission to Japan’ knowledge transfer event was organised in 2006, 2007, 2008 and 2010. Consequently, it helped transformed four industry participants in North America and Europe from conventional housing suppliers to early adopters of ZEMCHs in their local contexts. Moreover, the mission led to the establishment of ZEMCH Network that aims to solidify today’s dispersed knowledge and diverse individual experiences into universal expertise that can be taught and examined rigorously at academic institutes and turned into the practice.

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