Chapter 2

ECO-EFFICIENCY

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Eco-efficiency

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INTRODUCTION

"New materials, products and technologies are in the long term the necessary way to reduce environmental impacts. Construction products play a major role in improving the eco-efficiency of building. Radical innovations are needed for a real change towards sustainability." Memorandum of Understanding, COST C25, Sustainability of Constructions: Integrated Approach to Life-time Structural Engineering.

Sustainable development, is development that is pursued in a manner that whilst meeting the present needs, does not compromise the ability of future generations to meet their own needs.

The papers presented in this chapter focus on two main areas:

- Identification & Evaluation of existing & new functional materials, construction products & processes, to comply with a reduction in the use of materials, a reduction of waste, reduction of emissions and energy saving goals.
- Improvement of the environmental performance of constructions, improvement of comfort in buildings, energy performance and the integration of innovative systems in buildings.

Sustainability in Construction, necessitates a better comprehension of construction materials, their performance, and the impact of construction techniques, with the objective of the Conservation of Resources.

Increased conservation of resources is one of the most significant principles of sustainability of buildings and constructions, which can also be achieved through the adoption of rational structural solutions, and the selection of construction materials of improved performance characteristics and increased strength.

Increase in the specific strength of structural elements, leads to a decrease in material consumption. Serdjuks D. et al discussed the possibility of the development of hybrid composite cables of increased specific strength, using carbon fiber reinforced plastics (CFRP), glass fiber reinforced plastics (GFRP) and Vectran, instead of steel cables. Hybrid composite cables with increased specific strength were considered for a prestressed saddle-shaped cable roof having dimensions 50m x 50m, leading to savings on materials and energy in the production process. (Serdjuks D., 2007, Composite Cable of increased specific strength, for large span structures.)

Silva N. et al, analysed the benefits of the incorporation of Phase Change Material (PCM) in gypsum plasters. This system presents environmental advantages leading not only to enhanced comfort but also economic benefits, with respect to conventional gypsum plaster. The assessment demonstrates that the PCM system is characterised by similar impacts in all categories; however it reveals a reduced impact in terms of Global Warming Potential due to energy conservation. (Silva N. et al, 2007, Environmental characterisation of gypsum-PCM plasters.)

The assessment of the performance of materials in practice is important in view of durability. Norvaisiene R. et al carried out a number of experiments intended to improve the test methods for the investigation of facade paint durability, by allowing for the impact of air pollution. The results for samples after 96 days of exposure in the climatic chamber, were compared with results obtained for unexposed and naturally weathered samples. The correlation between natural weathering and the accelerated artificial ageing was found to be sufficient. (Norvaisiene R. et al, 2007, The development of a new methodology for the estimation of durability of facade paints.)

The main concerns in wood construction, are associated with a relative reduced efficiency of the material, the low strength spectrum, anisotropy and preservation. Haller P. assessed the potential for innovation of wood, through the efficient use of the raw material, by improving its properties, cross-sections and production techniques. These developments lead to various improvements which include the reduced prices of materials; the densification of wood that surmounts the limits of the strength classes; the use of textile reinforcement as a technology that solves the problem of anisotropy at a favourable price and provides weather protection; and the shaping of efficient cross-sections. (Haller P., 2007, From tree trunk to tube or the quadrature of the circle.)

Welzbacher C.R. et al assessed the biological and mechanical properties of Norwegian spruce, which was densified in a common industrial scale process and afterwards thermally modified in an Oil-Heat treatment process. It was reported that the durability increased considerably as a result of Oil-Heat treatment. While the dynamic mechanical properties of densified and Oil-Heat treated spruce were reduced when compared to controls, the static bending strength was equal to untreated spruce. Densified and thermally modified samples demonstrated improved dimensional stability when compared to untreated densified material. (Welzbacher C.R., 2007, Biological and mechanical properties of densified and thermally modified Norway spruce.)

The concept of conservation of resources was discussed by Borg R.P., in the assessment of practical solutions with regards to the management of excavation, construction and demolition waste. The waste hierarchy provides an order of priorities for deciding on waste management practices, including the Reduction in Waste, and therefore minimizing on the use of resources and reducing the quantities of waste; Reuse of materials; Recycling and reprocessing of the waste material, for use in the manufacture of the same or different materials; Recovery of energy; and Disposal of waste, whereby waste is disposed without energy recovery only if there is no other appropriate solution.

Various proposals for waste reduction, reuse and recycling were assessed within the framework of the Waste Management Strategy. Potential measures need to be analysed in terms of environmental impact and economic feasibility. Solutions for waste management include the recycling of excavation, construction and demolition waste for use in Civil Engineering applications. The potential disposal of inert waste was also assessed with reference to disposal in quarries, and reclamation of land from the sea. (Borg R.P., 2007, A Sustainable Waste Management Strategy: Construction & Demolition Waste.)

The use of recycled materials was further analysed through experimental work conducted by Jevtic D. et al, on the properties and performance of cement composites based on recycled brick aggregate. In particular the density, compressive strength, flexural strength and shrinkage were assessed. The test results obtained for the mechanical properties of fiber reinforced recycled brick composites indicate that the addition of polypropylene fibers generally leads to improvements of these properties. The results indicate that there can be a wider scope for the application of concrete produced using crushed recycled brick aggregate. (Jevtic D et al, 2007, Properties and performance of cement composites based on recycled brick aggregate.)

The properties of concrete were also investigated by Malesev M., et al, in an experimental investigation on the use of recycled concrete as aggregate for structural concrete. A comparative analysis of the properties of fresh and hardened concrete with natural coarse aggregate, combination of natural and recycled coarse aggregate and with recycled coarse aggregate, was carried out. Concrete mixtures with recycled aggregate were noted to be very similar to concrete mixes with natural aggregate, and the performance of the Recycled Aggregate Concrete was satisfactory. (Malesev, M. et al, 2007, Recycled concrete as aggregate for producing structural concrete.)

In the selection of construction materials, the entire life cycle of the building must be considered, covering not only construction, use and maintenance, but also waste disposal. Factors that need to be assessed in planning an environmentally sustainable and cost effective building include minimal energy, minimal maintenance, minimal waste and suitability for local climate. Ermolli S.R. et al discussed the contribution of aluminium systems towards the sustainability of structures. New building systems and innovative design concepts incorporating aluminium alloys are adopted to provide more sustainable solutions. (Ermolli S. R. et al, 2007, Sustainable Aluminium Systems.)

Kozłowski A. et al, present inventory data collection for a light gauge steel frame structural system that can be used for residential and commercial buildings. The Life Cycle Inventory analysis of the system was performed for boundaries covering manufacturing processes. (Kozlowski A., 2007, Preliminary Life Cycle Inventory analysis of light gauge steel frame system.)

Numerous methods are utilised for the estimation of the energy consumption in buildings. A brief state of art of various methods is given by L. Berevoescu,et al. The methods used to assess the consumption of energy, are grouped into direct methods and reverse methods. (Berevoescu,L. et al, 2007, Energetic audit methods, part of sustainable development process.)

An analysis of the housing stock situation in Romania is presented by Dan D. et al. This is followed by an assessment of the requirements for the resistance to heat flow of elements of the building envelope, and a discussion on the latest trends in construction. The building enevlope solutions adopted before 1984 were inadequate, while new improved solutions that were developed for exterior walls, were not used in practice due to initial higher investment costs. The Order issued by the Romanian Government in 2000, concerns the thermal rehabilitation of existing buildings and stimulates energy saving in buildings. A commercial center in Timisoara, Romania is used as an example of good practice, and illustrates this positive trend. (D. Dan, at al, 2007, Energy efficiency of old and new buildings in Romania.)

Dan D. et al discussed the efficacy of the thermal rehabilitation of a student hostel, and analysed the economical benefits of the solution adopted. The solution adopted includes improvements in the global thermal resistance of the building envelope, with the aim of reducing the loss of energy. The amortization period of the investment is reported to be about 6 years. The energy classification of the building stock, can be considered as an effective management tool. (D. Dan, at al, 2007, Thermal rehabilitation of a student hostel belonging to the Politehnica University of Timişoara.)

The thermal performance of houses built using different construction techniques in the Izmir region in Turkey, were compared by Altin M., et al. Houses built using traditional and conventional techniques are compared to light-weight houses. (Altin M. et al, 2007, Comparison of the improvement of comfort in Turkish houses which are built by using traditional, conventional and semi-industrialized construction methods.)

Werner G., reviewed a study conducted by the Swedish building and energy sectors, with the aim of identifying the most cost-effective and resource-efficient measures for the reduction of the environmental impact of buildings. The goal was to attain a system for energy supply, with the least possible environmental impact. (Werener, G, 2007, Low energy building design with sustainable energy end use.)

An integrated approach is necessary for an adequate assessment of construction materials, construction techniques and structural systems. The papers presented in this chapter address a variety of subjects, but have a unifying principle: Conservation of Resources. Innovation in construction and the potential development of emerging technologies and new materials, are essential towards achieving the goals of energy efficiency and resource management, within the context of sustainability in construction.

Improved performance requirements of buildings, necessitate an adequate analysis of energy efficiency of buildings. This enables the formulation of strategies based on adequate priorities for rehabilitation and construction, in the context of improved comfort and sustainability. The challenge is also to assess successful low energy building design solutions in different climate zones, and to gain sufficient knowledge towards effective solutions in different circumstances.

The contributions presented in this chapter, are yet another step, towards the objectives of COST C25, and for an integrated approach in the assessment of sustainability in construction.

Composite cable with the increased specific strength for large span structure

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ABSTRACT: Increase of specific strength of structural elements enables to decrease materials consumption and use more rationally natural resources. Possibility to develop hybrid composite cable with the increased specific strength in comparison with the steel cables was considered. Increase of specific strength was obtained by using of composite components, such as carbon fiber reinforced plastics (CFRP), glass fiber reinforced plastics (GFRP) and Vectran. Rational components for composite cable with the increased specific strength were evaluated. Hybrid composite cables with the increased specific strength were considered as materials of several cable groups for a prestressed saddle-shaped cable roof with dimensions 50x50m. The saddle-shaped cable roof was loaded by the design vertical load combination: dead weight and snow. Possibility to decrease consumption of cable net materials and to decrease pressure on the environment was stated.

1 INTRODUCTION

Reduce of resources consumption is one of the most significant principles of sustainability of buildings and constructions (Pinheiro 2007). Reduce of resources consumption for constructions could be obtained by the two following methods:

- use of rational type of structure;
- use of the materials with the increased specific strength.

The rational is a such type of structure, where materials with the increased specific strength can be used in the full scale. Large span cable structures, where nearly all main load-bearing elements work at tension are rational from the point of view of materials consumption (Serdjuks & Rocens 2003a).

High strength materials such as FRCC and FRP possess potential for their application as constructional materials in combination with the steel (Pakrastinsh et al. 2001). Carbon fiber reinforced plastic (CFRP), glass fiber reinforced plastic (GFRP) and Vectran are examples of such materials. As constructional materials they have following advantages:

- high specific strength;
- good durability in aggressive surrounding;
- CFRP is adaptable to be used in structures not allowed to be magnetic or electric conductive;
- low density.

However, CFRP, GFRP and Vectran have a number of disadvantages, which limit their application as constructional materials. Relatively small elongation at break (Serdjuks & Rocens 2003), probability of surface damages and increased cost (Serdjuks & Rocens 2004) are most significant disadvantages of CFRP, GFRP and Vectran in comparison with the steel cables.

Small elongation at break significantly decreases safety of construction due to probability of brittle failure during short time growing of the load. This disadvantage could be improved by the adding of steel component, which enables to increase reliability of the cable. Addition of distribution layer, which could be made of glass fiber reinforced plastic (GFRP), significantly decreases the possibility of surface damages of CFRP in hybrid composite cable (Fig.1.).

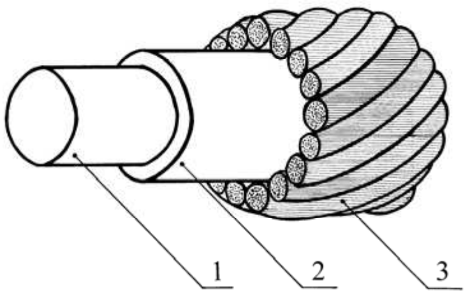

Figure 1. Hybrid composite cables on the base of steel and FRP: 1 – FRP core; 2 – FRP distributional layer; 3 – steel component.

Yet the volume fractions of the components should be evaluated. So, the purpose of the study is evaluation of rational volume fractions for hybrid composite cable components. Environmental assessment of hybrid composite cable with the increased specific strength using for saddle-shaped cable roofs also should be done.

2 DESCRIPTION OF TECHNOLOGY

2.1 *Material combinations for hybrid composite cable*

The main directions of the considered hybrid composite cables application are prestressed nets of saddle-shaped roofs. Here two types of hybrid composite cables with the increased specific strength should be investigated. First of them is a hybrid composite cable with an increased, in comparison with the CFRP ultimate elongation and decreased in comparison with that of steel dead weight. These types of the cables could be used for the tension and suspension cables of the prestressed net. Second is a hybrid composite cable with relatively high ultimate elongation for the stressing cables of the prestressed nets. Combination of high strength and increased ultimate elongation is the main requirement for the first hybrid composite cable type. But the second type, unlike the first, should possess first of all, an increased ultimate elongation.

Thus, the first cable type should obligatorily contain two types of materials: one material with a large limit of strength and the other with an increased ultimate elongation. Third type of materials should be added to transfer perpendicular to the direction of axial force action pressure of the external layer at the surface of the internal one.

Steel wire strands can be treated as a material with an increased up to 10% ultimate elongation for the first type of the cable. Properties of GFRP (E-glass and epoxy matrix at 60% fiber content), CFRP (AS4/3501-6 graphite fibers and epoxy matrix at 60% fiber content), Vectran HS 1500 and strands of steel wire are taken in accordanca with the sources (Beers 1990, Bengtson 1994, Berger 2002, Blum 2000, Costello 1997, Houtman 2003, Kumar & Cochran 1997). Moduli of elasticity of steel wire strands, GFRP, CFRP and Vectran are equal to $2•10^5$; $0.75•10^5$; $1.37•10^5$ and $0.65•10^5$ MPa, respectively. Limits of strength are equal to 1900; 760; 2100 and 2850 MPa, respectively (Beers 1990, Bengtson 1994, Berger 2002, Blum 2000, Costello 1997, Houtman 2003). Ultimate elongations are equal to 10, 2.64; 1.6 and 3.3 %, respectively.

Basing on the above mentioned materials properties, two following materials combinations can be considered for the first type of hybrid composite cable: steel, GFRP, CFRP and steel, Vectran, CFRP. Second type of the cables should be based on the material with the increased ultimate elongation and limit of strength, which is enough to take up tension forces, acting in the stressing cables of the net. Combination of steel, Vectran and GFRP, probably, enables to obtain hybrid composite cables with such properties.

So, three three following variants of hybrid composite cable will be considered next. First variant is on the base of steel, GFRP and CFRP. Second and third are on the base of steel, Vectran, CFRP and steel, GFRP and Vectran, accordingly.

2.2 *Evaluation of rational volume fractions of steel*

Increase of volume fraction of steel causes the increase of load bearing capacity of the cable and the decrease of it specific strength from other side. Yet there is a minimum volume fraction of steel, which enables to prevent failure of single cable or cable net in the case of emergency, when all the components of hybrid composite cable, excluding the steel, are disrupted. The minimum volume fraction of steel was considered as a rational.

Diagonal suspension cable of saddle-shaped cable roof with dimension 50x50 m was considered as an object for evaluation of rational volume fraction of steel for three variants of hybrid composite cables. Design scheme of diagonal suspension cable was a prestressed simple cable with the supports at one level, which is loaded by the uniformly distributed load.

Initial deflection and span of the cable were equal to 20 and 70.71 m, accordingly. Intensity of uniformly distributed load was equal to 1.97 kN/m. The value of prestressing is assumed as a 20% from the tension force, which acts in the cable due to the vertical design load. Three above mentioned variants of hybrid composite cable were considered. Volume fraction of steel changes within the limits of 0.1 to 0.7 from the initial area of cross-section. The dependences of stresses, acting in the steel component of hybrid composite cables after other components disruption on the volume fraction of steel, are given in Fig.2.

The dependence illustrates, that the minimum volume fraction of steel, which prevents failure of the cable in the case, when other components are disrupted, is equal to 0.23, 0.28 and 0.29 for the first, second and third variants of hybrid composite cable, respectively. So, the hybrid composite cables with the rational volume fraction of steel possess following mechanical properties.

Moduli of elasticity are equal to $1.32 \cdot 10^5$; $1.35 \cdot 10^5$ and $1.36 \cdot 10^5$ MPa, for the first, second and third variant of the hybrid composite cable, respectively. Maximum axial forces, which can be taken up by the cables, are equal to 1242; 1313 and 1294 kN, for the first, second and third variant of the hybrid composite cable, respectively. Specific strengths are equal to $43.00 \cdot 10^3$; $41.00 \cdot 10^3$ and $40.50 \cdot 10^3$ m, for the first, second and third variant of the hybrid composite cable, respectively.

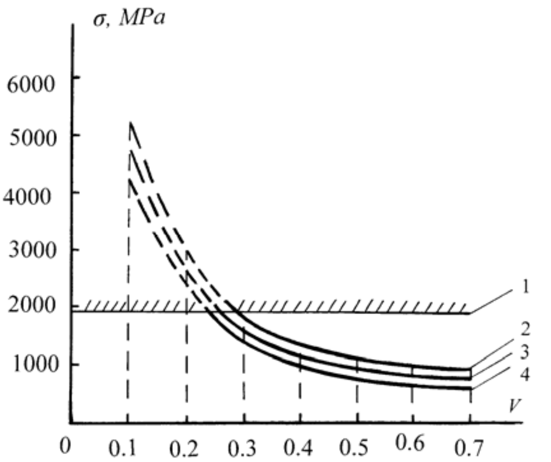

Figure 2. Evaluation of rational volume fraction of steel (at constant vertical load): 1 – limit of strength of steel; 2 – dependence for variant of hybrid composite cable on the base of steel, GFRP and CFRP; 3 – dependence for variant of hybrid composite cable on the base of steel, Vectran and CFRP; 4 – dependence for variant of hybrid composite cable on the base of steel, GFRP and Vectran; σ - stresses, acting in the steel component of hybrid composite cables after other components disruption; *V* - volume fraction of steel.

However a single cable can not characterize behaviors of the cable roof in the full scale. So, hybrid composite cable on the base of steel, GFRP and CFRP was considered as a material of tension and diagonal suspension cables of saddle shaped cable roof with dimensions 50x50 m. The behaviors of the cable roof were evaluated for the diagonal suspension and tension cables in the cases, when all the components of hybrid composite cables, excluding the steel, were disrupted. Parameters of cable roof and methodology of numerical experiment are explained in chapter 3.

It was stated, that the maximum vertical displacements of the cable roof grows by 3 mm in the case of GFRP and CFRP components disruption of diagonal suspension cable. Maximum growing of the stresses from 899 to 1110 MPa took place in the suspension cables, which are neighboring to the diagonal suspension cables. The maximum vertical displacements of the cable roof grows by 1.37 m in the case of GFRP and CFRP components disruption of tension cables. Maximum growing of stresses from 897 to 1050 MPa took place in the diagonal suspension cable. Still the growing of stresses and maximum vertical displacements did not cause failure of any more cables.

3 USING OF COMPOSITE CABLE FOR INCREASING OF SADDLE-SHAPED CABLE ROOF RIGIDITY

Let us to consider how the using of hybrid composite cable in combination with the cable truss application enables to increase the rigidity of saddle-shaped cable roof.

A saddle-shaped cable roof 50x50 m in the plan was investigated. The existence of two symmetry planes allows us to regard, as a design scheme, a quarter of the cable net of a saddle-shaped cable roof with a main stressing cable as the shape of the cable truss, which is subjected to the prestressing and vertical design load (Fig.3).

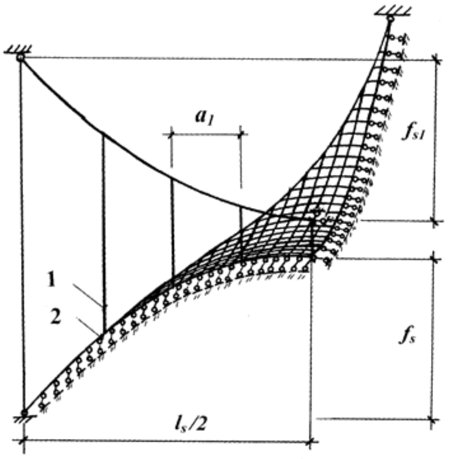

Figure 3. Design scheme of cable roof:1– cable truss; 2 – cable net; f_{s1} – initial deflection of top chord of cable truss; f_s – initial deflection of main stressing cable; a_1 – distance between the support points of tee-bars.

Three quarters of the cable roof are replaced by the bonds imposed on its one-quarter part. Hybrid composite cables on the base of steel, GFRP and CFRP with an elastic modulus of $1.32 \cdot 10^5$ MPa were assumed as a material of cable truss elements. Steel cables with an elastic modulus of $1.3 \cdot 10^5$ MPa were assumed as a material for the suspension, stressing (excluding main diagonal) and tension cables.

From the viewpoint of material consumption, the saddle-shaped cable roof has rational geometrical characteristics: the initial deflection of the contour cables was 8.6 m, the initial deflection of suspension and stressing cables 20 m, and the step in plan of the latter ones was 1.414 m (Serdjuks et al. 2000, Sedjuks & Rocens 2003b).

The structure was calculated for the basic combination of loads – the dead weight of the structure (0.27 kPa) and the weight of snow (1.12 kPa) – evenly distributed on the horizontal projection of the roof. The design load in the form of pointwise forces was applied to the nodes of the cable net. The roof had the following layers: a glass net coated with polymer resin (2 mm), foam plastic, reinforced with a glass net (120 mm), and saddle-shaped plywood sheets (6 mm) (Rocens et al. 1999).

The cable net was prestressed by applying tension forces to the suspension and stressing cables, such that the residual tension forces in the stressing cables were equal to 20% from their initial values under the vertical design load.

Two variants of support points of the main diagonal suspension cables fixation were considered:

– the displacements of the cable net at the support points were restricted by the deformation of the guys;
– the relations excluding any displacements were imposed on the support points of the cable net.

The cross-sectional areas of the cables occurring in the symmetry plane (the main diagonal cables), as well as the pointwise forces applied to the nodes of these cables, were divided by two. The pointwise force applied to the intersection node of the main diagonal cables was divided by four.

Maximum vertical displacements of the cable roof for all combinations of the main geometrical characteristics of the cable truss were determined as a maximum difference in the vertical coordinate of the cable net nodes before and after application of design vertical load. The dependence of the maximum vertical displacements of cable net on the initial deflection of top chord of the cable truss and distance between the support points of tie-bars is shown in Fig.4.

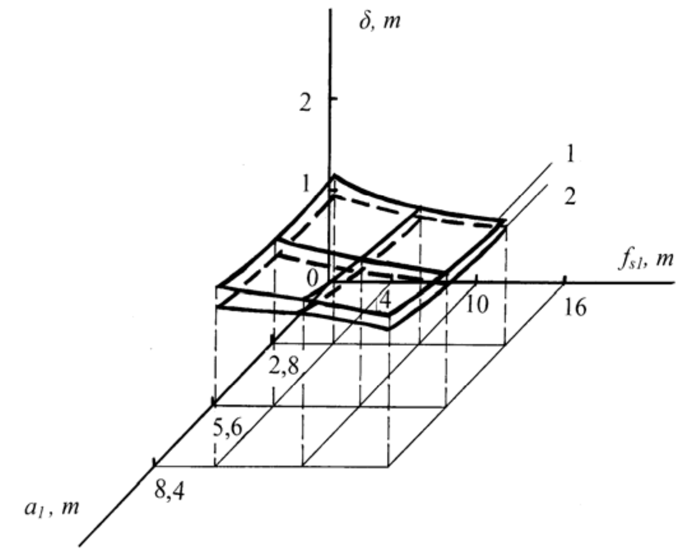

Figure 4. Maximum vertical displacements δ vs. the initial deflection f_{s1} of top chord of cable truss and distance a_1 between the support points of tie-bars: 1– displacements of the cable net at the support points are restricted by the deformations of the guys; 2 – the support points of the cable net are fixed.

The dependence shows, that the minimum values of vertical displacements of cable net were obtained, when the initial deflection of top chord of cable truss was equal to 16 m and distance between the nodes of the cable truss was equal to 2.8 m for both variants of support points fixation.

The dependence of the effectiveness of cable net materials using for maximum vertical displacements decrease on the initial deflection of the top chord of cable truss and distance between the cable truss nodes is shown in Fig.5.

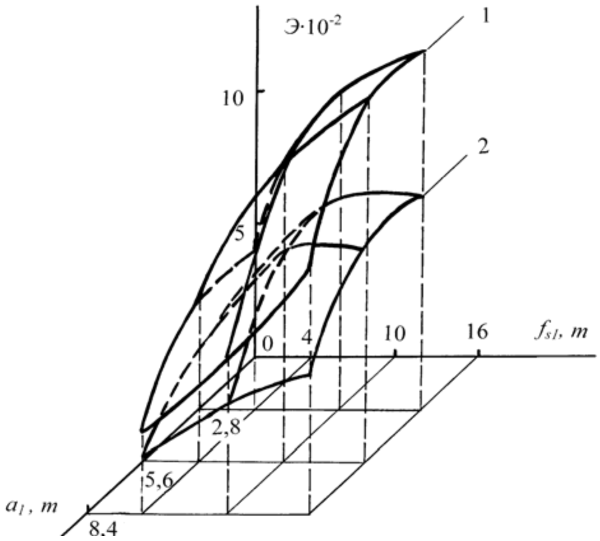

Figure 5. Effectiveness of the cable net materials use for maximum vertical displacements decrease *Э* vs. the initial deflection f_{s1} of top chord of cable truss and distance a_1 between the support points of tie-bars: 1–displacements of the cable net at the support points are restricted by the deformations of the guys; 2 – the support points of the cable net are fixed.

The effectiveness of cable net materials used for maximum vertical displacements decrease was determined from the formula:

$$Э = \frac{\Delta\delta}{V / A} \quad (1)$$

where *Δδ* is maximum vertical displacements decrease, *V/A* is the volume of the material of the cable net per unit of the covered area (relative volume).

The cross-sectional areas of the cables were found according to the recommendations given in (Serdjuks & Rocens 2003b), from the formula:

$$F \geq \frac{1{,}6N}{kR} \quad (2)$$

where *F* is the cross-sectional area of the cable, *N* is the design force in the cable, *k* is a coefficient, taking into account the drop in the breaking force of the cable caused by the inhomogenity of stress distribution, *R* is the ultimate strength of the cable material, and 1.6 is the reliability index of the material.

The area, covered by the roof was found with regard to the initial deflections of tension cables.

The dependence shows, that decrease by 31% of maximum vertical displacements values is joined with the growing by 24% of relative volume of cable net materials expenditure for the variant, when the displacements of the cable net at the support points are fixed. Maximum vertical displacements decrease by 38% in the case, when displacements of cable net were restricted by the deformations of the guys. Relative volume of the cable net materials consumption grows by 27% in the case.

The maximum value of the cable net materials consumption was obtained, when the initial deflection of top chord of cable truss was equal to 16 m and distance between the nodes of the cable truss was equal to 2.8 m.

4 EVALUATION OF RESOURCES ECONOMY DUE TO THE USING OF COMPOSITE CABLE WITH THE INCREASED SPECIFIC STRENGTH

The environmental effect of hybrid composite cable with the increased specific strength using was evaluated as the decrease of the materials and energy consumption.

The decrease of materials consumption was obtained due to the increased specific strength of CFRP, GFRP and Vectran components of hybrid composite cable. The using of hybrid composite cable on the base of steel, CFRP, GFRP and Vectran enables to decrease dead weight of the cable from 2.4 to 2.6 times in comparison with the steel ones. The decrease of relative consumption of cable net materials for saddle-shaped cable roofs with dimensions from 10x10 to 50x50 m is illustrated by the Fig.6.

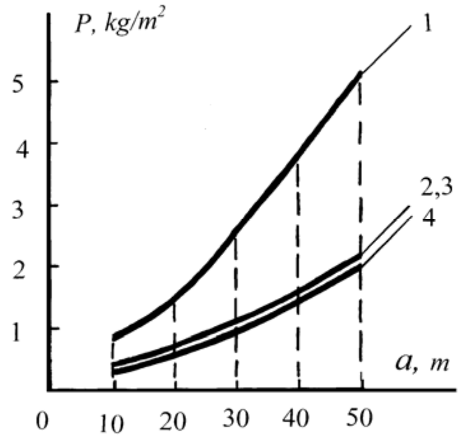

Figure 6. Dependence of cable net materials relative consumption on the dimensions of structure: 1 – cable net is made of steel cables; 2,3 – cable net is made of the hybrid composite cable on the base of steel, GFRP, Vectran and steel, Vectran and CFRP; 4 - cable net is made of hybrid composite cable on the base of steel, GFRP and CFRP; *P* - cable net materials relative consumption; *a* – dimension of saddle-shaped cable roofs.

The decrease of energy consumption due to the using of hybrid composite cable on the base of steel, CFRP, GFRP and Vectran also was evaluated for saddle-shaped cable roofs with dimensions from 10x10 to 50x50 m. Two types of energy were taken into account:

- energy for the producing of structural materials;
- energy for structural materials transportation.

It was shown, that the using of hybrid composite cables instead of steel ones enables to decrease energy for the producing of structural materials consumption up to 4 times. Energy for structural materials transportation decrease up to 2.6 times.

5 CONCLUSIONS

Rational components for hybrid composite cable with the increased specific strength were chosen. It was shown, that the minimum volume fraction of steel component is within the limits of 0.23 to 0.29 for the cables on the base of steel, CFRP, GFRP and Vectran.

Opportunity to decrease the displacements of composite saddle-shaped cable roof by the using of cable trusses as the main stressing diagonal cable structure was investigated.

It was shown, that the using of cable truss as a structure of main stressing diagonal cable enables to decrease by 31–38% the maximum vertical displacements of the cable net and to increase by 24–27% the relative volume of the cable net materials consumption in the case, when the main stressing diagonal cable is strengthened by the truss, which is made of hybrid composite cable but suspension and tension cables are made of steel.

It was shown, that the using of hybrid composite cables instead of steel ones enables to decrease energy for the producing of structural materials consumption up to 4 times. Energy for structural materials transportation decrease up to 2.6 times.

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Environmental characterization of gypsum-PCM plasters

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1 ABSTRACT:

Improvement in materials and building technologies can contribute to energy efficiency towards more sustainable construction. In this paper it is presented new gypsum based interior plastering system, incorporating phase change materials (PCM). Although for PCM no data is yet available, environmental assessment of gypsum plaster impact from extraction to construction phase is presented. Difference between systems operational energy and related Global Warming Potential was also considered, for a life time horizon of 30 years. Comparison with conventional gypsum plaster is made as reference. Results from experiments carried out in Passy's test cells show the potential for energy savings of these materials.

2 DESCRIPTION OF MATERIAL

2.1 *Field and range of applications*

The building sector accounts for about 40% of the energy and greenhouse gases emissions. About one-third of energy's end-use is consumed directly in buildings, mainly for regulating thermal comfort parameters and general services. In 2000, heating was responsible for nearly 80% of the total energy consumption in an EU average household (Ardente et al., 2007). The most effective ways to improve buildings energy performance are by thermal insulation of the building elements and by energy storage. This way is possible to reduce heat losses, save energy and operational costs with heating and cooling.

Phase change materials (PCM) have been used for improvement of thermal comfort inside buildings by thermal energy storage. PCM have the ability to change its physical state by absorbing or releasing latent heat at constant temperature, with much greater energy than the energy stored by sensible heat. PCM can be either organic, such as paraffin waxes or fatty acids, or inorganic, usually salt hydrates. Organic PCM have lower thermal storage capacities when compared to salt hydrates but have the advantage of lower thermal conductivity, leading to uniform transitions and stability of properties in time, under thermal cycling. Paraffin's are cheap and present a wide range of melting temperatures, allowing the suitable choice to the end-use, result of the widespread refining process facilities and processes. Nevertheless their price tends to increase, with fossil fuels prices rising.

Gypsum wallboard incorporating PCM has been studied as passive solar system in lightweight construction has a mean to reduce overheating problems in summer and to decrease heating needs during winter. In buildings with high thermal mass, this problem is not so effective.

The incorporation of PCM seems therefore also a logical way to shift peak demands from network to night period.

Gypsum plasters exhibit good insulating properties due to low conductivity and high thermal inertia, very good hygrometric behaviour acting as a moisture regulator, high composition stability, good tensile and bending strength absorbing background movement, very good fire resistance and acoustic properties.

In order to avoid leakage during melting and freezing cycles and ensure density through materials lifetime, containment of the PCM inside the gypsum plaster matrix must be ensured. One way to do it is by microencapsulation in a thermosetting resin, supporting volume variation of the PCM during transition and increasing surface transfer area. The microencapsulated PCM exhibits good latent heat (thermal storage), low thermal conductivity and good fire properties. In the form of a powder it is easy to incorporate in plasters during production or mixing stage.

By incorporating PCM, the construction elements' thermal mass is significantly increased. When compared to conventional plaster, the system contributes to a more effective interior temperature regulation, reducing maximum and increasing minimum temperatures, by absorbing and releasing latent heat. It is expected that mainly in autumn and spring, energy costs be reduced by shifting energy consumption to night period, when the cost is lower. Besides that, this advantage is archived with just a small increment in the initial cost, when compared to conventional solutions. As little maintenance is required, life-cycle period is not affected when compared to conventional solutions.

2.2 *Components*

The presented product is a finishing plaster that incorporates PCM and gypsum and is based in a conventional plaster, containing over 50% gypsum binder, fillers, water retainers and setting retarders mixed with a dispersion of commercial hexadecane paraffin wax, micro-encapsulated in a melamine-formaldehyde resin (low formaldehyde content), with an average particle size distribution of 20-30 µm, melting temperature around 20 ºC and a latent heat of fusion of 140 kJ/kg.

The final mixture, containing 20% weight PCM (70-80% weight paraffin), is mixed with a water/plaster ratio of 65%. Bending, compressive and adhesion strengths were determined according to European Standard EN 13279-2:2004 (CEN 2004) and are presented in Table 1. In-situ specific consumption around 0,75 kg/m^2 is expected, assuming support regular levelling.

Table 1. Mechanical properties of the gypsum-PCM plaster (Silva et al., 2006).

Bending Strength (MPa)	Compressive Strength (MPa)	Adhesion Strength (MPa)
1,77	2,70	0,48

2.3 *Installation Techniques*

It is possible to apply the presented system using conventional tools and techniques. This system is suitable for every conventional wall support material and is built with a plaster layer of 15 mm thick and three thin hands of gypsum-PCM finishing plaster, which can also be applied over cement render.

The first layer is applied directly to the support and covered with a very thin gypsum finishing plaster layer, manually applied. After at least 12 hours it is applied the first hand of the gypsum-PCM plaster layer, assuming dry weather, temperature bounded between 5 to 40 ºC and good ventilation conditions. There should be an interval of at least 1 hour between the last two hands of gypsum-PCM plaster.

A remark should be made, referring to the mixture procedure of the plaster with water. In order to guarantee the integrity of the microcapsules and the effectiveness of the system in time (i.e. avoid the leakage of the PCM by degradation of the container), it is important to keep the mixer speed low and under control. Additionally, sharp metal paddle edges should be avoided.

2.4 *Maintenance*

Gypsum plasters require little or no maintenance. Most of the degradation problems are related to moisture and support surface conditions. Maintenance is usually limited to surface treatment consisting in painting within undefined periods. Procedures, equipment and tools are the same as for conventional gypsum plasters.

As mentioned above, gypsum presents very good thermal and hygrometric properties, making it more suitable for interior plastering, due to moisture and comfort regulation effect, when compared to cement mortars. The main disadvantage of gypsum-PCM plasters when compared to conventional gypsum plasters and cement mortar is lower mechanical properties.

When in situ, mainly walls, plaster is sometimes exposed to accidental mechanical actions caused by different object shapes. Analysing the bending, compressive and adhesion strengths, a significant fall in the impact strength is expected. Nevertheless, it is not expected to have big differences in the mechanical behaviour in the final system, when compared to the conventional gypsum rendering, since the gypsum-PCM layer is very thin, and the support layer is assumed to be the same as in the conventional system.

2.5 *Demolition*

Gypsum recycling is a simple process, consisting mainly in crushing and dehydrating the material at temperatures around 160 ºC. Melamine-formaldehyde resins are thermosetting plastics with good temperature resistance. Thermal gravimetric analysis performed (Su et al, 2005), reported degradation of the microcapsules with mass (mainly water) loss up to 20%, at this temperature, therefore further thermal studies should be carried in order to accurate define the recycling procedures for this type of product. Nevertheless selective demolition, dehydration of the product at the mentioned temperature and the incorporation of recycled mixture in new product would be a solution for the life-cycle' end of the presented solution.

3 ENVIRONMENTAL ASSESSEMENT

3.1 *System boundaries*

For this scope, system boundaries are defined from raw materials extraction to final application of the system, in construction site. Difference between systems operational energy and related Global Warming Potential was also considered, for a life time horizon of 30 years. The selected functional unit for this assessment is the quantity of material and related environmental impacts necessary to cover 1 m^2 of wall.

3.2 *Data of considered example*

This assessment is based on experimental work that is being carried out in Passy's type test cell in the University of Minho. The cell, oriented North to South in length, is 4,10 m length x 2,60 m width x 2,50 m high (internal dimensions). Interior floor, ceiling and walls are thermal insulated with a double layer of expanded polystyrene 5 cm thick plates, except for the south façade, consisting in a hollow polycarbonate sheet mounted in a wood frame.

Figure 1. Experimental wall (gypsum-PCM).

An 11 cm hollow brick wall with 4,05 m x 2,50 m was built, dividing the cell in two rooms each with 4,10 m x 1,20 m and leaving an aperture of 65 cm x 60 cm, to allow plastering, instrumentation and maintenance of the East room (this opening was then closed with a double layer of expanded polystyrene 5 cm thick plates and polyurethane foam).
Each surface of the wall was covered with a 1,5 cm thick and 14 kg/m^2 density levelling layer of conventional gypsum plaster. After 24 hours, three very thin layers of finishing plaster were manually applied in both surfaces. In the West surface, gypsum-PCM mixture was used as finishing (Figure 1), while in the East surface was used only conventional gypsum plaster (comventional solution) . Table 2 presents the characteristics of the finishing used on both wall surfaces.

Table 2. Material unit data for both solutions in study.

