Hotel Module in Glassfiber Sandwich
Environmental Study

Anna Hedlund-Åström

KTH Industrial Engineering and Management

KTH Machine Design
SE-100 44 STOCKHOLM
Stockholm, Sweden 2008

KTH Machine Design

Hotel Module in Glassfiber Sandwich
Environmental Study

Anna Hedlund-Åström

Department of Machine Design
Royal Institute of Technology
SE-100 44 Stockholm

TRITA - MMK 2008:06
ISSN 1400-1179
ISRN/KTH/MMK/R-08/06-SE

KTH Industrial Engineering and Management	**TRITA - MMK 2008:06** Hotel Module in Glassfiber Sandwich Environmental Study	
Date 2009-04-19	Author(s) Anna Hedlund-Åström	Version 5

Abstract

In this report the structural material for a hotel module is qualitatively studied with focus on environment. The module is designed in composite sandwich material with cellular polymeric foam, Pet or PVC, covered by two glass fiber laminates on each side. This type of material construction is traditionally used in transportation industry i.e. aerospace, aircraft, military ships and yacht, demanding high stiffness in combination with low weight. But an increase in the use within the construction area can be seen especially within offshore industry were the environment is extremely corrosive.

The investigated structure of a room and a bathroom includes floor, roof and three walls for each module. A life cycle perspective, from cradle to grave (cradle) is used for the study starting with raw material production, product manufacturing, use of product and finally waste treatment in different forms. Parallel to the sandwich module building in conventional technique is included for comparison. This technique includes walls of wood joints with insulating material as mineral wool in between and then covered with gypsum wallboard. Joists are produced in concrete.

As result environmental arguments are formed for the new sandwich alternatives and for the conventional technique. By just adding the arguments, for and against, turns out on favor for the PET sandwich module. For the material production the constituent materials for the sandwich generally presents higher CO_2 emissions than the conventional building materials. But when it comes to production and mounting of the module a number of arguments for the module can be stated. Better control of internal environment (working environment), efficient use of raw material, effective transports. Compared to the conventional design the risk for problems with moisture is non-existing for the sandwich structure.

The best alternative for waste treatment of the sandwich module is reuse. Other alternative is material recycling of glass fiber in combination with energy recovery for polyester and core material.

For fire safety a recent full-scale test of a ship cabin point out the potential to design a fire safe sandwich structure with appropriate insulating materials.

1. Content

2. Introduction

The word composite indicates a combination of at least two different components. The two main components in this case, polymeric fibre composites, are polymer matrix and fibre. Composite material has existed as a structural concept for a long time in forms of straw-brick, paper and reinforced concrete. However, it has existed as natural material since almost the very beginning, for example, in form of wood and bone. The polymer composites, analysed here, belong to a relatively new group of materials that have been in use for about half a century.

Specific for composites is that the final structural material is produced at the same time the product is manufactured. By combining the two materials, fibre and matrix, unique properties are tailor made for the specific product. Strength and stiffness is received from the reinforcement, the fibres, which can be placed randomly or oriented in both continuous and discontinuous forms. Examples of mostly used fibres are, glass, carbon, and aramid. Interest in natural fibres is increasing since they originate from renewable resources.

Dependent on the matrix material, polymer composites are divided in two groups, thermoplastic and thermoset. The differences between these two groups are explained by the differences in their chemical structure. For thermosets, a three-dimensional network of cross-linked polymer chains is formed during the curing process. This process is irreversible, that is, the material does not soften if it is heated. On the contrary, the reaction is different if the thermoplastics are heated, they soften since no chemical reaction occurs. The mainly used thermoplastic matrices for composites are polypropylenes, polyamides, and polyketones. Commonly used thermoset matrices are unsaturated polyester, vinylester, epoxy, and phenolics.

In structures where the demand is high stiffness in combination with low weight, an alternative to using high modulus fibre composites is to design the structure in composite sandwich. The sandwich constitutes of two faces separated by a foam core, see figure 1. The main core materials are expanded foams of polyvinylchloride (PVC), polyurethane (PUR), polystyrene (PS), honeycomb of corrugated metals or paper, and wood (balsa).

By forming a sandwich construction the bending strength and flexural stiffness increases several times, depending on core thickness, compared to a single skin structure with the same weight, see figure 1 to the right. This explains the large interest for these types of constructions in lightweight applications, especially for transporting structures. Thereby the fuel consumption can be decreased or the payload increased. Both alternatives results in better economy and decreased environmental effects in total or per transported volume over the life cycle of the product.

The main advantages of composite materials including sandwich constructions, compared to conventional engineering materials, are the followings:

- Low weight
- High specific strength and stiffness (specific means normalised with density)
- Good fatigue properties

- Corrosion resistance
- Electrical insulation
- Sound and heat insulation
- Easy to design complex shapes resulting in fewer details
- Decreased maintenance

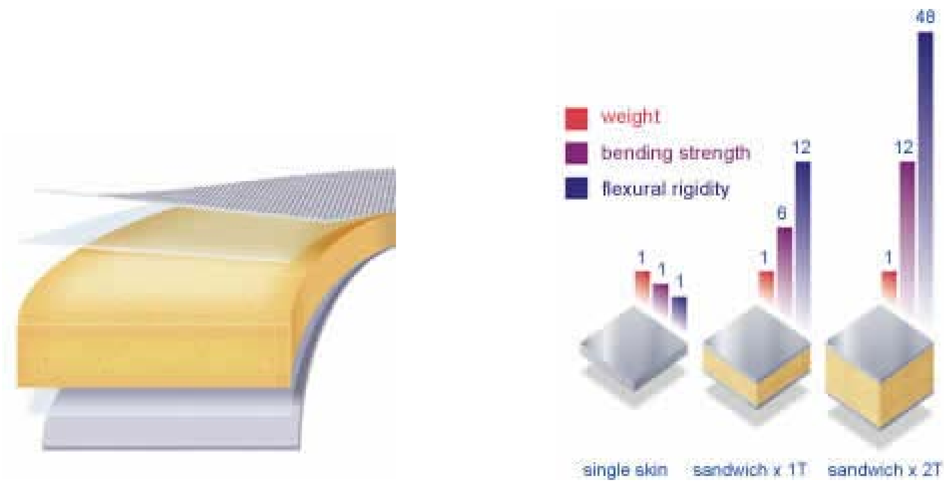

Figure 1. The sandwich concept, (DIAB).

Examples of other structural applications of polymer composites within construction are bridges, containers, building panels, pipes, and tanks. Especially in offshore applications with extremely corrosive environment the composite applications are expected to increase. In figure 2 an early application of glassfiber composite in a roof construction is illustrated. “Villa Spies” was built from 1968-1969 (Villa Spies, 1996).

