Passive House Construction – What is the Difference Compared to Traditional Construction?

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Abstract: For some years an intense debate regarding the building costs has been ongoing in Sweden and reducing construction costs is highly prioritised among the construction companies. At the same time, passive houses have started to appear on the Swedish market and so far the construction costs for these have been higher compared to tradition1al houses. It is therefore important to investigate the construction methods to find out where to focus and where to improve the process so the energy performance can be increased while at the same time construction costs can be reduced. Based on an interview study with construction site managers, seven key areas could be identified which were different compared to traditional housing; system design, building documents, construction planning, working methods, quality control, leadership and attitudes. Projects that were successfully accomplished from an economical and productivity point of view had been planned with special focus on these aspects. In the less successful projects, the importance of the understanding of the concept had been ignored and underestimated which led to additional time consuming activities which could be described as waste of time. There is a need to find alternative production methods which prioritize the product quality in an integrated and efficient manner.

Keywords: Energy efficiency, construction efficiency, passive houses.

INTRODUCTION

Two main areas of the construction industry are currently in focus: energy efficiency and construction efficiency. Energy efficiency refers to the lifecycle performance of the building and is mainly driven by increased energy prices as well as expected climate change. Construction efficiency refers to reducing inefficient working operations, material costs etc. In order to improve construction efficiency, many companies standardize their production at different levels and/or they develop their own building systems or technology platform [1-3]. The main stream building systems available on e.g. the Swedish market today provides an energy performance that meets the current regulations but not much more than that. Furthermore, in many cases the energy performance targeted in design is often not met in the finished buildings due to uncertain prediction methods and lack of quality in the construction process [4, 5]. Generally, the construction market has been too much focussed on minimizing the initial construction cost and optimisation of life cycle costs has not been prioritised. As a result, energy performance has so far not been highly prioritised in the development of building systems and construction productivity.

However, low energy houses have since a few years back appeared on the market driven by increased energy prices. The debate whether the energy regulations should be more strict is an ongoing process. Furthermore, the awareness among clients and end-users has grown and the energy prices are predicted to increase further, and there is now a significant demand on the market for more energy efficient houses. [6-8].

This has led to the introduction of so called passive houses. The basic idea of the passive house concept is to improve the thermal performance of the building envelope to a level where the heating system can be kept very simple [9-11]. Passive houses are hence built with a well insulated and airtight envelope, together with a mechanical ventilation system with heat recovery [12, 13] External supply of heat energy is needed only occasionally and is supplied through electrical heating of the inflowing ventilation air. This means that radiators for heating are not installed in passive houses in contrast to what is common in traditional buildings in colder climate. In principle so far, passive houses are rather similar in technical design to standard buildings and can be produced with products now available on the market [14. 15].

But the question is how this concept affects the traditional housing construction process in practice. When the building industry aspires to cut construction costs and at the same time build low energy houses, the question is whether the current construction methods are the most efficient or if we need to change the building process in order to achieve a rational and cost efficient construction where energy efficiency issues are integrated? The purpose of the present paper is to investigate how traditional construction activities are affected when the product is aimed at passive house standard, in order to identify problems, differences and prerequisites. To start with, a brief description of the present building process is made, with focus on the construction process, to obtain an overall view of the current status.

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THE BUILDING PROCESS

The building process considered here consists of all activities from the origin of the idea to the handover of the building to the client [16]. It can be divided into five main phases namely the program phase, the project planning phase, the construction phase, the sales phase and the handover phase [17]. To set the scene for the upcoming work, these phases are briefly described.

The building process in Sweden, where the present investigation was made, starts with the program phase, where the clients' needs are identified and summarized. The point of departure is the intended use of the building and the expected activities. The space needed for these activities is investigated, how many rooms are needed etc. Technical and environmental investigations are executed as well. The results from these investigations are then gathered in a building program that describes the building with respect to the needs of the client.