Property	Reference Solution	Studied Solution
Plastered area (m^2)	9,74	9,74
Gypsum plaster used (kg)	10	7,5
PCM used (kg)	---	1,9
Gypsum specific consumption (kg/m^2)	1,03	0,77
PCM specific consumption (kg/m^2)	---	0,20
Storage capacity (Wh/m^2)	---	7,6

3.3 *Environmental impact categories*

Table 3 presents data for the environmental impact of the three different systems: reference and studied solutions and a third, considering different transportation impacts for the studied solution. ,The probable solution represents the possibility of premixing the components of the gypsum-PCM plaster in the gypsum plant.. This possibility was assessed because is the most plausible from the commercialization point of view. Impacts shown are based on inventory results presented below, in paragraph 3, considering all materials of both systems, life-cycle from extraction of raw materials to the end of construction.

Table 3. Environmental impacts of the considered solutions.

Impact categories	Unit	Reference Solution	Studied Solution*	Probable Solution*
Water use	l/m^2	247,3	232,4	232,4
Energy use	MJ/m^2	33,6	33,1	33,2
Global Warming Potential (GWP)	g_{CO2}/m^2	1075	1046	1055
Eutrophication Potential (EP)	g_{NOx}/m^2	0,04$^{(1)}$	0,03$^{(1)}$	0,03$^{(1)}$
Acidification Potential (AP)	g_{SO2}/m^2	38,6	30,4	36,3
Photochemical Oxidant Creation Potential (POCP)	g_{NOx}/m^2	2,9$^{(2)}$	2,6$^{(2)}$	2,8$^{(2)}$

*PCM impacts were not considered, since life-cycle inventory data is not yet available
[1]Considering only the transportation impact
[2] Not considering the materials transportation impact

Considering 30 years of operational energy for both solutions, according to the experimental and inventory results, the Global Warming Potential of the studied solution is lower than the reference solution in about 92x10^{6}g of CO_2 per net square meter of the test cell.

4 INVENTORY RESULTS

4.1 *Components*

The results for inventory of the environmental impacts of system components were collected by Berge (2000) for Central Europe. Gypsum data is based in plasterboard while for PCM no data was found. Table 4 presents data collected.

Table 4. Materials environmental impacts inventory.

Impact categories	Unit	Gypsum
Water use	l/kg	240
Energy use	MJ/kg	5
Global Warming Potential (GWP)	g_{CO2}/kg	265
Acidification Potential (AP)	g_{SO2}/kg	3
Photochemical Oxidant Creation Potential (POCP)	g_{NOx}/kg	2

4.2 *Package & Transport*

For this study, it is considered that system components produced in different plants were mixed at construction site. Gypsum plaster was packed in recyclable Kraft paper bags of 30 kg, stacked in wood pallets and wrapped in PE film, while PCM was packed in reusable plastic bags.

Both gypsum plaster and PCM were transported by road in diesel truck, although from different locations. The distance from gypsum plant to construction site is about 240 km and from PCM plant to construction site is about 30 km.

In case the gypsum-PCM is pre-mixed in the gypsum plant , what for commercial reasons is a possibility that must be taken into account, the total transportation distance for this product would be around 480 km for PCM and 240 km for gypsum.

Table 5 presents the energy consumption and air pollutant emissions, considering both solutions studied and the third possibility presented.

Table 6 presents the transportation's environmental impacts of the materials to construction site, for the two analyzed systems, as well in the case of the pre-mixed solution.

Table 5. Air pollutant emissions and primary energy consumption during materials transportation (Energy Research Group 1999).

			Reference Solution	Studied Solution	Probable Solution
		Emissions (g/t.km) Energy (kWh/t.km)	Emissions (g/m^2) Energy (kWh/m^2)		
Emissions	CO_2	207	51,0	39,5	58,0
	CH_4	0,3	0,07	0,06	0,07
	NOx	3,6	0,89	0,69	0,83
	CO	2,4	0,59	0,46	0,56
	VOC's	1,1	0,27	0,21	0,25
	Energy	0,8	0,20	0,15	0,19

Table 6. Environmental impacts related with materials transportation.

Impact categories	Unit	Reference Solution	Studied Solution	Probable Solution
Energy use	MJ/m^2	0,71	0,55	0,67
Global Warming Potential (GWP)	g_{CO2}/m^2	52,7	40,8	49,6
Eutrophication Potential (EP)	g_{NOx}/m^2	0,04	0,03	0,03
Acidification Potential (AP)	g_{SO2}/m^2	35,5	27,5	33,4
Photochemical Oxidant Creation Potential (POCP)	g_{NOx}/m^2	0,89	0,69	0,83

4.3 *Installing*

For installation no difference between reference and studied solution is verified. Except for the mixture of the plaster, all the work is manually done and no additional energy consumption is required. Table 7 presents data for the installation environmental impacts. According to the Portuguese energy mix, 500 g of CO_2 equivalents are produced per each kW of delivered energy. The mixture was performed with a 1500 W plaster mixer, during 1 minute per hand.

Table 7. Environmental impacts of installation procedures.

Impact categories	Unit	Reference Solution	Studied Solution	Probable Solution
Water use	l/m^2	0,72	0,63	0,63
Energy use	MJ/m^2	27,7	27,7	27,7
Global Warming Potential (GWP)	g_{CO2}/m^2	750	750	750

4.4 *Operation – Thermal monitoring*

In order to evaluate systems performance and assess environmental impacts during operation, temperatures and relative humidity of both rooms and wall surface temperatures were monitored. Figure 3 presents temperature data collected during the first 3 monitored days of approximately 26 days of experiment (640 hours).

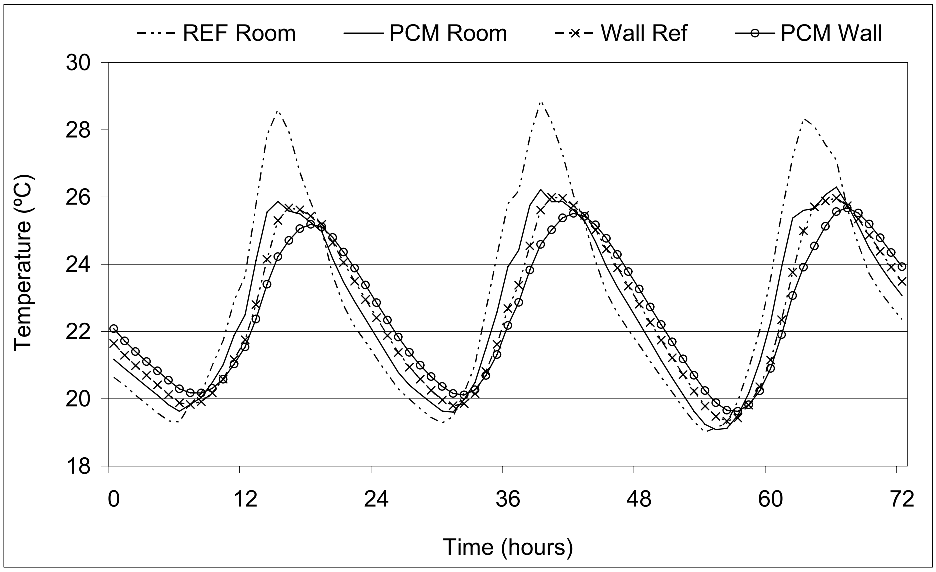

Figure 3. Measured air and wall temperature profiles for the two test rooms.

From the results obtained was possible to verify that PCM has a benefit effect in room environment, decreasing maximum and increasing minimum temperatures up to 3ºC and 1ºC respectively. Higher minimum temperatures in PCM room were expected, however, the high outside temperatures during the period in which this experiment ran, inhibited in large extent the material from freezing, releasing the stored fusion heat (hexadecane paraffin has a melting temperature around 20ºC but the freezing temperature is around 18ºC).

The amplitude between wall and room temperatures is higher for the reference side as expected. For the reference room, 3ºC in maximum and 1ºC in minimum temperatures were observed, while in the PCM room, these values were both about 1ºC. Additionally, the delay between maximum wall temperatures shows the heat absorbing during melting and heat transfer from the room to the wall.

In rooms with low thermal mass such as test cells used, the incorporation of PCM effectively contributes to the increase of this characteristic. This can be seen in Fig. 3 with the delay in maximum temperature of the PCM wall, in particular occurring for temperatures over 22ºC, after PCM fusion.

From temperatures measured, the different heat fluxes between the wall and the air were calculated for both solutions, in order to isolate the PCM effect. Table 8 presents the results achieved. Here are represented the thermal resistance between wall surface and air (R), wall and room areas (A_{wall} and A_{room}), the difference of heat fluxes between wall surface and air for both solutions during the total period analysed and hourly (ΔQT_{640} and ΔQ_H) and these heat fluxes per functional unit considered (ΔQ_W, ΔQ_{annual}, ΔQF and ΔQ_{WF}).

Table 8. Difference between heat fluxes for the considered solutions.

R ($m^2.ºC/W$)	A_{wall} (m^2)	A_{room} (m^2)	ΔQT_{640} (W)	ΔQ_H (W)	ΔQ_W (W/m^2_{wall})	ΔQ_{annual} (MW/m^2)	ΔQ_F (W/m^2_{floor})	ΔQ_{WF} ($W/m^2_{wall}.m^2_{floor}$)
0,13	9,74	4,92	12164	19,0	2,0	61,6	3,9	0,4

4.5 *Maintenance*

Assuming regular use of the habitation and its elements, maintenance is almost irrelevant, as stated in paragraph 1.3. Should there is any accidental impact by a sharp object, it could be necessary to repair the affected area. In this case, procedures which are similar to reference solution, involve the application of new plaster in the affected area. Repairing procedures, equipment and tools of these plasters are the same as for conventional plasters, with the remark of paragraph 1.3.

4.6 *Demolition*

The presented system shows no difference to reference system when selective demolition is carried. Both solutions require the transport of construction waste to gypsum plant for recycling.

5 COMPARISON BETWEEN SOLUTIONS

Comparison between presented solutions should be done in terms of physical, mechanical and thermal properties. An interesting extra comparison can be made with other possible solutions, namely cement renders.

In terms of mechanical properties, as referred in paragraph 1.2, the gypsum-PCM system presents lower performance due lower binder content of the final plaster with the PCM not presenting binding nor filling characteristics. Obviously when compared to cement mortars, both reference and studied system have lower performance however, considering appropriate use, durability of the studied system is very good.

Hygrometric behaviour is at some extent improved with the incorporation of PCM. From the experiment that was carried out it was observed that relative humidity (HR) in the PCM room is lower (average around 55% versus 62%) and with narrow amplitude (around 20% versus 40%). Both systems present better moisture regulation effect when compared to cement render.

Thermally the studied system presents the advantage of latent heat storage, which occurs at approximately constant temperature and can contribute both to delay in time and reduce maximum temperature and increase minimum temperature. In the study presented, the effect on minimum temperature was not verified due to outdoor high temperatures, disabling the PCM to discharge, however an increase in thermal mass was observed. In terms of thermal conductivity, both systems should present similar values, since PCM is approximately the same as gypsum (0,25 W/m.ºC). Both solutions present better thermal performance when compared to cement mortar, which has higher thermal conductivity (0,70 W/m.ºC).

The lack of LCI data available for PCM and the outdoor weather conditions (high temperatures) for the period during which the experiment ran are difficulties to overcome for the accurate assessment. It is expected that mainly during autumn and spring when during daytime temperatures can rise up to 20-25ºC but in the night fall to 5-10ºC, PCM used can more efficient, loading and discharging energy, instead of mainly acting as inertia thermal mass, as in the case of this experiment.

In spite of not considering the environmental impacts of the PCM, it is expected that the studied solution presents higher impacts until the end of the construction phase, since PCM is petroleum derived.

Although, in a life-cycle assessment that involves operation phase, the lower operational impacts dilute the materials' embodied impacts. Considering a time horizon of 30 years, data collected and the Portuguese energy mix, reference system would need to be provided with 61,6 MW/m^2, for the same energetic performance of the studied system, corresponding to more $92x10^6$ g_{CO2}/m^2 GWP.

6 CONCLUSION

From the performed assessment it is possible to see that the benefits of the incorporation of PCM in gypsum plasters. This system presents environmental advantages that produce both indoor comfort and economic benefits. The calculated environmental assessment shows that the PCM system presents similar impacts in all categories but a much smaller impact in terms of GWP due to energy conservation during operation phase.

Comparison between the studied solution and the probable solution presented shows no significant difference in all considered impacts, which from the commercial point of view is very positive, revealing that is possible to develop a new sustainable product, based in some materials whose sustainability has been very discussed, like PCM petroleum derived.

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The development of a new methodology for the estimation of durability of facade paints

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ABSTRACT: The Laboratory of Building Thermal Physics at the Institute of Architecture and Construction in Kaunas has carried out a number of experiments to improve the test methods of facade paint durability investigation by including the impact of air pollution. A painted rendering with the roughened surface was the principal test material. The paper offers a detailed description of the improved accelerated weathering test. The test results obtained after 96 days of exposure to the UV radiation, temperature and acidic rain in the climatic chamber have been compared with the ones obtained with the unexposed and naturally weathered samples. The performance assessment is based on the intermittent measurements of water permeability properties of the paint coatings expressed by 2h surface water absorption rate of the painted samples during the weathering process. The correlation between natural weathering and the accelerated artificial ageing has been established to be sufficient.

Facade paints decorate the building facades and protect them against the deteriorating atmospheric effects. Since rendering is an expensive procedure requiring high skill on the part of the workers the choice of a proper and durable paint coating is of extreme importance.

With the increase of the paint coating's water permeability during exploitation, the rendering under the coating is affected by the climatic factors more intensively – it gets aged sooner. One of the least investigated factors that play an important role in the acceleration of the facade finishes deterioration is air pollution causing the phenomenon of acidic rains. Due to acidic precipitation caused by air pollution, additional acidic effects occur. Together with other climatic factors such as the ultraviolet radiation, temperature and moisture, air pollution is considered a deteriorating agent badly affecting the building materials (Yates 2002, Haneef et al. 1988, Haynie et al. 1984, Norvaisiene et al. 2003).

It is important to define the laboratory parameters of the cyclic accelerated artificial ageing of the facing materials in order to find out the relation between climatic ageing and natural weathering thus affording the opportunity to prognosticate the real durability of the facade paints under natural ageing conditions.

The results of accelerated laboratory ageing of the painted rendering in the climatic chamber are compared with the ones obtained during natural weathering.

The paper discusses the development of the climatic ageing cycle for the painted building facades modelled on the basis of the obtained results and Lithuanian statistical climatic data.

1 ANALYSIS AND MODELING OF CLIMATIC FACTORS

During the last decades, the ageing of facing materials of the building enclosures has grown more intensively which determined the demand for a more accurate prognosis of the state of the building finish with regard to the main climatic destructive agents. The growing requirements for the quality of building construction and increasing atmospheric pollution urge to investigate the reasons that determine the ageing of the exterior finish under the impact of outdoor climate.

1.1 *Modelling of solar impact in a climatic chamber.*

In Lithuania, the ultraviolet (further UV) radiation makes only 6% of the whole solar radiation, however, in the spectrum of all solar radiation waves its impact on the ageing of the finish material is the most extensive. That is why, during the analysis of the impact of solar radiation on the ageing of the building materials, only the impact of the ultraviolet waves has been modelled.

The intensiveness of ultraviolet radiation in a climatic test chamber has been calculated on the basis of the highest hourly intensiveness of solar radiation onto a vertical south-western surface. In the 290-450 mm ultraviolet radiation wave range, under the conditions of the climatic chamber the radiation intensiveness was 40 W/m^2. The calculated radiation period embraced 456 h/yr.

1.2 *Modelling of temperature impact.*

Temperature fluctuation causes the deformations in the painted rendering's external layer, which by frequent recurrence exhaust the material. Actually, the intensity of drying as well as the moisturous state of the tested materials depends on temperature conditions. Thus, in the climatic chamber, the drying of tested materials was modelled with respect to:

1) high outdoor temperature;
2) incandescence of the surface due to direct solar radiation.

Heating. The following temperature regimes have been worked out:

- ambience temperature 29 °C, relative humidity (45-50)% – 180 h/yr,
- ambience temperature 39 °C, relative humidity (25-30)% – 100 h/yr,
- ambience temperature 49 °C, relative humidity (15-18)% – 75 h/yr.

Unilateral freezing. The greatest deteriorating effect has been suffered by the external surface layer of the moistened wall in which water gets frozen up and thawed. On the basis of the climatic data it has been found out that the impact of the annual natural frost cycles on the painted rendering should be imitated by 10 freezing cycles per year each lasting for 5 hours at the ambient air temperature of −0.5 °C.

1.3 *Modelling of rain impact.*

Acidic rains are formed due to the entering of sulphur and nitrogen combinations into atmospheric air (Sopauskiene 2001). Under solar radiation and due to the chemical admixtures found in the air as well as humidity these harmful materials turn into sulphuric and nitric acids. Naturally, unpolluted precipitation is subacidic – the average pH value makes 5.6 because atmospheric water reacts with CO2 thus forming carbonic acid. The pH values of acidic rains formed by air pollution are 4-4.5 or sometimes lower. Fog water comes out to be the most acidic one (pH = 2.5).

Acidic rain and clean rain duration periods and their amounts affecting the southwest building wall in its most moistened places (where the intensity of the rain is about 2.5 times higher than the average value) were calculated with the use of the specially composed computer calculation program "Moisture". The results of calculations are presented in Table 1. This program has been written for the purposes of this research in the Laboratory of Building Thermal Physics at the Institute of Architecture and Construction.

Table 1. Average amounts and duration periods of acidic and clean rains per year (1988-1998) on a vertical southwest oriented surface, calculated with the computer calculation program "Moisture"

Data collection of acidic rain (pH=4.5)*	
Total rain duration 183 h/yr (49 times)	Rains during which water absorption is $\Delta\omega \leq 1{,}5\%$ were neglected
Average rain duration 5 h	Rain duration 3-4 h, water absorption $\Delta\omega \cong 2\%$ - 15 times; Rain duration 5-6 h, water absorption $\Delta\omega \cong 3\%$ - 11 times; Rain duration 7-8 h, water absorption $\Delta\omega \cong 4\%$ - 7 times.
In average water absorption during acidic rain $\Delta\omega \cong 2.8$ %, repetition – 33 times/yr	
Data collection of clean rain (pH=5.6)	
Total rain duration 347 h/yr (36 times)	Rains during which water absorption is $\Delta\omega \leq 1{,}5\%$ were neglected
Average rain duration 9.6 h	Rain duration 4-5 h, water absorption $\Delta\omega \cong 2.5\%$ - 8 times; Rain duration 6-7 h, water absorption $\Delta\omega \cong 3.5\%$ - 8 times; Rain duration 8-9 h, water absorption $\Delta\omega \cong 4.5\%$ - 4 times; Rain duration 10-12 h, water absorption $\Delta\omega \cong 5.0\%$ - 7 times; Rain duration 13-18 h, water absorption $\Delta\omega \cong 6.5\%$ - 8 times; Rain duration ≥ 19 h, water absorption $\Delta\omega \cong 7.0\%$ - once.
In average water absorption during clean rain $\Delta\omega \cong 4.4$ %, repetition - 36 times/yr	
Both acidic and clean rain average duration is 7.35 h, average water absorption during rain $\Delta\omega \cong 3.6$ %, clean rains – 36 times/yr and acidic rains – 33 times/yr.	

*Note: it was based on assumption that an acidic rain is to be if the amount of rain is not more than 2 mm.

On the basis of ten-year statistical climatic data (rain, its intensity, amount and duration; wind speed and direction; average monthly temperatures and monthly round day temperature fluctuation amplitudes) the moistening of the painted rendering during rain has been calculated as well as the duration periods of acidic and clean rains. To work out the calculation program, laboratory tests were carried out and the surface water absorption and drying curves for the samples of the painted rendering were determined at different temperatures, wind speed and relative air humidity.

The laboratory experiments led to the determination of the fact that the winds of average velocities and relative air humidity do not have a significant drying effect on the painted surfaces (Paukstys 2002, Norvaisiene 2004) as temperature does. Therefore the computer program was employed exclusively for the estimation of the impact of temperature to the drying rate to the outside painted rendering layer.

Materials used for tests. For the working out of the painted rendered facade durability tests related with the climatic destructive factors, the tests were performed with the standard factory prefabricated plastic cement-lime rendering mixture (mark SIIa, S5, 0/2). The CO_2 analysis showed that the amount of chalk in the mixture was higher than 30 %; the ratio of water and dry materials in the rendering mixture made 20 %. Out of it the 100 mm in diameter and 25 mm thick circle samples were made, some used for the laboratory tests and others exposed to natural weathering (Fig. 2. The samples were formed in plastic rings until they set. After samples begin to set, the excess of material was whisked out and surface blotted – to get a naturally rough surface as it does on building site. The size and shape of samples was chosen in order to measure the water vapour resistance of them during ageing tests.

The following facade rendering paints of four different sorts were chosen: water vinyl co-polymeric (V); acrylic, modified by silicon water dispersive (A); water polyurethanes (P) and the PVA latex paints (E). These are the typical examples of the rendering finish paints most often used in Lithuania. The sides of the samples were covered with several layers of the epoxy paint coating. For the research purposes 70 peaces of samples have been prepared.

The acidity of precipitation in 1981 – 1990 at an average was pH = 4.5, the acidity of fog water, in its turn, at an average made pH = 2.5. The acidic water solution composed of H_2SO_4 and HNO_3 acids with pH = 2.5 was used to imitate the impact of natural precipitation and fog during the artificial accelerated ageing process of samples in the climatic chamber. Acidic water solutions affect the render material by penetrating through the paint cover (the more water-permeable the paint cover, the greater absorption is caused) and encourage chemical reactions in it, during which new calcium compositions are formed. The authors relied on the research results, obtained during the earlier laboratory tests (Norvaisiene 2004), during which the relationship between the impacts the painted samples after moistening them in different water solutions (whose acidities pH = 2.5, pH = 4.5 and pH = 7.0) was determined. On this basis, the total weathering time in a climatic chamber to imitate one natural year with use of acidic water solution pH = 2.5 was enabled to shorten to 24 round days.

Types of the employed ageing tests. The two types of durability tests have been carried out − under natural weathering and artificial accelerated weathering in a climatic chamber. For natural weathering the sample panel was constructed and attached to the external southwest wall of the building in a height of 3.5 m from the ground. The surface and air temperatures, relative humidity of air were monitored and recorded every 15 min. In order to create the conditions close to natural ones, the joints at the perimeter between the panels and the wall were insulated and sealed.

Artificial accelerated weathering has been carried out in a climatic chamber. The results of both types of tests have been compared with each other.

Evaluation of ageing. The physical ageing of paint coating has been considered in the research. It is considered that the paint coating has lost its protective quality as the 2h water absorption value reaches the value of unpainted render (Norvaisiene 2006).

2 DURABILITY TESTS OF THE PAINTED RENDERING SAMPLES

2.1. The Cycle of Climatic Tests

The climatic chamber used for the experiment was made in the Laboratory of Building Thermal Physics at the Institute of Architecture and Construction in Kaunas.

The aim of the complex accelerated climatic tests was to verify the suitability of the worked out methodology for ageing of the painted rendering by investigation of the impact of the temperature-moisture caused deformations on the ageing of the painted rendering.

The climatic cycle by which the samples were treated was worked out to imitate the natural climatic factors on the most unfavourable places of facade. In the climatic cycle, the imitation of the UV solar radiation, temperature alterations and precipitation as based on the calculations of annual statistical data (Table 2).

Table 2. Processes in the climatic chamber

Process No.	Process	Temperature, °C	Tempera-ture change rate, °C/h	Relative humidity, %	UV radiation	Spraying	pH	Duration
1	Spraying	+7	–	–	UV	yes	2,5	1 minute
2	Freezing/ Heating	+7	–	–	UV	–	–	29 minutes
3	Spraying	+6	–	–	–	yes	2,5	7 h
4	Freezing	-10,5	–	–	–	–	–	5 h
5	–	–	–	–	UV	–	–	0,5 h
6	Heating	+29	60	–	UV	–	–	18 h
7	Heating	+39	60	40	UV	–	–	2 h
8	Heating	+39	–	–	UV	–	–	8 h
9	Heating	+49	–	–	UV	–	–	7,5 h

The natural climatic impacts of a round year suffered at the most unfavourable places of the building's facade were imitated in the climatic test chamber (Table 3).

Table 3. Cycling in the climatic chamber

Duration	Sequence of processes in cycling	Repetition
2 days	Alternation of 1 and 2 processes	once
2 days	In course 3,4,5,6,7,8,9 processes	5 times
2 days	Alternation of 1 and 2 processes	once
2 days	In course 3,4,5,6,7,8,9 processes	5 times

During 24 round days the natural one-year ageing effect was imitated in the climatic chamber:

- For 48 h the impact of fog and dew at 9 ºC (alternation of 1 minute spray with water solution whose pH = 2.5 with break for 29 minutes);
- For 456 h the impact of the UV radiation: intensity 35 - 40 W/m^2 @ 290 – 400nm;
- Freezing 10 times for 5h at -10.5 ºC;
- 10 times for 7 h rain imitation with the help of the water solution whose pH = 2.5;
- High temperature impact: drying at 29 ºC for 180 h; 39 ºC for 100 h; 49 ºC for 75h.

2.2. WATER ABSORPTION OF THE SAMPLES AGED IN THE CLIMATIC CHAMBER AND THE COMPARATIVE ANALYSIS OF THE CHAMBER AND THE NATURAL TEST RESULTS

Water permeability of the wall's external surface coating depends on the water absorption rate and the potential of penetration depth into the wall's construction during rain. The surface water absorption rate of the building materials shows what amount of water has been absorbed by the surface due to the material's capillary sucking potential. The transfer of the liquid moisture in a material was caused by the capillary attraction, osmotic and gravitational forces. The earlier investigation (Norvaisiene 2004, Norvaisiene 2006) revealed, that the 2h (initial) water absorption rate of the painted rendering should be considered a reliable and simple indicator of the ageing of the protective properties of the paint coating. However, the 24h water absorption coefficient of the painted renderings is not so sensitive and reliable. The same samples every 4 months (natural weathering) and 24 days (artificial ageing) were taken out and capillary water absorption, drying rates curves as well as initial intensities of water absorption rate were determined: after drying in the oven at 50ºC, the samples were immersed, exposed faces down into 1-3mm of distilled water and then were weighted at various time intervals.

After the 4 years imitation in climatic chamber, an obvious increase of the samples' initial surface water absorption rate was discovered (Fig 1).

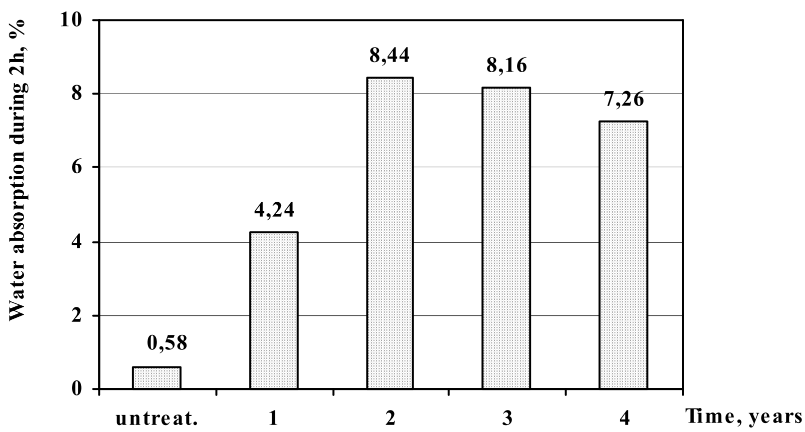

Figure 1. The 2h surface water absorption rates of the samples (V) painted with water based vinyl co-polymeric paint during the weathering in the climatic chamber

Table 4 presents the results of the 2h surface water absorption rate alterations observed under natural weathering and during the climatic tests in the chamber.

Table 4. The 2h initial surface water absorption rate of samples during the climatic tests and under natural weathering, % of mass by mass moisture content

Sample	Untreated	Imitation of the natural year in the climatic chamber (‘strong’ cycling test)				Natural weathering	
		1 year	2 years	3 years	4 years	1 year	2 years
V	0.58	4.24	8.44	8.16	7.26	6.97	6.42
E	1.65	8.52	10.69	10.54	-	5.94	9.47
P	0.49	5.29	9.18	7.09	6.63		
A	0.22	0.20	0.41	1.86	2.53		

Note: the 2 h water absorption rate of unpainted rendering − in average (11-12)%.

In the case of the imitation of a natural year in the climatic chamber, the water absorption rate of the painted rendering samples (E) approaches the water absorption rate of the unpainted render already within two years. When in the climatic chamber, well rendering protective acrylic paint coating (A) undergoes ageing very slowly yet considerably. After four years of ageing their protective properties still remain a bit better than those of the vinyl co-polymeric (V) paint coating after a year of ageing.

Having compared the ageing of the samples (E) in the chamber with that under natural weathering in the panel, it has been observed that both cases demonstrated a similar degree of ageing. The degree of the water absorption rate got diminished after a few years of weathering due to the new combinations composed in the rendering material, in other words, due to salt crystallization.

Due to the impact of the seasonal changes on the properties of the naturally aged samples’ water absorption (Norvaisiene 2006) all the results of the water absorption rate during each calendar year of natural weathering were averaged. The increase of the averaged water absorption rate after one year of weathering reached 0.57 % (Fig 2). Fig 1 demonstrates that, after one year of imitation, the growth of the surface water absorption rate of the samples (V) aged by the climatic cycles in the climatic chamber made 3.66 %.

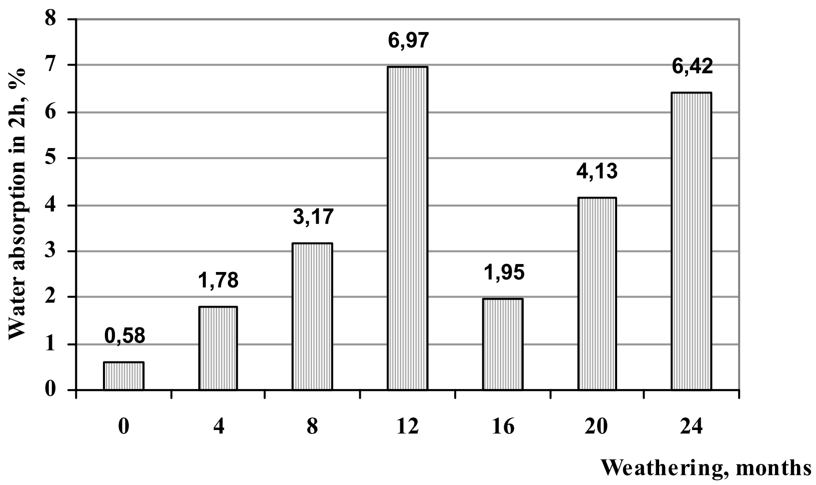

Figure 2. The 2h surface water absorption rate of the samples (V) painted with the water based vinyl co-polymeric paints during natural weathering

The ageing of the painted coating during natural weathering was slower than in the climatic chamber. Natural weathering lasted for 2 years and the climate of the period was mild in comparison with an average statistical year. The complex climatic cycle was worked out on the basis of the 10-year climatic data. The test panels used for natural weathering were located in the middle of the southwest wall, i.e. the place that was inconsiderably moistened by the driving rain (about 0.41 times in comparison with an undisturbed vertical plane (Lvov 1982). The rain intensities onto most unfavourable places of a vertical wall surface affected by the driving rain are being 2-3 times greater than the intensity onto undisturbed vertical plane (Lvov 1982).

During the complex climatic weathering tests in the climatic chamber the water spraying intensity was increased 2.5 times thus imitating the most unfavourable rain-washed and moistened places on the vertical southwest wall. Hence by having estimated the discussed coefficients, during natural weathering the annual increase of the water absorption rate in the samples (V) coated with the water-based vinyl co-polymeric paints could make up to $0.57\% \cdot 2.5/0.41 = 3.45\%$. Therefore, it is possible to claim that, practically, the accelerated ageing in the climatic chamber corresponds to the ageing of the samples under natural conditions.

After four years of weathering in the climatic chamber, the decision was made to stop the tests due to the physical and aesthetic deformity of the samples. The paint coating lost its physical protective properties; blisters appeared and the paints got deteriorated (i.e. the samples were worn out aesthetically).

3 CONCLUSIONS

The carried out experiments demonstrated that the improvement of the methods for determining the facade paint durability is a relevant field of scientific enquiry and practical achievement. Therefore the method determining the durability of the exterior wall finish with regard to the impact of air pollution might be widely applied for the more accurate prognosis of the exterior wall finish durability dependant on the climatic specificity of a particular locality.

One of the most significant factors for the facade paint durability is the impact of the moisture deformations caused by the moistening-drying cycling which is strengthened by acidic precipitation. Therefore, the accelerated climatic tests should also contain the precise and exhaustive modelling of the effect of the moistening-drying cycling and acidic precipitation.

The physical ageing of the paint coating usually appears before the visual defects. This physical degradation of the paint coating put on the rendering is faithfully defined by the increment of the sample's 2h (initial) surface water absorption rate.

In order to increase the durability of rendered facades, the paint coatings demonstrating low water permeability yet preserving good vapour permeability should be used.

The composed artificial ageing methodology is adapted for Lithuanian climate conditions, but the principals are common to use it in other localities with similar climate too. The offered methodology for the investigation of the painted rendering's durability may be employed both for the determination of the physical ageing of the paint coating and for the estimation of the alteration of its aesthetic appearance.

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From tree trunk to tube or the quadrature of the circle

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ABSTRACT: Generally spoken, difficulties in wood construction arise from four sources: the bad material efficiency compared to technical materials, the low strength spectrum, anisotropy as well as preservation. This paper deals with several technologies coping with these drawbacks. A new technology that transforms raw wood into profiles which considers the material as a cellular solid is being presented. Technical textiles turn out as a versatile technique that improves structural performance and serviceability.

1 INTRODUCTION

The importance of wood as a building material and its role to be played in a sustainable development will decisively depend on the amount to which it will guarantee an economic and high-quality solution of our tasks. Therefore it is not enough to possess a renewable raw material it also has to come up to today's and future expectations.

Engineers decide on the use of certain materials according to technical and economic points of view. In the course of their academic education they deal with a great variety of building and engineering materials that still will increase in the future. In contrast to craftsmen engineers are not bound to use a special material, nevertheless wood is excluded from use in many fields of engineering right from the beginning. Only in civil engineering there is the application of wood still seriously taken into account. Despite ecological advantages a decision in favour of wood always requires technological and economical arguments. For that reason science and technology should create the preconditions for an efficient and more frequent use of this resource.

The forest is not only one of the greatest but also one of the cheapest producers of material in the world. It is difficult to believe that a material produced on one third of the area of our country with the help of solar energy is inferior with regard to its price to materials that are produced using large amounts of fossil energy and capital. One significant reason for this can be seen in the fact that the forest is not considered as producer of material but as producer of cross sections. We will have a closer look at this later.

Moreover, we have to ask what further disadvantages prevent the use of wood for technical applications and whether they can be removed or not. In particular these are

1. the low strength spectrum as compared to structural materials
2. the directional dependence of the mechanical properties, the so-called anisotropy, and
3. the low weather resistance.

2 DENSE, DENSER, DENSEST

Wood has a well-balanced profile of properties, but nearly always specialised materials surpass certain properties of wood. It is without question that wood is ecologically beneficial as long as

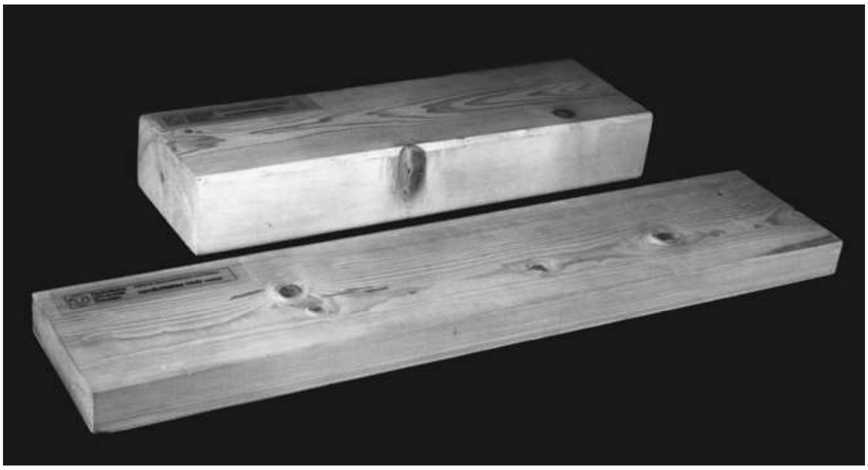

Figure 1. Spruce squared timber cross section before and after densification.

this is not ruined by additional treatment. Also the price per unit mass, that even allows a thermal use, is cheaper than of most other materials of our time.

The mechanical parameters play a central role for load bearing structures and mostly depend on density and growth structure. The differences among different kinds of wood amount to approximately one order of magnitude. The comparison between structural building timber and timber with parallel fibres and without knots and irregularities in growth presents additional differences so that the unused strength potential increases to a total of a good order of magnitude.

The densification of wood (see fig. 1), especially hard wood, using heat and pressure is a technique in wood production known since long. Also nowadays resin-bonded veneer panels, e.g. for electric installations, are produced in this way. The precondition for the densification is the cell construction of the wood that allows densification by means of a press after the softening temperature of the lignin was reached. Thanks to this thermo-mechanical treatment strength and stiffness can be increased proportionally to densification. Further heating above 200 °C leads to an increase in biological resistance, so that the heat influences two important properties, i.e. strength and durability.

Figure 2 presents strength classes of different building materials and their compounds. In this regard wood shows low increments that can be significantly increased by the use of timber with parallel fibres and densification (see fig. 3).

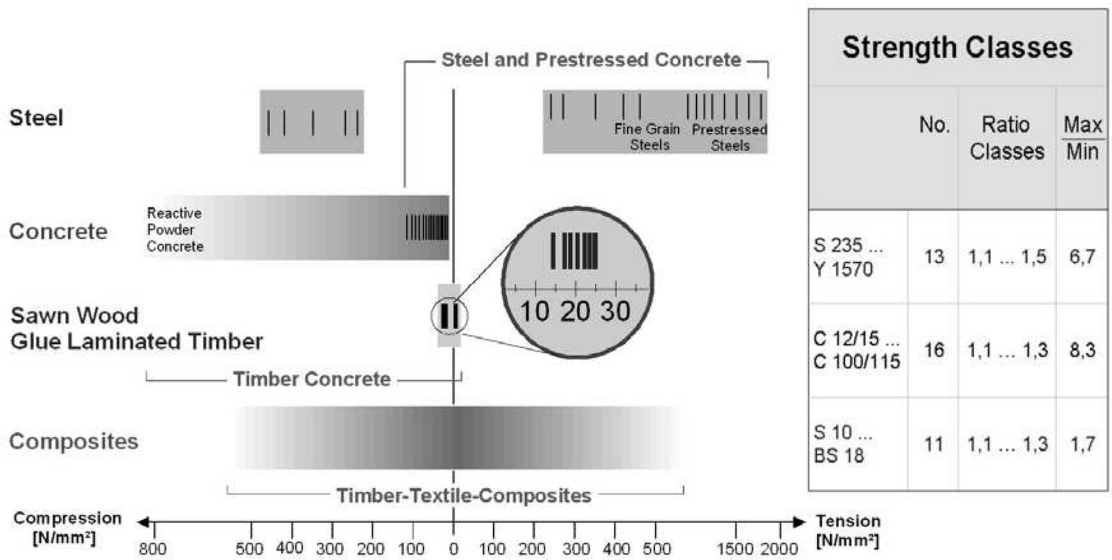

Figure 2. Strength values and classes of today's building material and newly developed building materials.