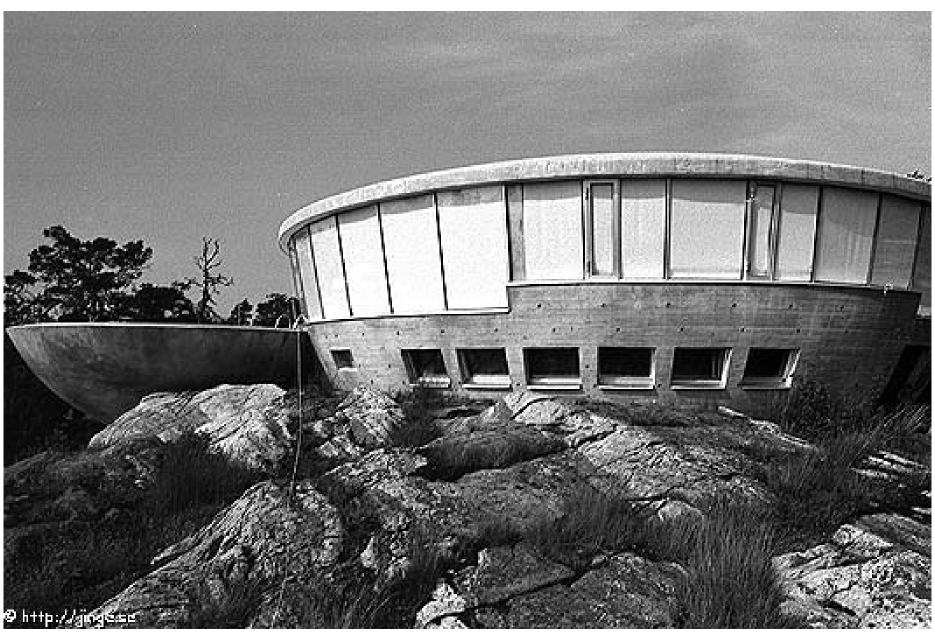

Figure 2. ”Villa Spies”, roof construction in glassfiber composite material.

Another important issue is well functioning transport of goods, which is necessary in modern society of today with increased global businesses. As the transport increases also the emissions increases, which are causing effects on both health and environment. In a prediction, (Ett energieffektivare Sverige, 2008) for Swedish conveyance of goods until year 2020 the road transports will increase by 30%, but this is of course dependent on future price on crude oil. Sensitivity analysis show that a re-distribution from road transports to rail and sea is probable. This will then decrease the cost and emissions per tonne kilometre transported goods. In a product life cycle many activities involves transports, which therefore is of large importance to consider.

In this study a hotel module in sandwich construction is investigated with focus on environmental issues, from both an internal (working environment) and external (global environment) point of view. Also included in the discussion are transports, mentioned as important above, as well as fire safety included in a specific chapter. A comparison is made with conventional building technique. The study is mainly qualitative meaning that environmental effects are not quantified or measured for the specific product.

3. Description of product

Here the new product, the sandwich module is described. To give a comparison also conventional type of building technique is shortly described.

The product in focus is a structure aimed for hotel building. The structure is designed as a module with dimensions of 6 x 4,2 x 2,5 meter, see fig 3 and 4, (Oceanic-Creation AB, 2008). The complete module, one room and bathroom with permanent installations is manufactured and assembled at the same plant, which today is at Kockums in Sweden and in the future in Bulgaria.

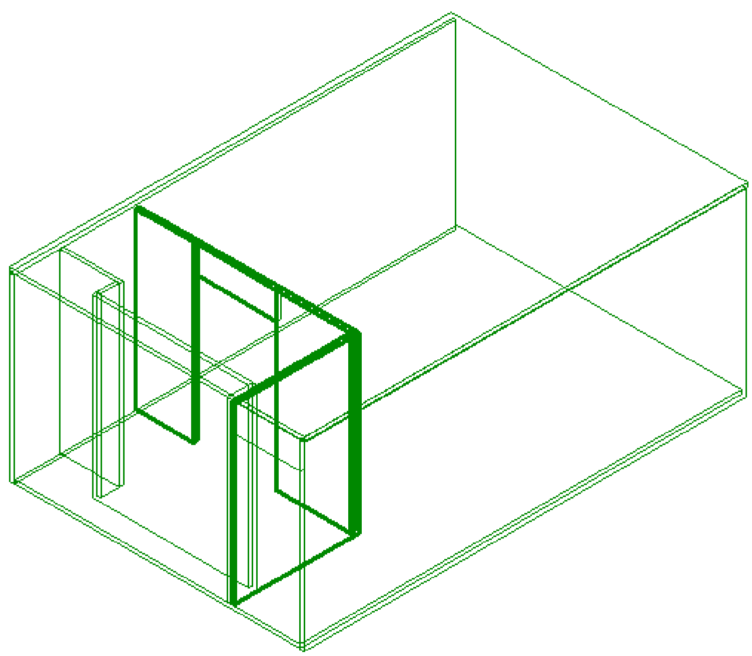

Figure 3. Drawing, of hotel module, (Oceanic-Creations AB, 2008).

Installations consist of two doors, electrical cables, air cooling and heating devices, toilet, shower, hand-basin and finishing of surface layers with glazed title in bathroom and parquet flooring in the room.

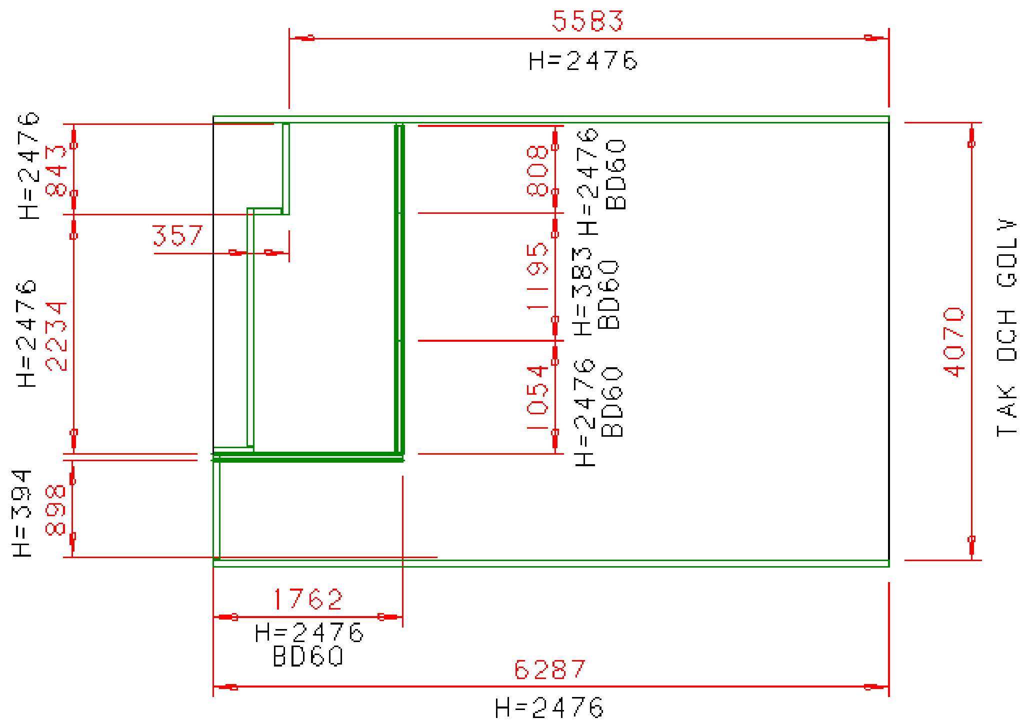

Figure 4. Plan of hotel module, (Oceanic-Creations AB, 2008).