The next step is the project planning phase, where the building program is translated into more detailed descriptions. The project planning phase refers to creating the building in the form of construction drawings and descriptions. Based on this information, the building is later constructed, sold and handed over. Fig. (**1**), schematically, shows the different comprehensive phases within the building process. The process varies slightly depending on when and where the purchasing of tender is carried out. If the client does the tendering after the program phase, the contractor will take over and do the project planning as well as the construction; hence the form of the process varies depending on when the contractors are invited.

THE CONSTRUCTION PROCESS IN TRADITIONAL ON-SITE HOUSE CONSTRUCTION

Following the project planning phase, the construction phase starts. Before the construction can start, the contractor needs to procure construction facilities and arrange a "temporary factory" on site. Portable cabins for the staff, temporary supply system for electricity, water and sewer, lift, transport and other mechanical equipment are needed. This procedure is called the construction site establishment.

Then, the construction itself begins. At this stage, for a new building, six activities can be identified, see Fig. (**2**). The ground works start with excavation to prepare for the foundation structures and external pipes etc and ends with planning the landscape. Hence the ground works continues through the whole construction phase in intervals. However, when the ground work for the foundation is ready the foundation work begins. Most commonly, an insulated, reinforced concrete slab is used as building foundation.

Fig. (1). Phases within the building process.

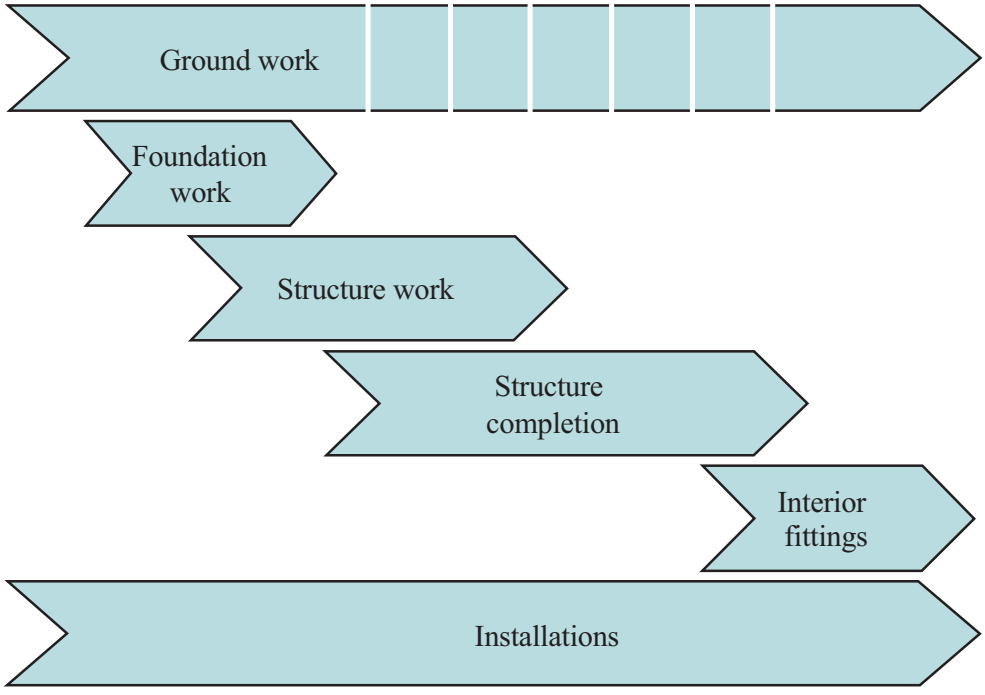

Fig. (2). Activities in the construction phase.

The next activity is the load bearing structure, which can be produced in different ways. It can for example be made of concrete, wood or steel and it can be prefabricated or made on site. After finishing the load bearing structure, the completion phase starts. This phase can be divided into two parts, exterior completion and interior completion. The work with the exterior completion implies working with finishing the building envelope and therefore operations involving the facade, roof, windows and doors etc are included in this activity. Following this activity, or as soon the building is weather proof, the work with the interior completion begins. The interior completion implies finishing the interior surfaces, interior walls, floors etc. In all, the completion activity consists of a number of different work operations and is ongoing from the structural works almost until the building is finished. The most time consuming activity is the installation works which are ongoing from the beginning to the end of the construction phase consisting of all from external tubing to the installation of control systems. The activity that ends the construction phase is the interior fittings which include installations of wardrobes, cabinets, shelves, mirrors as well as kitchen appliances.