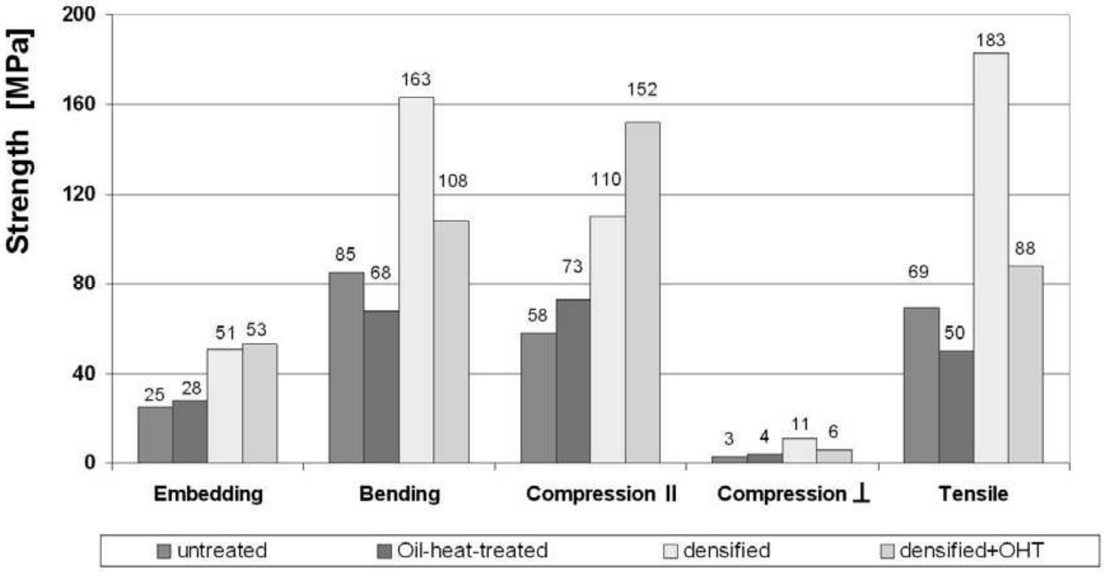

Figure 3. Strength values of soft wood (spruce) with parallel fibres, untreated; oil-heat treated; densified; densified and oil-heat treated.

3 FROM A TRUNK TO A CROSS SECTION

The growth of a tree and its cutting in the saw mill on the one hand lead to a lot of waste and on the other hand to full cross sections that as compared to technical profiles reach low area moments. The forest as producer of material belongs to the most low-priced sellers, but its competitiveness gets lost while the raw material is transformed into cross sections. Therefore it is absolutely necessary to check all possibilities of material economy in the production of cross sections.

The techniques in the saw mill present the first and most important step in the production of cross sections. The relation between output and waste significantly determines the processing and thus the price margin of other partly competing wooden products. This technique considers only one dimension and favours "one-dimensional" kinds of trees. So that in case of reforestation coniferous soft wood, especially spruce, is preferred to hard wood typical for the region as e. g. oak-trees or beeches with their widespread tree-tops.

Wood is said to be worked easily, but the opposite is true. Wood is transformed into cross sections by cutting and joining with synthetic bonding agents afterwards. This does not demand any knowledge of the microstructure. But just this presents a great potential for the development of new techniques and products that has not been paid sufficient attention to in science and technology until now.

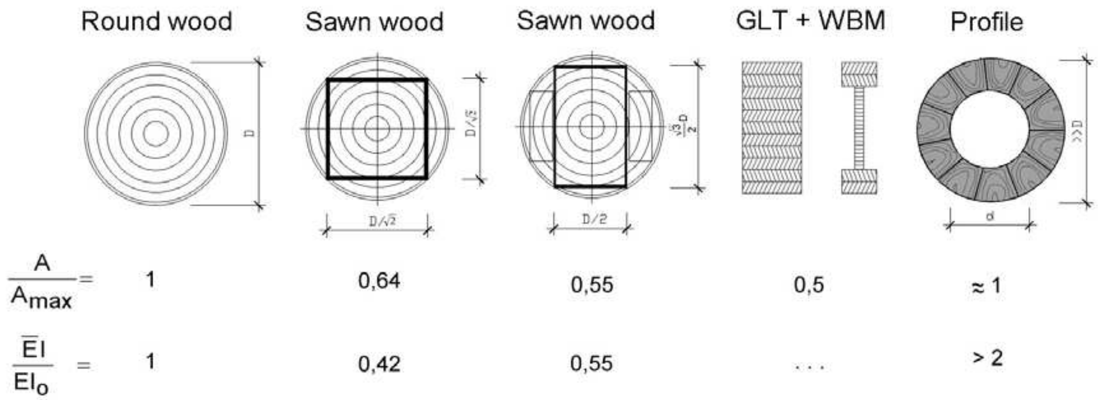

Figure 4. Output of wood with reference to round timber and flexural rigidity EI for different techniques of cross section production.

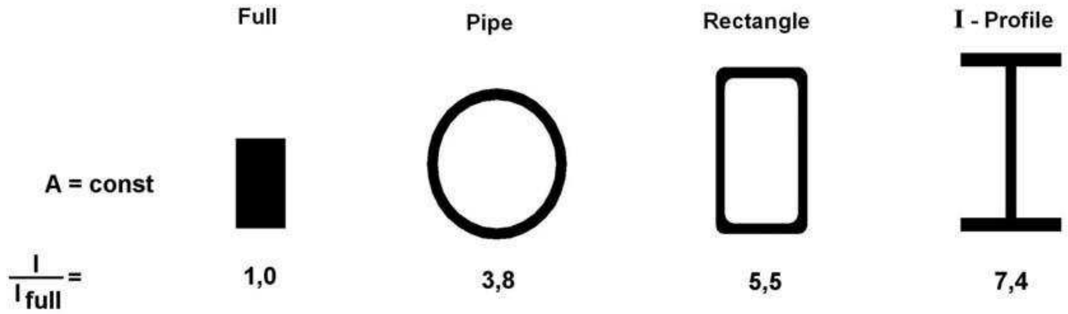

Figure 5. Comparison of area moment I of the square solid cross section with profiles of the same area.

The saw mill delivers a squared rectangular cross section that - as compared to technical profiles made of metal or plastic - has a low efficiency of material. If one adds the bad output of wood by sawing one receives a quite dramatic result. Starting from round timber figure 4 demonstrates the output of material and the area moment reached in the production of different kinds of cross sections.

At first sight we are tempted to assume especially good qualities for bearing structures there where we find high strength. But this has to be looked at more closely. What do engineers do when they are planning bearing structures? They transfer forces and moments with the help of the product of a material factor, i.e. the strength, and a geometrical factor, i.e. the cross-sectional area or the moment of area. In simple words: if a material is only half as strong its cross-sectional area will be doubled. But it cannot be more than doubled because with area moments the distance between cross section and neutral fibre is raised to a power. Therefore structural components are easier to be dimensioned by varying the dimensions of the cross section but by changing the strength class.

The way of choosing round or square solid cross sections in timber engineering hides the fact that the resource productivity is low. In this respect a comparison between squared timber and technical profiles shows a relation of approximately 1:15, what on the one hand results from the losses in the saw mill and on the other hand from the low moment of area of the solid cross section (see fig. 5).

Since timber does not directly depend on the cross section it has to be optimally placed there according to mechanical considerations and has to fulfill the following three conditions:

1. the cross section must not be limited by transverse or longitudinal dimensions of the tree
2. it has to be efficient, i.e. it has to have a great area moment for a given area
3. a cheap production of large quantities must be guaranteed

Squared timber does not meet condition 1 and 2; glued timber does not meet condition 2 and 3. Only the shaped timber profile shown in figures 6 and 7, based on a new understanding of the material, has the potential to meet all tree conditions.

4 TIMBER IN TOP FORM

As far as production techniques are concerned timber construction relies on two basic processes: dividing, i.e. sawing, planing, shredding etc., and then joining by synthetic or metallic fasteners. Already nowadays there is a great variety of possible constructions based on each of these basic processes and their combinations. Imagine this variety could still enlarged by one or two additional ones.

Domestic soft wood has a porosity of about 60 %. Its polymeric structure allows slight plastic deformation transversally to grain at a temperature of 140 °C and a pressure of 5 MPa. Thus the dimension of the cross section can be approximately halved (see fig. 1), whereby the microstructure of the wood folds up. This possibility to improve mechanical properties was already mentioned in the preceding paragraph.

It is also important to know that it is possible to nearly completely reverse and fix the compression without causing any damage to the microstructure if a suitable process is applied.

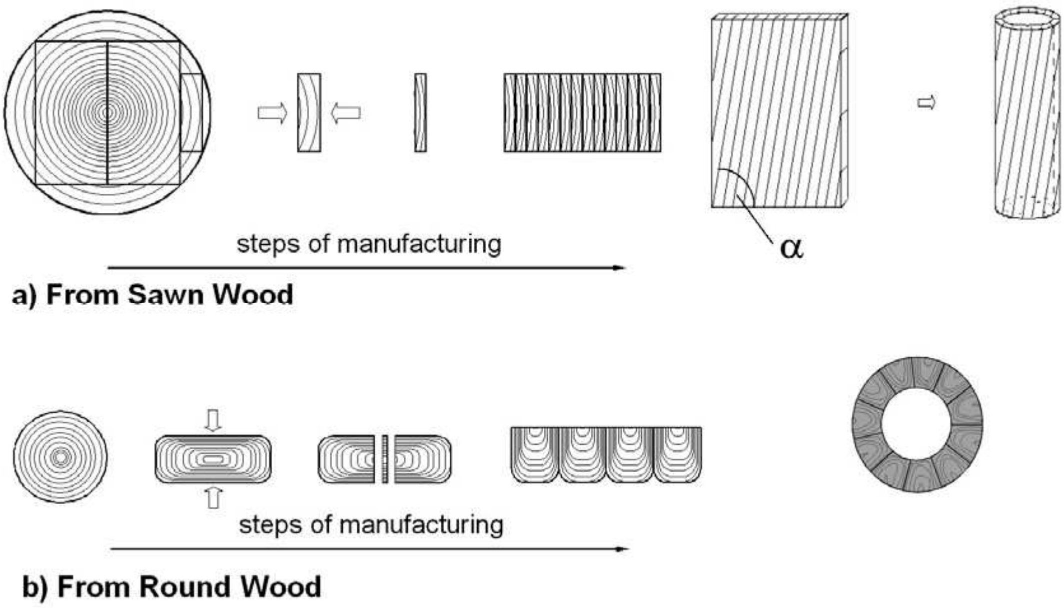

Figure 6. Process of production of shaped wooden profiles made of square or round timber.


Figure 7. Ring-shaped cross section made of densified half-round timber

Its great porosity allows to consider the wood in a completely new manner as a foam-like, cellular material that now indeed becomes a material easily to be processed. Thus fracture elongation transversally to grain increases from one to 100 per cent, i.e. by two orders of magnitude. Soft and hard wood are both suited for this.

Starting from these thoughts at the Institute for Steel and Timber Structures there were made glued laminated timber boards and densified in the direction of the plane. Afterwards under certain heat and humidity conditions there were produced prismatic cross sections reversing the compression by completely folding up the cells.

The bending radius of the deformation depends on the preliminary densification. Depending on the production technique the minimum bend corresponds to about twice the thickness of the board. This way basically all open and closed prismatic cross sections of any length can be produced.

According to this method, which meanwhile was patented, tubes of structural dimensions have been successfully produced. Figure 6 shows an example that begins with the densification of round timber. The division in the direction of maximum density and subsequent gluing lead to a solid panel that can be transformed into a tube by means of thermo-mechanical treatment. As compared with the round timber material economy amounts to about 80 per cent. 50 per cent of it can be saved by avoidance of waste in the saw mill and the rest by an efficient placement in the profile.

5 TREAD MEETS FIBRE

When timber is used for bearing structures not only mechanical and biotical behaviour are of great importance but also its anisotropy. The first-mentioned can be improved by sorting and thermal and/or thermo-mechanical procedures whereas the directionality of strength is met by different measures in design.

Strength and rigidity can very efficiently be compensated in the course of dimensioning the cross section in longitudinal direction. But even experienced structural engineers face problems dealing with shear and transverse stresses. Meanwhile a lot of different solutions and design methods are available that led to complex special knowledge. Therefore it is desired that the problems connected with anisotropy shall be met by a universal technology.

A look at nature could teach a lot of things because many natural constructions meet mechanical stresses by optimally directed fibres: as e.g. crotches of a tree, blades of straw or muscles. Fibre reinforced plastics present a technical application according to this example. The connection of threads to flat or three-dimensional structures is a subject of textile technology. The Collaborative Research Centre (SFB, Sonderforschungsbereich) 528 “Textile Reinforcement for Structural Strengthening and Retrofitting” at the Faculty of Civil Engineering examines their application in civil engineering.

This Collaborative Research Centre also elaborates the fundamentals of textile reinforcement of timber structures. The cooperation with the Institute of Textile and Clothing Technology enables the timber engineers in Dresden to apply fully fashioned stress related textile reinforcements made of glass, carbon, aramide or natural fibres that are glued on by synthetic resins afterwards.

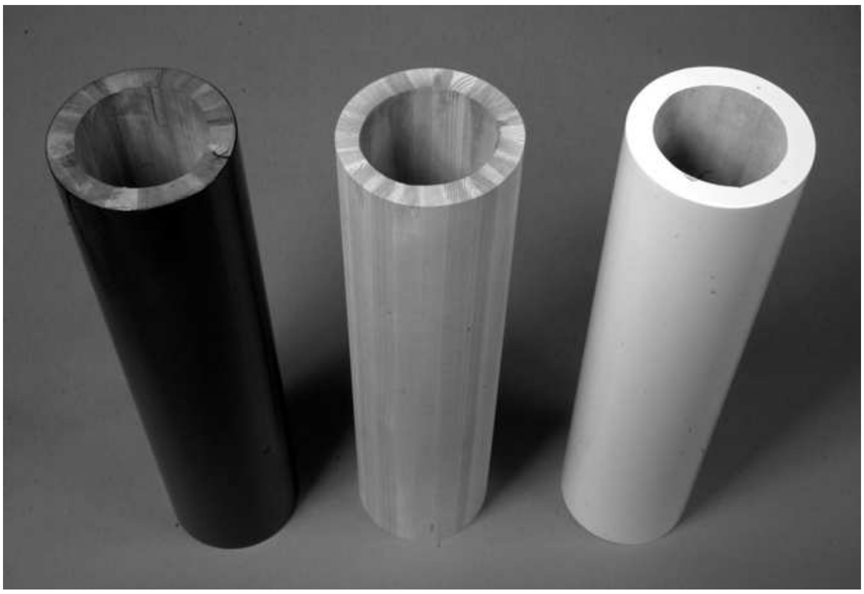

Figure 8. Cross sections of tubes with textile reinforcement; left – carbon fibre; Center – without reinforcement; right – glass fibre, varnished

Technical textiles help to build a bridge between timber engineering and light weight construction what is thought to lead to a completely new quality in the use of this renewable resource.

Besides the mechanical behaviour of the construction the low durability of organic building materials proves to be a decisive disadvantage for exterior application that nowadays is answered by modified wood properties and structural design. But in both cases will arise additional costs.

The complete reinforcement of whole building components in connection with surface treatment as in light weight construction will not only provide structural reinforcement but also an effective protection against weathering. This is an important advantage not only what concerns humidity but also with regard to a corrosive environment.

6 CONCLUSION

The presented developments deal with all shortcomings of present technical applications of wood and in the author's opinion fundamental solutions are offered. This concerns the efficient use of the raw material that leads to low material prices; the densification of wood that surmounts the limits of the strength classes; textile reinforcement as technology that completely solves the problem of anisotropy at a favourable price and also provides weather protection; and the shaping of efficient cross section profiles as probably the most far-reaching innovation.

These new developments can be applied everywhere where cross sections are needed. These may be bearing elements in civil engineering as columns and girders, in light-weight and equipment construction, but also non-bearing parts for furniture or interior work. Moreover a lot of things with an open or closed prismatic cross section can be produced this way, e.g. cable drums, poles, barrels, tanks, rotor blades or hulls.

Wood will become of greater technical importance if its properties, cross sections and production techniques can come up to the expectations of engineers more properly. Old constructions always are bound to meet old reservations. So it is easier to apply new methods as astonishingly as this may sound. Wood has the potential for innovations based on material and techniques. That there are few innovations is not to be explained by the wood itself but by structures impeding its development.

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Biological and mechanical properties of densified and thermally modified Norway spruce

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ABSTRACT: For the first time, untreated Norway spruce (*Picea abies* Karst.) was densified in a common industrial scale process and afterwards thermally modified in an Oil-Heat treatment process. Biological and mechanical properties were investigated on axially matched samples. Wetting and drying cycles were performed to determine the change in dimensional stability of densified and heat treated samples compared to references. Biological tests of restistance to basidiomycetes on malt agar according to EN 113 (1996) and soil block tests according to prEN 807 (2001) showed substantially reduced mass losses with densified heat treated material, compared to untreated controls. According to the classification of natural durability (EN 350-1, 1994) the densified and Oil-Heat treated material was classified as 'very durable' (durability class 1). The bending strength of densified and Oil-Heat treated material was only slightly reduced compared to untreated Norway spruce. The MOE of densified and Oil-Heat treated material was increased by 42 %, whereas the impact bending strength was decreased by 44 % compared to untreated Norway spruce controls. Densified and thermally modified samples showed improved dimensional stability compared to untreated densified material.

1 INTRODUCTION

The natural durability of most European wood species restricts the use of wood without wood preservation in outdoor application. As an alternative to chemical preservation systems, thermal modification processes as non-biocidal techniques of wood protection were developed and promoted in recent years (Leithoff and Peek 1998). Thermal treatments improve some wood properties, e.g. dimensional stabilization and decay resistance (Militz and Tjeerdsma 2001, Rapp and Sailer 2001), but also reduce the strength properties of wood (Bengtsson et al. 2002, Brischke and Rapp 2004). To overcome this disadvantage of decreased strength, thermo-mechanically densified material with increased initial strength properties compared to non-densified wood was applied to an Oil-Heat treatment process.

Densification of solid wood is an established process to improve selected mechanical and physical properties e.g. MOE, MOR, surface hardness, transversal shear strength and dimensional stability (Morsing 1997, Navi and Girardet 2000). The combination of mechanical load in radial direction and elevated temperature during the densification process is conversant since the beginning of the 20th century (Kollmann 1936, Seborg et al. 1945). Nevertheless the transformed compression-set during densification is unstable and leads to set-recovery under the influence of liquid water or even elevated moisture.

Prior examinations on densified wood predominately deal with the problem of dimensional stabilisation, fixation of set-recovery and increased mechanical properties. In contrast, this study aims on the examination of biological properties of densified wood, in particular the change in natural durability due to a densification process with elevated temperatures and an subsequent Oil-Heat treatment to stabilise the compression set.

2 EXPERIMENTAL

2.1 *Material*

Untreated Norway spruce (*Picea abies* Karst.) with an average density of 0.52 g/cm³ at an initial moisture content of 12 % was applied to the thermo-mechanical densification process. Untreated non-densified and untreated densified spruce was furthermore thermally modified by an Oil-Heat treatment (OHT) process. Besides the densified and thermally modified material, untreated pine sapwood controls (*Pinus sylvestris* L.), untreated Norway spruce, Douglas fir heartwood (*Pseudotsuga menziesii* Franco), oak heartwood (*Quercus petraea* Liebl.) and pine sapwood specimens vacuum-impregnated in treating solution containing 0.7 % and 2.8 % CCB were taken in biological tests as references. All samples were cut into the respective test specimens and tested at the Federal Research Centre for Forestry and Forest Products (BFH), Hamburg, Germany.

2.2 *Thermo-mechanical densification and Oil-Heat treatment*

Solid spruce samples of 1000 by 150 by 40 mm³ were densified in radial direction by 'Deutsche Holzveredelung Alfons & Ewald Schmeing oHG', Kirchhundem, Germany, using a conventional industrial hot press. The intermittent thermo-mechanical densification process was divided into three steps: heating up, compression, and cooling/conditioning, wherein the heat transmission was achieved by contact of the samples and the heated upper and lower press plates. A diagram of the densification process is given Figure 1.

Untreated non-densified and densified spruce specimens of 500 by 140 by 20 mm³ were thermally modified by an Oil-Heat treatment at 220 °C for four hours at BFH. The treatment temperature was measured inside the specimens by means of thermocouples.

2.3 *Resistance to basidiomycetes*

The resistance to basidiomycetes was tested according to EN 113 (1996) with the following alterations: n = 10 specimens of 40 by 10 by 10 mm³ were incubated in large Petri dishes (120 mm diameter) for 12 weeks. In preliminary tests with brown and white rot causing fungi (Welzbacher and Rapp 2002), Poria placenta caused the highest mass losses on heat treated wood compared to all other tested fungi including Coniophora puteana and Coriolus versicolor. Therefore the following strain was used for the study: Oligoporus placenta var. Monticula = (Fr.) Gilbertson et Ryv. FPRL 280 BAM, 8/1997.

To assess the grade of durability, the relative durability was calculated as the quotient of mass loss of the tested material and untreated Scots pine sapwood controls (X-Value, EN 350-1 1994), as is normally done for the classification of naturally durable timber.

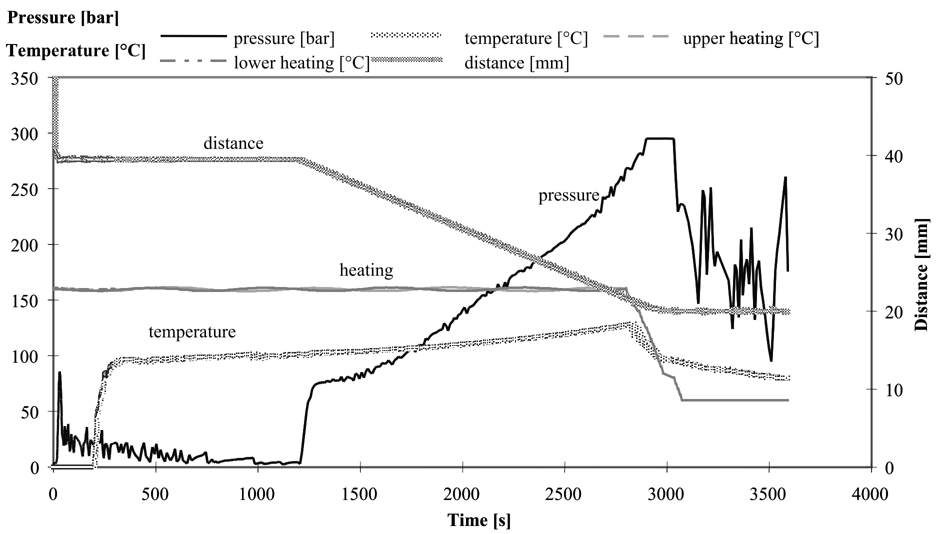

Figure 1. Scheme of a distance controlled densification process for compression of solid wood form 40 to 20 mm

2.4 *Resistance to soft-rotting micro-fungi and other soil inhabiting micro organisms*

The resistance to soft-rotting micro-fungi was tested according to prEN 807 (2001). Therefore n = 20 specimens of 100 by 10 by 5 mm³ were incubated for 32 weeks in natural top soil substrate (compost and test fields) from two different areas at BFH in Hamburg, Germany.

2.5 *Mechanical testing*

The bending strength (MOR) and the MOE was determined in a three point bending test according to DIN 52 186 (1978) with n = 40 specimens of 200 by 10 by 10 mm³.

Impact bending strength was tested according to DIN 52 189 (1981) applied on n = 40 specimens of 200 by 10 by 10 mm³ using a Louis Schopper pendulum impact machine.

2.6 *Dimensional stability*

Specimens of 10 by 20 by 20 mm³ (n = 20) were cut from non-densified Norway spruce and densified Norway spruce both heat-treated and untreated. Eight cycles of oven drying at 103 °C for 24 h followed by a soaking phase by means of water pressure impregnation at 8 bar/20 min with subsequent water storage of 24 h at 60 °C were performed to determine the change of dimensional stability due to densification and heat treatment. Swelling and shrinking was measured after each wetting and drying phase in radial direction by determining the radial length.

3 RESULTS AND DISCUSSION

3.1 *Resistance to basidiomycetes*

Both processes, the thermo-mechanical densification and the Oil-Heat treatment, applied to spruce specimens, resulted in significantly increased resistance against fungal decay compared to the mass loss found in untreated spruce (figure 2). Untreated spruce showed mass loss of 30.7 %, significantly lower mass loss of 7.5 % was observed in densified spruce wood. An average weight loss of 8.9 % was found for Oil-Heat treated spruce (spruce OHT), whereas densified and Oil-Heat treated spruce (densified spruce OHT) exhibited a mass loss of 0.8 % only.

The effect of increased resistance against fungal decay of densified wood compared to controls was also observed by Welzbacher et al. (2004) and Schwarze and Spycher (2005). In both studies Norway spruce specimens, subjected to the two-stage THM procedure of Navi and Girardet (2000), were tested. In tests with *Poria placenta* Schwarze and Spycher (2005) found an average mass loss of about 13 % in densified spruce (21 % in controls), whereas Welzbacher et al. (2004) observed 27 % mass loss in densified specimens (36 % in controls). Nevertheless, a post-treatment of the densified specimens at 180 °C for 30 min in saturated steam conditions only reduced the mass loss slightly to 10 % (Schwarze and Spycher 2005), and 17 % respectively (Welzbacher et al. 2004). The influence of a steam post-treatment on durability seems to be negligible compared to the impact of an Oil-Heat treatment.

3.2 *Resistance to soft-rotting micro-fungi*

The compost substrate was taken to determine the resistance against soft-rotting micro-organisms, since it generated higher mass loss to the specimens than the field substrate. The mass loss of densified and non-densified spruce specimens was reduced significantly by an Oil-Heat treatment (figure 3).

A mass loss of 30 % was found in untreated spruce and about 18 % in densified spruce specimens. Oil-Heat treated specimens showed significantly lower values: 5 % mass loss was observed in spruce OHT whereas 3 % mass loss occurred in densified spruce OHT. The Oil-Heat treatment increased the resistance against decay to a higher extent than the densification. The highest increase in durability was found as a result of both processes combined. This can be seen from the classes of natural durability according to EN 350-1 (1994) based on the tests according to prEN 807 (2001) and based on the tests according to EN 113 (1996), as listed in table 1.

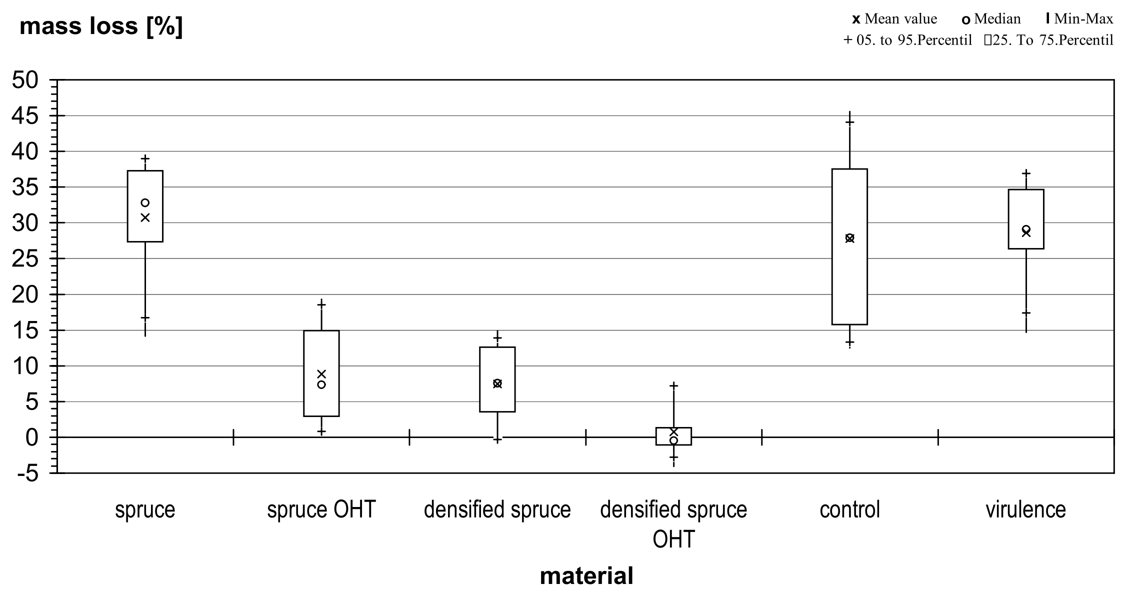

Figure 2. Mass loss after fungal attack by *Poria placenta*

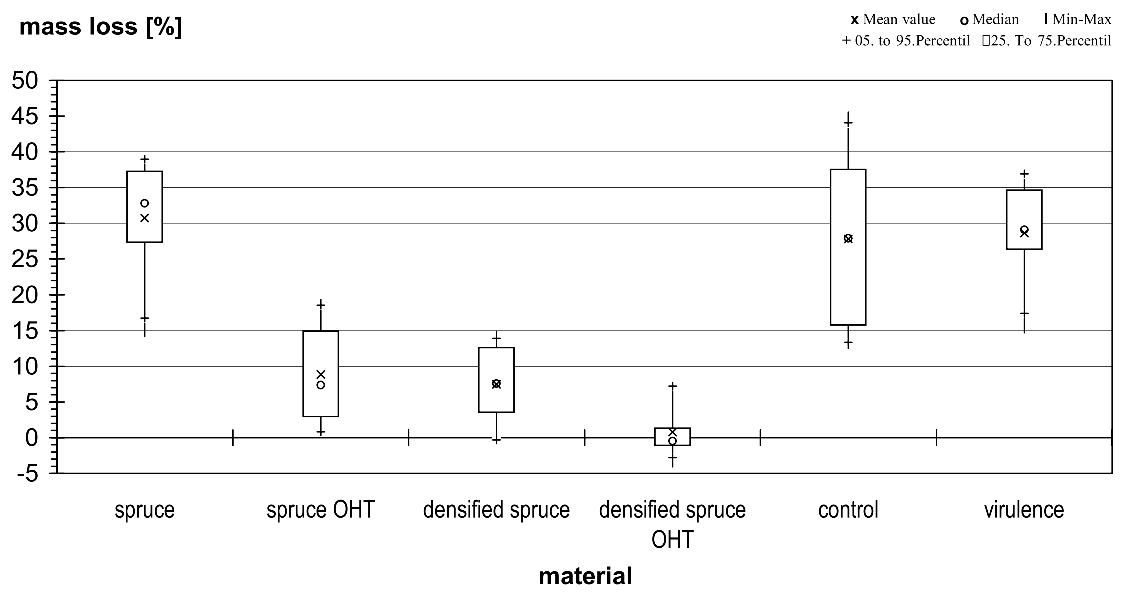

Figure 3. Mass loss after 32 weeks exposue in compost soil according to prEN 807 (2001)

Spruce was classified as not durable (class 5) in tests with *Poria placenta* as well as in tests in compost soil against soft-rotting micro-organisms. As a result of the thermo-mechanical densification, durability class 3 (moderately durable) was achieved by densified spruce. An Oil-Heat treatment increased the natural durability to a higher extent: spruce OHT was durable to moderately durable (class 2-3) in tests according to EN 113 (1996), and very durable (class 1) in tests according to prEN 807 (2001) respectively. In addition, the combination of densification and subsequent Oil-Heat treatment resulted in durability class 1 (very durable) in both applied biological tests.

Table 1. Density of the different materials tested and assigned classes of natural durability according to EN 350-1 (1994) based on absolute (g-basis) and proportional (%-basis) mass loss after biological tests according to EN 113 (1996) and prEN 807 (2001)

material	Oven dry density	durability classification based on tests according to EN 113		durability classification based on tests according to prEN 807	
	[g/cm³)	on g-basis	on %-basis	on g-basis	on %-basis
spruce	0.48	5	5	4	5
spruce OHT	0.43	2	3	1	1
densified spruce	1.08	3	3	4	3
densified spruce OHT	0.86	1	1	1	1

Table 2. Average values of density, MOR, MOE and Impact bending strength; untreated spruce is taken as basis for proportional examination of mechanical properties

material	density	MOR		MOE		Impact bending strength	
	[g/cm³]	[N/mm²]	[%]	[N/mm²]	[%]	[kJ/m²]	[%]
spruce	0,50	108,0	100	13966	100	31,8	100
spruce OHT	0,43	84,7	78	12304	88	16,5	52
densified spruce	1,09	209,3	194	23577	167	38,2	120
densified spruce OHT	0,86	105,0	97	19815	142	17,7	56

3.3 *Mechanical testing*

Densification of solid Norway spruce improved MOR, MOE and Impact bending strength significantly (table). This is causally connected to increased density (Morsing 1997, Navi and Girardet 2000, Heger et al. 2004).

The Oil-Heat treatment reduced the MOR of densified spruce significantly by 50 %, but densified spruce OHT still had an average MOR equal to untreated spruce. The influence of the Oil-Heat treatment on the dynamic strength was more critical: Impact bending strength of densified spruce OHT was reduced by 44 % compared to spruce (Table 2). The influence of the heat treatment on MOE was rather negligible since MOE of densified spruce OHT was still increased about 50 % compared to untreated spruce.

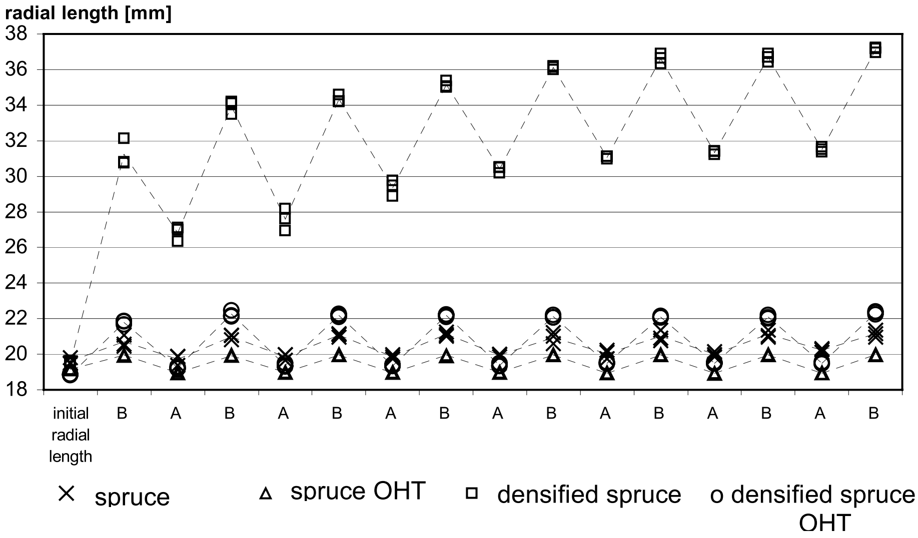

Figure 4. Radial swelling and shrinking after eight cycles of oven drying at 103 °C for 24 h (A) followed by water pressure-impregnation at 8 bar/20 min and subsequent water storage for 24 h (B)

3.4 *Dimensional stability*

After eight cycles of wetting and drying, densified spruce specimens showed maximum swelling in radial direction of about 88 %, whereby a set-recovery of approximately 60 % was observed (Figure 4). Thermal modification resulted in significantly decreased maximum swelling (19 %) and in addition, permanent fixation of compression-set was achieved (set-recovery 3.5 %). This is exactly what Heger et al. (2004) observed on THM-densified wood, since the set-recovery was below 3 % and maximum swelling in a range from 15 to 20 % after post-treating the THM-densified specimens at 180 °C for 30 min.

4 CONCLUSIONS

Both, the post-treatment according to Heger et al. (2004) as well as the Oil-Heat treatment achieved permanent fixation of compression-set of densified spruce. In contrast to the steam-post-treatment, significantly increased durability was a result of an Oil-Heat treatment. As a drawback, the dynamic mechanical properties of densified and Oil-Heat treated spruce were reduced by 40 % compared to controls, though static bending strength was equal to untreated spruce.

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A Sustainable Waste Management Strategy: Construction & demolition waste

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ABSTRACT: Malta is a small Island State, with a high population density, and consequently large demands on the land use. The extensive pressure on the limited mineral resources is a major concern. The disposal of waste, particularly excavation, construction and demolition waste also constitutes a major challenge. The Solid Waste Management Strategy for the Maltese Islands is considered to be an integrated approach to waste management. Its objectives are assessed with reference to construction and demolition waste. The drawbacks and benefits of relevant proposals that are considered for implementation and discussed by stakeholders in various instances are analysed. Different potential options are discussed and include the utilisation of disused quarries for the disposal of inert waste, land reclamation, and the potential use of waste material in civil engineering applications including the use of waste material in concrete. Practical short and long term solutions need to be assessed in terms of environmental impact and economic feasibility. The aim is to promote the conservation of resources, and to exploit construction and demolition waste as a potential resource.

1 INTRODUCTION

The impact of the construction industry on the environment is significant at all stages. Large demands on mineral resources and the environment result due to the extraction of raw materials, to service the construction industry. The waste generated from construction-related activities is also considerable and need to be assessed within the framework of a comprehensive strategy.

In a small densely populated Island State like Malta, the management of solid waste through environmentally sound and sustainable systems offers major challenges to develop and maintain, because of the economies of scale. There is a growing concern on the depletion of resources and the generation of waste material.

The sustainable management of waste refers to the more efficient use of resources, reduction in waste produced and where generated, dealing with it in a way that will help achieve the goals of sustainable development; that is development pursued in a manner that whilst meeting the present needs, does not compromise the ability of future generations to meet their own needs.

The aim of this paper is to assess the objectives of The Solid Waste Management Strategy for the Maltese Islands (Ministry for the Environment, 2001) as an integrated approach to waste management, and to analyse potential practical solutions, for the conservation of resources, and the effective reduction, reuse and recycling of excavation, construction and demolition waste.