The module is built in sandwich technique of following elements; three inner walls, ceiling and floor. The face material consists of glass fibre reinforced polyester laminates and the core material consists of a thermoplastic PET, polyethylene terephthalate or PVC. The sandwich elements, walls etc are each manufactured separately through a vacuum infusion technique and are thereafter laminated together with glass fibre and unsaturated polyester resin. On the inside of the sandwich wall a board of calcium silicate for heat resistance is mounted.

After completing the module, it is transported to the hotel building site. The modules are then mounted in a steel frame and covered with the façade including window. The finishing installations include connecting of electricity, water and sewage as well as furnishing for completing the hotel room.

The conventional building technique, (Åström, 2008), starts with a frame of either steel or concrete. Since the sandwich module is mounted in a steel frame it is assumed that the same frame is used for the conventional building. Inside the steel frame walls are made starting with wood joints (spruce or pine) were in between insulating material as mineral wool is applied which is covered with gypsum wallboard were the final surface layer is mounted. Joists in conventional building are made of concrete. This way of constructing is made at the site for were the building is placed and involves a lot of independent subcontractors skilled in different parts of the design. This demands a specific contractor who coordinates the completing of the building.

4. Product life cycle

To structure the following analysis a subdivision is made in life cycle phases. This procedure is common when performing life cycle assessment, LCA (environmental impact analysis) and life cycle cost analysis, LCCA. This means that the product is investigated from cradle-to-grave or a perspective more common nowadays from cradle-to-cradle.

The ideal is to create a closed life cycle, to resemble the natural life cycle. The raw material used from the beginning in a product, virgin material, should be possible to reuse in the same product or in another product with the same function as the first. In reality a closed life cycle for a product is almost impossible to achieve. The discarded product is very often travelling many different roads and mostly not in a closed cycle. Besides this, waste is also generated in other parts of the life cycle, during manufacture and maintenance. This is also happening in the natural circle, for example when the leaves are falling from the trees in autumn, but these come to use in nature.

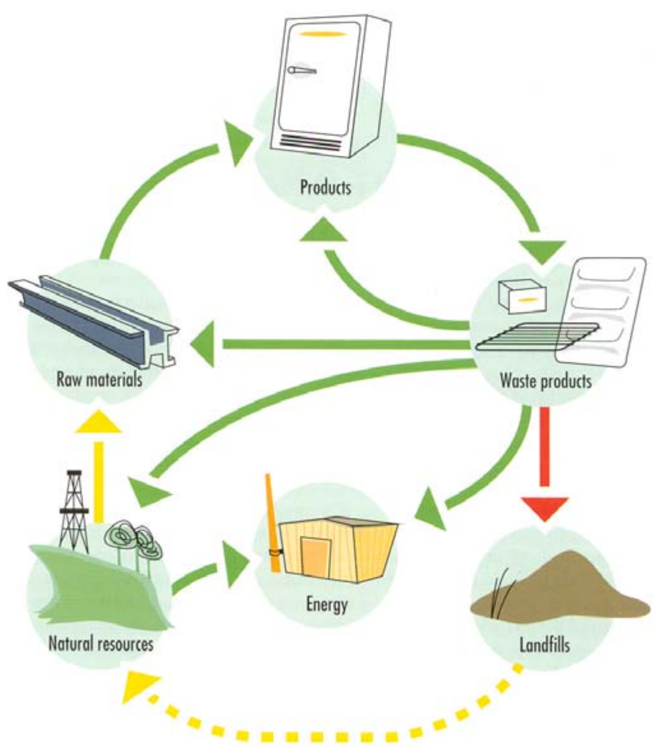

Figure 5. Illustration of life cycle for a refrigerator.

As an example of a product life cycle the life cycle for refrigerator is illustrated in figure 4. Here also a number of waste treatment alternatives are included.

These alternatives are reuse; of parts mainly, material recycling, energy recovery and landfill. Landfill is nowadays the least desirable way to go (the red arrow) which is expressed through legislation and other policy instruments, as prohibition against landfill for burnable and organic waste and increased fees for landfill, (NFS 2004:4).

The life cycle phases commonly used are; production of raw material (includes both extraction and processing), manufacturing of product, use of product, treatment of wasted product. These phases can then be further divided into several processes and activities depending on the refinement of the analysis.

The following division of the life cycle the phases are used for the environmental description of hotel module:

- Production of constituent materials
- Manufacture and assemble of module
- Mounting of module
- Usage and maintenance
- Waste treatment (used product and production waste)

For each life cycle phase the analysis includes both internal and external environmental issues. Internal environment treats issues connected to working environment as for example noise and particles. External environment treats influence causing global effects as increased global warming, acidification, ozone depletion etc. Also transports are discussed separately within each life cycle phase chapter.

Considered apart from the abovementioned parts is the occurrence of fire, which is discussed in a separate chapter.

4.1 Production of constituent material

The raw material production for the constituent material in the sandwich module including the fire insulating board is here described.

Material for the conventional building technique is included to give a comparison.

***Sandwich module*;** glass fibre, unsaturated polyester, PET foam or PVC foam, CaSi (calcium silicate), board

<u>Glass fibre</u>, manufactured from oxides with silicon oxides, SiO_2, as main ingredients. The mixture of oxides are melted at around 1300°C, then fibres are extruded and after cooling different types of products are manufactured as mats and woven fabrics, (Åström, 1997).