WASTE IN THE CONSTRUCTION PROCESS

For some years, an intense debate regarding the building costs has been ongoing in Sweden. Statistics indicate that the cost of producing buildings has increased heavily during the last years, in fact, the building costs increased by an average of two times the increase in consumer price index, from 1989 to 2006 [18]. In relation to this ongoing debate, a Swedish report [19] about waste, i.e. activities that consume resources but creates no value for the customer [20], within building projects was published. The authors argue that irrespectively how costs have changed over time or how they hold in an international comparison the participants in the construction process carry out a lot of activities that do not add value to the product and hence not to the customer. The survey shows that 30–35% of the projects construction costs are generated by waste. The report divided waste into four different main groups;

- Errors and control; the cost for visible and hidden errors is large as well as the cost for unnecessary control activities, insurances, burglaries and damages. Waste within this group is about 10% of the construction cost.
- Utilization of resources; this group refers to usage of working time, machines and building material and hence contains waiting, inactive machines and material spillage. This waste corresponds to more than 10 % of the projects construction costs.
- Health and security; the waste due to working related injuries is so great that it has its own group. The biggest share of the cost is in rehabilitation and early retirement and burdens the projects indirectly by increased taxes. The waste within this group is about 12 % of the projects construction cost.
- Management system and organizational structure; this includes for example protracted detailed development plan process, complex procurement process and extensive documentation. The waste corresponds to 5 % of the construction cost.

The report suggests that the building industry should aim to reduce the building cost by half in a long term perspective and concludes that the elimination of waste is the greatest and the most prioritised challenge for individual construction companies as well as for the whole industry.

METHOD

The passive house concept as such has been investigated extensively and is described in the international literature as mentioned in the introduction. However, very little information can be found about construction and production methods for passive houses. These aspects are addressed in the present paper, and to investigate how on site construction of a passive house differs from traditional construction a series of in depth interviews were carried out. The interviewees were construction managers with experience from passive house projects. The reason to interview only construction managers was because they have a good overview of the project, both in the planning phase and in the construction phase. Six recent Swedish projects were selected. Since the concept of passive houses is quite new in Sweden only nine finished projects were available at time of the investigation. The ambition was initially to investigate all these projects, but three of them were omitted. In one case the company responsible for the project did not want to participate, and in one case – the very first Swedish passive house project – the construction had been completed 6 years before the investigation. The authors considered this time lag to be too long to monitor the details in the construction process in a reliable way. The third project was omitted due to practical difficulties to arrange the interview. The interviews, on average, took two hours and included 32 main questions, excluding following up questions. The questions were grouped into the following five categories:

- Company structure, market orientation and general overview of the project; the interviews started off with questions related to facts about the company, their market orientation as well as facts about the actual project. The starting questions were helpful afterwards, when analysing the result, because the answers to some questions depended on factors like size of the company etc.
- Details of the building design; subsequent questions treated more in detail the design of the building, as the layout of the building envelope, loadbearing structure and installation systems. This also gave an overview and input for the analysis of the result.
- Differences between traditional construction and passive house construction; further on, questions about differences in building a passive house compared to traditional houses were asked as well as the interviewee's thought of the interaction between energy efficiency and construction efficiency today. This category contained a wide spectrum of questions, from conceptual differences in the planning- and construction phase, down to more detailed questions about installations, technical solutions, technical drawings, working methods, leadership, attitudes etc. Problems occurring during construction were also discussed as well as methods to control the quality of construction operations.