2 WASTE MANAGEMENT STRATEGY

The Waste Management Strategy for the Maltese Island is intended to provide a policy and decision-making framework for the management of wastes, and for the preparation of detailed implementation plans. (Ministry for the Environment, 2001) In this process waste management is implemented in accordance with national legislation and policies, international conventions of which Malta is signatory, whilst putting into practice the requirements of European Directives. The key principles taken into account in the implementation of the waste management strategy are;

- Sustainable development
- Proximity principle and self sufficiency
- Precautionary principle
- Polluter pays principle
- Waste hierarchy
- Best Practicable Environmental Option
- Producer Responsibility.

The Proximity Principle is based on the premise that the waste should be treated or disposed of as near as possible to the point where it is generated. The Precautionary Principle involves taking precautions now, to avoid potential environmental damage or harm to human health in the future, even though scientific basis for taking the precautions may be inconclusive. The Polluter Pays Principle means that the polluters should bear the full cost of the consequences of their actions. The Waste Hierarchy provides an order of priorities for deciding on waste management practices.

- Reduction in Waste: minimization of the use of resources and reducing the quantities of waste.
- Reuse: Using products once again for the same or different application.
- Recycling: reprocessing of the waste material, for use in the manufacture of the same or different materials.
- Recovery: Obtaining value from waste by energy recovery or other technology.
- Disposal: Waste is disposed of through land-filling or incineration without energy recovery only if there is no other appropriate solution.

The Best Practicable Environmental Option is the outcome of a systematic decision making process emphasizing the protection of the environment. For a given set of objectives and circumstances the process establishes the option or combination of options that provides the greatest benefits or least damage to the environment as a whole, at acceptable costs in the short and long term. The Producer Responsibility Principle means that the producer of products that lead to the generation of waste should take collective responsibility for the waste rather than expecting the community to beat the burden of arranging and paying for waste collection, treatment and disposal. The manufacturer of a product is considered to take the key decisions concerning the design and composition of the product, that lead to its waste generation potential and management characteristics. Therefore the producers shall take responsibility of the following;

- Minimise the waste arising
- Design and develop goods that are inherently recyclable and do not contain materials that pose unnecessary risk or burden for the environment.
- Develop markets for the reuse and recycling of the goods produced.

Further to these principles, it is also necessary to achieve and maintain an effective balance between economic development and protection of the environment. Within the constraints of a Small Island State, the markets for waste management service shall be encouraged. Where possible economic instruments shall be preferred to legal instruments, to induce and encourage changes towards the objectives of the strategy.

The strategy for an integrated and sustainable waste management system is based on different actions. The Strategy addresses the changes necessary to improve the practices and systems in the management of waste, including the need of new systems for the handling, processing and disposal of waste, and on closing and rehabilitating existing and former disposal sites. Furthermore it addresses the importance of legal and policy measure, to provide necessary incentives towards the goals of the plan. (Ministry for the Environment, 2001)

3 EXCAVATION, CONSTRUCTION AND DEMOLITION WASTE.

3.1 *General.*

The strategic management of solid waste is of highest priority towards sustainable development. In general the waste generated in Malta has been on the increase, with the largest source of waste production being the Construction Industry, exceeding 1 million tonnes of waste generated annually. (Ministry for the Environment, 2001).

Much of the waste generated from excavation, demolition and construction activity comprises soft stone, and is essentially inert. In excess of 80% by weight of the solid waste generated originates from excavation, construction and demolition activities. The Solid Waste Management Strategy for the Maltese Islands (Ministry for the Environment, 2001), reported that while some of the materials are reused and recycled as part of reclamation or landscaping schemes, the bulk of the waste is deposited in disused quarries, disposed at the Maghtab and Qortin Landfill sites in Malta and Gozo respectively, deposited at a designated site at sea, or illegally dumped. Soil from excavation works is deposited on agricultural land.

Quarrying activities, in particular soft stone quarrying, results in considerable material wastage and in the generation of limestone residues in the form of waste gravel and crushed rocks, and dusty and powdery wastes.

3.2 *Objectives for Construction & Demolition Waste*

The aim of the Solid Waste Strategy of the Maltese Islands is also to reduce the construction and demolition (C&D) waste generation, and recover C&D waste and excavation material. The targets set in the strategy included the banning of the land-filling of C&D waste co-mingled with other waste, the reduction of 20% of total waste, the recovery of 60% of rock / stone, and the recovery of 50% of mixed inert wastes by 2005. (Ministry for the Environment, 2001)

3.3 *Solid Waste Management: Constraints*

The main strategic issues and constraints include;

Legislation & Enforcement: Successful implementation of the strategy depends on legislation, and effective monitoring and enforcement.

Land use Availability: Land is a scarce resource in Malta, and the use of land for waste management purposes, and the selection of suitable sites is a major constraint. Therefore the landfilling of large volumes of waste is unsustainable.

Operational Reliability and Flexibility: The limited size of Malta leads to difficulties in making rapid adaptations for the handling of large volumes of waste.

Economic Factors: The capital investments and unit costs are important considerations. The economies of scale are particularly important leading to some processes not being effective on a small scale. The market for recyclable materials is limited in Malta

Public Perceptions: The development and implementation of a comprehensive programme for ongoing communication and consultation with the public and all stakeholders is important throughout the process.

3.4 *Strategic objectives*

Strategic objectives and targets for the future management of waste are necessary in the following areas and activities;

- Policy & Legislative Framework.
- Institutional & Organizational Arrangements.
- Human Resources.
- Financial / Cost recovery.
- Stakeholder Awareness and Communication.
- Data Availability & Reporting.
- Waste Avoidance & Reduction.
- Waste Recovery & Recycling.
- Waste Segregation, Storage, Collection & Transport.
- Waste Treatment & Processing.
- Final Disposal of Waste.

3.5 *Implementation Measures*

The strategic objectives lead to the development and implementation of interrelated measures which can be summarised in the following groups: policy and legislative; institutional and organizational; economic and financial; technical and operational; and other measures which include stakeholder awareness and communication. Specific measures that are outlined in The Solid Waste Management Strategy for the Maltese Islands (Ministry for the Environment, 2001), and which are specifically relevant to Excavation, Construction & Demolition waste, are discussed.

3.5.1 *Policy & Legislative Measures.*

Policy and Legislative measures include the adoption of the Waste Management Strategy (Ministry for the Environment, 2001) and the enactment of relevant regulations. Other measures include Assessment, Monitoring and Enforcement; Technical Standards; Land Use Planning Policy; and Producer Responsibility / Compliance Schemes.

Monitoring and Enforcement: Monitoring, inspecting and enforcement are necessary to ensure compliance, and need to be based on sufficient human and technical resources.

Technical Standards & Codes of Practice: The aim of the standards is to establish minimum technical requirements for specific materials, resources and operation & performance of specific activities. National standards need to compliment relevant EU standards.

Land Use Planning Policy: In the assessment of new waste management facilities, preference is given to waste recovery / recycling plants.

Producer Responsibility: Those responsible for processes which give rise to excavation, construction and demolition wastes should bear some or all of the responsibility for arranging and paying for their management in accordance with relevant legislation and standards.

3.5.2 *Economic & Financial Measures*

Charges for the Use of Publicly owned / Operated Waste management Facilities / Services: On the basis of the Polluter Pays Principle, the charges for the use of public waste management facilities were planned to increase progressively over a period of three years, reaching levels that recover the full cost of their provision and operation in accordance with national and European legislation and standards.

Development Planning: In order to achieve the targets for reducing and recovering excavation, construction and demolition waste, a developer is requested to prepare a waste management plan, to be assessed by the Planning Authority, prior to the granting of development permits. Such a plan includes assessments and estimates of the waste generated, clear proposals for the reduction, reuse and recovery as much as possible of the waste materials generated from the development, together with proposed methods for safe disposal of any remaining amounts.

Restricted use of Landfills: The strategy recommends the restricted the use of landfills for the disposal of some types of excavation, construction and demolition wastes by imposing progressive restrictions on the quantities that may be accepted, and requesting the adoption of a differential pricing structure in which the prices for accepting such wastes are substantially higher than for other types of wastes. The above can be implemented after sufficient capacity for the treatment / processing and recovery of the waste streams has been developed and in operation.

Preferential Public Service procurement: Preferential Public Service Procurement Policies are referred to in the strategy. The Government will give preference to recycled and recyclable products and materials when purchasing some types of products, as long as such products and materials are of adequate quality for the intended use, and the prices of the products and materials does not exceed the prices of the equivalent by an unreasonable or unacceptable amount.

Financial Incentives for Locally Manufactured Recycled Products / Recycling Processes: Financial incentives are planned in order to encourage the development of locally manufactured recycled products and recycling processes.

3.5.3 *Technical & Operational Measures*

Interim Storage, processing and Recovery of Excavation and other recyclable Excavation, Construction and Demolition Waste: The aim of the strategy is also to establish facilities for the interim storage, processing and recovery of excavation waste, and also recyclable construction, demolition and excavation wastes.

New Landfill facilities for Disposal of inert Waste: The strategy refers to the land-filling of inert waste in Malta. The engineering, operational and after-care requirements for inert waste landfill sites are considerably less demanding and expensive than for landfill sites receiving non-inert wastes. The capacity requirements depend on the possible reduction in quantities through waste avoidance, recovery and recycling. Even if the disposal of inert material is reduced, there will be the need to dispose of substantial volumes of inert material. The strategy refers to the potential for restoring the existing voids in the Maltese landscape, created by the extraction of stone and other minerals. The strategy gives preference to the restoration and reclamation of quarries, as against schemes involving the reclamation of land from the sea. However it refers to the latter as a likely option in the long term. The strategy also refers to the inert waste at the Maghtab landfill, and if economically beneficial it should be reclaimed and utilized profitably.

Rehabilitation and Restoration of Existing and Former Waste Dump Sites: Once the waste treatment facilities have been constructed and brought in operation, the strategy outlines the closure, restoration and reutilization of the waste disposal sites at Maghtab and Qortin.

4 ASSESSMENT OF POTENTIAL ACTION.

4.1 *General*

The implementation of The Solid Waste Management Strategy for the Maltese Islands (Ministry for the Environment, 2001) is an ongoing process, with action taken in line with recommendations, and detailed implementation plans. The strategy is dynamic, and requires constant review to ensure that the objectives are achievable. It is also necessary to allow for adjustments as new information and experiences suggest.

The following section outlines relevant proposals that are considered for implementation, or discussed by stakeholders in various instances. The proposals are not to be seen in isolation, but within the framework of the strategy and relevant regulations. The potential benefits and drawbacks of all proposals need to be assessed through an integrated approach.

4.2 *Construction and Demolition Waste.*

Organised stripping of the buildings and separation at source requires adequate recycling facilities and a market for the secondary products. Furthermore the products must be at competitive prices, and of sufficient quality for reuse. Construction and Demolition (C&D) waste should be kept separate from clean excavation material, and should be separated and stored until recycling facilities are available. Waste separation facilities are required in order to tackle the reuse and recycling of demolition waste. Alternative ways of safe and effective demolition of buildings should be considered. The potential dismantling of typical load-bearing masonry buildings, with stone and concrete block walls and reinforced concrete roof slabs, can lead to the effective separation of construction materials, but is normally not cost effective. Such separation has environmental and economic implications.

4.3 *Reuse of stone blocks.*

The re-use of stone blocks necessitates careful separation and dismantling, to reduce damage to the stones, resulting in extra costs. There is a market for the reuse of old stone, in the refurbishment of old buildings. Blocks resulting from dismantling might not be suitable for reuse due to various defects, including those arising during the dismantling operation, and their reuse may be limited to selected applications. Therefore classification and certification of the blocks according to specific criteria might be necessary. The feasibility of the dismantling of stone should be assessed from an economic and environmental point of view. The extra costs and energy in dismantling, stacking and transporting, modifying and re-working the stone blocks should be assessed. However the reuse of stone leads to a direct reduction in waste generated, and also to reduced demands and potential savings on new stone blocks, resulting in reduced quarrying and conservation of resources. The *Sustainable Development Strategy for the Maltese Islands* refers to potential incentives for the recycling of stone and disincentives associated with the use of new stone. (NCSD, 2006)

4.4 *Reduction of Excavation Waste*

Due to the limited land available for development and planning criteria, building development normally entails the excavation of the site, to maximize on the space available. This results in considerable amounts of excavation material. If the material originating from excavation is of good quality, it may be used for the production of aggregate for use in specific civil engineering applications. This is usually the case of hard stone material normally used as aggregate for the production of concrete and for road construction. If the material excavated is of inferior quality, it is normally not considered useful for most civil engineering works. This is typically the case of excavated globigerina limestone.

In such circumstances a potential measure can be the extraction of large blocks of stone from the excavation site, rather than the normal practice of breaking the material. The large blocks can then be transported and further processed in designated plants. This measure will lead to a reduction of waste material, and potential savings of a finite resource. The proposal should be assessed through feasibility studies, based on different methods of excavation, quality of the material extracted, cost implications, and the time and energy necessary for extraction and processing.

4.5 *The Use of Waste material in Civil Engineering Applications*

The Waste Management Subject Plan encourages the recycling of natural spoil and construction wastes for reuse as secondary aggregate or as a material for landscaping or restoration. (Planning Authority, 2001). In general the excavation and demolition waste can be classified and assessed for potential use in specific civil engineering applications. These can include the processing of the material for the potential use as aggregate for different applications including concrete production, and road construction, if specific requirements of the material properties are satisfied.

Other potential initiatives can include the infilling of concrete caissons with inert waste, which are eventually sealed and used in civil engineering applications. Various other potential reuse and recovery options have been considered or adopted including the reuse as cover-up material for landfills, and the use as a soil substitute. Limestone waste can potentially also be used for the production of cement.

The use of excavation, construction and demolition waste for the production of concrete products, including concrete block-work has been considered. In this case, strength and durability characteristics need to be assessed, together with other properties like for example thermal properties and sound insulation. The production of reconstituted stone with waste limestone material is another potential alternative that requires further research.

A market for the secondary products is required. Feasibility studies are necessary, in order to assess the actual quality and quantity of material that can be utilised effectively for specific applications.

4.6 *The Use of Waste material in Concrete*

4.6.1 *General.*

Concrete can be produced using alternative materials as substitutes for the conventional materials. The alternative materials can include waste material. Important factors to be considered are costs and economic viability of the use of waste material. Costs are generally associated with handling, processing and transportation. Important consideration should be given to energy requirements for processing and production of the concrete, and pollution, before a concrete product using waste material can be assumed to be a better alternative. The stability and durability characteristics of the concrete produced with the waste material, over its life cycle, is important when considering its intended use in structural applications. This necessitates clear guidelines and specifications, and appropriate quality criteria in the use of specific wastes in concrete.

In general waste materials can be used in making concrete. Materials can be used as a replacement of the cement, or also as aggregates in the concrete. Reference is to be made to current standards and codes of practice on the quality and quantity of waste material used in concrete.

The use of waste materials leads also to a reduction in the use of new material, and to conservation of resources. Research on the use of these materials in concrete is necessary in order to assess the life cycle performance, and life cycle costs.

4.6.2 *Use of Globigerina Limestone in Concrete*

The potential use of crushed globigerina limestone as a substitute for part of the cement leads to a limited percentage use of the waste material. The processing of the materials should also be taken in consideration. In general crushed globigerina limestone used as aggregate in concrete results in a concrete of reduced strength. Good quality aggregate is normally extracted for important structural elements. However the materials of low quality can be suitable for specific applications, while respecting the requirements of standards and specifications.

The material is used in the production of crushed soft stone for specific applications, including lean concrete and specific concrete products.

4.6.3 *The Use of Recycled Concrete Aggregate*

Crushed hardened concrete can be used as aggregate in concrete. It is necessary to eliminate other demolition waste, namely stone blocks, from the concrete. The separation of reinforcement from the concrete is also necessary. The concrete manufactured with recycled concrete aggregate can be potentially used in selected applications, with reference to standards and specifications.

4.7 *Disposal of Waste*

4.7.1 *Disposal of Waste in Quarries*

The Waste management Subject Plan (Planning Authority, 2001) refers to the development of additional capacity of inert wastes in former mineral workings (generally disused quarries) or derelict sites that cannot be satisfactorily reclaimed in any other way. It also refers to the disposal of waste by land-raising, with due regard to specific criteria including assessment of environmental impacts. The utilization of disused quarries for disposal of the inert waste has the advantage of providing a solution for both the disposal of the material, and also for the regeneration of the quarries. Waste is best separated at source rather than at the quarry, where it is difficult to separate. Important screening of the waste is necessary before deposition at the point of disposal. Furthermore the potential contamination of the aquifer has to be assessed. Waste material can be considered as a resource, and the dumping of selected and controlled material will allow for its potential future extraction and reuse. (Borg R.P., 2006) The landfill capacity required in the future is influenced by the extent of waste reduction, reuse and recycling.

4.7.2 *Disposal at Sea*

The disposal of inert waste at sea has attracted continuous debate. It can be seen as a practical solution to the disposal of the large volumes of inert waste. However the dumping of inert waste at sea is also considered as the wastage of a potential resource. Furthermore according to the Waste Management Subject Plan (Planning Authority, 2001), the dumping of material at sea should be avoided as much as practically possible, and the dumping at sea should be considered as an option of last resort. The disposal of inert waste will only be permitted at an official dump site if the proposal meets specific criteria;

- Land based alternatives have been discounted.
- Only uncontaminated inert waste shall be acceptable.
- The disposal will only be allowed in dump sites that have an environmental monitoring programme in place.

Proposals for new dumpsites need to demonstrate that marine ecosystems and features of acknowledged importance will not be affected. Such an option has direct implications on the ecosystem and on the sensitive coastal environment of Malta. As against the dumping of the inert material in quarries, where it can be re-extracted in the future, the deposition of inert waste at sea can be considered as the dumping and wastage of a potential resource.

A distinction is usually made between the deposition of inert waste at sea for purposes of land reclamation, and the deposition of this waste for purposes of disposal. Controlled land reclamation can potentially be one of the main solutions.

The proposals for land reclamation should be assessed in view of detailed assessments of the inert waste material that is available for disposal, and the volumes of material required for specific projects. Land reclamation needs to be considered through a comprehensive assessment of various factors including the impact of the project on the marine environment, intended use, and viability of such projects. Such projects will necessitate further infrastructural works, which will inevitably take up more resources. Potentially recommended uses for land reclamation include projects associated with renewable and alternative energy.

4.8 *Conservation of Mineral Resources*

Limestone is extensively used in construction in Malta. It is broadly grouped into Globigerina Limestone, and Upper and Lower Coralline Limestone. Globigerina Limestone blocks are extracted and used as a building product. The Coralline Limestone is quarried for the production of crushed aggregate, which is used in various civil engineering applications. In general, the extraction of limestone blocks for construction, and aggregate for concrete and other civil engineering applications, results in large open pits, leaving scars in the landscape, and with negative impacts on the environment.

In order to reduce the demand of globigerina limestone, which is a non-renewable resource, alternative construction materials can be considered. The characteristics and performance of the globigerina limestone and alternative products needs to be assessed. Further potential action intended to reduce the demand of the globigerina limestone, is to limit the use of limestone to cladding panels in specific applications. Potential reduction in the waste generated during the extraction and production of globigerina limestone blocks for construction, should be considered.

A potential alternative to the extraction of hard stone aggregate from quarries, includes the importation of aggregate of consistent and improved properties, for specific applications. In assessing the costs and feasibility of such a proposal, it is necessary to consider the extensive environmental impact of quarries in Malta, and the reduced reserves of quality material, available for extraction. The characteristics and properties of the material, and the suitability for its intended use in specific civil engineering applications should also be assessed.

4.9 *General Considerations*

The conservation of resources is an important objective, which can be achieved through the adoption of rational structural solutions, and selection of construction materials of improved performance characteristics, and increased strength.

In the appraisal of construction materials, construction techniques and structural systems, the entire life cycle of the building needs to be considered, covering the building construction, maintenance, alterations and demolition. Alternative structural systems and construction techniques can be assessed in view of the potential reduction in waste generation, reuse and recycling of construction products. Specific construction systems can lead to a reduced demand on resources, and more effective waste management practices.

When one considers the broader spectrum of the building industry in Malta, a relevant concern is the surplus of property on the market, and the percentage of vacant houses (23%). (MEPA, 2005) Therefore incentives for the reuse of existing buildings, need to be considered. Furthermore, the potential for alterations and adaptations of existing building stock, rather than demolition and reconstruction can be assessed.

5 CONCLUSIONS

The potential measures recommended within the framework of The Solid Waste Management Strategy for the Maltese islands (Ministry for the Environment, 2001), are based upon practical attempts at addressing the issue of excavation, construction and demolition waste, and the current debate on waste in Malta.

Practical short and long term solutions need to be assessed in terms of environmental impact and economic feasibility. Ongoing research is necessary to support various options. Such research can also lead to the formulation of technical standards and recommendations, within the legal framework. Incentives are recommended for the reduction of construction and demolition waste (NCSD, 2006). Assistance and guidance from the responsible entities, together with the proper incentives are necessary in order to facilitate the implementation of potential measures through a practical approach.

The fundamental goal is to promote the conservation of resources, and to exploit Construction and Demolition Waste as a potential resource, through the objectives of sustainable waste management.

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Properties and performance of cement composites based on recycled brick aggregate

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ABSTRACT: The results of experimental testing conducted on mortar specimens made with crushed brick aggregate are presented in this paper. Certain specimen series were made with addition of monofilament polypropylene fibers. Six different mortar mixtures were tested. The experimental part of the investigation consisted of monitoring of the following time-dependant properties of recycled-brick based mortar: density (both in fresh and in hardened state), compressive strength, flexural strength and shrinkage. The testing results of mechanical properties of fiber reinforced recycled brick composites showed that the addition of polypropylene fibers generally leads to improvement of these properties. For example, the increase of compressive strength varies between 5 and 16% and the increase of flexural strength between 4 and 25%, in comparison to the non-reinforced mortar. These improvements can also vary with the change of the applied type of aggregate, i.e. depending on the adopted solution: making mortar with just recycled bricks or combining recycled bricks with regular river sand.

1 INTRODUCTION

The idea to use crushed brick as the aggregate for mortar and concrete is not a new one. The first known attempts to make this type of composite material go back to the age of ancient Greeks and Romans, and it was a mixture of lime, sand and water with addition of crushed bricks.

Generally, concrete based on crushed building ceramics is made using following types of aggregates:

- Old bricks collected from the destroyed walls (so called recycled bricks);
- Shattered ceramics – waste left after the production of building ceramics;
- Naturally baked clay, which is often present at coal excavation sites.

In the western, technologically highly developed countries, recycling represents the usual way of production of crushed brick aggregate. This is the case, because of the frequent and thorough reconstructions of central city areas in these countries. In that process, the old and ruined buildings (or even whole blocks of buildings) are being partially or completely destroyed and the waste material has to be removed from these locations. Also, there are a lot of buildings that should be replaced with newer, technologically and economically superior solutions, because of their long-term degradation and expired exploitation period. Regretfully, in recent years we are witnessing numerous natural catastrophes (like earthquakes, floods, tsunamis or fire) and unnatural disasters (such as wars or terrorist attacks). All these events are unavoidably being followed by cleaning operations in order to remove the waste building material. Therefore, storing of such material becomes a growing problem, especially in the densely populated urban areas. The solution of this problem represents a special challenge in technical, technological, economic, but also in ecological sense. The number of recycling plants for crushed brick material is growing very fast: for example there are more than 60 plants working today just in Holland – which is a fact that places this country among world leaders in this field.

In Serbia, the recycling of used bricks has not yet become a regular procedure, which practically means that this type of aggregate could be obtained only from the waste material left after the production of building ceramics. However, as the quantities of these byproducts are not large (in the case of modern technology application they amount to 3-5% of the whole production) there is a question whether it is economical or not to use this waste material as concrete aggregate. Namely, the producers of building ceramics often find it more profitable to return this waste material into the production process (as a new raw material) or to grind it into powder and sell it as a "dirt" surface for tennis courts. On the other hand, if we take into account that more than 80% of all buildings in our country are completely or partially built using brick material, it is obvious that the future lies in recycling of old, degraded bricks.

During the recycling process, special attention should be paid to the presence and removal of undesirable and/or harmful ingredients (such as lime, clay, gypsum, humus, etc.) which makes this process even more complicated and expensive.

However, if we put all advantages and disadvantages together and especially if we bear in mind the growing popularity of so called ecologically suitable materials (and ceramic materials certainly fall into that category), the conclusion could be drawn that mortar and concrete based on recycled bricks shall become more extensively applied in the near future.

2 COMPONENT MATERIALS

During the concrete mix design, special attention should be paid to the selection and quality control of component materials. This is mainly related to the aggregate because the application of other components (cement, water, admixtures) does not particularly differ from the classical concrete. The quantities of cement vary between 250-400 kg/m^3, while the water content required for plastic consistency amounts to 400-450 kg/m^3 – which is considerably more than the usual values. The quality of aggregate largely depends on the quality of basic material – ceramics which is crushed in several phases, separated into standard fractions and eventually dusted using air-stream. The most important properties of recycled-brick aggregates, which must be tested in the lab, are water absorption (in relation to the significant porosity of the basic material) and compressive strength (triaxial compression test). Beside its physical-mechanical properties, the granulometric composition of the aggregate largely affects the quality of mortar, i.e. concrete. Also, there is the so called pozzolanic activity effect (considering the smallest ceramic particles) that should be taken into account. Namely, the research has shown that if the aggregate contains between 15-20% of particles which are smaller than 0,063 mm, this contributes not only to the larger final strength of the composite, but also affects the fresh mixture acting as a plasticizing – water retaining agent. On the other hand, because of the presence of such pozzolanic admixture it is possible (if necessary) also to reduce the amount of cement.

For the experimental mortar mix the waste from the ceramics (left after the production of building ceramics), which was separated into three fractions (I:0/2mm, II:2/4mm and III:4/8mm), in combination with river sand (fraction IV: grain size 0/4mm), were used as aggregates. The grading properties of these aggregate types are given in Table 1. The mortars were made using two different mixtures of aggregates. Aggregate mixture 1 was made using 35% of fraction I, 30% of fraction II and 35% of fraction III. On the other hand, aggregate mixture 2 was made using 20% of fraction I, 25% of fraction II, 35% of fraction III and 20% of fraction IV. Physical properties of aggregates (such as bulk density, organic matter and clay content) are given in Table 2. The mean value of density of crushed brick aggregate was determined to be 2540 kg/m^3. The measured water absorption of crushed brick aggregates was in average 41%. Fraction III (4/8 mm) was also submitted to triaxial compression test, which showed the mean compressive strength value of 1,44 MPa.

Among other component materials, there are different types of fibers (acting as a special micro-reinforcement) whose application is constantly increasing. These fibers generally improve certain physical-mechanical and deformational properties of otherwise brittle composite materials like mortar or concrete. Steel and synthetic fibers (polypropylene, polyethylene, nylon, etc.)

are most frequently used. The fibers may be single (monofilament) or connected (fibrillated). The polypropylene fibers are usually added in relatively small quantities (app. 0,1%-Vol) and their greatest contribution is in the field of shrinkage reduction and crack propagation control. During the mixing process it is important to pay attention to the order of addition of component materials, but also to the mixing time which should be at least doubled in relation to the classical mortar and concrete mixes. Some of the experimental mortar mixtures were made using monofilament polypropylene fibers "Fibrin23", which technical data is given in the Table 3. A photo showing (Fig. 1) different types of polypropylene fibers is given next to the Table 3.

Table 1. Grading properties of different aggregate types

Fraction /	Passage through sieve opening (in mass%)							
Sieve (mm)	0,125	0,25	0,5	1,0	2,0	4,0	8,0	11,2
I(0/2mm) crushed brick	32,5	41,0	57,5	74,0	99,5	100	100	100
II(2/4mm) crushed brick	0,5	0,7	0,9	1,0	8,5	98,5	100	100
III(4/8mm) crushed brick	-	-	-	1,5	1,7	6,3	99,7	100
IV(0/4mm) river sand	3,9	14,7	60,2	73,2	86,2	99,2	100	100
Aggregate mixture 1	11,5	14,6	20,4	26,7	38,0	66,8	99,9	100
Aggregate mixture 2	7,4	11,3	23,8	30,2	39,8	66,7	99,9	100

Table 2. Physical properties of different aggregate types

Fraction	I (0/2 mm)	II (2/4 mm)	III (4/8 mm)	IV (0/4 mm)
Bulk density (kg/m^3)	1072	840	871	1724
Bulk density compacted (kg/m^3)	1177	930	965	1862
Organic matter content	acceptable	acceptable	acceptable	acceptable
Clay content (%)	0	0	0	0

Table 3. Properties of fibers "Fibrin23"

Synthetic fibers	Fibrin 23
Basic material	100% Polypropylene
Production method	Streching by pulling
Fiber type	Monofilament fibers
Cross section	Rounded
Diameter	0,018 mm
Length	12 mm
Aspect ratio (L/d)	667
Number of fibers/kg	~ 300 million
Specific surface	~ 230 m^2/kg
Tensile strength	560 MPa
Modulus of elesticity	4200 MPa
Melting point	160 ºC
Usual dosage	0,6 – 0,9 kg/m^3

Figure 1. Different types of polypropylene fibers

3 EXPERIMENTAL TEST RESULTS

Prior to the adoption of the final mix design of the mortar (or concrete) it is essential to make trial mixes in order to confirm the quality of the composite, both in the fresh and in the hardened state. At the end, between several different mixtures the optimal one can be chosen, considering the desired properties and performance of the composite.

Having this in mind, six different mortar mixtures (marked with capital letters A, B, C, D, E and F) were made and tested. All mixtures were made using 400 kg/m^3 of Portland cement blended with 15% of pozzolana. Other properties of these mixtures are following:

1. Mixture A – mortar based on crushed-brick aggregate fractions 0/2, 0/4 and 4/8 mm.
2. Mixture B - mortar based on crushed-brick aggregate fractions 0/2, 0/4 and 4/8 mm with addition of 900 g/m^3 monofilament polypropylene fibers - type ″Fibrin″(Adfil, Great Britain).

3. Mixture C - mortar based on crushed-brick aggregate fractions 0/2, 0/4 and 4/8 mm and river sand with grain diameter between 0/4 mm.
4. Mixture D - mortar based on crushed-brick aggregate fractions 0/2, 0/4 and 4/8 mm and river sand with grain diameter between 0/4 mm with addition of 900 g/m^3 monofilament polypropylene fibers - type ″Fibrin″ (Producer: Adfil, Great Britain).
5. Mixture E - mortar based on crushed-brick aggregate fractions 0/2, 0/4 and 4/8 mm with addition of 2% of ″Iriplast″ superplasticizer (Producer: Iris, Skoplje, R. of Macedonia).
6. Mixture F - mortar based on crushed-brick aggregate fractions 0/2, 0/4 and 4/8 mm with addition of fibers (same as mixture B) and superplasticizer (same as mixture E).

The adopted mix designs for all of the six tested mortars are presented in the Table 4. The quantities of water shown in the table represent the total doses, which means that one part of the used water was absorbed by the aggregate, and another part provided the desired consistency of the fresh mixture.

Table 4. Mortar mix design

Mortar type		A	B	C	D	E	F
Cement (kg/m^3)		400	400	400	400	400	400
Aggregate (kg/m^3)	(I) 0/2 mm	574	574	328	328	574	574
	(II) 0/4 mm	492	492	410	410	492	492
	(III) 4/8 mm	574	574	574	574	574	574
	(IV) 0/4 mm	-	-	328	328	-	-
	Total	1640	1640	1640	1640	1640	1640
Water (kg/m^3)		490	490	416	416	430	430
Polypropylene fibers (kg/m^3)		-	0,9	-	0,9	-	0,9
Superplasticizer (kg/m^3)		-	-	-	-	8	8

The experimental part of the investigation consisted of monitoring of the following time-dependant properties of recycled-brick based mortar: density (both in fresh and in hardened state), water absorption, compressive strength, flexural strength and shrinkage.

The results of measuring of density in the fresh state are given in the Table 5, whereas the change of density in the hardened state during time could be analyzed according to the data presented in the Table 6. All final results are calculated as the mean values based on three testing results.

Table 5. Density of fresh mortar $\gamma_{m,sv}$ (kg/m^3)

Type of mortar	A	B	C	D	E	F
Density (kg/m^3)	1922	1984	2017	2051	2000	2002

According to their properties, these composites are somewhere in between mortar and concrete. If we place them into the group of fine-aggregate based concretes, the final conclusion could be drawn (also regarding the achieved values of fresh-state and hardened-state densities) that they belong to the class of light-weight concretes.

Table 6. Density of hardened mortar γ_m (kg/m^3)

Type of mortar	Age of specimens (days)			
	3	7	28	180
A	1920	1920	1721	1680
B	1982	1980	1734	1692
C	2015	2012	1805	1785
D	2050	2045	1810	1790
E	1995	1992	1725	1685
F	1997	1992	1748	1697

Analizing the measured values of water absorption, which are given in the Table 7, the conclusion can be drawn that crushed brick aggregate mortars show considerable increment of this physical property (up to two times higher values when compared to "normal" mortar).

Table 7. Water absorption of hardened mortar

Type of mortar	A	B	C	D	E	F
Water absorption (%)	18,7	18,6	16,1	16,0	17,1	17,0

As it was already said, the testing of mechanical properties consisted of compressive strength and flexural strength tests. These properties were tested at the age of 7, 28 and 180 days, and each test was carried out on three specimens (with dimensions 4x4x16 cm) from each of the six series. Table 8 contains the compressive strength testing results of mortar specimens of series A, B, C, D, E and F.

Table 8. Compressive strength values f_p(MPa)

Type of mortar	Age of specimens (days)		
	7	28	180
A	20,10	30,50	31,80
B	20,97	32,08	32,85
C	20,02	31,69	32,60
D	21,30	36,82	37,23
E	22,60	32,40	33,80
F	22,60	34,65	35,68

Although the valid Serbian and European standards do not regard flexural strength test as an obligatory experiment for quality control of mortar, it still represents an important mechanical property of such composite materials. Especially in the case of polypropylene fiber reinforced mortar, the flexural strength test represents one of the best ways to compare different mixtures as well as to evaluate the efficiency of the applied micro-reinforcement.

Table 9. contains the flexural strength testing results of mortar specimens of series A, B, C, D, E and F.

Table 9. Flexural strength values f_{zs}(MPa)

Type of mortar	Age of specimens (days)		
	7	28	180
A	4,04	5,82	6,00
B	4,29	6,14	6,20
C	4,02	4,83	5,10
D	4,28	6,04	6,30
E	4,42	5,96	6,10
F	4,75	6,20	6,42

As the rheological properties are concerned, the experiment consisted of shrinkage measurement which was performed on mortar prisms with dimensions 4x4x16 cm. This part of the test was especially important because of the fact that the shrinkage values for crushed-brick mortars and concretes are usually 20-60% higher than the same values for normal composites. Because of the limited space, only the most interesting results will be highlighted here instead of the more detailed or complete presentation. So for instance, at the age of 28 days the specimens of series B had 8 % smaller average shrinkage than the specimens of series A, whereas the mortar marked as series D showed a 17% decrement in shrinkage deformation in relation to the mortar C. These relative rheological improvements in mortar quality can be contributed mostly to the presence of monofilament polypropylene fibers at series B and D.

4 FINAL DISCUSSION AND CONCLUSIONS

As a part of the final discussion, current situation and possibilities as well as future perspectives for application of recycled brick aggregate should be mentioned. Investigation of the current state-of-the-art in the Serbia's civil engineering showed that the scope of usage of recycled brick aggregate is still very limited. Namely, this material is mostly used for road embankments (factories "Opeka" from Smederevska Palanka and "Podunavlje" from Čelarevo), for tennis courts surfaces (production of "Tenisit" factory and "Kubršnica" from Aranđelovac), as well as for production of three-layered prefabricated "YU chimneys" based on "Schiedel" system (GIP "Građevinar", "YU chimney" from Bačka Palanka).

If we apply a corresponding technological procedure in order to produce a porous (cavernous) concrete, such material will primarily posses good thermo-insulation properties and thus it should be used for production of various full or hollow bricks. Mortars based on recycled bricks made with addition of polypropylene fibers may be successfully used as facade mortars, but also as thermo-insulation or soundproofing composite materials (the fiber reinforcement can improve to some extent thermical and acoustical properties of these materials, but the basic effect of its application is not direct - it consists of simultaneous increment of ductility, resistance to different actions and durability in general). Also, because of their appropriate characteristics, such fiber reinforced composite materials could be successfully applied as fireproofing mortars.

The testing results of mechanical properties of fiber reinforced recycled brick composites showed that the addition of polypropylene fibers generally leads to improvement of these properties. For example, the increment of compressive strength varies between 5 and 16% and the increment of flexural strength between 4 and 25%, in comparison to the non-reinforced mortar with the same consistency in the fresh state. These improvements can also vary with the change of the applied type of aggregate, i.e. depending on the adopted solution: to make the mortar using just recycled bricks or to combine recycled bricks with regular river sand. As the time-dependant shrinkage deformations are concerned, they usually tend to have higher values if the composite is based on recycled brick aggregates, but such negative effects can be diminished to some extent with addition of fiber reinforcement. This hypothesis was confirmed during laboratory testing, which showed maximal decrement of shrinkage in amount of approximately 17%.

Although the application of "ceramic concrete" which is based on "pure" crushed brick waste material has not yet became accepted worldwide, it certainly has a good future. The main reasons for such estimation could be found both in ecological and economic aspects of its application, but also within the fact that this composite material possesses quite a few of the advantageous physical-mechanical properties - a fact that was supported also by the experimental research that is described in this paper. Future directions for research in this field could be pointed towards testing of thermo-technical properties of the given composite material. An example that could confirm the relevance of such opinion may be the fact that a 10 cm thick wall made of recycled brick concrete is equivalent (in the sense of thermo-insulation) to a 30 cm thick wall made of normal concrete with the same compressive strength.

Having in mind everything that has been said before, the authors of this paper strongly believe that in the near future mortar and concrete based on recycled brick aggregate (with or without fiber reinforcement) will find much wider scope of application in our civil engineering practice.

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Recycled concrete as aggregate for producing structural concrete

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ABSTRACT: A comparative analysis of experimental investigation of properties of fresh and hardened concrete with natural coarse aggregate, combination of natural and recycled coarse aggregate and with recycled coarse aggregate, is presented in the paper. Three types of concrete mixtures were encircled by this experimental research. Kind and quantity of coarse aggregate were varied in the following way: the first concrete mix has 100% natural river coarse aggregate (R0), the second concrete mix has 50% natural river coarse aggregate and 50% recycled coarse aggregate (R50) and the third concrete mix has 100% recycled coarse aggregate (R100). Ninety nine samples were formed for the testing of basic properties of hardened concrete. On the basis of obtained test results and their analysis it was concluded that concrete mixtures with recycled aggregate are very similar to concrete mixes with natural aggregate if rules for design and production of this new concrete type are taking into account. Obtained test results of hardened concrete samples showed that recycled aggregate concrete had satisfactory performance that did not differ from properties of ordinary concrete significantly, if quality recycled concrete coarse aggregate was used. For example, mechanical properties of all three kinds of concrete (concrete compressive strength, splitting and flexural strength) had almost the same values.