<u>Polyester (unsaturated polyester)</u>, is one of the most common thermosets used as matrix for composites, especially together with glass fibre. Manufacturing of polyester occurs through a condensation polymerization from alcohol and acid resulting in water as a rest product. Molecule chains with 10 -100 units of the monomer is formed during the process. For delivery to the product producer the polymer is dissolved in a solvent. This

makes the polymer easy floating, which is necessary for the manufacturing of the composite. The most common solvent used is styrene, with a blend of 35-50 weight-per-cent. To induce the cross linking process, hardening, an initiator is added, around 1-2 weight-per-cent, commonly an organic-peroxide. Worth mentioning is that the styrene solvent is actively participating in the cross linking process. Abundance of styrene passes into fumes, (Åström, 1997).
PET foam, PET raw material is dried and injected together with gas into an extrusion processing machine. Thereafter sheets are welded and cut into blocks in an automated cutting device, (DIAB AB, 2008).
PVC foam, 93% of the feedstock is PVC, two isocyanates; TDI and MDI, and anhydride PhAA. The remaining 3% contains expanding agents (azo-compounds), stabilizers, filler, softener, pigment. The manufacturing comprises a four-step process. First ingredients as PVC, isocyanates, anhydrides are mixed with blowing agents and stabilizers. Then the mixture is transferred to a mould and gelated under pressure at elevated temperature, 200-300 bar and 160-175°C. Here the cell structure is created by thermal decomposition of the expanding agent. In the third step, the foam is expanded in a reaction between the two isocyanates by the forming of CO_2. After completing the expansion, the foam is cured to complete the reaction.
Finally the moulding skin is removed and blocks are formed to customer ready sizes. This last manufacturing step results in production waste by 30-35%, (Baczynska, 1996), (Danielsson, 1998).
CaSi board, consists of minerals; lime and amorphous silicate oxides. The minerals are grinded and mixed with water. The board is formed and cured in an autoclave process with high pressure and temperature. The process parameters are dependent on the final quality of the board. The product name LiteCore is an insulating panel especially developed for marine lightweight applications, (Skamol).

Conventional building; wood, mineral wool, gypsum wallboard, concrete
Wood, is an organic material, growing with nourishment from sun and soil. The most common for buildings in Sweden are spruce and pine. After felling the wood is sawed and dried.
Mineral wool, could be stone wool manufactured from diabase and dolomite or glass wool manufactured from sand, dolomite, borax, soda and glass for recycling, which share is increasing, (Bokalders, 2004).
Gypsum wallboard, contains gypsum with glued cardboard, to give strength and stiffness as for a sandwich, (Bokalders, 2004).
Concrete, consist of, cement, water, ballast and additives. Ballast is usually in form of coarse gravel. Additives occur in multitude, to speed up or slow hardening, increase float ability. Additives to increase float ability usually contain formaldehyde. Cement is made of minerals containing calcium (from limestone) and silicon, aluminium, iron (from clay and sand). The raw material is grinded and heated in a kiln up to 1500°C, were the material is partly melted, (Cement manufacturing).

4.1.1 Internal environment
All presented exposure limits are occupational exposure limits, 8 h (one day of work) time-weighted average.

Sandwich module

Glass fibre, when manufacturing woven fabrics, maths, etc. from glassfibres; dust, particles and fibres of different lengths will appear. Exposure may take place through inhalation and contact with skin or eye, which may cause irritation.

Threshold values for dust and fibres are:

Dust, inorganic, respirable, 5 mg/m^3, (AFS, 2005:17).

Fibre, glass like (amorphous), 0,2 fibre/cm^3, (AFS, 2005:17).

Following information regarding respirable dust and glass fibre are from, (Åström, 1997).

Respirable dust has a dimension less than 3,5-5 µm and is small enough to penetrate the alveolar surfaces in the lungs.

Non respirable dust is considered to have dimension of 7-10 µm and are trapped by the body's normal defence.

Glassfibres in composites usually have diameters larger than 10 µm and are therefore considered nonrespirable,

To avoid exposure a number of protective measures can be made:

- Administrative control; isolation of operations, worker rotation, continuous cleaning of workplace, clear labelling, etc.
- Engineering control; process automation, different levels of ventilation
- Personal protective equipment; respirators, gloves and clothes, safety glasses.

Unsaturated polyester, here the most important concern is connected to the cross-linking agent, styrene, which is a solvent. It is therefore very volatile and is mainly a hazard during inhalation. It has a very low odour threshold 0,1 ppm and the threshold value is 20 ppm, (AFS, 2005:17). It is classified as possible carcinogen and it can be stored in fat tissue since it is soluble in fat, (AFS 2005:18). At exposure above 20 ppm immediate irritation in eyes and respiratory tract can occur as well as affection of the central nervous system. For handling of styrene medical controls are demanded.

Organic-peroxides irritate skin and mucous membranes and risk for allergic reaction is increased at repeated exposure.

PET foam, cutting operation may generate dust and particles of organic material.

PVC foam, here the threshold value for isocyanates are 0,002 ppm, (AFS, 2005:17). Isocyanides is sensitivating, meaning that after repeated exposure allergic reactions can occur, and for handling medical controls are demanded. During cutting the plates, dust will appear, the threshold value for PVC dust is 0,5mg/m3, (AFS, 2005:17).

CaSi board, no risks has been shown when working with amorphous silicates. Lime in contact with water can irritate. Dust is kept below threshold values, (Skamol, 2007)

Conventional building

Wood, when sawing dust will appear threshold value respirable, 2 mg/m3, (AFS, 2005).

Mineral wool, the same threshold values as for glass fibre above.

Gypsum wallboard, inorganic, the same threshold values as for glass fibre above.

Concrete, inorganic, the same threshold values as for glass fibre above.

4.1.2 External environment

The following effects, energy consumption, raw material consumption and especially CO_2 emissions causing global warming is discussed.

Sandwich module
Glassfibre, since manufacturing involves high temperatures, 1300°C, the energy consumption is high. Non renewable resources are used for production.
CO_2 emission for manufacturing of C-grade is 1,4-1,5 kg/kg, (CES EduPack).
Unsaturated polyester, manufacture based on non renewable resources as petroleum. CO_2 emission for manufacturing 2,8-3,1 kg/kg (for termoseth polyester), (CES EduPack).
PET foam, only information on PET (amorphous) and PE foam H60 available, CO_2 emission for manufacturing; 2,2-2,4 respectively 3,6-4 kg/kg, (CES EduPack). Non renewable resources used for production, though some part can be recycled material.
PVC foam, similair to Airex C and Klegecell, CO_2 emission for manufacturing, 6,8-7,6 kg/kg, (CES EduPack). Non renewable resources used for production.
CaSi board, main environmental effects comes from landfill of calcium silicate and energy consumption during processing, CO_2 emission for manufacturing, 1,1 kg/kg, (Skamol, 2007). Non renewable resources are used for production.