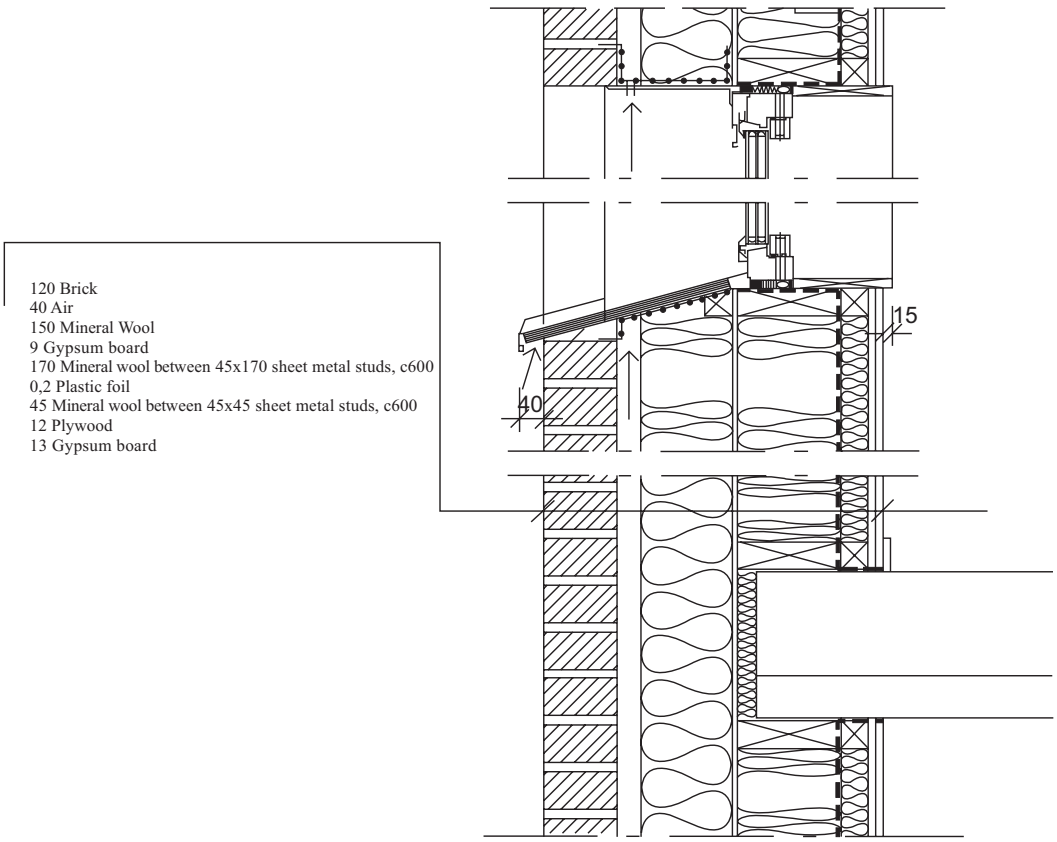

Fig. (3). Exterior wall from one of the projects.

- Examination of the concept; these questions focussed on the manager's opinion about the passive house concept itself, critical technical solutions, time and costs.
- Concluding questions; finally, the managers were given the opportunity to describe what they would have done differently if they now would start another passive house project.

Before the interviews were conducted, the list of questions was discussed in detail and revised in collaboration with a reference group consisting of ten persons with long experience from the construction process as well as specialists on low energy housing. All the interviews were made by the first author, who has several years of experience in managing positions in building construction projects. During the interviews the above mentioned questions were used as a check list, although the communication with the interviewees was only partly structured. The interviewees were often carried away by their strong engagement, answering some questions before being asked.

The study can mainly be regarded as being qualitative, which was opted because of the first author's background as manager in traditional housing and hence following up questions and discussions were of great interest.

RESULTS FROM THE INTERVIEWS

All interviews were recorded and listened through afterwards and the answers were summarised in written form by the interviewer. The analysis mainly focussed on aspects where differences and special problems could be identified compared to the main-stream or traditional on-site construction process. All answers and gathered information from the interviews seen as relevant were compiled and grouped into the following seven categories.