1 INTRODUCTION

Demolishing of old and deteriorated buildings and their substitution with new buildings is frequent phenomenon in urban areas and in the scope of traffic infrastructure. Main reasons for demolishing of existing buildings is change of their purpose, ageing of structures, rearrangement of a city parts, expanding of traffic directions and increasing of traffic load, natural disasters (earthquake, fire, flood) etc. For example, in countries of EEC, forty years ago 50 million tons of concrete was demolished per year and the prediction was that in the beginning of this millennium that quantity will increase three times (Rilem Report No.6, 1992). In USA the construction waste produced from building demolition alone is estimated to be 123 million tons per year (FHWA National Review, 2004). The most common method of managing this material has been through disposal in landfills. In that way huge deposits of construction waste are created and consequently agriculture land is decreasing and that becomes real ecological problem, because construction waste is a potential polluter of human environment. For that reason in developed countries, restricted laws in a form of prohibitions or special taxes for creating of waste areas are bring into practice.

From the other hand, production and application of concrete is rapidly increasing which results in increasing of consumption of natural aggregate as a largest concrete component. This can be proved by example that two billion tons of aggregate are produced each year in the United States . Production is expected to increase to more than 2.5 billion tons per year by the year 2020 (FHWA National Review, 2004). This situation led to question about the availability of natural aggregates and where will we find new aggregate sources. Many European countries have placed a tax on the use of virgin aggregates.

The solution of these problems state agencies and the aggregate industry find in recycling concrete debris as an alternative aggregate.

2 RECOMMENDATIONS FOR PRODUCTION AND BASIC PROPERTIES OF CONCRETE WITH RECYCLED AGGREGATE

In this chapter recommendations for production and the most important properties of fresh and hardened concrete with recycled aggregate are briefly presented. Presented data are results of comparative testing of properties of ordinary concrete and concrete with recycled aggregate of other researchers.

Recycled aggregate compared to natural aggregate has following properties:

- increased water absorption,
- decreased bulk density,
- decreased specific gravity,
- increased abrasion,
- increased crushability,
- increased quantity of dust particles,
- increased quantity of organic impurities (if concrete is mixed with earth during building demolition) and
- possible content of chemically harmful substances (depends on service conditions in building from which by demolition and crushing recycled aggregate is obtained).

It is recommended to use aggregate from recycled concrete only as a course aggregate if quality concrete have to be produced. In USA it is allowed partial substitution of natural fine aggregate with recycled fine aggregate up to 20%.

Technology of production of concrete with recycled aggregate is different from the production procedure for ordinary concrete. One possibility to provide design consistency of fresh concrete is to previously saturate recycled aggregate to the condition "water saturated surface dry".

Available testing results of concrete with recycled aggregate vary in wide limits, sometimes are even opposite, but general conclusions about properties of concrete with recycled coarse aggregate compared to concrete with natural aggregate (Rilem Report No.6, 1992), are:

- Increased drying shrinkage (up to 40%),
- Increased creep (up to 50%),
- Water absorption depends on differences between water-cement ratio of new and old concrete which was used for recycling (there are no differences if new concrete has bigger water-cement ratio from recycled concrete),
- Decreased compressive strength (5-30%),
- Decreased splitting tensile strength (0-10%),
- Decreased flexural strength (0-10%),
- Decreased modulus of elasticity (10-30%),
- Same or increased frost resistance.

3 OWN EXPERIMENTAL INVESTIGATION

The aim of this investigation was comparison of basic properties of referent concrete (concrete with natural aggregate) and concrete with recycled aggregate.

Research program encircled three concrete types (Malešev et al. 2006). Compositions of the tested concrete types were determined in accordance to the following conditions:

- same cement quantity,
- same consistency after 30 min,
- same max. grain size (32mm),
- same granulometric curve of aggregate fractions,
- same kind and quantity of fine aggregate,
- variable kind and quantity of coarse aggregate.

Kind and quantity of coarse aggregate were varied in the following way:

- the first concrete mix has 100% natural river coarse aggregate (R0), referent mixture
- the second concrete mix has 50% natural river coarse aggregate and 50% recycled coarse aggregate (R50)
- the third concrete mix has 100% recycled coarse aggregate (R100)

Mentioned conditions for determination of mixture compositions enable to find out the influence of used quantity of coarse recycled aggregate (0%, 50% i 100%) on tested concrete properties. The following properties of concrete were selected for testing:

Δh - consistency (slump test) immediately after mixing and 30 min after mixing,
$\gamma_{b,sv}$ - bulk density of fresh concrete,
Δp - air entrained quantity,
$\gamma_{b,o\check{c}}$ - bulk density of hardened concrete,
u_v - water absorption (age 28 days),
h - waterproofness according to DIN 1048, (age 28 days),
- wear resistance (age 28 days),
f_p - compressive strength (age 2, 7 and 28 days),
f_{zc} - splitting strength (age 28 days),
f_s - flexural strength (age 28 days),
E - modulus of elasticity (age 28 days),
ε_s - drying shrinkage (age 3, 4, 7, 14, 21 and 28 days),
f_{at} - bond between reinforcement and concrete (ribbed and mild reinforcement),

For the testing of listed properties of hardened concrete 99 samples were formed.
Component materials for concrete mixtures were:

- Portland-composite cement CEM II/A-M(S-L) 42.5R, (Lafarge -BFC)
- Fine aggregate (river aggregate, separation Luka Leget, fraction 0/4mm)
- Two kinds of coarse aggregate:
  - river aggregate, separation Luka Leget, fractions 4/8, 8/16 and 16/31.5mm,
  - aggregate form recycled concrete (fractions 4/8, 8/16 and 16/31.5mm)
- Potable water.

Aggregate from recycled concrete was produced by crushing of "old" concrete with class C30/37 and C40/50. Raw materials for crushing were concrete cubes used for compressive strength testing (Fig. 1) and one precast reinforced concrete column, which had inappropriate dimensions (Fig. 2). The primary crushing was done with pneumatic hammer (Fig. 2) and the secondary crushing was performed in rotating crusher. Obtained material after primary crushing is shown in Fig. 3, and after secondary crushing in Fig. 4.

Crushed concrete particles were separated in standard fractions of course aggregate (4-8mm, 8-16mm and 16-31.5mm) (Fig. 5).

Fig. 1 – Concrete samples (cubes)

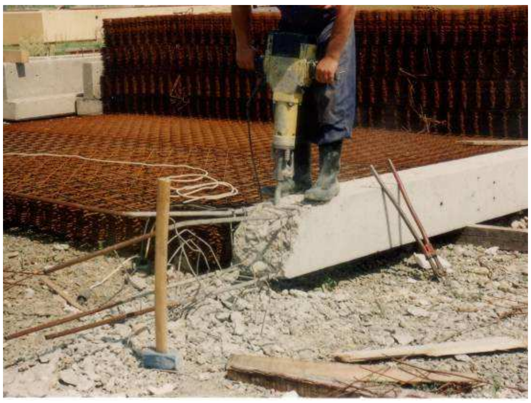


Fig. 2 – Precast RC column

Fig. 3 – Material after primary crushing

Fig. 4 – Material after secondary crushing

Fig. 5 – Fractions of recycled concrete aggregate

All component materials were tested before mix design. Regarding test results it was concluded that tested cement and river aggregate satisfy prescribed requirements of quality. The results of testing of recycled concrete aggregate are shown in Table 1:

Tab. 1 - Results of testing of recycled concrete aggregate

Tested property	Measured value	Fraction			quality requirement
		4/8	8/16	16/32	
Crushing resistance (in cylinder)	mass loss (%)	18.3	26.7	30.7	< 30
Freezing resistance test	mass loss (%)	2	1.4	1.0	< 12
Chemical testing (mortar part of recycled aggregate)	chloride content	0	0	0	< 0.1
	sulfate content	in traces	in traces	in traces	< 1
	pH	9.85	9.85	9.85	-
Content of weak grains	(%)	0	3.7	7.1	< 3 (4)
Crushing resistance (machine "Los Angeles")	mass loss (%)	29.6	33.7	34.0	< 30
Water absorption after 30 minutes	(%)	4.59	2.87	2.44	-
Fines content	(%)	0.45	0.23	0.36	< 1

3.1 *Mix design*

Compositions of concrete mixtures were chosen on the basis of following conditions:

- cement content 350kg/m³,
- water content according to required consistency (slump test, $\Delta h=10\pm2$cm after 30 minutes from mixing of concrete),
- aggregate content from the amount of absolute volume of component materials in 1m³ of concrete, ($\gamma_{s,a}$=2670 kg/m³, $\gamma_{s,ar}$ =2500 kg/m³ and $\gamma_{s,c}$ =3060 kg/m³)
- granulometric content of aggregate mixture according to the Fuler grading curve,
- air content $\Delta p=1\%$.

Designed compositions of all tested concrete mixtures are shown in Table 2 and quantity of each aggregate fraction in Table 3:

Tab. 2 - Design quantities of component materials

Concrete mixture	Cement (kg/m³)	Water (kg/m³)	Aggregate (kg/m³)	Additional water * (kg/m³)	Bulk density (kg/m³)
R0	350	180	1857	0	2387
R50	350	180	1816	19	2365
R100	350	180	1776	37	2343

* - dry recycled aggregate, basic water content and additional water quantity were used to achieve required concrete consistency. Additional water quantity was calculated using results of water absorption of recycled aggregate after 30 minutes.

Tab. 3 - Design quantities of aggregate fractions

Concrete mixture	Content of natural river aggregate (kg/m³)				Content of recycled aggregate (kg/m³)		
	0/4	4/8	8/16	16/32	4/8	8/16	16/32
R0	612	298	390	556	0	0	0
R50	600	145	191	272	118	136	354
R100	586	0	0	0	231	266	693

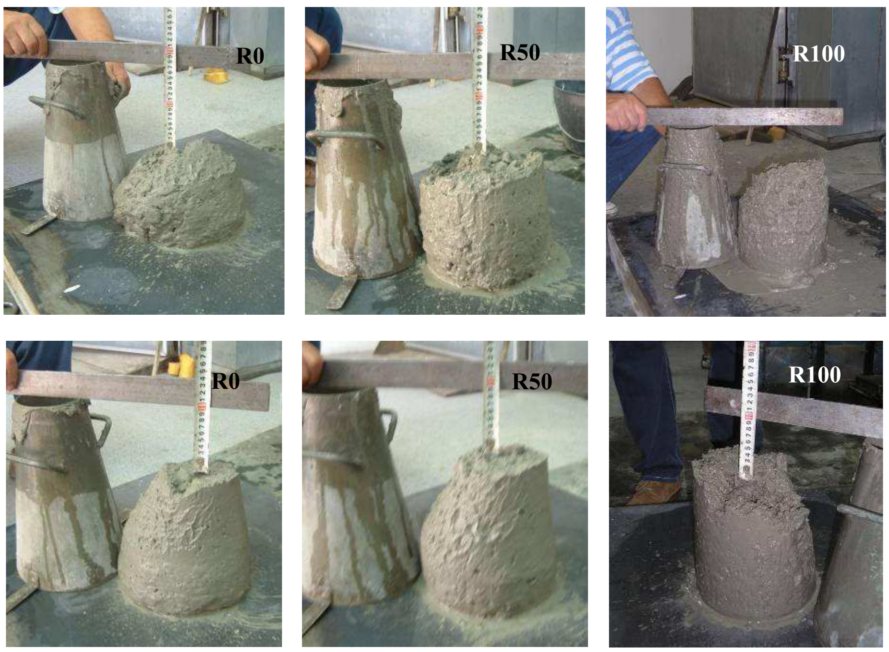
3.2 *Results of testing of fresh concrete*

Results of testing of consistency (Fig. 6), air content and bulk density are presented in Table 4. In the same table calculated real quantities of component materials, are shown also.

Tab. 4 - Testing results of fresh concrete

Concrete mixture	$m_{c,stv}$ (kg/m³)	$m_{v,stv}$ (kg/m³)	$m_{a,stv}$ (kg/m³)	m_v/m_c	m_a/m_c	Δh_1 (cm)	Δh_2 (cm)	Δp (%)	$\gamma_{b,stv}$ (kg/m³)
R0	352	181	1866	0.514	5.306	16	10	1.5	2399
R50	352	200	1826	0.5683	5.188	14.5	8.5	1.4	2378
R100	348	216	1765	0.62	5.074	11	9	1.3	2329

Δh_1 - measured slump immediately after mixing, Δh_2 - measured slump after 30 minutes



Slump after mixing

Slump after 30 minutes

Fig. 6 – Consistency (slump test)

Differences in water content which are necessary to achieve the same consistency after 30 minutes are shown in table 5.

Tab. 5 - Differences in water content between concrete mixtures R0, R50 and R100

$m_{v,R0}$ (kg/m³)	$m_{v,R50}$ (kg/m³)	$m_{v,R100}$ (kg/m³)	$m_{v,R50}-m_{v,R0}$ (kg/m³)	$(m_{v,R50}-m_{v,R0})/m_{v,R0}$ (%)	$m_{v,R100}-m_{v,R0}$ (kg/m³)	$(m_{v,R100}-m_{v,R0})/m_{v,R0}$ (%)
181	200	216	19	10.55	35	19.33

Comparisson of air content (Δp) in concrete mixtures R0, R50 and R100 (Tab. 4) showed that differences are insignificant.

By analysis of bulk density values, it was concluded that bulk density of concrete with natural aggregate was maximum 3% bigger than bulk density of concrete with recycled aggregate.

3.3 *Results of testing of hardened concrete*

Results of testing of compressive strength of concretes R0, R50 and R100 at age of 2, 7 and 28 days (Radonjanin et al. 1989), are presented in Table 6. For testing 15cm cubes were used.

Tab. 6 – Compressive strength of concrete R0, R50 i R100, at age of 2, 7 and 28 days

Vrsta betona	$\gamma_{b,o\check{c}v}$ **(kg/m³)**	$f_{p,2}$ **(MPa)**	$f_{p,7}$ **(MPa)**	f_{p28} **(MPa)**	σ **(MPa)**
R0	2424	27.55	35.23	43.44	1.57691
R50	2379	25.74	37.14	45.22	1.2089
R100	2332	25.48	37.05	45.66	3.50163

Measured values of drying shrinkage of concretes R0, R50 and R100 are shown in Table 7. The samples were prisms 10x10x40cm and for measuring of dilatation changes extensometer with base of 25cm was used.

Tab. 7 – Results of testing of drying shrinkage of concrete R0, R50 and R100

Concrete type	$\varepsilon_{s,4}$ **(mm/m)**	$\varepsilon_{s,7}$ **(mm/m)**	$\varepsilon_{s,14}$ **(mm/m)**	$\varepsilon_{s,21}$ **(mm/m)**	$\varepsilon_{s,28}$ **(mm/m)**
R0	0.0173	0.124	0.2027	0.2773	0.3387
R50	0.0360	0.086	0.1760	0.2540	0.3060
R100	0.0907	0.204	0.2507	0.3347	0.4067

Results of testing of other properties of hardened concrete are presented at Table 8.

Tab. 8 – Results of testing of properties of hardened concrete at age of 28 days

Concrete type	R0	R50	R100
Water absorption, (%)	5.61	6.87	8.05
Waterproofnees , (mm)	26	18	35
Splitting strength, (MPa)	2.66	3.20	2.78
Flexural strength, (MPa)	5.4	5.7	4.2
Wear resistance, (cm³/ 50 cm)	13.40	15.58	17.18
Bond between mild reinforcement and concrete, MPa	6.48	5.87	6.76
Bond between ribbed reinforcement and concrete, MPa	8.22	7.50	7.75

Waterproofness of concrete R0, R50 and R100 was tested on cubes 20cm. Splitting strength of concrete was tested on cubes 15cm and flexural strength on prisms 10x10x40cm.

Cylindrical samples with diameter 10cm and height 15cm and with embedded ribbed and mild reinforcement (R∅12mm and ∅12mm) were used for testing of bond between reinforcement and concretes R0, R50 and R100. Length of embedded part of reinforcement was 15cm. For testing of bond, axial tension procedure and tearing device were used (Fig. 7).

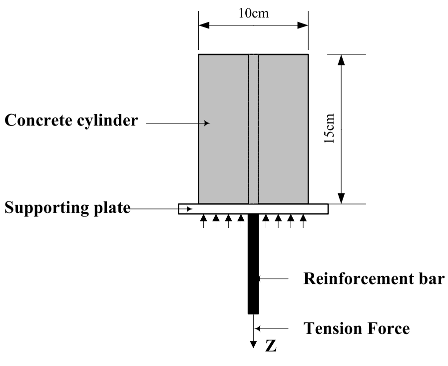


Fig. 7 – Testing of bond between concrete and reinforcement

Testing results for concrete compressive strength (Table 6) and established functional relations fp(t) for concrete R0, R50 and R100 are illustrated in Fig. 8.

According to the analysis of the concrete compressive strength values, it was concluded:

- all three concretes have bigger 28-day compressive strength than 40MPa.

– differences between compressive strengths of concrete R0, R50 and R100 are negligible for the same concrete age.

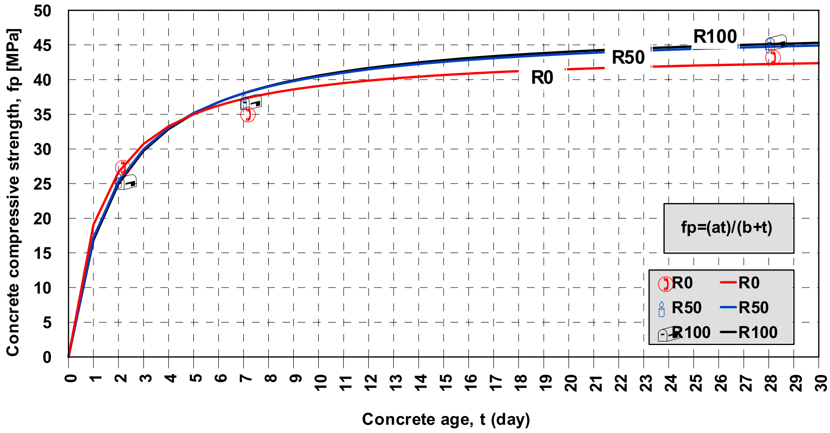


Fig. 8 – Concrete compressive strength gain through time

To find out if differences between obtained compressive strengths of concrete R0, R50 and R100 at age of 28 days are accidental or not, difference between their mean values was statistically tested. For that purpose pairs of corresponding 28-day strength were formed (R0-R50, R0-R100 and R50-R100). The statistical analysis showed that differences between tested compressive strengths are accidental (all results belong to the same set of results). This conclusion led to the fact that coarse aggregate kind didn't influence on concrete compressive strength value.

According to the analysis of 28-day drying shrinkage values (Table 7), it was concluded:

– The lowest shrinkage has concrete R50 (0.3mm/m), and the highest R100 (0.4mm/m).
– Drying shrinkage of concrete R100 is 20% higher than shrinkage of concrete R0.
– Difference between 28-day shrinkage of concrete R0 and R50 is less than 10%.

Testing results of wear resistance are shown in Fig. 9. It was concluded that the highest material loss has concrete R100 and the lowest concrete R0.

Analysis of water absorption values (shown in Fig. 10), pointed to the following:

– The lowest water absorption was registered in concrete R0 and the highest in R100.
– Concrete R50 has 22% higher absorption, while concrete R100 has 44% higher absorption than referent concrete R0.

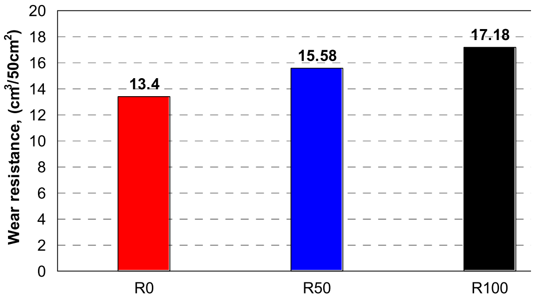


Fig. 9 – Testing results of wear resistance

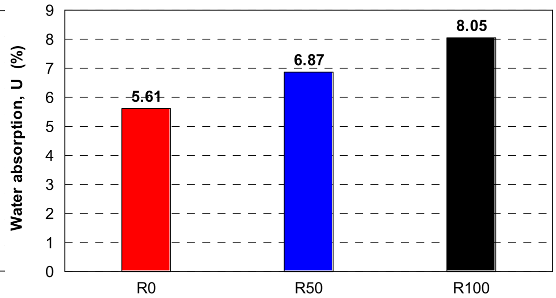


Fig. 10 - Values of water absorption

According to the analysis of water penetration depths (Table 8), it was concluded that almost there are no differences in waterproofness between tested concretes because they all satisfy prescribed condition of waterproofness according to standard DIN 1048.

Statistical analysis of presented values of splitting strengths (Table 8), showed that differences between tested splitting strengths were accidental (all results belong to the same set of results). The same conclusion was drawn after comparison of obtained flexural strengths results (Table 8).

Analysis of obtained values of bond between mild and ribbed reinforcement and concrete R0, R50 and R100 (Table 8) showed that:

– Difference between lowest and highest bond for both reinforcement types is about 10%.
– Bond between tested concretes and ribbed reinforcement is higher at least 15% than bond between tested concretes and mild reinforcement.

4 CONCLUSION

On the basis of comparative analysis of testing results of basic properties of concrete with natural coarse aggregate, concrete with combination of coarse aggregate (natural and recycled) and concrete with recycled coarse aggregate, it was concluded:

- Kind of course aggregate has no influence on air content;
- Bulk density of concrete is slightly decreased with increasing of quantity of recycled aggregate;
- The way of preparing of recycled aggregate for concrete mixtures has influence on concrete consistency. Consistency of concrete with natural and with recycled aggregate will be almost the same in the case of use of "water saturated - surface dry" recycled aggregate. If dry recycled aggregate and additional water quantity are used, the same consistency could be achieved after a prescribed time. Additional water quantity depends on time when same consistency has to be achieved and is determined with water quantity which recycled aggregate absorb for the same period of time.
- Concrete compressive strength mainly depends on the quality of recycled aggregate. If quality aggregate which is obtained by crushing of higher strength class concrete is used for production of new concrete, the recycled aggregate will have no influence on decrease of compressive strength. Quantity of replaced natural coarse aggregate with recycled aggregate has no influence on concrete compressive strength in this case. The same conclusion is valid for concrete tensile strength (splitting and flexural).
- Water absorption depends on quantity of recycled aggregate. The quantity of absorbed water is proportionally increased with increasing of recycled aggregate participation.
- Concrete with recycled aggregate could achieve satisfactory waterproofness. The concrete waterproofness depends on porosity of cement matrix in new concrete and porosity of cement matrix of recycled concrete. If recycled aggregate is produced from low porosity concrete, waterproofness of new concrete depends on aggregate grading and achieved structure of new cement matrix.
- Wear resistance of concrete depends on quantity of recycled aggregate. Concrete wear resistance decreases with increasing of recycled aggregate content, due to the increased quantity of hardened cement paste, which wears easier than grains of natural aggregate.
- Bond between recycled aggregate concrete and reinforcement is not significantly influenced by recycled concrete aggregate because bond is realized through new cement paste.
- According to these tests, performance of recycled aggregate concrete could be adopted as satisfactory ones, regarding not only the compressive strength of recycled concrete, but also all the other requirements related to mixture composition design and production of this concrete type.

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Sustainable aluminium systems

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ABSTRACT: In the present paper, an analytical presentation of some popular aluminium systems that contribute to sustainability of structures is presented. Special emphasis has been shown to the properties of aluminium members, while the influence of these systems in the overall performance of the structure regarding environment and economy is described. In particular, characteristics of aluminium elements as high reflectivity and recyclability and their role into life cycle analysis (LCA) are analysed, while the connections between energy efficiency and conservation of buildings and aluminium applications is discussed. Building applications such as curtain walls, window frames and facades sheets are presented and thoroughly investigated regarded environmental and economic aspects. Furthermore, many innovative techniques, where aluminium elements collaborate with other systems in order to produce renewable energy c.f. eg solar panels and photovoltaics are being introduced. Finally, environmental innovations like optimised ventilation mechanisms and light and shade management systems based on aluminium members are presented.

1 INTRODUCTION

As the consequences of environmental impacts have day by day more negative influence to our daily life, the need for taking immediate measures for the protection of the environment is imperative. There is a global ecological concern being developed and the need for adopting environmentally friendly policies is deeply felt by more and more factors (society, industries, governments etc). The climate change, the greenhouse effect
and the depletion of the ozone layer are some of the impacts of the uncontrolled industrial activities.

The building sector is the biggest consumer of raw materials and energy, while the role of environmental parameters regarding the design and construction of building applications is becoming more significant. In the construction field, , buildings consume significant amounts of energy, namely energy consumption in buildings represents today about 40% of the total energy consumption in the member states of the European Union (EU) and contributes about 45% of the carbon dioxide emissions released in the atmosphere. In this framework, the need to reduce the consumption of fossil sources of energy, to deal with the problem of material flow and waste production and its treatment is imperative. In the last years, the green building perception has started to become a nowadays trend, whereas the necessity to adopt an approach in assessing the impact of building activities on the environment, economy and society is recognized by all factors in construction business.

The scope of the present research effort is to focus on environmental perception and to investigate the relationship of sustainability and aluminium building systems. Aluminium is a new constructional material comparable to steel or concrete and can contribute to sustainability of structures, where its physical and mechanical properties can provide buildings a green performance in terms of ecology and economy besides functionality and structural stability. This paper aims at presenting some of the most commonly used aluminium systems and all their special features that contribute to sustainability.

2 ALUMINIUM IN THE CONSTRUCTION

2.1 *Structural Aluminium: The material*

Lightweight materials such as aluminium offer the construction industry an opportunity to design and manufacture high performance structures that are safe, energy- efficient and environmentally friendly and much lighter than traditional designs. The introduction of these materials and their wide applications challenge can fully realize the potentials that can be gained in the interaction between these materials, structural design and the manufacturing process.

In civil engineering works, aluminium is concerned usually as a metal whose basic ingredient is either aluminium or aluminium alloys. Pure aluminium is a metal with a strength varied from 90 N/mm^2 to 140 N/mm^2, thus its use in construction is reluctant. When it is added with other metals such as Mg, or Si though, aluminium alloys are formed whose strength is high and in some cases it can reach to 500 N/mm^2 (Kissel & Ferry 2002). Aluminium alloys are classified in various categories regarding their chemical composition and their further process they are subjected to, where every alloy is characterized by unique properties and exhibits different structural behaviour. They represent a wide family of constructional materials, whose mechanical properties make them extremely popular in civil engineering works and cover an extended range of application fields.

In addition, their physical properties, such as lightness give advantages as erection phases can be simplified, as the loads transmitted to foundations can be reduced and as the physical labour can be reduced. Another characteristic of aluminium alloys is their corrosion resistance which results in reducing the maintenance costs and adopting a good performance in highly corrosive environments (Efthymiou 2005). It is noteworthy that the functionality of aluminium alloys regarding geometrical shapes can make them really competitive as the geometrical properties can be improved through the design of sections, as stiffened shapes can be obtained without using built up systems and as simplifying connecting systems among different structural members, thus improving joint details (Baniotopoulos 2003). Aluminium applications can be both structural and non structural. Regarding structural applications, aluminium alloys are usually used in large span roof systems, where live loads are small compared to dead loads. In addition they are used in structures located in inaccessible places far from the fabrication shop, thus they can provide transport economy and ease of erection. In structures like swimming pool roofs, harbour elements, river bridges, which are characterized be humid environments, the aluminium alloys is preferable (Mazzolani 1995).

2.2 *Sustainable features of aluminium alloys*

The concept of "sustainable construction" has been developed which involves minimizing building costs, materials and waste, minimizing energy use and improving energy efficiency of the structure. Sustainability also includes low operating and maintenance costs, along with creating the conditions for healthy, safe and comfortable living. Furthermore, it includes also the choice of recyclable construction materials and products, as saving energy is a major objective and the removal or not of materials at the end of their life cycle is dependent on this choice. In addition, sustainable design means considering the whole lifetime of a structure, investigating ways of reducing the environmental impacts of building activities, importing the assessment of life-cycle costs of buildings in the primary process. In this framework techniques and methods of minimizing the release of emission and the consumption of resources in the construction of building products in transport, installation and maintenance during their service life, are also included in sustainable design. Generally, sustainable building is the building where the principles of sustainable development in the construction industry are applicated. These are to optimize struc-

tures depending on their requirement at 3 levels simultaneously, namely ecological, economic and socio-cultural (Maydl 2006).
Sustainability in architecture means buildings which combine comfort for the user with respect for the environment and minimum energy usage. Energy performance, user comfort, building functionality and cost over the lifetime of the building are the main objectives. Sustainable buildings emit less "greenhouse" gases and their materials can be infinitely recycled. Aluminium can justifiably be described as the "green metal": it is non-toxic and recyclable, easily formed yet strong, durable yet modern. Large savings in energy usage can be achieved using Aluminium façades, which act as solar reflector and thermal buffer. An aluminium facade can be integrated into the diversity of the architectural tradition.
From the sustainable point of view, aluminium alloy structures provide great credibility when a long term approach is being adopted. Despite the initial high cost and the great amounts of energy consumption during production, the special features of alloyed aluminium enable sustainable performance when the consideration refers to the whole service lifetime of the structure (Radlbeck et al. 2004).

To begin with, building aluminium material has a very long life cycle, ranging from 30 to 50 years and due to durability, the maintenance costs are very low over the lifetime of the structure. In addition, the majority of alloys used in construction are weather-proof and corrosion resistant, thus a long serviceable lifetime is assured. Another important characteristic of the material is its high reflectivity, which can be exploited in several building techniques and systems. An example of this is when aluminium solar collectors are installed to lower energy consumption regarding heating in winter and artificial lighting while there is the case of aluminium shading devices reducing the need for air-conditioning in the summer. Furthermore, aluminium alloys exhibit excellent recyclability. Used aluminium products and scrap can be recycled and at the same time the environmental impact related to recycle processes is reduced. As almost all aluminium material used in construction can be recycled, the considerable energy invested in the production of primary aluminium can be reinvested into other aluminium products. Scrap may not necessarily be recycled back into its original product or even reused in the country in which it was first manufactured, but the original energy investment will not be lost.
Concerning structural applications and aluminium alloys, their strength, weight and versatility make them ideal building and cladding materials. Since they are corrosion resistant, they are mostly used in maintenance-free applications such as siding, windows, skylights, doors, screens, gutters, down spouts, hardware, canopies and shingles, etc. Regarding aluminium siding, systems are also available with insulation and reflective foil backing, so walls can be made weatherproof and energy-efficient. A layer of insulated aluminium siding is four times more effective than uninsulated wood siding, four inches of brick or ten inches of stone masonry.
In addition, the relatively low melting point (660°C) of aluminium alloys means they will "vent" early during a severe fire, releasing heat and thereby saving lives and property. Regarding recycling, aluminium not only has important economic implications but also contributes to environmental production, whereas depositing or incineration does not have harmful side-effects even if inadvertently dispersed in the environment.

2.3 *Life Cycle Analysis and Aluminium*

When choosing a material for any application it is important to look at the whole of the product's life cycle. Life cycle analysis in fact goes far beyond the production processes alone. The life cycle of aluminium alloys is divided into several stages. In the first phase which refers to design and calculation, various alloys with different characteristics and strength values are considered. According to the type of alloy, high strength values, even within the range of steel, are available. The low material density values of aluminum can reduce the total weight of structures significantly, with savings up to 50% of comparable steel sections. Static design and quality control are covered in various standards, currently being further developed and harmonized. The second phase includes the production, transport and assembly. Production of 1ton of aluminium requires 4 tons of bauxite. The subsequent chemical and electrolytic processes consume a rather high amount of energy. For the production of one ton primary aluminium currently an average of 15.5 MWh sufficient for the production of 5 tons of steel are required. Depending on product, cross section form and respective energy price the initial cost is rather high, but may vary widely. Due to its light weight and its high grade of formability aluminium cuts costs, energy and time in transport and erection too. The next stage is the use- service phase. The natural corrosion resistance provides a high level of durability, together with minimum inspection and maintenance requirements. This leads to significant cost and energy savings, especially in comparison to other materials requiring regular painting. Aluminium in the building envelope requires well-planned thermal insulation because of its high heat conductivity value (λ_{RAlu}=200, λ_{RAlloy}=160) compared to other building materials (λ_{RGlass}=0.80, λ_{RSteel}=60). The dismantling, transport and recycling procedures are the final phase in the life cycle, as the disposal of a relevant matter, being non-hazardous and of high scrap value.

Aluminium structures are easy to dismantle and transport, while the recycling process is carried out with only 5% of the input energy for primary aluminium and with no loss in quality. Currently, a recycling rate of 85% is achieved in the building industry. In total 6% of recycled aluminium is reused in building structures. The final phase of a building's life needs to also be considered when making material choices. Ideally the material will be recycled in an economically and environmentally sustainable way. Usually the least desirable option is landfill, whereas a large amount of waste building materials goes to landfill sites at a cost to both the economy and the environment; others are recycled at a cost to the community. In contrast, aluminium is recycled in a way that pays for itself and is sustainable. Aluminium has a low melting temperature and is therefore able to be recycled with comparatively little energy. The energy required to produce secondary ingot from scrap is only about 5% of that required to produce primary aluminium. About 30% of the world's annual aluminium usage is supplied from processing post-consumer scrap.

3 SUSTAINABILITY AND ALUMINIUM SYSTEMS

Aluminium applications can be both structural and non structural. Regarding structural applications, aluminium alloys are usually used in large span roof systems, where live loads are small compared to dead loads. In addition they are used in structures located in inaccessible places far from the fabrication shop, thus they can provide transport economy and ease of erection. In structures like swimming pool roofs, harbour elements, river bridges, which are characterized be humid environments, the aluminium alloys is preferable (Mazzolani 1995).

In the building sector popularity of aluminium alloys in load carrying structures as well as in secondary or decorative elements has increased significantly over the past 50 years. Currently, a total of 26% of all aluminium products is used in building applications. All kinds of aluminium products are used in new home construction and in rehabilitation and renovation of existing structures. The range of building applications of aluminium is wide: it is commonly used in the building envelope for facades, glazed and roofing systems, curtain walling, window frames and doors. It is also applied for railings, balconies, staircases, heating/ air conditioning and solar elements.

The use of aluminium cladding on building facades is a promising construction alternative for building or the renovation of non-insulated buildings. Aluminium cladding is placed at a proper distance from the external wall, ranging from 5-10 cm for alignment purposes. The air gap that is created between the building’s wall surface and the aluminium cladding, acts as a thermal buffer zone. In particular, curtain walling or roofing can use aluminium with glazing or other transparent and semitransparent materials, creating uninterrupted large surfaces and atriums. Large curtain walling is usually recommended in climates with heating loads (Fig. 1).



Figure 1. Aluminium based curtain-wall applications(Etem 2007, Alumil 2007)

There are also facade and roof systems where aluminium is used in window and glazing frames and glazing spacers. The function of these systems is to provide daylight, visual contact between the exterior and the interior, provide protection against the weather (rain and wind), provide passive solar heating gains, help keep interior thermal comfort and keep the energy use for operation at its minimum (Adresen et al 2001)

In addition, the ventilated facades are complex systems of construction which offer both aesthetic quality and effective insulation permitting energy savings (Andresen et al 2001). This kind of system consists of an outer cladding, an air space at least 40 mm deep, a sub-structure generally made of aluminium anchored to the building and an insulating layer secured to the outer wall of the building. The main functions of the outer cladding are aesthetic and protective and the air gap is essential for activating the natural ventilation that is necessary for the system to function as a whole. The aluminium sub-structure ensures stability of the cladding system, while the insulating layer, usually consisting of self-supporting water-repellent glass wool panels, takes care of adequate thermal stability. These claddings provide an ideal means to achieve the increased energy performance of buildings and to contribute to the improvement of the urban environment.

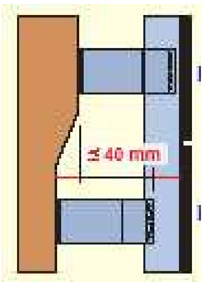

Figure 2. Ventilated facades (Etem 2007)

Regarding shading systems, there are venetian blinds, screens, overhangs, sidefins and others. Aluminium is used in lamellas, screens and fins. The function of these systems is to prevent glare and overheating and thereby minimise the energy use for space cooling. The literature survey did not identify any studies dealing with the environmental impacts of such systems that are relevant for this project (Fig 3). There are also Daylighting systems: this includes devices that enhance the daylight penetration and distribution into the room, e. g. light shelves, light-reflecting lamellas, etc. Better daylight availability and distribution in the space makes it possible to save electricity for artificial lighting, by turning the lights off when there is sufficient daylight. This may also, in turn, reduce the needs for cooling. Aluminium may be used as light directing devices. However, no studies were found that included environmental analysis of such systems.

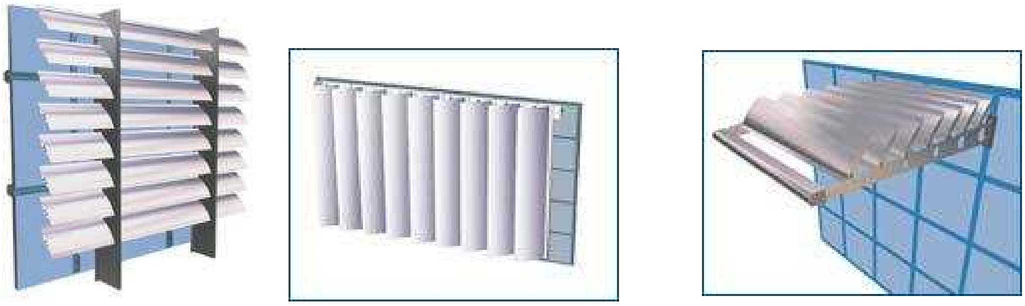

Figure 3. Shading systems (Etem 2007)

Aluminium is used also in window frames where it provides flexible and popular window geometry and operation. Since aluminium is a good heat conductor, it is necessary to use proper thermal breaks for enhanced thermal performance. Regarding insulation, it offers high levels of heat and noise insulation and the flexible design of systems used in doors and windows enables you to choose from among traditional or modern structures. Aluminium is a material that does not wear out in time, thus ensuring the longevity of your frames. It is also appropriate for areas with high temperatures and intense sunlight. The maintenance and care of frames is quite easy, and they can be cleaned periodically. Aluminium is of natural origin, and there is plenty of it in nature. As it is environmental friendly and 100% recyclable, it does not have a negative effect on human health and the environment.