Conventional building
Wood, (pine), is a renewable resource, meaning that it is growing continuously using CO_2. For wood as a common building material manufacture, (includes cutting, sawing drying), consumes CO_2 of -1,2 - -1,1 kg/kg (CES EduPack).
Mineral wool glass foam, the manufacturing process of glass wool produces CO_2 emissions of 2,3-2,5 kg/kg(CES EduPack). Non renewable resources used for production, though some part can be recycled material.
Gypsum wallboard, no information on CO_2 emissions. Non renewable resources are used for production.
Concrete, high energy consumption for crushing, grinding and high manufacturing temperature 1500°C. CO_2 emissions for manufacture of concrete 0,16-0,18 kg/kg, (CES EduPack). Non renewable resources used for production, though some part can be recycled material.

4.1.3 Transports
The transports for production of the raw materials for producing the constituent materials are assumed as efficient to decrease emissions to air. Transports are made by lorry, train and ship.

4.2 Manufacture and assemble of module
Under this chapter only the sandwich module is treated since the manufacturing concept is different compared to conventional building.

Manufacturing of sandwich modules occurs at a plant with controlled environment. With controlled environment is meant that the building is heated, devices for engineering control of solvent as styrene, dust, particles and fibres in the air is easily applied. Also personal control equipment as gloves, safety glasses is placed and organized in well-known places. If an accident will occur devices for treatment are found in well-known places for the staff.

The manufacturing technique for the composite sandwich elements is vacuum infusion. This technique has been developed to replace open manufacturing methods as hand layup and spray-up of large structures as boat hulls. By using the infusion technique the styrene emissions decreased with 98%. In a study were spray-up was compared to vacuum infusion for manufacture of a boat hull the average styrene exposure was below 0,5 ppm compared to 45 ppm during spray-up, (Lindgren, 2008).
The constituent materials, core and glass fibres are placed in a vacuum bag. The resin, unsaturated polyester is vacuum drawn from a container into the glass fibres through a carrier layer. Here vacuum is the driving force for impregnating the fibres. After impregnation the element is heated to a temperature about 60°C which is made to increase the hardening and consumption of the cross-linking agent, styrene.

After producing the sandwich elements they are put together by laminating the corners together with glass fibre and polyester, which is made by hand.

During the building production waste will be produced, this is discussed in chapter 4.4. In general this technique with building modules could resemble a moving assembly line, were the resources are effectively utilized and a high quality is achieved.

4.2.1 Internal environment

At the plant for manufacturing the modules, the constituent is handled in many different ways, which can cause risks for exposure. Example is handling the glassfibre when preparing the vacuum infusion, cutting and laminating glassfibre. Also care for the heating procedure, for decreasing rest styrene, at 60°C should be considered.

As for the production of constituent materials dust and fibres can occur as well as exposure to styrene during hand lamination. The vacuum infusion technique though is favourable for the internal environment causing minor exposure of styrene.

After hand laminating the sandwich elements, permanent installations are made in the module. Here eventually risks for exposure of glass fibre in forms of dust or fibres can occur if the laminates need working up as grinding, drilling or other mechanical treatment.

One other issue is the cleaning of equipment after hand-laminating, which is made with solvent. Here personal protection and technical control as ventilation is important.

For threshold values see 4.1.1.

4.2.2 External environment

The plant as a whole can be seen as a cause for environmental effects due to use of materials and energy when building it. This will not be included here since the plant will be used for many years and perhaps for different purposes. It is the processing around building the sandwich modules that is interesting.

The main cause for external environmental effect is consumption of energy, with the main emission CO_2 causing global warming. Examples of activities are:

- Heating of plant
- Produce vacuum for the resin infusion
- Heating to 60°C to improve cross-linking
- Use of hand held machines for installations

Out of these the heating of the plant is probably the largest energy consumer.

Added is also consumption of different materials around the vacuum process (no information) and equipment for the hand-laminating including cleaning material for equipment.

4.2.3 Transports

Transports made to and from the plant include transport different types of constituent materials and transport of the finished modules to the site for the hotel building. Here all types of transports are involved, car, lorry, train, ship and aircraft.

The focus is here on the main transport of the hotel module, which is made by ship with around 100 modules at a time to nearest harbour.
Evaluating the best transport alternative is very difficult. But comparing transport by lorry, (4 modules, 1000 km) to ship (100 modules, 1000 km) by calculating and comparing gives at hand that transport by lorry results in twice the CO_2 emission to ship transport, (NTMCalc). For the same calculation with train (2 modules in one vehicle, 1000 km) 100 % water powered electricity driven, the CO_2 emission is about 300 times lower when compared to ship transport. But this result is strongly dependent on production of electricity.

4.3 Mounting of module

In this chapter a comparison to conventional building is made since mounting of the sandwich module is made at the same place as conventional building of the hotel.

As described in chapter 4 conventional building involves many different specialized contractors who must be organized in an effective way. This will not be necessary for the finalization of the sandwich module, which only needs connecting of electricity, water, heat and furnishing. No waste will be produced at the site as compared to conventional building. Also loss of material is minor in comparison. The insulation is inbuilt in the sandwich module and will not be exposed to moisture as is the risk for conventional building. Another difference is the need for a crane to lift the modules in position.

4.3.1 Internal environment

Regarding installations eventually the presence glassfibres should be known. If drilling is made formation of dust and fibres will occur. Threshold values see 4.1.1. Since the sandwich is preheated for effective cross-linking no solvent should be emitted, as styrene.
One obvious advantage compared to conventional building is that the final mounting of installations will be made inside, giving protection to bad weather.
The crane lifting of the modules involves a risk for the staff.
Comparing module to conventional building the noise to the surroundings will be decreased.

4.3.2 External environment
Here the largest emissions are caused by road transport of building materials.

4.3.3 Transports
The sandwich modules are as described in former chapter transported by ship to nearest harbour. Thereafter unloading is made and storage. Probably the modules are transported some kilometre by truck but eventually train transport can be possible, which is the best choice for environment.

Comparing this to conventional building where a lot of different activities and transports by foremost lorry with the mounting of the sandwich module this last alternative seems more effective and environmental friendly. The noise and the local emissions at and near the building site become lower for the module concept due to minor truck transports.

4.4 Usage and maintenance
Here the largest environmental impact comes from heating of the module. The differences in insulation capability between the constructions can be analysed with information of coefficient of heat transmission, denoted λ-value. The value, which is a material constant, indicates the heat flow through the material, a lower figure means a lower heat loss.

Information on λ-value for the constituent materials in the sandwich construction is as follows:

Airex C70.40(PVC)	0,031	W/mK (Alcan Airex)
Divinycell P100(PET)	0,033	W/mK (DIAB)
Glass fiber polyester	0,6	W/mK (Arbin, 2008)
CaSi board	0,06	W/mK (extrapolation of values from Skamol)

Information on λ-value for the constituent materials of conventional building technique:

Wood	0,18	W/mK (Builddeskonline)
Mineral wool	0,034	W/mK (Builddeskonline)
Gypsum wallboard	0,25	W/mK (Builddeskonline)
Concrete (not in the wall)	2,5	W/mK (Builddeskonline)

When comparing these values it can be seen that the core materials, PVC and PET are comparable to the value of the mineral wool, with the lowest heat transmission, around 0,03 W/mK. For the conventional building the wood joints acts as cooling bridges, due to higher λ-value. This is solved by increasing the thickness of the insulating material, mineral wool.