- System design
- Building documents
- Construction planning
- Working methods
- Quality control
- Leadership
- Attitudes

In the following subsections, the results from the interviews within these seven categories are presented. The focus is mainly on the implications of introducing the passive house concept into the traditional construction process.

System Design

The loadbearing structures within the projects were the same as in traditional housing and were not significantly changed because of the passive house concept. However, the design was adjusted to minimize thermal bridges as far as possible, for example the edge of floors was placed deeper into the building envelope to leave room for more insulation. The materials in the loadbearing structure were either composed of concrete combined with steel framing or timber,

which are the most common materials also in traditional housing. However, the production and erection of the loadbearing structure did not affect the construction process in a significant way.

The building envelope design, however, was significantly affected by the passive house concept. The exterior walls were based on a wooden framework (4 cases) or a steel framework (2 cases) and in all cases a plastic foil was used as a vapor barrier and to make the building envelope air tight. This is very common also in traditional building projects, but the high requirements for airtightness in passive house construction creates very strict demands on workmanship and quality of the installation of the plastic foil in the studied projects. In mainstream construction the plastic foil is mainly seen as a vapor barrier and the degree of airtightness provided by the installed plastic foil is generally far below the level required for a passive house.

The exterior walls were thick and contained lots of insulation, often built up in cross layers to minimize thermal bridges, see Fig. (**3**). Five projects used an installation space on the inside to protect the plastic foil from being penetrated under construction, and when the occupants apply fasteners on the walls.

The window bays had a distinguishing design; they were built in an angle to let more sunlight into the room. This design made operations to secure airtightness more difficult than they would have been if the window bays been straight. However, every project developed their own method to handle this operation.

The attics in two of the studied projects consisted of wooden roofs built on concrete slabs and in the other four just wooden roofs on wooden frameworks. From a construction perspective, these two solutions differ a lot. The concrete is airtight and, therefore, operations with the roof construction was similar to traditional procedures, while the wooden roof construction needs to be made airtight by installing a plastic foil. In one project this operation took eight times longer compared to traditional housing, because of the increased accuracy needed within the passive house concept. In the other three projects the extra time needed varied from three to six times, compared to traditional housing.

The foundation works were similar to traditional works except that the foundation elements were designed to minimize thermal bridges. The ground floor slab was also more insulated.

Within all projects mechanical supply and exhaust air systems with heat recovery were used. This did not necessarily affect the construction in a negative manner, but when the ventilation system was integrated in the loadbearing structure, it did. It then affected other professional groups as they had to accomplish operations in sequence instead of in parallel. This phenomenon occurred in one project and led to extension of the total building time. Operations to secure airtightness at the interface between the plastic foil and piping penetrating the external walls were also time consuming. Many projects facilitated this operation by installing cuffs on the pipes.

The fact that traditional heating systems were not necessary, simplified the construction process. None of the projects used traditional radiator systems but instead used a heating battery on the supply air side of the heat exchanger unit for space heating. The battery was heated by electricity or by water. However, the heating system in passive houses simplifies the construction process as the heat is supplied within the ventilation system and not in a separate supply system.

Building Documents

In three projects the building documents were considerably more detailed than they are normally. Instructions and descriptions mainly concerning the airtightness were written on the drawings. The construction managers appreciated this detailed level as they experienced solutions to be more thought-through. In projects where the documentation level was similar to traditional housing, more problems needed to be solved on site. Traditionally it is not common that drawings show every solution in detail since the operations should be well established among the workers, and the workers are well skilled in construction as well. Hence if problems occur, workers often solve these on-site. For the passive house projects this was not possible to the same extent. In general, workers do not possess the knowledge of how different designs affect the energy performance. In projects where these problems did occur, considerable time was occasionally spent to consult the right person before it was possible to handle the issue.