In places like Mediterranean where the ample sunlight and wind potential offer plenty of solar and wind power the exploitation of renewable energy sources is the main objective. The maximum energy from sunlight is produced at peak consumption times and solar energy is converted to a usable form of energy (electricity) through the photovoltaic effect (Fig 4). Photovoltaic Systems in developing countries and isolated areas (e.g. the Greek islands) can offer energy solutions and improve the standard of living. The functions of these thermal systems is to provide energy for domestic hot water heating and/or space heating in order to reduce the auxillary energy use. The function of photovoltaic systems is to produce electricity that can be used directly for running lights and equipment in the building or fed into the electric utility grid. In this case, aluminium is used for absorbers, frames and casings for thermal collectors and for frames and support structures for photovoltaic modules.

Figure 4. Photovoltaic systems (Etem 2007)

4 CONCLUSIONS AND FUTURE SUGGESTIONS

The construction industry is faced with a number of environmental issues ranging from its direct impact on climate change to its choice of materials and its methods of waste disposal. The entire life cycle of a building must be considered when assessing these issues. At the same time environmental considerations need to be balanced against the realities of design, function and economy. When choosing the optimum material for each building an approach which takes account of the full lifetime of the material should be adopted, covering construction, use, maintenance and disposal phases. When planning an environmentally sustainable and cost effective building, factors like minimal energy minimal maintenance, suitability for local climate and minimal waste should be considered.

Nowadays, new building systems and innovative design concepts regarding aluminium alloys cooperating with building elements are adopted in order to provide more sustainable solutions and to meet future ecological demands. In particular facades incorporating aluminium systems can decrease energy consumption in buildings up to 50% have just started to appear in european construction era. Shading systems, photovoltaic systems which are based on aluminium are characterized by constructive interaction with the exterior, markedly reducing heating, cooling, ventilation and lighting energy demands. New technologies mean solar power captors can be inserted in aluminium frames, thus saving considerable amounts of energy and protecting the environment. Numerous techniques are being adopted and processes need to be verified and tested in order to ensure long term sustainability and at the same time static stability and fitness.

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Preliminary Life Cycle Inventory analysis of light-gauge steel frame system

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ABSTRACT: Paper presents the draft inventory data collection for light gauge steel frame structural SUNDAY system. This technology may be used for residential and commercial buildings. The LCI analysis of considered system was performed for boundaries covering manufacturing processes, in which light-gauge, galvanized steel (strip coil) is pre-formed (into C or U channel sections) and pre-cut (into studs or truck) using a SUNDAY roll-form machine. Still under the roof of the fabrication shop, these pieces are combined and fastened with a screw gun into building elements (wall panels, roof trusses, floor joists, and headers). Results of the LCI analysis could be used as input data for LCIA of buildings.

1 GENERAL DESCRIPTION OF THE TECHNOLOGY

1.1 *Range of application*

SUNDAY system may be used for residential and commercial buildings over ground structural systems basically in form of wall panels, ceiling girders and roof trusses. Ready made prefabricated units are delivered to site were they are assembling to designed form.

Figure 1. SUNDAY System under construction

The structure is fixed (screwed) on a previously prepared foundation or existing sub structure (in case of extending stories). The range of application results from bearing capacity and deformation limits of elements and units calculated according to standards requirements. Generally, it is limited up to four stories and 12 m span.

The technology is based on cold-bent and zinc-coated four basic steel profiles, which are combined and fastened with the use of self-drilling screws to form wall panels, ceiling girders, roof trusses and auxiliary elements.

1.2 *Input materials: profiles and connectors*

1.2.1 *Zinc-coated steel sheets*

The profiles and gusset plates are manufactured from zinc-coated steel strips or sheets by cold forming and cutting in special machines adapted for the support of the system. The steel is characterized by the following durability parameters:

– Yield stress point R_e = 195 MPa.
– Tensile strength R_m = 315 MPa.

The galvanic zinc layer offers protection for bend and surface scratches as well as for the cut edges of the elements. The minimal thickness of zinc coating measured on both sides should amount to 275 g/m^2,

1.2.2 *Basic profiles*

The main steel profiles used in the system are the following:

– the U 90 and U 140 U-shaped profiles
– the C 90 and C 140 C-shaped profiles

The height of these profiles is 9 cm and 14 cm respectively, whereas their thickness is 0.9, 1.25 and 1.5 mm.

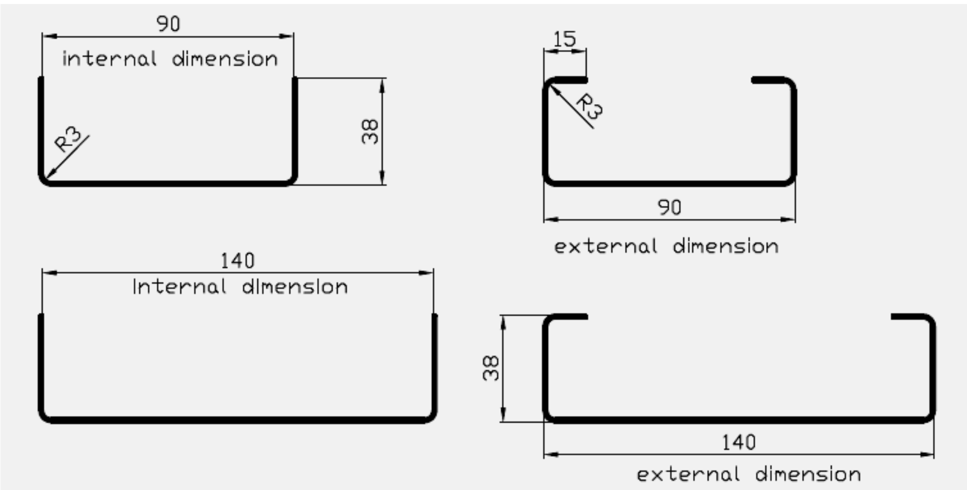


Figure 2. Basic system profiles and dimensions U (left) and C (right)

1.2.3 *Auxiliary profiles*

Auxiliary profiles used in system are listed in Table 1

Table 1. Auxiliary profiles.

Symbol	Dimensions
	mm * mm * mm
U38 * 0.90	38 * 16 * 0.90
U38 * 1.25	38 * 18 * 1.25
U38 * 1.50	38 * 18 * 1.50
½ * U90*0.90	45 * 38 * 0.90
½ * U140*1.50	70 * 50 * 1.50
BL 160	160 * 0.90

Gusset plates (joint sheets) in trusses are made from steel sheets 1.25 and 1.50 mm thick cut to appropriate shape.

1.2.4 *Connectors*

Connections between profiles in unit and units in structure are made by self-drilling screws. Types of used screws are presented on Figure 3.

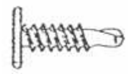
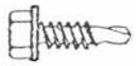
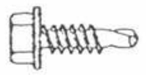
ITEM	SIZE	HEAD TYPE	MAXIMUM DRILLING THICKNESS	SCREW-DRIVER BIT	APPLICATION	APPERANCE
1	4.8 PAN	PAN	4.5 mm	Ph 2	For mounting the posts and lintels in the wall panels and for other connections where s smooth surface is required	
2	4.8 HWH	HWH	4.5 mm	Hexagonal 8 mm	Any other connections not specified in Item 1	
3	5.5 PAN	PAN	5.3 mm	Ph 2	As for Item 1	
4	5.5 HWH	HWH	5.3 mm	Hexagonal 8 mm	As for Item 2	

Figure 3. Connectors used for units prefabricating

1.2.5 *Hot-rolled steel profiles*

In particular cases for stiffening the building structures, frames of welded hot-rolled I- and channel sections steel profiles are used. The steel is characterized by the following durability parameters:

- Yield stress point R_e = 235 MPa.
- Tensile strength R_m = 360 MPa.

1.3 *Manufacturing processes*

Manufacturing process on production plant covers two main operations: shaping the elements and prefabrication of the mounting or shipment units.

Shaping the elements consist in forming the profiles by cold bending of steel strips and cutting to desire length (also for gusset plates and hot-rolled profiles).

Prefabrication (of wall panels, roof trusses etc.) consist of geometrical arrangement of elements on mounting table and fixing them together by connectors (self-drilling screws). In particular cases additional undercutting and bending is done. Scale of prefabrication depends both on dimensions of ready to install units and means of transport to site. For local transport (mainly used for family houses in distance up to 50 km) generally size limits are 2.4 m height (wall panels) and 6 m length (roof girders and ceiling beams). For long distance transport by heavy trailer prefabrication is generally limited to linear parts. In this case, completing of mounting units is performed on site.

For some applications, additional elements made from hot-rolled steel profiles are prepared by cutting and welding with prefabrication limits as above..

For all manufacturing operations electric equipment is used.

1.4 *Mounting (framing) units characteristics*

The system distinguish three basic units:

1.4.1 *External (bearing) wall panels*

Wall panels are made of steel posts (the C 90 or C 140 C-shaped profiles), their spacing equal to 60 cm, placed in the U 90 or U 140 U-shaped profiles, which constitute the basis and the closure of a wall.

Transverse bracing and spandrel beams are made of steel strips or appropriately cut profiles. Wall panels, assembled in the factory, provide for window and doorway openings, and include lintels of a special design.

Post-to-longitudinal elements connection requires one screw on every flange of post and additional one screw for every second post. In case where two or more elements run together parallel (terminal or opening posts, lintels) two rows of connectors spaced 30 cm are applied.

1.4.2 *Inter-story floors (ceilings)*

For inter-story floors, the C 90 and C 140 C-shaped profiles, as well as the U 90 and U 140 U-shaped profiles are used, in different configurations. In the case of larger span lengths, floor girders are made of profiles of a greater height. The optimal span length is up to 4.5 m. The typical spacing of the beams is 60 cm.

In case where two profiles run together, two rows of connector spaced 30 cm are applied.

1.4.3 *Roof trusses*

The load bearing structure of the roofs is constituted of steel trusses made of the C 90 and C 140 C-shaped profiles. Truss joints are covered with metal sheets (gusset plates), on both sides for the span length > 6.0 m. Connections are executed with the use of sheet-metal screws. The constituent elements of the girders are joined directly. Buildings with a usable attic are provided with a special roof structure. Bracing of the roof structure is executed with the use of the C 140 or C 90 C-shaped profiles. The typical roof girder spacing equals 60 cm.

In every connections, minimum distance to element edge and distance between connectors should be 19 mm. In case of joints with gusset plates on both sides, on the web side of the profile design number of screws should be applied, and on opposite side at least 2 for every profile. Minimum distance of connectors must be not less than 100 mm. Direct connection of profiles webs or with gusset plate between should be done with two rows of screws.

2 RANGE OF LCI ANALYSIS

2.1 *Function and functional unit*

The basic function of considered system is to provide steel structure as a part of buildings framing. The assumed functional unit is 1 tone of prefabricated steel structure ready for shipment to construction site.

2.2 *Analyzed impact categories*

Following environmental impacts and their indicators were collected and calculated:

- Extraction of abiotic resources
- Chemical Oxygen Demand – COD
- Eutrophication Potential P_{tot}
- Nitrification Potential N_{tot}
- Global Warming Potential – CO_2, CH_4 and N_2O emissions
- Acidification Potential (eq. SO_2)
- Photochemical Ozone Creation Potential (NO_x)
- Human toxicity (NMVOC)
- Process wastes

2.3 *System boundary*

The considered analysis is performed for system boundary shown on Figure 4 covering:

1. On-plant transport of materials (steel strips and sheets)
2. Profiles forming and cutting, gusset plates cutting
3. Prefabrication of shipment units
4. On-plant transport of shipment units

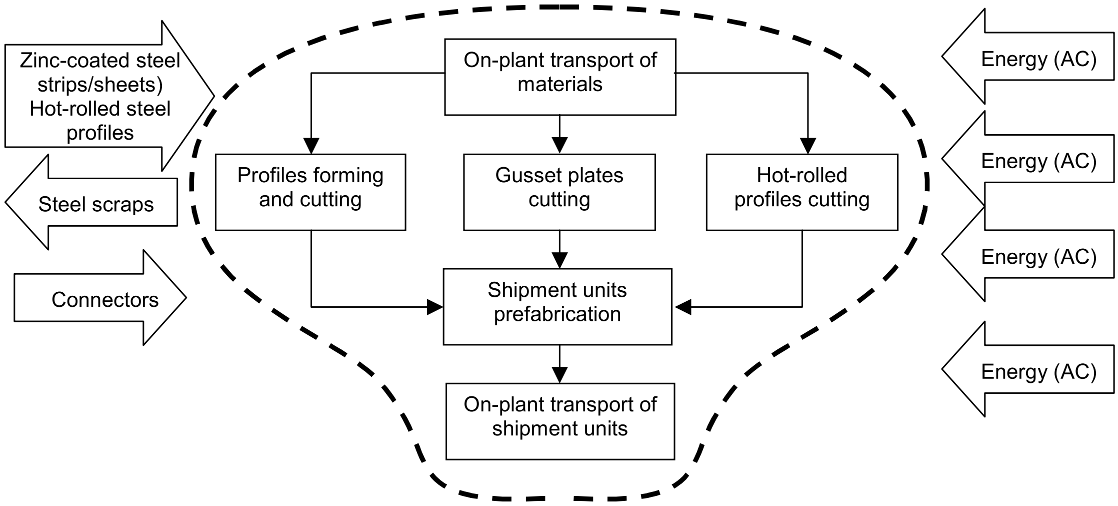


Figure 4. System boundary scheme

2.4 *Data collecting procedures*

For input materials (zinc-coated steel sheets, hot-rolled steel and connectors) data were collected from public sources – databases . The same way was for energy consumption.

Materials and energy flow per assumed functional unit (1 ton of shipment unit) was obtained based on direct information from producer for one year production.

2.5 *Inputs and outputs*

Zinc-coated steel and hot rolled steel profiles are the main input materials for analyzed technology. In assembling process connectors in form of self-drilling screws are added.

In all processes covered by system boundary only electric AC energy from public network is used.

The considered outputs are prefabricated shipment units and steel scraps.

3 INVENTORY RESULTS

3.1 *Inputs and outputs*

Inputs and outputs related to functional unit are presented in Table 2 below:

Table 2. Inputs and outputs factors (related to FU=1 ton)

	quantity	unit
1. Inputs:		
Zinc-coated steel	91.37	%
Hot-rolled steel	6.86	%
Connectors	1.77	%
Energy (AC)	324.24	MJ/t
2. Outputs		
Shipment unit	100.00	%
Steel scraps	5.00	%

Data presented above were collected by producer analysing 1 year production and energy consumption in production plant.

3.2 *Impact category indicators for inputs*

3.2.1 *Zinc-coated steel sheets and connectors*

Data were obtain from U.S. LCI Database Project. Due to leak of available particular data for connectors the same data as for zinc-coated steel sheets were assumed.

Table 3. Inputs and outputs for zinc-coated steel sheets and connectors

Indicator	quantity	unit
1. Energy	18.6	GJ/t
2. Raw materials	196.0	%
3. Emissions to water		
COD	83.0E-3	‰
P_{tot}	4.3E-3	‰
N_{tot}	45.0E-3	‰
4. Emissions to air		
CO_2	1001.0	‰
CH_4	1.1	‰
N_2O	7.8E-3	‰
SO_2	3.4	‰
NO_X	1.2	‰
NMVOC	15.0	‰
5. Process waste	260.0	‰

3.2.2 *Hot rolled profiles*

Data were obtain from ELCD Data System

Table 4. Inputs and outputs for steel hot-rolled profiles

Indicator	quantity	unit
1. Energy	12.91	GJ/t
2. Raw materials	100.77	%
3. Emissions to water		
COD	39.1E-3	‰
P_{tot}	2.8E-3	‰
N_{tot}	16.5E-3	‰
4. Emissions to air		
CO_2	109.96	%
CH_4	0.72	‰
N_2O	162.6E-3	‰
SO_2	2.05	‰
NO_X	16.87	‰
NMVOC	0.1	‰
5. Process waste	449.8	‰

3.2.3 *AC Energy (public network in Poland*

Data were obtain from ELCD Data System

Table 5. Inputs and outputs for public AC network in Poland

Indicator	quantity	unit
1. Energy	3.6	MJ
2. Raw materials	23.25	kg
3. Emissions to water		
COD	0.4E-3	kg
P_{tot}	31.1E-6	kg
N_{tot}	0.2E-3	kg
4. Emissions to air		
CO_2	12.21	kg
CH_4	8.0E-3	kg

Table 5. Inputs and outputs for public AC network in Poland -continued

Indicator	quantity	unit
N_2O	1.8	kg
SO_2	0.02	kg
NO_X	0.18	kg
NMVOC	1.1E-3	kg
5. Process waste	4.99	kg

3.3 *Energy (AC) consumption*

Cumulative energy consumption for functional unit was calculated based on energy consumption indicator values for particular material input collected in Tables 3 to 5 and weighted by input indicators presented in Table 2. Total cumulative energy consumption is presented in Table 6.

Table 6. Cumulative energy consumption for functional unit

Component	Component Unit	CU consumption GJ	Product Quantity for FU, %	FU consumption GJ
Zinc-coated steel	t	18.60	91.37	16.99
Hot-rolled steel	t	12.91	6.86	0.88
Connectors	t	18.60	1.77	0.32
Process energy	t	0.32	100.00	0.32
			Total (GJ/t)	18.53

3.4 *Impact category indicators for Functional Unit (output)*

Table 7 summarized impact category indicators analyzed in this study.

For cumulative energy consumption, covering both consumption for input materials and production processes (presented in first “numerical” cell of Table 7), the same indicators were calculated. Impact category indicators values for particular input materials (weighted by input factors from Table 2.) were summarized with energy indicators in last column.

Table 7. Calculated impact category indicators for FU

Indicator	Unit	Energy (total)	Zinc-coated steel	Hot-rolled steel	Connectors	Total
1. Energy	GJ	18.53	16.99	0.89	0.33	
2. Raw materials	t	119.66	1.79	0.07	0.03	121.55
3. Emissions to water						
COD	kg	2.23	0.08	2.7E-3	1.5E-3	2.31
P_{tot}	kg	0.16	3.93E-3	0.2E-3	0.1E-3	0.16
N_{tot}	kg	0.94	0.04	1.1E-3	0.8E-3	0.98
4. Emissions to air						
CO_2	t	62.84	0.91	0.08	0.02	63.85
CH_4	kg	41.13	1.01	0.05	0.02	42.21
N_2O	kg	9.18	7.12E-3	0.01E-3	0.01E-3	9.19
SO_2	kg	117.21	3.11	0.14	0.06	120.52
NO_X	kg	964.08	15.47	1.16	0.02	980.73
NMVOC	kg	5.73	13.71	6.8E-3	0.26	19.71
5. Process waste	t	25.71	0.24	0.03	4.6E-3	25.98

4 SUMMARY

Presented analysis is the authors fires attempt on this field, based on standard ISO 44040:2006. It covers only part of live cycle of analyzed system, but could be a useful database for Life Cycle Impact Assessment of a case or comparative study of a building constructed with analyzed SUNDAY technology.

Enery efficiency of old and new buildings in Romania

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ABSTRACT: Once Romania has joined the European Community, environmental protection and energy saving have become top priority domains. European standards have become Romanian reference standards and norms. The present-day housing stock in Romania was mostly built between 1960 and 1989, without the adoption of any efficient solutions for thermal insulation. The operation of buildings more than 30 years old, has led to the occurrence of certain damages, because of the condense phenomenon into the walls. In Romania a governmental programme is carried out for the thermal rehabilitation of blocks of flats built before 1989. The investment for the thermal rehabilitation of buildings is financed equally by the government and the owners. This paper presents the situation of the housing stock in Romania, the requirements regarding the resistance to heat flow for the elements of the building envelope as well as the latest tendencies concerning the erection of durable constructions.

1 GENERAL PRESENTATION

An essential element of the sustained development of constructions is the promotion of efficiency and the rational use of energy. As the specific heat consumption and the consumptions involved in the hot water preparation in Romania are rather double compared to the ones found in the Western countries of the European Union, it seems of outmost necessity that special programmes designed for the increase of the energetic efficiency of buildings should be developed.

The experience of Western European countries, and especially Northern countries, that have carried out, after the energetic crisis they had to face in 1973, national programmes designed for thermal protection, stand out as real examples for the national politics regarding the implementation of thermal rehabilitation of the Romanian housing stock.

Based on the statistic data gathered through the census survey carried out for population and residences in Romania in 2002, the total number of housing stock is 4,846,572 buildings that practically comprise 8,110,407 residences. Out of the mentioned number, 1,138,945 buildings that comprise 4,257,964 residences are situated in the urban areas. 97% of the residences are private property. Most of the residences are situated in buildings aged between 15 and 55 years, with a reduced level of thermal insulation and a high degree of run-out. The structure of the Romanian housing stock depending on the age is illustrated in Figure 1.

The heating supply is being ensured for blocks of flats, at a rather high rate (90%), through a centralized system. In large Romanian cities, there have been created and extended, along the latest 40 years, centralized heating systems, that have as a source either thermal-electric power plants (urban central heating), or a local heating plant, responsible for the area, the neighborhood or a group of blocks. Most of the urban heating supply is connected to sources of heating production that belong to the national private power plant, the rest of the systems belonging to the local administrations and being managed by specialized enterprises controlled by the municipalities.

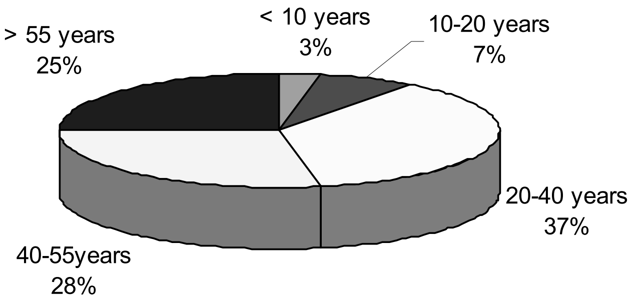
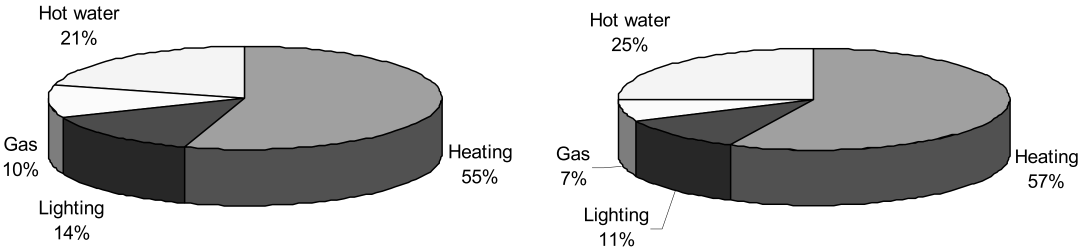


Figure 1. Status of the Romanian housing stock

2 STRUCTURE OF THE ENERGY CONSUMPTION WITHIN THE RESIDENTIAL SYSTEM

The weight of the energy consumption within the annual energetic balance of a medium-size apartment built between 1970-1985 is shown in Figure 2:



a. Romania b. Western European countries

Figure 2. Structure of energy consumptions for an apartment

Considering the whole Romanian housing stock, the efficiency of the heat use for heating, hot water and cooking rises to only 43% from the total quantity of heat supplied by the sources. There can be noticed that the heating of the space is by far the largest final consumer of energy, both in Romanian and in Western European buildings.

3 TYPES OF ENVELOPE ELEMENTS USED FOR RESIDENTIAL BUILDINGS BETWEEN 1960-1989

The types of walls used for civil buildings until 1984 are different, therefore there are different thermal performances that depend on the composition of the walls. The main types of design used for the envelope walls of buildings built until 1984 are presented in Fig.3. A comparative study of the minimum resistances to heat flow required and the effective resistances to heat flow of the types of exterior walls used shows that the latter didn't meet the minimum requirements of thermal insulation. The walls show resistances to heat flow between the limits R_o=0,54...0,97 m^2K/W, that is 45...81% from $R_{o,nec}$. Table 1 shows the ratios between the effective resistances to heat flow and the resistances to heat flow required by the standards in force on the mentioned date, for each type of wall.

Tabel 1 The ratios between the effective resistances to heat flow and the resistances to heat flow required

Exterior wall type	A	B	C	D	E	F	G
Thermal resistance $R_{0,ef}$ [m^2K/W]	0.68	0.57	0.54	0.57	0.97	0.93	0.67
Ratio $R_{0,ef} / R_{0,nec}$	0.57	0.48	0.45	0.48	0.81	0.77	0.56

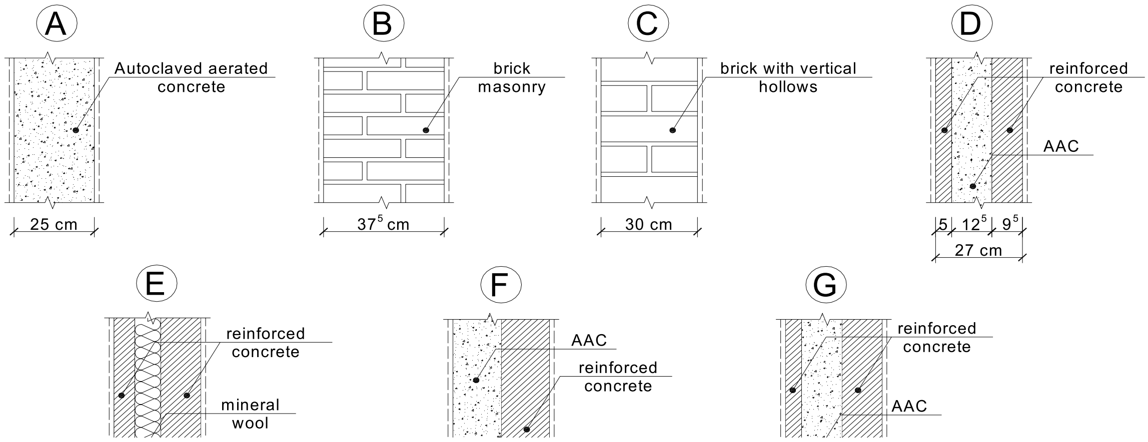


Figure 3. Design details for walls used until 1984

After 1984, the imposing of energy saving has led to a change of the design solutions for exterior walls used in residential buildings. The new solutions adopted have led to the exceeding of the minimum resistances required for envelope elements. Fig.4 gives the design details for exterior walls used for residence buildings starting with 1985.

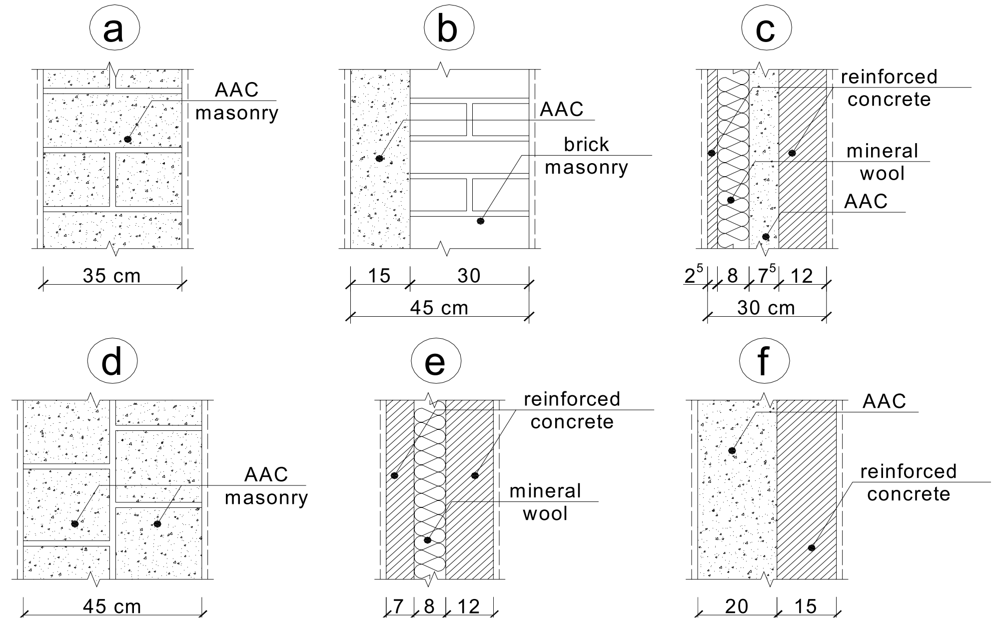


Figure 4. Design details for walls after 1984

Table 2 Comparative ratios between the effective and required resistances to heat flow

Exterior wall type	A	B	C	D	E	F
Thermal resistance $R_{0,ef}$ [m^2K/W]	1.84	1.38	1.63	2.43	1.56	1.61
Ratio $R_{0,ef}$ / $R_{0,nec}$	1.53	1.15	1.35	2.02	1.30	1.34

Table 2 shows the comparative ratios between the effective resistances to heat flow and the resistances to heat flow required according to the standards in force on the given date. There can be noticed that the principle solutions proposed for the improvement of the heat flow resistance exceeded the minimum resistance required, but in practice the solutions were not observed, this resulting in short-comings of the envelope elements, regarding energetic and comfort performances. The thermal insulation materials used were the cellular autoclaved concrete and the mineral wool, with various hygro-thermal characteristics. Polystyrene was considered as an expensive material at the time.

Therefore, we can conclude that, for most of the buildings, the elements of the envelope in contact with the exterior do not meet the thermal and hygro-thermal requirements, and a general rehabilitation is needed, with consequences on the hygro-thermal comfort and the energy saving.

4 THE EVOLUTION OF ROMANIAN STANDARDS REGARDING THERMAL INSULATION

Along the years, the Romanian standards that concern thermo-technics have introduced different values for the minimum resistances to heat flow, but also additional conditions regarding the diffusion of moisture within the constructional elements. The codes valid until 1989 comprised the following requirements regarding the envelope elements:

- the effective resistance to heat flow should be higher than the minimum resistance required determined upon the climate zone that the building is being erected and interior climate parameters;

$$R_0 > R_{0,nec} \quad (1)$$

R_o –Total resistance to heat flow [m^2K/W];
R_{oc} –Total resistance to heat flow taking into account the massiveness of the material [m^2K/W];
m – massiveness coefficient in function of the thermal inertia;
$R_{o\ nec}$ – Minimum required resistance to heat flow [m^2K/W].

- preventing the condense to occur on the interior surface of the envelope element, meaning to satisfy the following condition:

$$T_{si} > \tau_r \quad (2)$$

T_{si} –Temperature on interior surface [°C];
t_r – Temperature of dew point [°C].

- limiting the mass of condensed water inside the exterior envelope element, that corresponds to the satisfying of the following conditions:

$$m_w - m_v \leq 0 \quad (3)$$

$$\Delta W_{ef} \leq \Delta W_{allowed} \quad (4)$$

m_w – Mass of water condensed during the cold period of the year;
m_v – Mass of water evaporated during the hot period of the year.
ΔW_{ef} – Increase of water percentage condensed during the cold period of the year;
$\Delta W_{allowed}$ – Increase of water percentage allowed.

Tables 3 shows the time variation of the requirements regarding the resistance to heat flow of the envelope elements of Romanian buildings.

In the past 10 years, there have been developed in Romania a series of new standards, along with their specific guidelines for application. It is essential that there has been introduced a new concept regarding the thermal insulation of buildings, through the evaluation of the global insulating coefficient of the building, respectively through energetic certification.

Table 3 Time variation of the requirements regarding the resistance to heat flow

PERIOD	CODE	R_{min} [m²K/W]			R' [m²K/W]		
		Exterior walls	Flat roof	Floors over base-ment	Exterior walls	Flat roof	Floors over base-ment
1950 … 1961	-	-	-	-	-	-	-
1962 … 1968	STAS 6472 – 61	0.76	0.96	0.82	-	-	-
1969 … 1973	STAS 6472 – 68	0.80	1.02	0.87	0.60	-	-
1974 … 1975	STAS 6472/3 – 73	0.80	1.02	0.87	0.60	-	-
1976 … 1984	STAS 6472/3 – 75	0.80	1.02	0.87	0.60	-	-
1985 … 1987	STAS 6472/3 – 84	0.76	0.87	0.56	0.76	0.87	0.56
	NP 15 - 84	1.20	1.55	1.08	1.20	1.55	1.08
1988 … 1989	STAS 6472/3 – 84	0.76	0.87	0.56	0.76	0.87	0.56
	NP 15 – 87	1.20	1.55	1.08	1.20	1.55	1.08
1990 … 1997	STAS 6472/3 – 89	1.00	1.24	0.67	1.00	1.24	0.67
1998 … 2000	C107/3 – 1997	-	-	-	1.09	1.46	1.25
	C107/1 – 1997	-	-	-	1.40	3.00	1.65

The Romanian law states that, until the year 2010, all buildings should be energetically certified. Based on the energetic certification, advantages will be obtained concerning the systems of insurance, loans, taxes etc. The graph shown in Figure 5 presents the variation of the standards number and design guides that refer to the requirements of energetic performance.

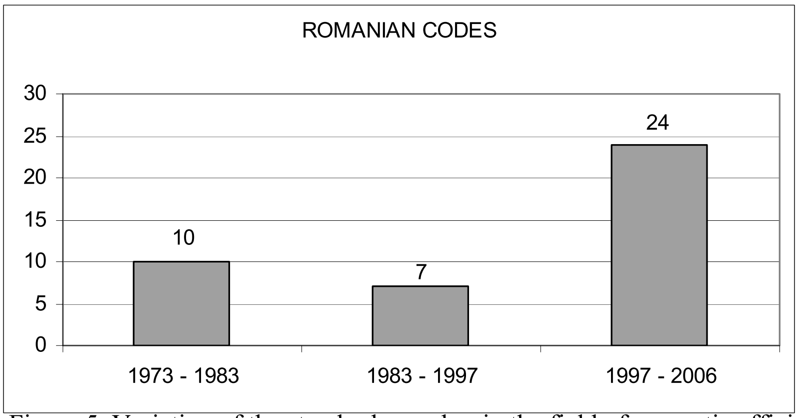


Figure 5. Variation of the standards number in the field of energetic efficiency in Romania

4.1 *Politics regarding the energetic efficiency. National programme for the rehabilitation of residence buildings*

From the analysis of the graph presented in Figure 5, there can be clearly noticed the last decade's trend to also introduce in Romania the concept of sustainable development directly referring to the energetic efficiency of new and existing buildings.

The Romanian Government has issued the Government Order no. 29/2000 regarding the thermal rehabilitation of the existing buildings and the stimulation of thermal energy saving; the provision sets up the legal framework for the thermal rehabilitation and modernization of all existing buildings and the installations thereof, aiming to the improvement of the conditions of hygiene and thermal comfort, to the decrease of the heat flow, the energetic consumptions, the cost of heating and hot water, and the polluting emissions generated by the production, the transportation and the consumption of energy. It is about the buildings situated in urban and rural areas (residences, public buildings, productions halls, etc.), where there are performed activities that require a certain degree of thermal comfort, according to the technical requirements in force. Based on the legislation in force, the local administrations financially support the investments that aim to the thermal rehabilitation of the housing stock, by supporting 50% of the investment, the other half being imposed on the owner.

The Government's programme for thermal rehabilitation of the existing housing stock also comprises some fiscal facilities for the owners. Thus, the ones who decide to rehabilitate their building shall beneficiate of an expertise, an energetic audit and projected design for thermal rehabilitation funded by the state budget, the relief from taxation when it comes to the issuing of the energetic certificate of the building and of the construction permit regarding the thermal rehabilitation works, respectively the relief from taxation regarding the residence all along the period of reimbursement of the credit obtained for the purpose of thermal rehabilitation.

5 EFFICIENT SOLUTIONS USED IN THE CONSTRUCTION OF THE „IULIUS MALL" COMMERCIAL CENTRE OF TIMISOARA

After 1989, one of the most important investment in the Western part of Romania is the "Iulius Mall" commercial centre. The completion of the building structure was a decisive stage of the investment. The quality control of the building erection is a component of the quality system.

The commercial centre is made up of several sections, each of them with an independent structure. The first development stage of the area and the building of the commercial centre consists in the construction of 15 blocks and one technical block. The building has a constructed area of 73, 000 square meters distributed on 3 levels and one terrace, hosting over 200 shops. Beside the shops, there is a movie theatre with several halls, a supermarket, restaurants, food courts, bars, kids land and sports centers.

A general view of the "Iulius Mall" Commercial Centre at the end of the construction works is presented in Figure 6.

Figure 6. General view of the main entrance of "Iulius Mall" Centre of Timişoara

The photos included in Figure 7 show aspects from the execution of the exterior walls.

a. Detail from the installation of the envelope walls on the Southern facade

b. General view of the Southern facade

Figure 7. Aspects from the execution of the exterior walls

The application of the thermal protection and hydro-protection on the terrace is shown in Figure 8.

a. Terrace hydro protection

b. Terrace thermal protection

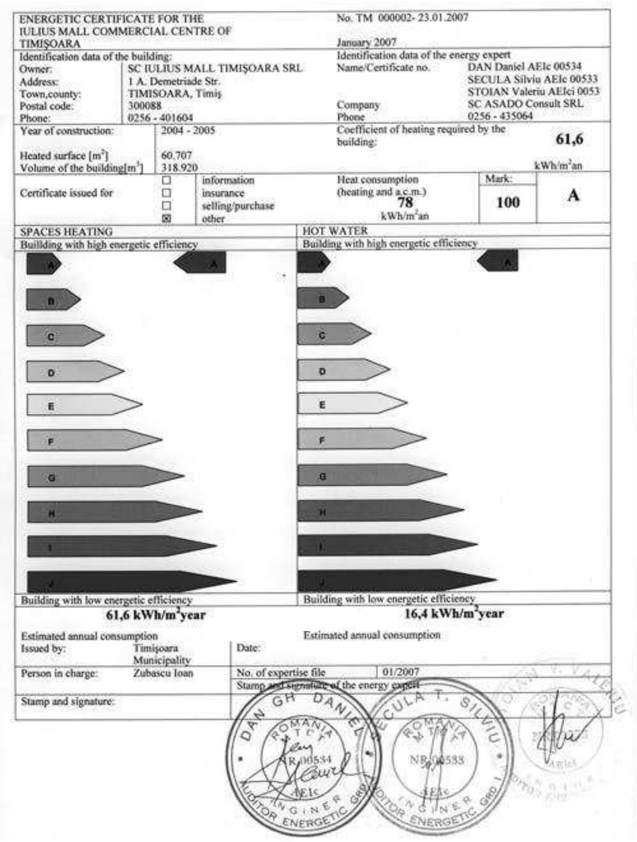
Figure 8. Details from the execution of the terrace hydro and thermal protection.

The most important material used for the constructional work of Iulius Mall Center is presented in the table 4.

Table 4 Materials used for the constructional work of Iulius Mall Center

No.	Material	Quantity
1.	Reinforcements and structural steel	> 3.000 t
2.	Concrete cast in site	> 80.000 m^3
3.	Mineral wool 5 cm thickness	13.847 m^2
4.	Sandwich panels 6 cm thickness	13.847 m^2
5.	Polystyrene 10 cm thickness	18.500 m^2
6.	Windows and doors	> 4.200 m^2

Based on the characteristics of the materials used and on the execution details of the „Iulius Mall” commercial centre, there was drafted the certificate of energetic performance of the building, presented in Figure 9.