But, due to the module construction the comparison with the conventional building seems not adequate. All the walls in the module can more or less be regarded as inner-walls. This means that the temperature difference will not be that large and the difference in energy consumption will not be very large.

For noise distribution specific requirements must be fulfilled, (Ljunggren, 2001), (Arbin, 2008). These are as follows:
Step noise insulation from corridor: L´nTw 52 dB
Air noise insulation from corridor: R´w 40 dB
Step noise insulation from other room: L´nTw 56 dB
Air noise insulation from other room: R´w 52 dB

Since solvent, styrene, is used for cross-linking of the polymeric matrix material it is of large importance that this not causes any effects as smell or long term human effects in the ready made module. Since heating to improve cross-linking is made this results in increased cross-linking resulting in a decrease in styrene content to around 0,2-0,3%, (Reichhold Sweden AB, 2008). A method to decrease the rest styrene even further is steam washing at 80°C for 2 hours. This treatment is used for water storage tanks manufactured in glass fibre polyester, (Reichhold Sweden AB, 2008).

For both structures normal maintenance will not differ, as repainting, refurnishing etc.

4.4.1 Internal environment

Information of glassfibre content should be given in case of maintenance or repair. Threshold values see 4.1.1.

Measurement of noise insulation will be made.

4.4.2 External environment

If difference in insulation capacity, the energy consumption will differ, this will be further investigated.

The life length for a sandwich structure is very long. One example illustrating this is the first sandwich hull for a mine sweeper manufactured in 1974 by Karlskronavarvet AB. This ship still exists, though refurbished, after more than 30 years of use.

4.4.3 Transports

No differences between sandwich module and conventional building.

4.5 Waste treatment – from manufacture and used product

EU has stated seven key principles as important for waste treatment, (EU, 2003), were the first describes the hierarchy for waste treatment as follows:

- Avoid or minimize the amount of waste
- Reuse the product or parts of the product
- Material recycling
- Energy recovery, incineration
- Landfill

The waste hierarchy presents the methods in the order from best to worst regarding environmental effects, shown in several research studies. Avoiding is then the obviously the best choice and landfill the worst. Reuse and recycling of products and material is also beneficial for the environment since virgin material is saved.

For fibre composites the most common methods today for treatment of waste is incineration and landfill. An information model for assessing possible treatments of composite waste has been developed (Hedlund, 2005). Here several treatment methods are presented, as mechanical material recycling, energy recovery and combination of material recycling and energy recover or chemical recovery. The most investigated method is mechanical recycling were the composite waste is treated in a series of mechanical processing, from cutting to grinding. The grinded material can then bee utilized as filler material, or replace virgin fibres depending on fibre fraction. Drawback though with mechanical recycling is that the fibre length is decreased.

Figure 6. Pyrolysis process applied on wind turbine blade, (Grove-Nielsen, 2003)

Two interesting methods exist at research level; these are fluidized bed and pyrolysis. Here the resin is gasified in a high temperature process, resulting in released fibres for material recycling, see figure 5 above.

In a Swedish project VAMP 18, (Hedlund-Åström, 2005), (VAMP 18), for studying waste treatment, several different types of fibre composite material including sandwich composite were included. Here both costs and environmental effects were investigated, for both material recycling and energy recovery. The result pointed out material recycling as the best alternative from environmental perspective. But energy recovery is also possible as long as the composite waste replaces non renewable fuels as oil and coal.

For the sandwich modules and the manufacturing waste the waste hierarchy should be followed if possible. The first alternative minimize waste is fulfilled since very little

waste is produced from the manufacturing of the module. The manufacturing waste produced can either be material recycled through grinding or incinerated with energy recovery.
For the sandwich module reuse seems as a good possibility, the façade is demounted and the module picked out from the frame. Then it can be refurbished and used in a new application. The life length of this type of material is very long and will not break down since it is not affected by moisture as conventional building materials.

If reuse is not possible the module must be dismantled and cut. The composite face and PET or PVC core can then be separated and separately recycled or incinerated. One advantage though for the PET core material is that it is thermoplastic and can be formed by heating.

4.5.1 Internal environment

For all mechanical treatments as cutting, grinding etc. dust and fibres will appear. Threshold values see 5.1.1. Also noise can be a problem, threshold value 85 dB, (AFS, 2005)

4.5.2 External environment

According to the waste hierarchy reuse is the most environmental friendly alternative.
But in reality as mentioned in the beginning of this chapter landfill and incineration are the most common methods today.
From the production of CaSi board, SuperPro LightCore one of the environmental effects is landfill of calcium silicate manufacturing waste, (Skamol, 2007).

The same applies from the production of PVC foam, here large quantities of manufacturing waste also are put on landfill.

Within the VAMP 18 project a large scale test including totally 13 tons of mixed composite waste was incinerated at a waste incineration plant, (Nyström, 2002). Ordinary waste was mixed in a blend of 10% composite. No disturbances during the combustion were noticed, although the preparation by crushing required increased efforts.

Although the above large scale test went well one should be aware of that incineration of PVC can result in generation of hydrochloric acid. Also under specific circumstances dioxin can appear during combustion of PVC. Copper for example act as a catalyst for the process of forming dioxin, (VAMP 18).

4.5.3 Transports

Transports of waste should be made effective. The transport of a discarded module is a volume transport. By cutting the module to pieces after demounting the transport is made more effective. In an investigation comparing waste treatment of a sandwich boat hull, the emissions of CO_2 was decreased by 30% by cutting the structure resulting in a more effective transport, (Hedlund-Åström, 2004).

5. Fire protection

The sandwich structure for the hotel module is covered with CaSi board, SuperPro LiteCore for protection of fire. This material is designed for maximum service temperatures of 1000°C, (Skamol). If this board for some reason should be damaged the polyester in the composite face material will burn. Then CO_2, particles and soot will be produced, and since the fire probably will occur in lack of air (oxygen) also CO is produced, (Hertzberg, 2008).

Fire test has been made for the sandwich structure investigated in this study by Skamol A/S. In the test, the side with the LiteCore was mounted inside the furnace were the heat was applied. During the test, temperature was measured at five different points over the panel; three points inside the LiteCore and two points in the sandwich structure, see figure 7.