Construction Planning

Two projects were developed in cooperation between involved professional personnel at an earlier stage than normal in traditional construction. This gave the projects a good balance between architecture, construction adaptation and energy performance. The balance was appreciated among the construction managers since they found solutions more adapted to efficient construction. It was also found to be a decisive factor for the success of the project from a construction perspective. In projects where the construction manager did not participate in early stages many unnecessary problems arised, which in the worst case continued through the whole construction phase.

Since the passive house concept and its consequences were new for all projects, the construction planning was generally more extended. Three projects prepared the construction phase by building a prototype, simulating the building envelope in the size of a garden cabin. The prototype made it possibly for the workers to practise their upcoming operations and at the same time test airtightness. This was a very effective tool for making the participants understand the accuracy that is needed to fulfil the requirements on airtightness. Another positive effect the prototype brings is that the client, among others, can see for themselves how different solutions appear in a 1:1 scale. Within the prototype stage many solutions and details were evaluated and if necessary improved before the actual construction started. Construction managers claim that this extra preparatory stage saved a lot of time and costs seen from a wider perspective.

The understanding of the passive house concept was also decisive for the final result. The importance of knowledge emerged from all interviews and hence a great part of the planning consisted of education. Few, or none, knew what a

passive house was before they started the project. The education has therefore dealt with the concept as such but to a great extent also airtightness and moisture safety in buildings. In all projects education activities were arranged even though the extent of the education varied between the projects.

During the construction phase and before new working operations were about to start it was common that the manager together with workers went through the operation and discussed how the operation best could be performed. This procedure is common in traditional housing as well but within the passive house projects it was a clear difference in the weight of its importance.

The construction site managers had the view that it is of a great importance in the passive house projects to continuously inform the construction workers of the projects' general status. Teamwork was identified as an important issue in the early planning stage as well as during the actual construction. Projects where information meetings were held continuously, led to enthusiasm and improved performance. The information mostly dealt with current problems and how to tackle these but also operations and solutions that worked out well.

Working Methods

In all projects the construction was to a great extent based on manual methods. One company that normally prefabricates their houses went back to build on site. The reason was that they wanted to control and verify the airtightness on site. The work to achieve an airtight building envelope was the most challenging and critical operation in the passive house construction according to all construction managers.

Quality Control

The importance of an airtight envelope devoid of any thermal bridges made it necessary to extend the self-monitoring programs in all projects. Traditionally, the airtightness and the build-up of the envelope are given less importance but in these projects it was the opposite. Well organised projects had continuous control of working operations and details to ensure that the right quality was achieved. Checklists were used in two projects to ensure that no detail in operations was forgotten by misunderstanding or carelessness. The usage of checklists worked out well in one project but not in the other. Problems with misunderstandings occurred when someone forgot to mark the list or when some workers did not bother to use it.

To check the airtightness, the air leakage was measured at a certain pressure in a blower-door test. This procedure is also performed in traditional housing but in the passive house projects the importance was at another level. Clients specified in their contracts the requirement of the airtightness and hence the contractor needed to verify the result.

Control of moisture content in organic materials was highlighted in all the passive house projects. The construction managers feared moisture to be built into the building elements because of the reduced drying capacity of the thick walls. Hence, the material storage and handling were more carefully executed in these projects.

Leadership

To avoid misunderstandings and unnecessary problems a clear and strong leadership was necessary in all the passive house projects. All construction managers argue that the leaders must never loose control of the construction because the consequences can become too severe. The construction managers need to know when to do something, how to do it and why it should be done.

In three of the projects the responsibility was delegated from the managers to the construction workers. Different workers were in charge of different critical operations and this delegation of responsibility differs from traditional projects.

Attitudes

There were different attitudes toward the passive house concept. Compared to traditional house construction some remarkable aspects were observed. In projects where enough time was taken to carefully plan and prepare the construction, the majority experienced the construction process more satisfying, they felt more involved and they also regarded the construction as efficient. There was enough time to accurately carry out different critical operations because quality was a higher priority than time. The planning and preparation solved potential problems before they occurred which reduced the stress among the construction workers, which was appreciated.