ENERGETIC CERTIFICATE FOR THE IULIUS MALL COMMERCIAL CENTRE OF TIMIŞOARA

No. TM 000002- 23.01.2007

January 2007

Identification data of the building:		Identification data of the energy expert	
Owner:	SC IULIUS MALL TIMIŞOARA SRL	Name/Certificate no.	DAN Daniel AEIc 00534 SECULA Silviu AEIc 00533 STOIAN Valeriu AEIci 0053
Address:	1 A. Demetriade Str.		
Town,county:	TIMISOARA, Timiş		
Postal code:	300088	Company	SC ASADO Consult SRL
Phone:	0256 - 401604	Phone	0256 - 435064
Year of construction:	2004 - 2005	Coefficient of heating required by the building:	61,6 kWh/m²an
Heated surface [m²]	60.707		
Volume of the building[m³]	318.920		
Certificate issued for	☐ information ☐ insurance ☐ selling/purchase ☒ other	Heat consumption (heating and a.c.m.) 78 kWh/m²an	Mark: 100 — A

SPACES HEATING	HOT WATER
Building with high energetic efficiency	Building with high energetic efficiency
A B C D E F G H I J	A B C D E F G H I J
Building with low energetic efficiency	Building with low energetic efficiency
61,6 kWh/m²year	16,4 kWh/m²year
Estimated annual consumption	Estimated annual consumption

Issued by:	Timişoara Municipality	Date:	
Person in charge:	Zubascu Ioan	No. of expertise file	01/2007
		Stamp and signature of the energy expert	
Stamp and signature:			

Figure 9. The certificate of energetic performance of the building

6 CONCLUSIONS

The reduction of heat loss through the construction elements is necessary in order to increase the energetic efficiency of a building. National and international programmes now in force aim to the thermal rehabilitation of residence buildings, as a priority measure within the sustained development of constructions.

The energetic performances of residential buildings are being evaluated in Romania by authorized energy experts who issue the certificates of energetic performances of a building. The energetic audit of a building requires, beside the energetic certification, the establishment of intervention measures and execution details designed for the improvement of thermal comfort.

The reduction of heat loss leads to the reduction of pollution and of the costs caused by the building maintenance.

REFERENCES

C107/1-3/1007 - Romanian standard for the calculus of the global thermal insulation coefficients for the civil residences

E. Mladin, M. Georgescu, D. Duțianu – Eficiența energiei în clădiri – Situația în Romania şi Acquisul comunitar, Bucharest Seminar, 2003

GT 036- 2002 - Guide for the thermal and energetic audit for the existing buildings and for the preparation for the hot water necessary for these buildings

GT 037- 2002 - Guide for the elaboration and assignment of the energetic certificate for the existing buildings

STAS 6472/2-83 - Building Physics. Hygrothermics. External climatic parameters

Thermal rehabilitation of a student's hostel belonging to the Politehnica University of Timişoara

D. Dan, V. Stoian, T. Nagy-Gyorgy, C. Dăescu
Politehnica University of Timisoara

ABSTRACT: The student's hostels located in Timişoara-Romania were mostly built from 1970 to 1980 with the adoption of minimum solutions for the thermal insulation required at the time. The hostels are heated by using a district heating station. The use of the buildings without general repair work has led to the occurrence of certain damages, especially because of the asweat on the walls.The technical department of the university has promoted and sustained the improvement of the energetic performances of the hostels located in the campus area.
The paper presents one student hostel before and after thermal rehabilitation, along with the solution adopted and the economical study performed in order to sustain the execution of the constructional works. The solutions adopted referred to the improvement of global thermal resistance of the envelope elements in order to reduce the pollution and the energy loss.

1 INTRODUCTION

The "Politehnica" University of Timisoara, Romania is one of the largest and best-known technical universities in Central and Eastern Europe. Located in Western Romania, The "Politehnica" University attracts students both from the city and form the neighboring regions.

During the university years, the administration offers students the possibility to find accommodation in the campus. The students' campus located in the city centre hosts over 25 hostels. During a university year, over 5,000 students can be accommodated in the hostels of the Politehnica University.

The administration of the University is permanently concerned with the improvement of the accommodation offered to the students, therefore, the investments have been directed especially to the rehabilitation of the students' hostels. This activity has been carried out during the latest 3 years and the interventions were focused on the reconstruction of the finishing works, as well as the improvement of the comfort conditions. Taking into account the age of the buildings and the installations thereof, the works aimed at the total change of the installations, the complete remaking of the finishing, the improvement of the thermal insulation and installing of one thermal station for each hostel.

2 PRESENTATION OF A TYPICAL STUDENTS' HOSTEL

One of the students' hostel that has been rehabilitated is Hostel 20C (Fig.1). The building is included in the accommodation park of the Politehnica University of Timisoara, being erected in 1978. It has a basement, a ground floor and five storeys, each storey hosts ten apartments, each apartment includes two rooms, a shower room and a water closet. The apartments also have a hallway, with two sinks. Figure 2 shows the functional architecture of one apartment.

Figure 1. General view of hostel 20C

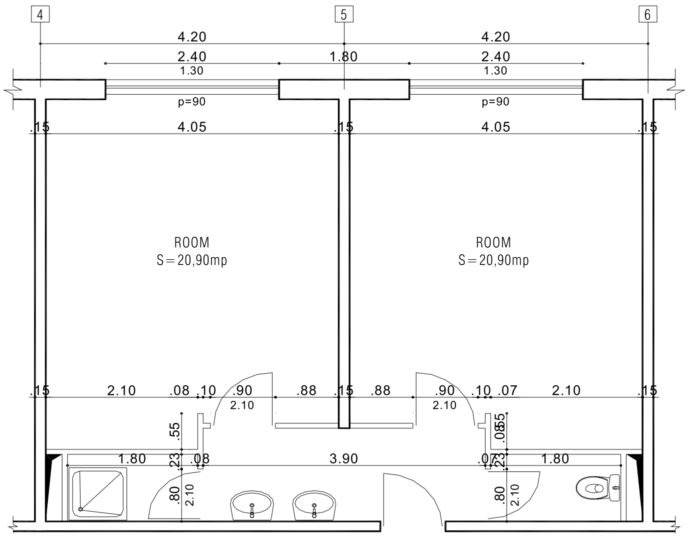


Figure 2. The functional architectural structure of one apartment

On each floor, at the end of the hallways, there are the stairways and 2 pantries, nowadays also used for students' accomodation, although, in the past, they contained electric cookers or washing machines. As a matter of fact, the hostel is part of a chain of 4 similar hostels, related by linking buildings that include the ground floor and two storeys and host the students' reading rooms. The total surface of the building is about 6566 square meters (out of which the 938 square meters of the technical basement). The surface of one floor is about 938 square meters.

From the point of view of the structure, the hostel has a vertical resistance structure composed by structural reinforced concrete walls made up of large prefabricated panels for the facade walls and cast in place structural reinforced concrete interior walls. The horizontal structure is made of reinforced concrete prefabricated panels. The partition walls between the rooms hallways and the bathrooms respectively the shower rooms are non-structural, made of reinforced light weight concrete blocks. The original roof was initially a terrace-roof. Nowadays, it has a sloping roof. The roof envelope and the envelope accessories are newer than the building, being built after 1985. The interior finishing of the walls is done with lime mortar coating and clay painting, that has to be entirely remade, due to the high level of degradation. On the building side that shows to the park nearby, in several rooms there have been noticed mouldiness caused by the insufficient thermal insulation and to the existing thermal bridge (Figure 3a). The access hallways to the hostel rooms are partially covered with tiles, that show degradation and need to be entirely replaced. The bathrooms also have tiles that are damaged (Figure 3c). The floor of the main hall is covered with cast mosaic or cast mosaic plates. The floors of the rooms are covered with linoleum, badly run out (Figure 3b). The carpentry is old and badly damaged (Figure 3d).

a. Mouldiness on the exterior walls

b. Degradation of the linoleum floors

c. Degradation of the tiles and piping

d. Situation of the exterior carpentry

Figure 3. Aspects of the hostel's status

3 EVALUATION OF THE ENERGETIC PERFORMANCES OF THE EXISTING BUILDING

In view to the rehabilitation of the hostel, there has been performed a technical and thermo-energetic expertise in order to decide upon the intervention measures. From the structural point of view, the building can take both gravitational and horizontal (earthquake) loads. No structural damages have been noticed during the operation along the years. The thermal-energetic expertise aimed at establishing the level of the energetic performances of the existing building and to decide upon the principle solutions for rehabilitation. The heating of the hostel was done by the centralized city system.

4 REHABILITATION OF THE STUDENTS' HOSTEL

4.1 *Structural solutions*

The good behavior in time of the structure led to the lack of imposing special rehabilitation steps. But the proposal to install the hostel's own heating station required the consolidation of the floor over the basement and the ground level, due to the increased loads brought to the installations. The floor intended to support the boilers of the heating station was made of reinforced prefabricated concrete 9 cm thick, designed for an effective load of 150 daN/m^2. The structural solution adopted was to build an additional floor over the existing one, the new floor coming with cross beams able to take over the vertical concentrated loads from the equipments and the elements of the station. In order not to overload the existing floor, between the beams of the new floor and the old floor there was laid a layer of polystyrene. The composition details of the proposed solution are shown in Figure 4.

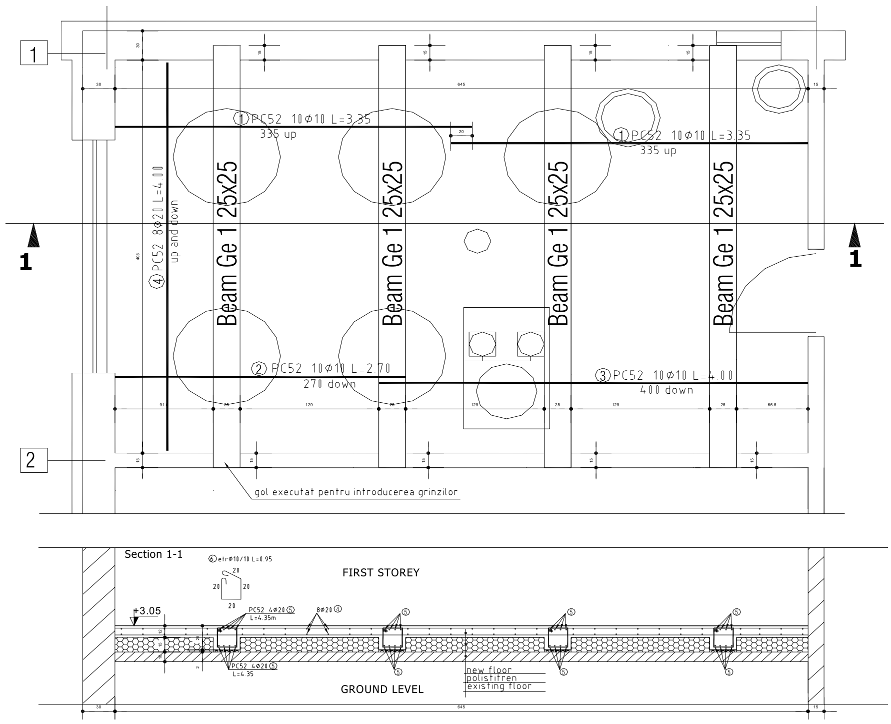


Figure 4. Details of the proposed structural solution

4.2 *Solutions for thermal rehabilitation*

The investigation performed led to the conclusion that exterior envelope elements were built as follows (from the interior to the exterior):

- The side panel, concrete 20 cm, Autoclaved Aerated Concrete 12.5 cm, concrete 6 cm, mortar coating 1.5 cm (Precast Panel Type 1);
- Between the windows: concrete 20 cm, Autoclaved Aerated Concrete 12.5 cm, mortar 0.5 cm (Precast Panel Type 2);
- The bottom panel under the window, concrete 10 cm, Autoclaved Aerated Concrete 12.5 cm, concrete 7.5 cm (Precast Panel Type 3);
- The front walls: concrete 15 cm, Autoclaved Aerated Concrete 12.5 cm, face brick work 7.5 cm (Precast Panel Type 4);
- Double-winged coupled windows;
- Single-wing windows;

- Metallic single-wing doors;
- The flat roof over the fifth storey: concrete 10 cm, vapour barrier made of bituminous membrane of 0.02cm, autoclaved aerated concrete 12.5 cm, cement flooring 10 cm, waterproof membrane with 5 layers of about 1cm thick;
- The floor over the basement, linoleum 0.5 cm, 10 cm cement flooring, 10 cm reinforced concrete.

Table 1 shows the heat flow resistances of the envelope elements, the minimum required resistances, the ratio between them and the average thermal resistance of the building.

Table 1 – Resistances to heat flow – current situation

Type	R' [m^2K/W]	R'_{nec} [m^2K/W]	R'/R'_{nec}	$\overline{R}$ [m^2K/W]
Precast Panel Type 1	0.82	1.4	0.58	
Precast Panel Type 2	0.78	1.4	0.55	
Precast Panel Type 3	0.77	1.4	0.55	
Precast Panel Type 4	0.9	1.4	0.64	
Double Coupled Window	0.39	0.5	0.78	0.61
Simple Window	0.17	0.5	0.34	
Metallic Door	0.17	0.5	0.34	
Roof floor	0.87	3.00	0.29	
Floor under basement	0.39	1.65	0.23	

In order to evaluate the energetic classification, there has been calculated the normal annual heat necessary and the normal annual heat necessary for hot water preparation. Based on the values obtained, there was established the energetic classification according to the Romanian codes in force (Figure 5).

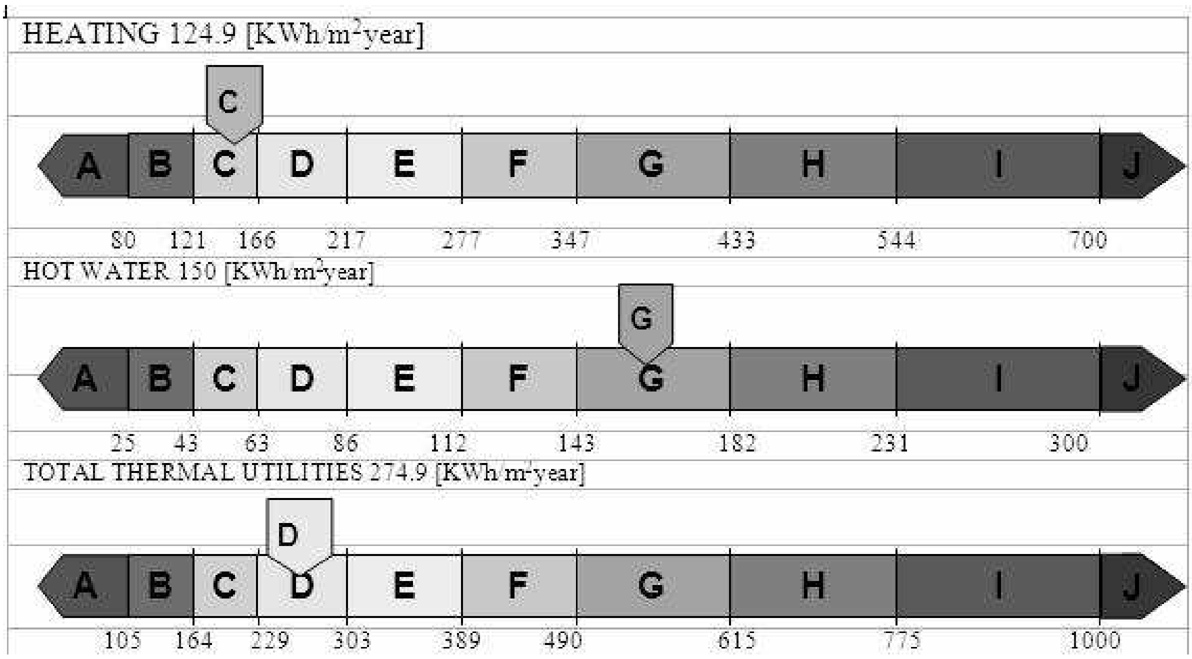


Figure 5. Energetic classification of the existing Hostel C20

Because all the envelope elements of the building show short-comings regarding the resistance to heat flow, the following measures have been proposed, in order to improve the performances of the building. Thus, concerning the exterior walls, there was proposed the execution of a thermal system, composed of an additional thermal protection applied to the exterior, made of polystyrene, over which there is applied a finishing layer on a support of glass fibre. The building will be painted in pastel colors. The existing carpentry will be entirely replaced by plastic carpentry and thermally insulated windows. For architectural reasons, the face brick facades will not be altered, in order to comply with the urban regulations of the area. The floor over the basement will be insulated by the application of a layer of polystyrene 5 cm thick, and the floor over the highest storey will be insulated by the application of a polystyrene layer 10 cm thick and a cement flooring minimum 2 cm thick. Based on the solution proposed, there have been recalculated the resistance to heat flow of the envelope elements respectively the average thermal resistance of the building. The values obtained are shown in Table 2.

Table 2 – Resistances to heat flow – current situation

Type	R' [m^{2}K/W]	R'_{nec} [m^{2}K/W]	R'/R'_{nec}	$\bar{R}$ [m^{2}K/W]
Precast Panel Type 1_R	2.17	1.4	1.55	1.37
Precast Panel Type 2_R	2.13	1.4	1.52	
Precast Panel Type 3_R	2.11	1.4	1.50	
Precast Panel Type 4_R	0.9	1.4	0.64	
Double Window_C	0.5	0.5	1	
Thermoinsulated Door_C	0.5	0.5	1	
Roof floor_R	3.49	3.00	1.16	
Floor under basement_R	1.65	1.65	1	

The analysis of the resistance to heat flow obtained after the application of the thermal rehabilitation solutions proved that the resistances to heat flow of the envelope elements exceed the minimum values required, except for the walls of the Eastern and Western facade. Although the solution of the application of a thermo-insulating layer over the interior sides of these walls could be adopted, this has not been done, since the areas neighbouring the non-rehabilitated walls housed the staircase and the common pantries. After the rehabilitation, the average resistance to heat flow of the building doubles.

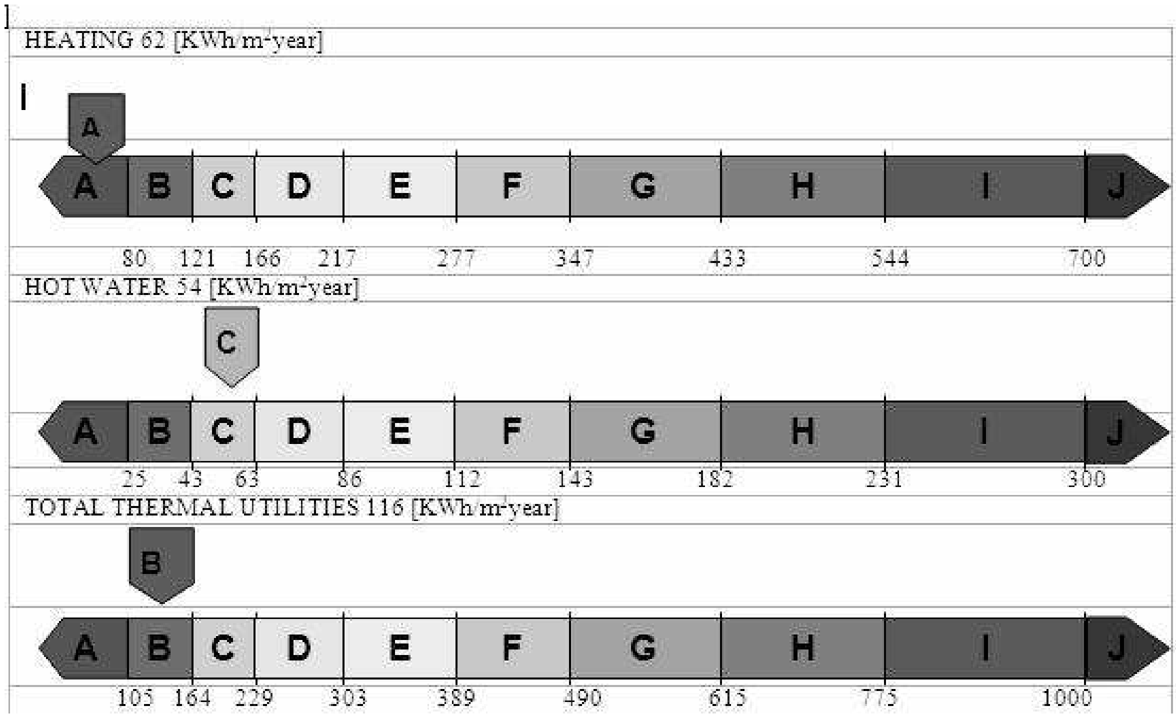


Figure 6 – Energetic classification of the Hostel C20 in the proposed solution

In order to improve the heating system and to reduce the losses, there has been proposed the installation of a heating station on gas, the overall replacement of the radiators and the heating system. The proposed pipe lines were made of high density polypropylene, pre-insulated in the basement of the building. Each distribution casing will have devices for evacuation and cleaning.

Figure 6 shows the new classification of the thermally rehabilitated building.

5 ECONOMICAL STUDY OF THE INVESTMENT. CONCLUSIONS

The evaluation of the investment was performed on the basis of the quantity of the determined works according to the proposed interventions. The graphs in Figure 7 show the distribution of the expenses by specialties.

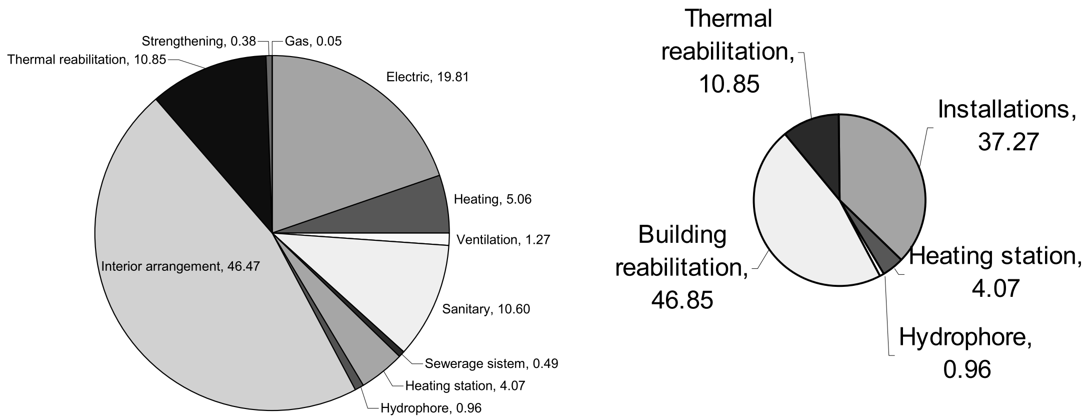


Figure 7. Distribution of the investment costs on specialties [%]

5.1 *Comparative study concerning the energy consumption*

Based on the theoretical evaluations performed, there can be noticed that the thermal rehabilitation led to the reduction of the heat consumption necessary for the heating of the area by nearly 50% from the initial consumption. The reduction of the total energy consumption is by more than 50% of the initial consumption. The heat consumption for the heating of the areas reduces because the average thermal resistance of the building doubles and because of the thermal station located within the building, thus reducing the losses along the distribution network.

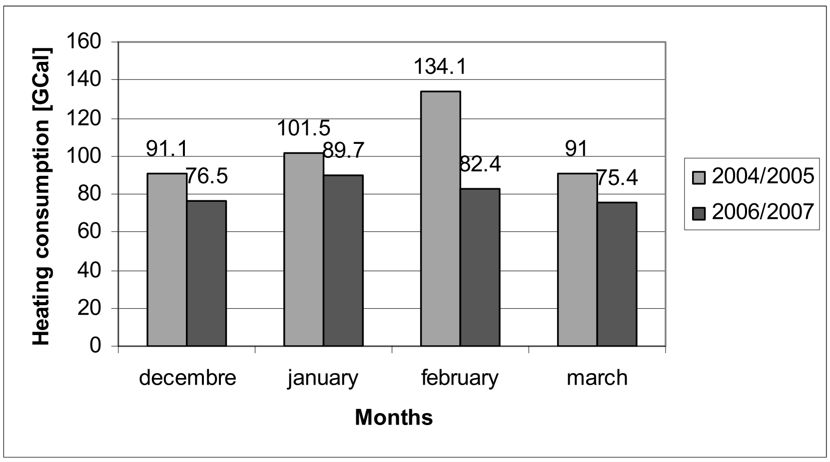


Figure 8. Variations of the heating consumption

The important reduction of the hot water consumption is due to the high efficiency of the thermal station, to the insulation of the distributions pipes and to the installation of timing taps in the shower cabinets. These timing faucets have actually led to a reduction of 40% of the hot water consumption in the whole building. Figure 8 shows the variations of the heating consumption, based on the real data gathered along two years of operation of the building.

As is shown in the Figure 8 the heating consumption during the winter decrease with 23% from the values registred before thermal reabilitation of hostel.

Taking into account the total amount of the termal reabilitation, that is about 110.000 Euros, and the economy achieved of 2100 Euros/month for heating and hot water, the value of the investment for the thermal rehabilitation is to be amortized in about 6 years. Figure 9 shows aspects of reabilitated hostel.

a. South facade reabilitated – general view

b. General view of student's room   c. Aspects of bathroom

Figure 9. Aspects of the hostel's status after reabilitation

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Comparison of the improvement of comfort in Turkish houses which are built by using traditional, conventional and semi-industrialized construction methods

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ABSTRACT: There is a relationship between sustainability and thermal comfort conditions. If a house is thermally comfortable, then it can be called "sustainable". In Turkish architecture, generally traditional, conventional and semi-industrialized construction systems are used. They have different properties and different construction materials and components are used during their construction process. This leads to different thermal behaviors. Therefore, the aim of this study is to examine and compare the thermal properties of the houses constructed by using these construction methods for Izmir conditions. In the end, the optimum one of them will be proposed.

1 INTRODUCTION

Sustainability and providing thermal comfort conditions are related to each other. That is due to the fact that a building is sustainable and it can be used for a longer time period if it provides comfort conditions to its inhabitants. Therefore it is important to provide comfort conditions in a house in order to maintain its sustainability.

In Turkey, there are generally two kinds of construction methods that are in use for housing. These are traditional construction methods which are generally used in rural areas and conventional construction methods which are generally used in cities and urban areas. In traditional construction, generally thermal comfort conditions are better provided due to the fact that these construction methods have been used, tried and experimented by the local people in that area for a very long time period and in the end the best results have been achieved. But on the other hand, conventional construction methods are in use for a very short time (less than a hundred years) and besides they are being used by the manufacturers, not the actual users of the houses, therefore these houses are generally poor in thermal protection. There are also semi-industrialized construction methods that are being used in housing in Turkey. Even though they are not used as much as the traditional and conventional methods, they still have a potential of being preferred more in the future. Therefore the aim of this study is to examine and compare the thermal properties of houses which are constructed by using different construction methods in Turkey for Izmir conditions. This is going to be done by explaining and examining the wall, roof and ground floor slab sections that are used in traditional, conventional and semi-industrialized construction methods, and then by comparing the thermal behaviour of them for Izmir conditions. In the end, the optimum one will be seen according to thermal comfort conditions for Izmir.

2 EXAMINATION OF DIFFERENT CONSTRUCTION TECHNIQUES GENERALLY USED IN HOUSES IN TURKEY FROM THE VIEWPOINT OF PROVIDING THERMAL COMFORT CONDITIONS

As explained above, generally traditional, conventional and semi-industrialized construction methods are being used in housing in Turkey. Here these are going to be explained and an examination will be done for each of them by giving the detail of the wall section.

A simple building is designed for examining the thermal comfort conditions and the role of the outer walls in providing this as seen in Figure 1.

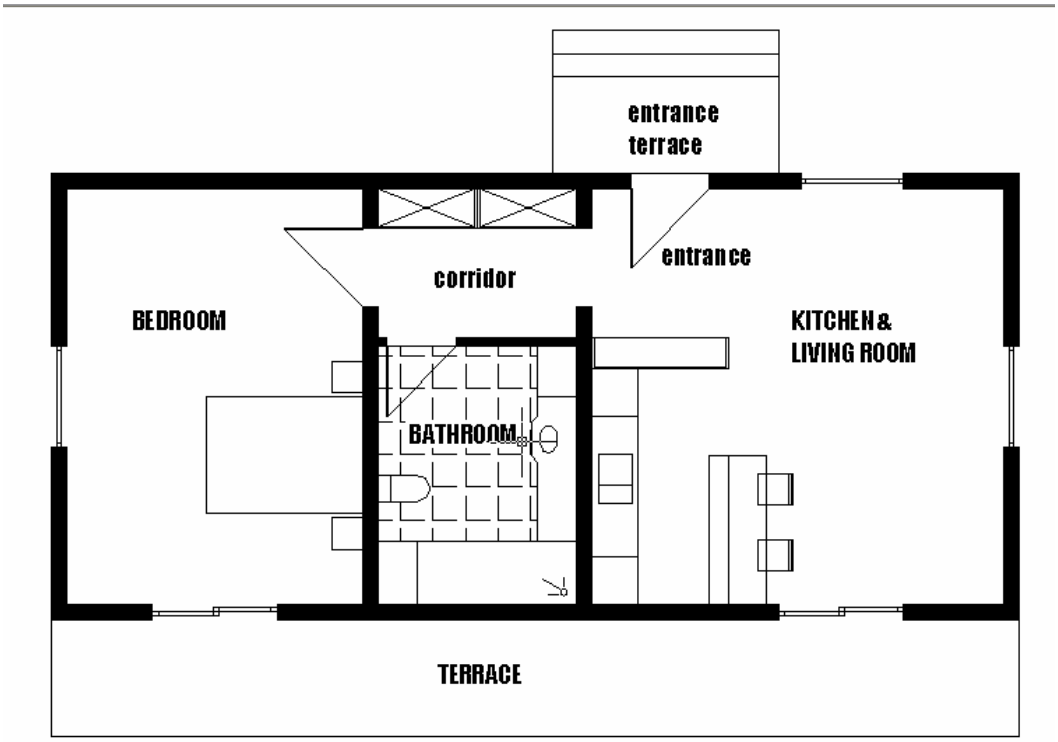

Figure 1. The plan of the designed house

2.1 *Traditional construction method*

In traditional construction method, generally conglomeration houses are constructed. There are also wooden skeleton buildings but they are not used as much as conglomeration ones. Therefore conglomeration construction will be used for examination here. Conglomeration constructions are constructed by using stones, adobe (sun-dried mud brick), bricks and (even though a little) wood. But among these materials, mostly brick is used. They are still preferred more than others. Therefore, brick conglomeration house example will be held in this examination.

In this method, only brick is used to construct the walls of the house. These are generally load-bearing and therefore they have minimum 20 cm width. Mostly solid or vertical-hollowed bricks are used. Inside and outside, a plaster is used to cover and protect the brick walls. Generally no heat-insulating material was being used before year 2000, but since then heat-insulating materials have to be used according to the new Turkish standard TS825 due to the fact that only these constructions are not enough for energy conservation.

In Table 1, Table 2 and Table 3, the layers of a traditional conglomeration house wall construction, roof construction and ground floor slab construction are given respectively. In the tables, the thicknesses and λ values (thermal conductivity) are shown.

Table 1. Layers of the wall of traditional construction method.

Layers	Thickness	λ
	m	(W/mK)
Plaster (inside)	0.025	1.4
Brick (with vertical hollows)	0.20	0.81
Thermal insulation	0.05	0.028
Plaster (outside)	0.03	1.4

The total area of this brick wall is 87,2 m^2. The U-value for this house is calculated as 0,446 W/m^2K. This is lower than the value let in the TS825 which is 0,80 W/m^2K.

Table 2. Layers of the roof construction of traditional construction method.

Layers	Thickness	λ
	m	(W/mK)
Gravel	0.05	0.7
Thermal insulation	0.10	0.028
Concrete (for protection)	0.05	1.74
Reinforced concrete slab	0.10	2.1
Plaster	0.025	1.4

Area of the roof is 69,44 m^2. The U-value is calculated as 0,255 W/m^2K. This is lower than the value let in the TS825 which is 0,50 W/m^2K.

Table 3. Layers of the ground floor slab construction of traditional construction method.

Layers	Thickness	λ
	m	(W/mK)
Marble	0.03	3.5
Concrete (for protection)	0.05	1.74
Thermal insulation	0.05	0.028
Concrete slab	0.10	1.74
Hardcore	0.15	0.7

Area of the ground floor is 69,44 m^2. The U-value is calculated as 0,441 W/m^2K. This is lower than the value let in the TS825 which is 0,80 W/m^2K.

Area of the doors and windows in total is 12,6 m^2. The same materials are used for both of them. Therefore the U-value for both doors and windows is used as 1,4 W/m^2K.

The room temperature is taken to be 20ºC. The maximum heating energy demand of this traditional house is calculated by using these values and the result is 21,23 kWh/m^3. But the actual energy demand of this example is calculated as 16,99 kWh/m^3. So this is a better result than the maximum energy demand. Annual heating energy demand is 3302 kWh.

2.2 *Conventional construction method*

In conventional construction method, generally reinforced concrete skeleton buildings are constructed in Turkey. In these buildings, generally brick is used to construct the walls of the houses between the reinforced concrete columns and beams. These are generally between 13-20 cm thick walls and generally they are not load-bearing walls. Mostly horizontally-hollowed bricks are used in the construction of these walls.

In Table 4, Table 5, Table 6, Table 7 and Table 8, the layers of a conventional reinforced concrete skeleton house brick wall construction, column part of wall construction, beam part of wall construction, roof construction and ground floor slab construction are given respectively. In the tables, the thicknesses and λ values (thermal conductivity) are shown.

Table 4. Layers of the brick wall of conventional construction method.

Layers	Thickness	λ
	m	(W/mK)
Plaster (inside)	0.025	1.4
Brick (with horizontal hollows)	0.20	0.45
Thermal insulation	0.05	0.028
Plaster (outside)	0.03	1.4

The total area of this brick wall is 60 m^2. The U-value for this house is calculated as 0,409 W/m^2K. This is lower than the value let in the TS825 which is 0,80 W/m^2K.

Table 5. Layers of the column part of the wall of conventional construction method.

Layers	Thickness	λ
	m	(W/mK)
Plaster (inside)	0.025	1.4
Column	0.40	2.1
Thermal insulation	0.05	0.028
Plaster (outside)	0.03	1.4

The total area of this column part of the wall is 11,20 m^2. The U-value for this house is calculated as 0,457 W/m^2K. This is lower than the value let in the TS825 which is 0,80 W/m^2K.

Table 6. Layers of the beam part of the wall of conventional construction method.

Layers	Thickness	λ
	m	(W/mK)
Plaster (inside)	0.025	1.4
Beam	0.25	2.1
Thermal insulation	0.05	0.028
Plaster (outside)	0.03	1.4

The total area of this beam part of the wall is 16 m^2. The U-value for this house is calculated as 0,473 W/m^2K. This is lower than the value let in the TS825 which is 0,80 W/m^2K.

Table 7. Layers of roof construction of conventional construction method.

Layers	Thickness	λ
	m	(W/mK)
Gravel	0.05	0.7
Thermal insulation	0.10	0.028
Concrete (for protection)	0.05	1.74
Reinforced concrete slab	0.10	2.1
Plaster	0.025	1.4

Area of the roof is 69,44 m^2. Therefore the U-value is calculated as 0,255 W/m^2K. This is lower than the value let in the TS825 which is 0,50 W/m^2K.

Table 8. Layers of ground floor slab construction of conventional construction method.

Layers	Thickness	λ
	m	(W/mK)
Marble	0.03	3.5
Concrete (for protection)	0.05	1.74
Thermal insulation	0.05	0.028
Concrete slab	0.10	1.74
Hardcore	0.15	0.7

Area of the ground floor is 69,44 m2. Therefore the U-value is calculated as 0,441 W/m2K. This is lower than the value let in the TS825 which is 0,80 W/m2K.

Area of the doors and windows in total is again 12,6 m^2 here as in traditional one. Therefore the U-value for both doors and windows is used as 1,4 W/m^2K.

The room temperature is taken to be 20ºC. The maximum heating energy demand of this conventional house is calculated by using these values and the result is 21,23 kWh/m^3. But the actual energy demand of this example is calculated as 16,71 kWh/m^3. So this is a better result than the maximum energy demand, but due to the fact that it is higher than the energy demand of the traditional case study which is 15,43 kWh/m^3, traditional one is better than this one. Annual heating energy demand of the conventional case study is 3249 kWh and this is also higher than the traditional case study's energy demand of 2999 kWh. But only the reinforced concrete columns and beams are added and the type of the bricks used are changed from vertical hollowed ones to horizontal hollowed ones.

2.3 *Semi-industrialized construction method*

In semi-industrialized construction method, different methods are being used. Here in this study, the lightweight-concrete panel construction systems (known as gazbeton in Turkey) will be examined.

In this method, only light-weight concrete panels are used to construct the walls of the house. The load-bearing types of these panels that have 20 cm width are chosen in this study. Inside and outside, a plaster is used to cover and protect the walls. The roof is constructed by using 10 cm. wide, reinforced light-weight concrete roof slabs.

In Table 9, Table 10 and Table 11, the layers of a semi-industrialized leight-weight concrete (gazbeton) house wall construction, roof construction and ground floor slab construction are given respectively. In the tables, the thicknesses and λ values (thermal conductivity) are shown.

Table 9. Layers of the light-weight wall of semi-industrialized construction method.

Layers	Thickness	λ
	m	(W/mK)
Plaster (inside)	0.025	1.4
Light-weight concrete panel	0.20	0.16
Thermal insulation	0.05	0.028
Plaster (outside)	0.03	1.4

The total area of this light-weight concrete wall is 87,2 m^2. The U-value for this house is calculated as 0,308 W/m^2K. This is the lowest of the case studies of the three methods calculated and also lower than the value let in the TS825 which is 0,80 W/m^2K.

Table 10. Layers of the reinforced light-weight concrete roof construction of semi-industrialized construction method.

Layers	Thickness	λ
	m	(W/mK)
Gravel	0.05	0.7
Thermal insulation	0.10	0.028
Concrete (for protection)	0.05	1.74
Reinforced light-weight concrete slab	0.10	0.16
Plaster	0.025	1.4

Area of the roof is 69,44 m^2. The U-value is calculated as 0,370 W/m^2K. This is lower than the value let in the TS825 which is 0,50 W/m^2K.

Table 11. Layers of the ground floor slab construction of semi-industrialized construction method.

Layers	Thickness	λ
	m	(W/mK)
Marble	0.03	3.5
Concrete (for protection)	0.05	1.74
Thermal insulation	0.05	0.028
Concrete slab	0.10	1.74
Hardcore	0.15	0.7

Area of the ground floor is 69,44 m^2. The U-value is calculated as 0,441 W/m^2K. This is lower than the value let in the TS825 which is 0,80 W/m^2K.