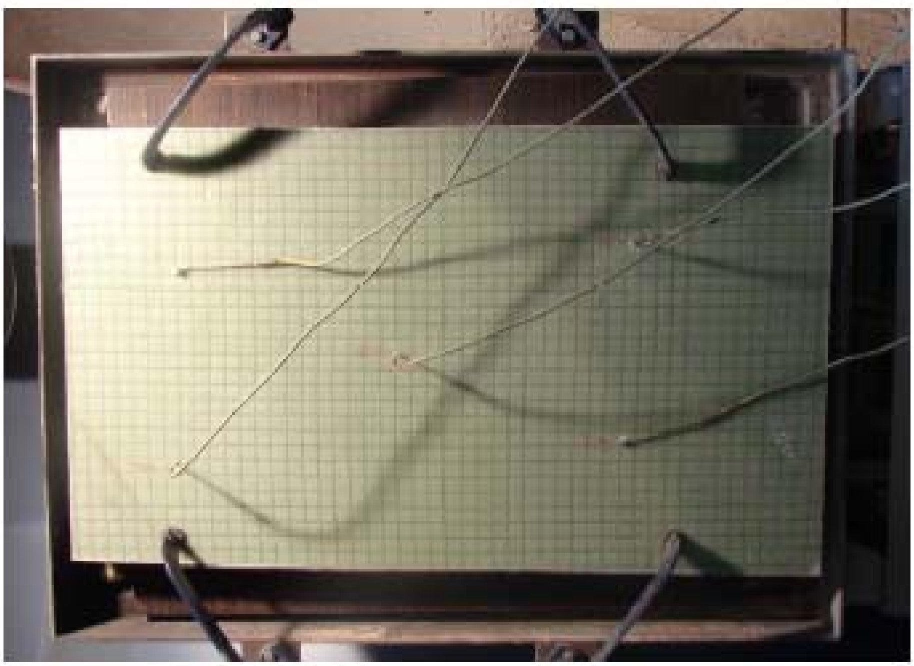

Figure 7. Mounting of thermo-elements for temperature measurement.

The results are presented in figure 8 below, showing a slow increase in temperature in the composite sandwich from around 30°C to about 50°C. The temperature in the LiteCore increased from 30°C to maximum 300°C. The exposure time was around 40 minutes.

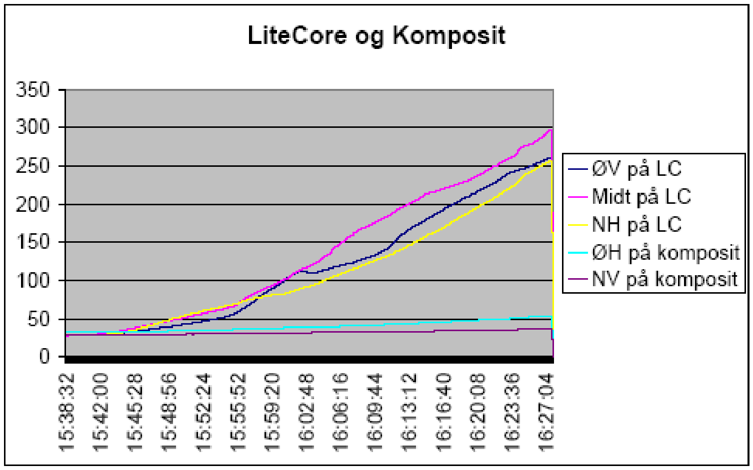

Figure 8. Results from temperature measurements during fire test.

Also results from a fire test for a ship cabin are presented since it eventually can resemble a fire in a hotel module.

Within the Swedish LÄSS-project, (LÄSS), Lightweight construction applications at sea, a large scale fire test was made to demonstrate the safety level according to new SOLAS Regulation 17 on ”Alternative design and arrangements” resemble possible fires in a RoPax cabin, (Arvidson, 2008). The outer and deck construction were built in sandwich technique with core of plastic foam and face of composite. All composite materials except the below deck were insulated using Thermal Ceramics certified FRD 60 Marine Plus insulation. A Rockwool floating floor system was used on the bottom deck.

The cabin and the corridor were constructed by sandwich panels with a core of mineral wool with galvanised metal sheeting. The panels had a decorative vinyl coating, with a thickness of 150 µm on both the inner and the outer surfaces.

Figure 9. Interior of cabin.

The cabin interior was made realistic and certified according to IMO, international maritime organization, see figure 9, above.

In the flashover test illustrated in figure 10, no sprinkler was used and the door was left open leading to an intense fire lasting for 35-40 minutes.

The fire involved all combustible interior materials and floor covering. After the fire
It was seen that the fire insulation under the upper deck and on the bulkheads was almost unaffected, except for a small spot.

Figure 10. Flashover fire test, were the flames are spread in the corridor from the burning cabin.

Conclusions from the test are:

- it is possible to obtain a high degree of fire safety in a composite construction using appropriate insulating materials
- a RoPax cabin-corridor fire using IMO accepted interior materials can be very intense and quick developing if the sprinkler system fails to operate properly

The fire test presented above demonstrates possibilities with fire insulation of composite sandwich structures.

6. Results

The results from the studies above are presented in one table each, for the three types of building structures; module in sandwich technique with PVC core, module in sandwich technique with PET core and conventional building technique. The tables include environmental arguments for and against the building technique for the studied life cycle parts; internal environment, external environment and transport.

Table 1. Environmental arguments for and against module in sandwich technique with PVC core.

Life cycle phase		Module in sandwich with PVC core	
		Argument for	**Argument against**
Production of materials	Internal		- risk for contact with particles, fibres - risk for contact with styrene - risk for contact with icocyanates
	External		- high energy consumption for production of glass fibre - non renewable resources for production of constituent materials - high CO_2 values for manufacture of PVC core
	Transport		
Manu-facture	Internal	- vacuum infusion, low styrene emission	- risk for contact with particles, fibres - risk for contact with styrene
	External	- easy to control, high quality	
	Transport	- efficient transport to plant	
Mounting	Internal		
	External		
	Transport	- effective transports to building site	
Use	Internal	- minor risk for moisture problems	
	External	- long life length	
	Transport		
Waste	Internal		- risk for contact with particles and fibres through mechanical treatment
	External	- small amounts of waste during manufacture and mounting of module - module can be reused - research show incineration with energy recovery as a suitable method	- large amounts of waste from PVC production - no methods on market for material recycling, today most of the composite waste is put on landfill - incineration of PVC may cause forming of hydrochloric acid and dioxin
	Transport		

Table 2. Environmental arguments for and against module in sandwich technique with PET core.