However, some construction workers were not enthusiastic about passive house construction. One construction manager estimated the number of dissatisfied workers to 50% of the staff. They thought the concept required too much time. They were used to and wanted to work fast but they considered operations in the passive house construction being too fragile and time consuming.

In general the construction managers think that the concept is the right way to go. They see it as clearly motivated, since a passive house radically reduces the energy consumption. All construction managers were also very proud to have accomplished a passive house project.

DISCUSSION

Three construction managers considered their projects as very successful, from a construction perspective. In these successful projects, proper preparation had been made regarding the construction activities within the above mentioned seven areas, and team work had been a top priority. Construction personnel had been involved earlier than usual which made the technical design more adapted to an efficient construction. During construction the information flow was increased in order to continuously make participants aware of the current situation, problems, results, changes etc. The communication with the client had also been continuously ongoing and hence the co-operation had been good between contractor and client.

However, these successful projects, that have used traditional construction methods, have to a great extent handpicked their construction staff because they declared that the best quality control is to let the right man do the right job. But is this a sustainable method for building energy efficient

Table 1. The Matrix Model

	KEY AREA						
OPERATION	**System Design**	**Building Documents**	**Construction Planning**	**Working Methods**	**Quality Control**	**Leadership**	**Attitudes**
Ground work							
Installations	X	X	X		X	X	X
Foundation work					X	X	
Structure work	X			X	X	X	
Structure completion	X	X	X	X	X	X	X
Interior fittings							X

houses on a long-term basis? What happens if the right man does not have the right job in the next project? Is the construction method then the right one?

Based on the results, a matrix model has been derived that shows where the identified key areas described above affect the different activities in construction, (see Table **1**). The idea is to illustrate which operations are most affected, as well as the key areas involved. The matrix is designed for use by participants in passive house projects, to give them knowledge and guidance as to where to focus and where to spend time on preparation.

The matrix shows that the passive house concept has a large impact on the construction activities. The most affected activity is the exterior structure completion which contains the work with the building envelope, which further includes operations with the buildings airtightness and insulation. Important to notice, is that all projects were using a plastic foil as air barrier. Other construction designs, like a concrete envelope, could facilitate operations concerning the airtightness, because the material is airtight in itself. Such construction designs have so far not been used in Sweden, for passive house construction.

CONCLUSIONS

Passive house construction is today a matter of high quality construction and hence the operations demand high accuracy in performance. This is the largest difference compared to traditional housing and it brings the construction process to a whole new level.

The passive house is not a remarkably complex product in terms of technical solutions but it becomes a very complex product as it does not allow anything but high quality workmanship. Ad-hoc solutions are very common within the traditional construction as the acceptance is larger (but perhaps should not be) and hence the culture and attitudes have been formed after that. Personnel in traditional construction are used to solve and fix problems on their own but when it comes to passive houses they do not have the sufficient knowledge to do so.

In all projects it took more time to build according to the passive house standard and it was more expensive, even though it varied how much more. All of the construction managers stated that it was not primarily the increased volume of material that influences the cost, but mainly the increase in working hours. The real impact on costs comes when the total building time is extended, not when a couple of craftsmen need to work overtime.

Hence time is a problem and it needs to be reduced in order to realize a passive house mainstream construction.

Hence, there is a clear need to find alternative construction methods which prioritize the product quality in an integrated and efficient manner, and, at the same time cut construction time and costs. More robust solutions need to be developed where the quality is designed into the product, not inspected into it. A more standardized industrialized production could be an effective tool within energy efficient housing, the product and its design could be better optimized and continuously improved. Industrial production is to a great extent about prefabrication, and developing prefabricated solutions could become a good substitute to the present unique, tricky and vulnerable solutions on-site. By moving parts of the manufacturing into factories, while at the same time solving the problems using an industrial process, reduces the necessity for repeated education on site and, for example, the waste associated with multiple working operations. Thus, also time can be reduced.

When energy performance stops affecting the construction process negatively, energy efficient houses could be developed on a broader basis and passive houses could become mainstream production.

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