Life cycle phase		Module in sandwich with PET core	
		Argument for	**Argument against**
Production of materials	Internal		- risk for contact with particles, fibres - risk for contact with styrene
	External	- recycled material for PET production	- high energy consumption for production of glass fibre - non renewable resources for production of constituent materials
	Transport		
Manu-facture	Internal	- easy to control by protection - vacuum infusion, low styrene emission	- risk for contact with particles, fibres - risk for contact with styrene
	External	- easy to control, high quality	
	Transport	- efficient transport to plant	
Mounting	Internal		
	External		
	Transport	- effective transports to building site	
Use	Internal	- minor risk for moisture problems	
	External	- long life length	
	Transport		
Waste	Internal		- risk for contact with particles and fibres through mechanical treatment
	External	- small amounts of waste during manufacture and mounting of module - module can be reused - PET can be material recycled - research show incineration with energy recovery as a suitable method	- no methods on market for material recycling, today most of the composite waste is put on landfill
	Transport		

Table 3. Environmental arguments for and against conventional building technique.

Life cycle phase		Conventional building technique	
		Argument for	Argument against
Production of materials	Internal		- risk for contact with particles, fibres
	External	- wood is a renewable resource, low CO_2 emissions - recycled material can be used for concrete production	- non renewable resources for production of constituent materials
	Transport		
Mounting (includes manu-facture)	Internal		- many contractors to coordinate
	External	- well known technique	
	Transport		- many transports with truck
Use	Internal		- risk for moisture problems
	External		
	Transport		
Waste	Internal		
	External	- known methods for demolition - material recycling of mineral wool possible - energy recovery of wood	- large amounts of production waste at building site - not possible to reuse complete structure
	Transport		

7. Discussion of results

When studying the tables by simply just counting and summarize the numbers of arguments for and against for each table, the module in sandwich with PET core comes out as the most favourable alternative with most arguments for; 11 for and 8 against. For the sandwich with PVC core it turns out as 9 for and 12 against, and for the conventional technique the result is 6 for and 7 against. Now this result must of course be carefully considered, since just summarising for and against is not a completely secure method. The values of the arguments may differ and there can be more arguments to include.

Regarding the distribution of the arguments, both for and against, most of them comes from production of materials and waste treatment. For all three alternatives non renewable resources are used, this has a large effect on environment. Also waste treatment is an interesting phase of the life cycle. For the composite sandwich structures there are problems today with waste handling but research show many possibilities for solving this in the future.

Comparing the arguments for the phases; manufacture and mounting the positive arguments are winning for the sandwich modules. These arguments are connected to increased effectiveness and higher quality resulting in better use of resources leading to decreased environmental effects and should of course also result in economical advantages.

Also tests for fulfilling demands on noise distribution must be made for the specific material combination. After knowing the exact materials for fulfilling the noise requirements a more thorough heat flow study can be made to investigate insulation capability and thereby compare energy consumption during usage of the structure.

Not included in the tables is the fire, since here probably some more testing is needed for the sandwich alternatives depending on which material combination will be used. But several tests show the possibilities to insulate against risk for fire.

8. References

ALCAN, www.alcanairex.com

Arbin, U., Kockums AB, Information of U-values, May 23, 2008

AFS 2005:17, ”Hygieniska gränsvärden och åtgärder mot luftföroreningar”, Arbetsmiljöverkets författningssamling, ISBN 91-7930-458-3, 2005

AFS 2005:16, ”Buller”, ISBN 91-7930-455-9

AFS 2005:18, ”Härdplast”, ISBN 91-793-459-1

Arvidson, M., Axelsson, J., Hertzberg, T., “Large-scale fire tests in a passenger cabin” SP Report 2008:33

Baczynska, M., “LCA as a tool for environmental impact description”, Divinycell International AB, Laholm, Sweden, 1996

Bokalders, V., Block, M., ”Byggekologi”, AB Svensk Byggtjänst, 2004

Builddeskonline, www.builddeskonline.com

Cement manufacturing, www.cement.org

CES EduPack, “Eco properties database”, Granta Design Ltd

Danielsson, M., “foam core materials for high performance sandwich constructions, Department of Polymer Technology, Chalmers University of Technology, ISBN 91-71-97-616-7, Bibliotekets Reproservice, Göteborg, 1998

DIAB, www.diabgroup.com

DIAB AB, information from H. Jönsson, June 17, 2008

“Ett energieffektivare Sverige”, Delbetänkande av Energieffektiviseringsutredningen, ISBN 978-91-38-22931-6, ISSN 0375-250X, Stockholm 2008

EU “Handbook for Implementation of EU Environmental Legislation”, Section 4, Waste Management Legislation, December 2003

Grove-Nielsen, E., “Material and Thermal Recycling of Wind Turbine Blades and other Fibreglass items”, presentation at the COMPOSIT Thematic Network Workshop, SICOMP, 2003

Hertzberg, T., Private communication, May 12, 2008

Hedlund-Åström, A., Luttropp, C., ”Conditions for Recycling and Recovery of Composite Materials”, Proceedings from the 11th International CIRP LCE Seminar, Belgrade, Serbia, 2004

Hedlund-Åström, A., “Model for End of Life Treatment of Polymer Composite Materials”, Doctoral Thesis in Machine Design, TRITA-MMK 2005:23, ISSN 1400-1179, KTH, Stockholm, Sweden 2005

Home properties AB, information from U. Arbin, Kockums AB, May 29, 2008

Lindgren, Maria, “Comparison of styrene emissions during manufacturing of boats with spray-up and vacuum injection”, SICOMP Technical Report 99-002, SICOMP Project Number 312, 1999

Ljunggren, S., ” Nordiska krav och rekommendationer för ljudförhållanden i byggnader” ISRN-KTH-BYT/AR—01/3—SE, ISSN 1404-9457, 2001

LÄSS, www.lass.nu

NFS 2004:4, “Naturvårdsverkets föreskrifter och allmänna råd om hantering av brännbart avfall och organiskt avfall”, Naturvårdsverkets författningssamling, ISSN 1403-8234, 2004

NTMCalc, www.ntm.a.se, NTM – nätverk för transporter och miljö

Nyström, B., “Förbränningsförsök av kompositer vid Norsa värmeverk inom VAMP 18”, SICOMP TR 02-003, 2002

Oceanic Creation AB, Information at project meetings, Jan-May, 2008

Reichhold Sweden AB, information from H. Engblom, June 18, 2008

Skamol A/S, www.skamol.dk/fpp_microsite/pdf/litecore_marine_panels.pdf

Skamol A/S, “Miljøredegørelse for CaSi fabrikken”, 2007

VAMP 18, www1.mtov.lth.se/vamp18

Villa Spies, Eriksson Ronnefalk förlag, ISBN 90-972660-0-0, Stockholm, Sweden, 1996

Åström, B. T., ”Manufacturing of Polymer Composites”, Chapman & Hall, London, UK, 1997

Åström, P., SAR, MSA Architect, Private communication, May, 2008