Area of the doors and windows in total is 12,6 m^2. The same materials are used for both of them. Therefore the U-value for both doors and windows is used as 1,4 W/m^2K.

The room temperature is taken to be 20ºC. The maximum heating energy demand of this semi-industrialized house is calculated by using these values and the result is 21,23 kWh/m^3. But the actual energy demand of this example is calculated as 16,29 kWh/m^3. So this is a better result than the maximum energy demand. Annual heating energy demand is 3166 kWh.

3 COMPARISON OF THE HOUSING CONSTRUCTION TECHNIQUES

Until here, the total annual energy demand calculations are done for three different house construction methods used in Turkey. Here, the results will be discussed.

Table 12. Annual energy demand of the three methods for heating.

Construction Methods	Qa (annual energy demand)	Q' (calculated energy demand)
	kWh	(kWh/m^3)
Traditional construction method	3302	16,99
Conventional construction method	3249	16,71
Semi-industrialized construction method	3166	16,29

It is seen that the heating energy demand of the house is decreasing with the developing technology. It is the most in traditional construction method, and the least in semi-industrialized construction method.

The results are used in a simulation program in order to calculate the cooling energy demand of the three methods. The results show the cooling energy demand of the three methods. These results are shown in Table 13 below.

Table 13. Annual energy demand of the three methods for cooling.

Construction Methods	Qa (annual cooling demand)	cooling demand absolute
	kWh/m^2	(kWh)
Traditional construction method	3,1	171
Conventional construction method	2,9	160
Semi-industrialized construction method	5,5	307

It is seen from the tables that the conventional construction method is the best one for the lowest cooling energy demand. But the semi-industrialized construction method is the worst of all for cooling energy demand. This is due to the fact that all parts of the house except the ground floor slab are constructed with light-weight concrete panels. And light-weight concrete is a light construction and has very low heat storing capacity. In the other two construction methods, the walls, the roofs and the ground floor slabs can lose the energy they gain during the day at night and they get cold, and they still can keep cool during the next day when the sun is up in the air. But the walls and the roof of the light-weight concrete house cannot keep that much cool during the day since they have very low mass. This proves that heat storage mass is important not only for heating, but also for cooling. Therefore, light-weight concrete construction can be a good choice for a lower heating energy demand but it is the worst choice for a lower cooling energy demand.

On the other hand, conventional construction method seems to be the best choice for the lowest cooling energy demand. Likewise, traditional construction method is only a little way behind the conventional method. This is just the opposite at heating energy demand. The traditional method is the best for the lowest heating energy demand, and the conventional method is only a little way behind it. Therefore, it is best to choose one of them according to which energy demand is important or a problem for the place of house that is going to be constructed. If cooling is more important than heating, then conventional method maybe chosen. But if heating is more important, then traditional method maybe chosen.

4 CONCLUSION

According to the results, why traditional construction system have been used in Turkey for such a long time and why it is still being used is explained very well. That is because of the fact that heating the houses was a problem for a longer period in a year (for more that 7 months) and you can keep the house heated for a longer time in a conglomeration house.

With the advancing technology, conventional construction system has entered the construction site. In this system, a worse insulation valued material concrete is being used, but also with a better insulation valued brick-the horizontally hollowed ones. These keep the new construction system equal. Therefore they can be used equally in the constructions. But the worst one is light-weight concrete construction system. It is obvious that this has been seen and not being used a lot in the construction of houses.

This is just an examination done for only one design project of a house. For a better result, more examples should be examined. The second step of this study can be the examination of the actual houses built in the same area with all of the three construction methods. In addition, cost issues maybe held for better choice criteria. In this study, only the thermal comfort conditions are held in order to give an exact result for providing comfort in the houses regardless of the prices. This gives nearly exact results according to the choice of the traditional architecture. And also shows us the reason why traditional architecture houses are still being constructed and being used today. That shows the reason of the sustainability of the traditional Turkish houses, and also the relationship between the thermal comfort conditions and the sustainability. If we want to design and construct sustainable houses, we should be careful to provide thermal comfort conditions in the houses.

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TS825 calculation tool

Energetic audit methods, part of sustainable development process

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ABSTRACT: In the context of studying the sustainable development, the energetic audit establishes, from economic and technical point of view, the solutions for thermal-energetic rehabilitation and modernization of the construction. For this problem, engineers have a great responsibility, in the way of finding the most efficient ways and techniques of establishing the energy consumption reduction and low costs, as a result of the investment in the measures of conserving the energy. The paper presents some techniques of the estimation energy consumption used to determine the spares which results from application of some conservation measures of the energy.

1 INTRODUCTION

The concept of sustainable development renounces to be against the nature in exchange of creating a friendship between them, trying to stop any process which may injury the next generations and to repair everything that still could be repaired. It is a solidarity manifestation above the limits of a life, evidence of our civilization maturity in a period of globalization and extra-terrestrial researches. There are requested immediate deep changes in fields of industrial activity, economic activity, educational activity, cultural activity, administrative and political activity; a decision factor being the science and the technology. Under the pressure of the existent situation, it is formed a correct base of thinking and are used synthetically methods of orientation, having catalyst role for engineering activity, their importance is exceptional in the industry of constructions because these are utilized for a very long period: sustainable development – integrated concept of built space and of energetic audit.

2 BUILDING-ORGANISM IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT OF THE ENERGY CONSUMPTION WITHIN THE RESIDENTIAL

A sustainable building or a green building is a construction which utilizes the key resources (energy, water, construction materials, soil, etc) in a more efficient way than the conventional buildings. These buildings are constructed in manner to offer to their inhabitants a healthy environment for working, studying or resting, by using the extensive natural light, fresh air and a high degree of comfort. The sustainable buildings are efficient from the point of view of maintenance and operation costs, and of which value increases in time, through positive impact on the natural and social environment.

3 THE ENERGETIC AUDIT-PART OF SUSTAINABLE DEVELOPMENT PROCESS

Energetic audit of a building – method which establishes, from economic and technical point of view, the solutions for thermal-energetic rehabilitation and modernization of the construction based on the results obtained from thermal and energetic activity of expertise of the building.

In the approved norms by MLPTL, NP 47, 48 and 49 / 2000 it is mentioned a division in three components:

- thermal expertise – in which are established thermal-technical characteristics of the building (elements of construction and installation) and energy consumptions for complying with normal functioning;
- the energetic certificate – which, starting from energetic expertise, establish the “energetic quality” of the construction and offer a qualificative. The energetic certificate is obligatory in different situations;
- the energetic audit – which presents solutions for reducing the energy consumption of the buildings.

For this problem engineers have a great responsibility, in the way of finding the most efficient ways and techniques of establishing the energy consumption reduction and low costs, as a result of the investment in the measures of conserving the energy.

In the next chapters it will be presented, shortly, some techniques of estimating the energy consumption (see Consult, Group, IP. 2003. Reference book of energetic efficiency for the buildings), used usually by buildings experts in order to determine the spares which results from application of some conservation measures of the energy.

4 THE METHODS OF ENERGETIC ANALYSIS

The existing methods of analyzing the energy consumption (applied in so called audits or energetic analysis) differ a lot in complexity and correctness. In order to choose the proper method of energetic audit, the expert / auditor have to consider more factors, which include: fastness, cost, and versatility, possibility of reproducibility, sensibility, precision and easiness in utilization.

There are hundreds of possibilities and methods for analyzing the energy, which are used in the whole world in order to discover the possible reduction in the measures of conservation of the energy.

Generally, the existent methods of analyzing the energy may be:

- direct methods (forward);
- reverse methods (feed-back)

In the direct method, as we may see in Figure 1, the energy estimations are based on physical description of the construction systems, as geometry, placement, construction details, and the type of system and operation HVAC (heating, ventilation and air conditioning). The most existent detailed methods of simulation of energy follow the method of simulation of direct approach.

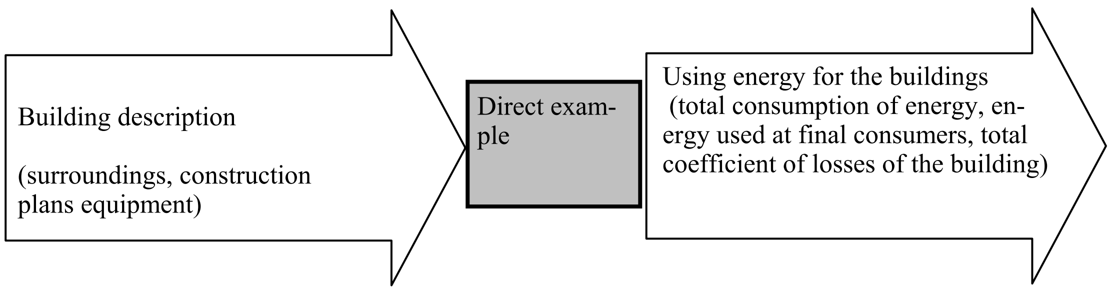

Figure 1. Direct approach of an energetic audit

In indirect approach, as we may see in Figure 2, the example of analyzing the energy consumptions tries to deduct the representative parameters of the building (as the coefficient Gv of the total losses of the whole building, main task of the building, or time constancy of the building) using the existent utilization of energy, weather and any others relevant data of the performance.

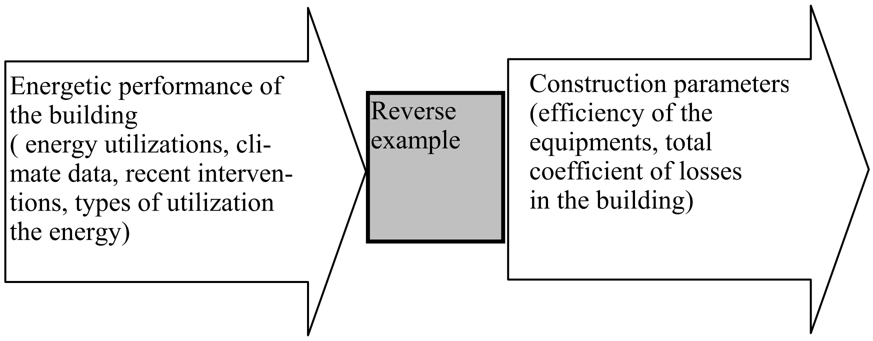

Figure 2. Reverse approach of an energetic audit

Generally the reverse examples are less complex as conception than the direct examples. Although, the flexibility of the reverse examples is limited by formulating the representatives construction parameters and by correctness of the construction performance data. The most existent reverse examples are based on regression analysis (as the examples degrees – days with variable reference), or on integrated approach in identification of construction parameters.
(*Number of degrees – days: has influence on annual energy consumption. Defined as difference between one given temperature and daily average temperature).

Among the frequent applications of direct and reverse approaches there are:
- verification of energy reduction which appear with help of measures for reducing the energy;
- establishing the malfunctions at the equipments;
- testing the energetic systems efficiency.

The energetic audit techniques may use either the approaches with stationary simulation or the ones with dynamic simulation.

Generally, the stationary examples are sufficient for analyzing the building performance for a season or for one year. Although the dynamic examples may be necessary in order to evaluate the transitory effects of the energetic systems in constructions, as are the ones seen at the systems of stocking the energy or at the control elements for beginnings optimization.

The energy analysis techniques are grouped, usually, in three categories:
- methods based on indicators (reports), which are approaches of pre-auditing type, based on energy densities / costs which allow a fast evaluation of construction performance;
- reverse methods, based either on stationary simulation or on dynamic one;
- direct methods, which more often constitutes the base for computer programs for energy consumption simulation.

4.1 *Methods based on indicators*

The methods based on indicators aren't in fact energetic analysis methods, but approaches of pre- audit type for establishment of the specific energy or of the cost indicators of the building.

These indicators of energy / cost of the building are compared with reference performance indicators (sometimes being known as landmarks) obtained from many other buildings with the same major characteristics. Energetic consumption indicators may offer sometimes relevant information regarding some potential problems of the building, such as leakages in the piping system of water / steam, or inefficiency of cooling system, or high quantity of water consumption.

More exactly, energy density consumption or energetic indicators of the buildings are utilized for:

- establishing if too much energy is consumed and if an energetic audit will be useful.
- verifying if it was realized a certain established level of energetic performance of the building. If not, the energy indicator may be used for establishing energy consumption reduction, needed for achieving the proposed level.
- monitoring the energy consumption evolution of the building and establishing the efficacy and profitability of any energetic management program realized post – audit.

In order to estimate some coherent energetic or cost indicators, are built large date bases, usually for estimating the reference indicators, are needed data for hundreds and thousands of similar buildings.

The cost or energy indicators are reports for which the numerator and the denominator are specific variables.

For the indicators of energetic performance, the present variables at denominator may be:

- total energy consumption of the building (including all the final consumers), in kWh or Gcal.
- The energy consumption per existent final consumer in the building (heating, ventilation and enlightening …)
- Energy needed (kW)

For cost indicators, it is usually used for the denominator a currency value(especially for the energy expense or for the whole building exploitation). For denominator may be used more variables, according to the type of the building and of the scope followed by calculation of indicator. Some of the variables used for the energy or cost indicators denominator are:

- Area or volume of the building (heated area or conditioning volume)
- Consumers of the building (in buildings of collective use, as hotels, schools)
- Degrees – days (with reference temperature of 20^0C)
- Production units (especially for manufacturing units, restaurants)

4.2 *Methods of reverse simulation*

Methods using reverse simulation are based on the existent performance data of the building in order to identify a certain set of characteristic parameters. The reverse methods may be valuable for increasing the energetic efficiency of the building, being used at:

- finding the malfunctioning, by identifying time periods or by identifying the energetic systems with very high energetic consumption.
- obtaining the estimations on energy reduction resulted after applying a set of distinctive measures,
- verification of energetic reductions as a result of modernizations.

In order to estimate, based on experimental data, the representative parameters of the building and / or of its systems (such as bearing coefficient of the building or effectiveness of the heating system), usually are used regression analysis. In general, stationary reverse simulations are based on monthly and / or daily data and comprise one or more independent variables. The dynamic reverse simulations are usually developed on sets of hour data or under-hour, being capable of rendering transitory effects, as in the case of the buildings where high thermal inertial delays the heating or cooling of the interior area.

4.2.1. Stationary reverse simulations

In general, these simulation search to identify the relation between building energetic consumptions and parameters depending of climate, such as average of exterior temperature (monthly or daily), degrees – days or degrees – hours. As it has been mentioned before, this kind of correlation it is realized by using statistic methods (based on analysis of monthly regression).

The stationary reverse simulations are applicable only for estimation on long term of the final consumptions of energy. So, in order to sustain the regression analysis, the data about energy consumption are collected on long periods of time (one season, one year).

The main advantages of reverse stationary simulations are:

- Simplicity: the reverse simulations may count only on few sets of obtained data, for example, from the building invoices for energy.
- Flexibility: the stationary reverse simulations have lots of applications, being important especially in estimation of residential buildings consumption and of small commercial buildings.

The stationary reverse simulations are recommended especially for measuring and verification of energy reduction after modernizations. There simplified simulations based on degrees – days methods, which can be used in order to determine the energetic impact which some improving energetic measures may have. Bellow, it shall be presented two such simplified reverse simulations:

Cummulative method degrees – days which consists of correlation (using a linear regression analysis) of cumulatively energetic consumptions of the buildings with cumulatively degrees – days (using a reference temperature of 20^0C). Figure 4 shows the base concept of the cumulative method degrees – days.

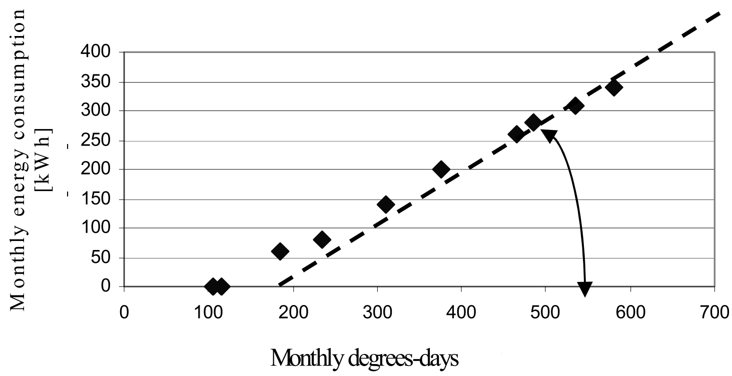

Figure 3. Typical application of cumulatively method degrees – days

It is shown the energy cumulatively consumption by using the relation:

$$E_{inc} = 0{,}024 \times \frac{G}{\eta_{inc}} \times V_{clad} \times I \times GZ_{inc} \qquad \text{[kWh]} \qquad (1)$$

where $E_{inc,lun}$ = cumulative energy consumption for heating the building [kWh];
G = total losses coefficient according to the building volume [W/m^3.K];η_{inc} =heating system average effectiveness during a season; V_{clad}=heated volume of the building [m^3];
GZ_{inc} = cumulative degrees – days for heating (related to 20^0C); I – correction factor which considers the settled reduction of the thermal charge (for example during the night or during the week-end); if it is no charge reduction, then I=1.

This method it is used in some European countries in order to control the energy consumption variation of the buildings during the warm season. Particularly, using the cumulative degrees – days allows to be aware of every modification of the energetic consumption after the modernization measures, by the curve of linear regression. Any improvement of thermal performances of the building (such as improvement of thermal insulation or increasing the efficiency of the heating system) will reduce the grade.

Method degrees – days with variable reference temperature which uses linear regression analysis in order to establish the balance temperature of the building. The method is a base for lots of analysis instruments and software products for estimation of monthly energy consumption for heating the building.

It is represented by chart, with points, the monthly energy consumption for heating, according to degrees days monthly for a calculation interior temperature of 20^0C.

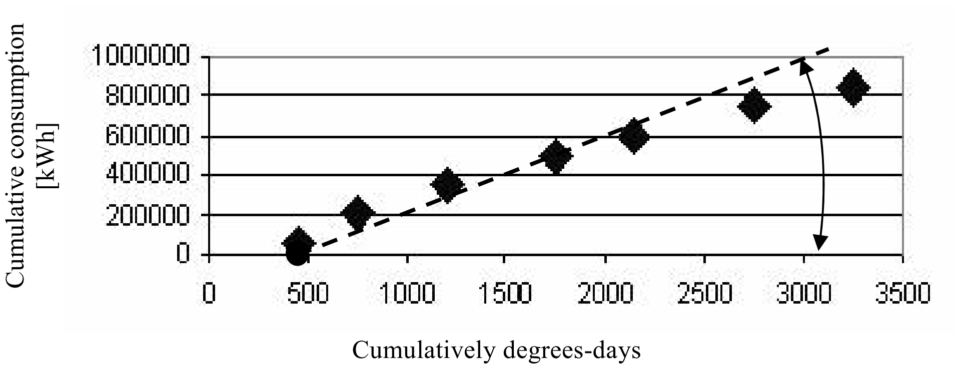

Figure 4. Typical application of the method degrees days with variable reference temperature

It is shown the energy monthly consumption by using the relation:

$$E_{inc,lun} = 0{,}024 \times \frac{G}{\eta_{inc}} \times V_{clad} \times I \times [GZ_{inc,lun} - (20 - T_{ech}) \times N] \text{[kWh]} \qquad (2)$$

where:

$E_{inc,lun}$ = monthly energy consumption [kWh]; $GZ_{inc,lun}$ =degrees – days heating for one month (related to 20^0C); T_{ech} =balance temperature of the building; N=number of the day from a month; G,I, $V_{clad,}$ η_{inc} – have the same signification as in equations (1)

In order to correlate monthly energy consumption with monthly degrees – days (related 20^0C) it is necessary the development of an linear regression analysis, using only data from the warm season.

The line of regression (dashed in Figure 3) intersects the abscissa in $GZ_{inc,lun\ ,0.}$ The balance temperature results from the condition

$$[GZ_{inc,lun,0} - (20 - T_{ech}) \ . \ 30] = 0.$$

Inclination of the regression line it results from 0,024G x $V_{clad.//}$ η_{inc}

If it is known the volume of the building and the season effectiveness of the heating installation, it may be determined the total coefficient of thermal losses, G.

4.2.2. Dynamic reverse simulations

The dynamic reverse simulations may be used for estimating the energy consumption variation, based on date collected in a short period of time (one week). In general, one dynamic reverse simulation is based on a building thermal model which uses a distinctive set of parameters, usually identified by application of a form of linear regression analysis. Besides the stationary models, the dynamic one request a higher degree of interaction with the user and knowing all the details of the building or of the modeled system. Such models are sophisticate and usually are base of some specialized soft.

4.3. Methods of direct simulation

The direct models are, generally, based on physical description of the energetic system of the building. Usually, these methods allow the final energy consumption, as the estimation of any energy reduction resulted after applying the measures of energy conservation.

4.3.1. Stationary direct methods

The stationary direct methods are, generally, easy to be used, and many of the calculations may be done manually or with electronic calculation sheets. It may be distinguished two such typical methods:

- degrees – days methods
- inter-current methods

Degrees – days methods which are using season degree – days calculated at a pre-established temperature (interior temperature of calculation of 20^0C or balance temperature) in order to estimate the necessary temperature for heating the building. Usually, these methods aren't adequate for calculating the needed energy for cooling. Although the method degrees – days with variable reference temperature it is more exact, the method degrees – days for heating, based on a reference temperature of 20^0C, it is still used in Europe for residential and commercial buildings.

The methods degrees – days allows the estimation of energy season consumption for heating, with equation 3.

$$F = \frac{0{,}024 \cdot G \cdot V_{clad} \cdot f \cdot GZ_{inc}(T_{ref})}{\eta_{inc}} \quad \text{[kWh]} \tag{3}$$

where: F – energy consumption (gas, liquid fuel, or electric energy for heating), [kWh];
G – total coefficient of losses of the building; V_{clad} – heated volume of the building [m^3];
F – correction factor which includes different effects, as functioning at partial charges, charge reduction during the night or free heating rapport; T_{ref} – balance or interior temperature of building calculation [^{0}C]; $GZ_{inc}(T_{ref})$ – degrees – days heating at reference temperature $T_{ref,}$ [k x day];

The methods degrees – days with variable reference temperature offers usually correct estimations on the energy consumption for heating in the case of the buildings where are important thermal losses through exterior walls (especially at low buildings, where the air infiltrations are relatively reduced). But, they are not recommended for the buildings where internal thermal matters are prevailing and / or with complex HVAC installations.

The inter-current methods are similar to degrees – days methods with variable reference temperature; in order to estimate energetic consumption for heating and / or cooling of the building, but, they are based on different climate date, on inter-current values for exterior temperature. In classical inter-current methods, the exterior temperatures are grouped in equal inter-currents, usually of 5^0C. For each inter-current, it is mentioned static number of the hours of appearances of the values from the inter-current. For the others climate variables are established only average values correspondent to the centered value from the exterior temperatures interval. Climate data from classical interval methods usually represents a one-dimensional set of data (exterior temperatures). The precision of interval methods it is useful only in case of the sensitive heated buildings (without phase changing) and without significant effects of thermal impulse. In order to increase the precision, especially at the buildings with high thermal latent charges, are introduced bi-dimensional sets of climate data based on two variables (as the dry thermometer temperature and relative humidity).

In both types of stationary methods, it is necessary to know the total coefficient of thermal losses, G.

4.3.2 Dynamic direct methods

Analytic dynamic methods are using numbering and analytical models in order to calculate the transfer of energy among the different systems of the building. In general, such models consisted in software products (with hour steps of time or smaller) which estimate accordingly the effect of thermal impulse due to stocking the energy into the building walls and / or into the heating system.

The most important propriety of those models of simulation is their capacity of taking into account more decisive parameters in correct estimation of energy consumption, especially at the buildings with pronounced thermal impulse, with night reduction of the charge, with stocking systems of the energy or prediction control strategy.

In general, a simulation program needs a detailed physical description (geometry, walls details, type of heating and conditioning systems).

5. CONCLUSION

From the sphere of principles, under the pressure of time which is passing, the sustainable development must comprise actions with effects in different fields, and especially, regarding energy consumption savings utilized for assuring comfort inside of the buildings.

Although, science researches may add more results in the field of energy distribution recovery, although the technological solutions which may be applied immediately, exists and should be introduced without delay, with government support.

As a brief conclusion may be retained the following important ideas:

- we are at the beginning of the transition process towards sustainable development which is absolutely necessary and urgent, and the necessary transformations must enter in every activity field, starting with energy and people information and continuing with all fields of national economy, first being constructions field.
- the existing methods of analyzing the energy consumption differ a lot in complexity and correctness. In order to choose the proper method of energetic audit, the expert / auditor have to consider more factors, which include: fastness, cost, versatility, possibility of reproducibility, sensibility, precision and easiness in utilization.
- the methods of analyzing the energy consumption give the possibility to analyze the building performance for a season or for one year, estimation and verification of energy reduction which appear with help of measures for reducing the energy consummtion.
- the methods of analyzing the energy consumption is an important criteria for the solution adopted in order to optimize the insulation systems of buildings.

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Low energy building design with sustainable energy end use

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ABSTRACT: When designing a low energy building there are always a discussion on how environmental correct the different energy saving measurements are, especially when heat pumps are used. The Swedish building sector and energy sector has conducted a joint project to study this question. The main objective was to identify the most cost- and resource-efficient measures to reduce the built environment's environmental impact, and to achieve an energy supply system with the least possible environmental impact. The results of this study are presented in Persson A. et all, 2006, show interesting facts to consider when designing low-energy buildings. Primary energy factors and primary CO_2 emission factors have been calculated and used as indicators of resource need and environmental impact.

- Environmental impact and cost-efficiency have been calculated for each efficiency measure in combination with sex different energy supply scenarios
- LCC from the end user's perspective have been used for cost efficiency calculations.
- In addition a comparison of the studied buildings has been made with four well-known Swedish low-energy buildings.

The main issues from studies made Persson A. et all, in 2005 and 2006, will be presented including the background to design of low energy buildings. It will be shown that a system's perspective including energy supply and energy demand is necessary to achieve a sustainable development.

1 INTRODUCTION

The Swedish building sector and energy sector has conducted a joint study aiming at identifying the most cost- and resource-efficient measures to reduce the built environment's environmental impact, and to achieve an energy supply system with the least possible environmental impact. In this study primary energy factors and primary CO_2 emission factors have been calculated and used as indicators of resource need and environmental impact. Input:

- Primary energy and CO_2 emission factors are calculated from a LCA perspective, from excavation through transformation and distribution, and losses in the individual building to actual energy end use.
- Primary energy factors and the primary CO_2 emission factors are given in kWh per m^2 heated area and kg CO_2 per m^2 heated area respectively.
- The analysis comprises one recently erected residential multi-family building and one new office building. For each of the two houses a number of efficiency measures have been simulated.
- Environmental impact and cost-efficiency have also been calculated for each efficiency measure in combination with sex different energy supply scenarios.
- LCC from the end user's perspective have been used for cost efficiency calculations.

In addition a comparison of the studied buildings has been made with four well-known Swedish low-energy buildings.

1.1 *The studied buildings*

Multi-family building:

- 15 apartments
- Situated in Stockholm
- Families moved in 2004
- Mechanical exhaust air ventilation system
- Good insulation performance
- A-labelled appliances
- Total yearly energy demand is 170 kWh/m^2
- Simulations have been made for e.g. balanced ventilation with heat recovery, heat pump, improved insulation standard, high performance (A+ and A++) appliances, and replacing electrical comfort heating in bathroom floors with district heating

Office building:

- New office building
- High performance insulation and windows
- Sun screens in south and west to avoid cooling demand
- Balanced mechanical ventilation with heat recovery with a good COP
- Total delivered energy 182 kWh/m^2
- Simulations have been made for e.g. "free cooling" (passive cooling), energy efficient lighting, day lighting solutions and division in building control system zones, high performance ventilation systems, improved sun screens, air born cooling, variable air volume ventilation systems, and decentralised cooling with a higher COP

1.2 *The studied supply systems*

80 % of all multi-family residential and office buildings in Sweden are supplied with district heating, hence it was natural to choose several supply system scenarios based on district heating.

1. District heating 2010 forecast
2. Biomass based medium sized district heating system
3. District heating based on biomass CHP
4. District heating based on natural gas CHP
5. Ground heat pump
6. Local biomass combustion

In the analysis electrical end use has been seen from an average European and a future marginal (natural gas combination) supply perspective.

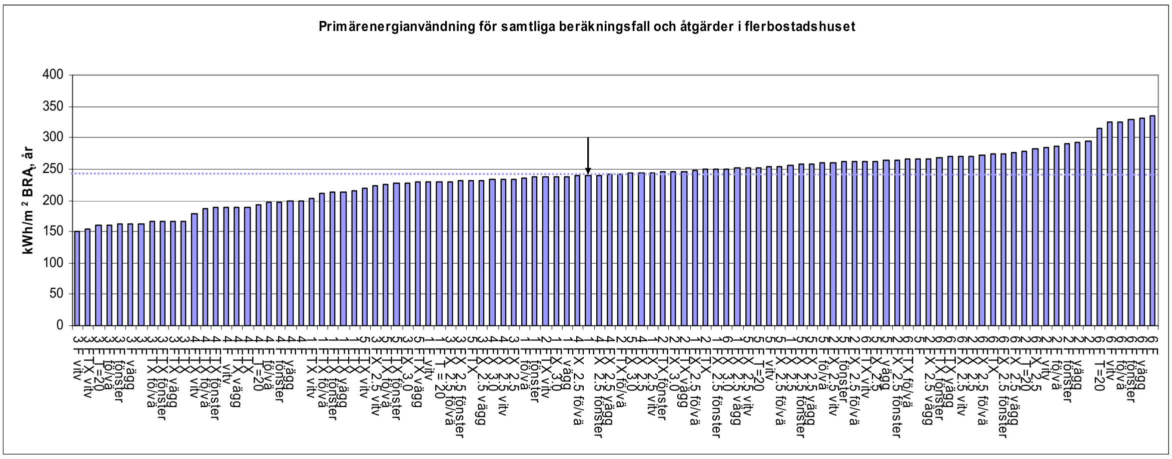

Figure 1. Primary energy consumption calculated for all different combinations of energy efficiency measurements and supply system with a multi family building

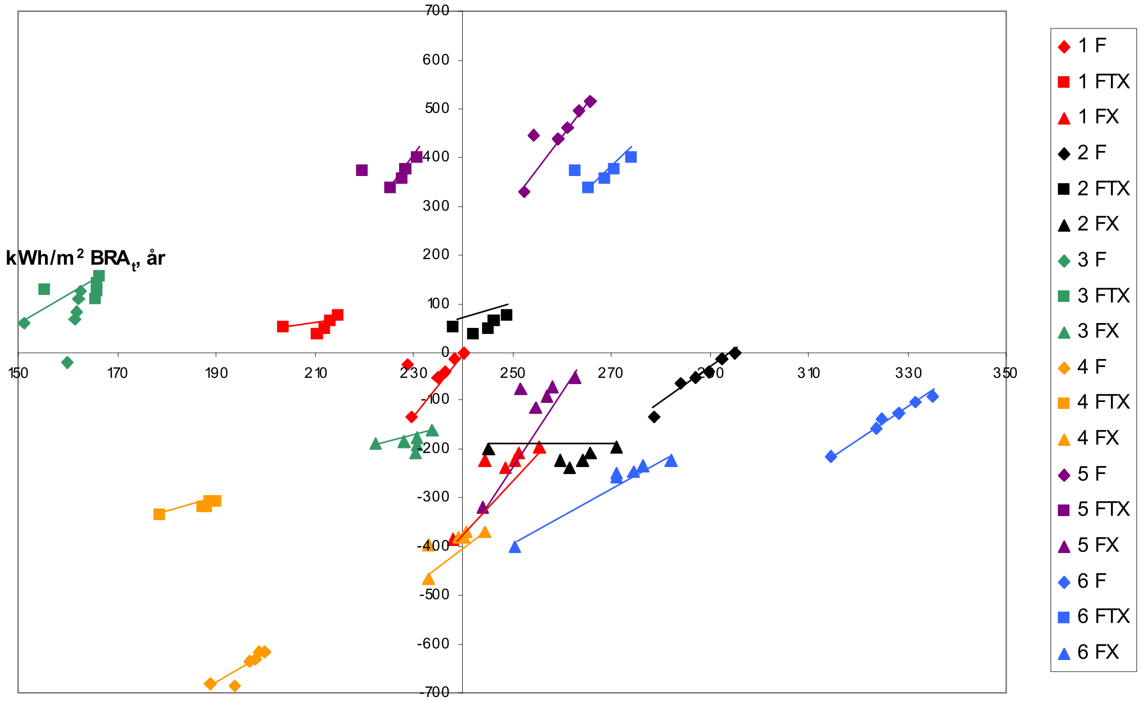

Figure 2. Case E-, ESX- and EX-ventilation for multi-family house, all simulated measures. Difference in LCC_{energy} and primary energy consumption.

2 SUSTAINABLE ENERGY END USE FROM A SYSTEMS PERSPECTIVE

2.1 *What is most efficient from an integrated energy, environmental and cost perspective – measures in the individual building or in the supply system?*

Achieving the societal sustainable development goal requires a system's perspective including both energy demand and supply. But how should efficiency measures best be prioritised, taken economical and other limitations into account? How can the best possible use of resources be reached from a system's perspective?

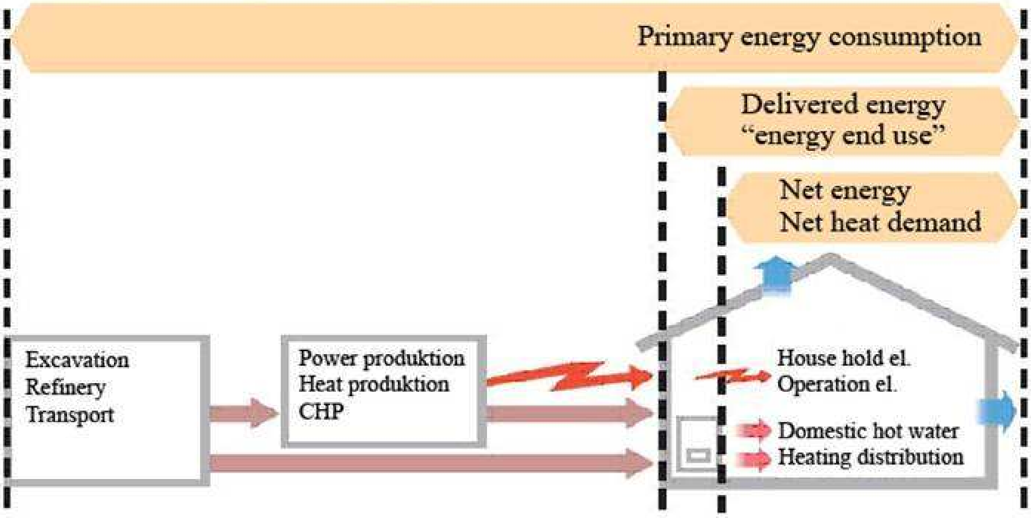

Figure 3. System boundaries for primary energy, delivered energy, and net energy respectively.

2.2 *Should you focus on delivered energy or primary energy?*

The Swedish building sector stands for 40 % of total energy consumption, CO_2 emissions are lower approximately 25 % of the national CO_2 emissions. Delivered energy has decreased by 7 % during the past three decades. However, if include all losses from exploiting the energy source and transports, energy transformation and distribution, the result is totally different. Such an analysis shows that the building sector's relative energy consumption despite all energy efficiency efforts has increased with 11 %!

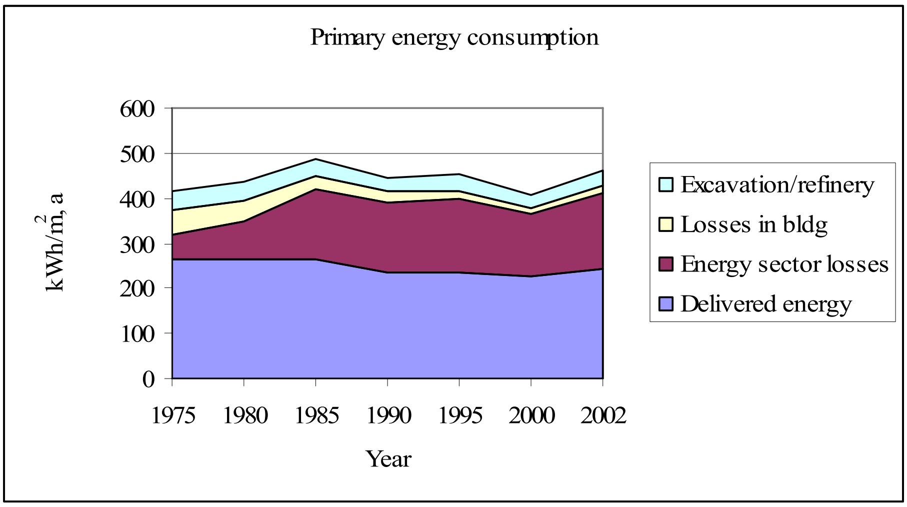

Figure 4. The Swedish building sector's energy end use from 1975 to 2002. The figure shows delivered energy and corresponding losses.

The study clearly shows that a system's perspective including both energy supply and energy demand is necessary to achieve a sustainable development. The study points out:

1. Measures and combinations of measures leading to both lower LCC costs, decreased primary energy consumption and decreased environmental impact.
2. Measures and combinations of measures which are cost efficient but lead to higher primary energy consumption and increased environmental impact, and
3. Measures which neither are cost efficient nor lead to decreased environmental impact.

The analysis carried out shows that primarily four measures or combination of measures are cost efficient (LCC) and at the same time leading to lower environmental impact compared to the two base case buildings used in the study. These four categories are (in cost-efficiency order):

1. Decreased use of electricity
2. Use CHP produced district heating
3. Reduced energy need for heating
4. Reduced energy need for heating at a minor increase of electricity end use

Some interesting conclusions from the study are:

- Environmental impact and resource need may vary by a factor two in a specific building with application of different measures, although the delivered energy only varies slightly.
- In combination with combined heat and power production (CHP) traditional exhaust air ventilation systems without heat recovery may be almost as resource efficient as balanced ventilation (exhaust and supply air system) with heat recovery, ESX.
- Primary energy consumption of heat pump solutions with an average coefficient of performance (COP) of 2.5 exceed the primary energy consumption of most solutions with exhaust air ventilation systems without heat recovery as well as systems with ESX ventilation (e.g. exhaust air heat pumps and ground heat pumps). To achieve lower primary CO_2 emissions the heat pump's COP has to exceed 2.5.
- Well-known examples of energy-efficient buildings such as Lindås Park (passive house), the Jöns Ols residential building in Lund, and the "Astronomihuset" office building in Lund show to be relatively normal regarding primary resource use (primary energy as well as primary CO_2 emission).

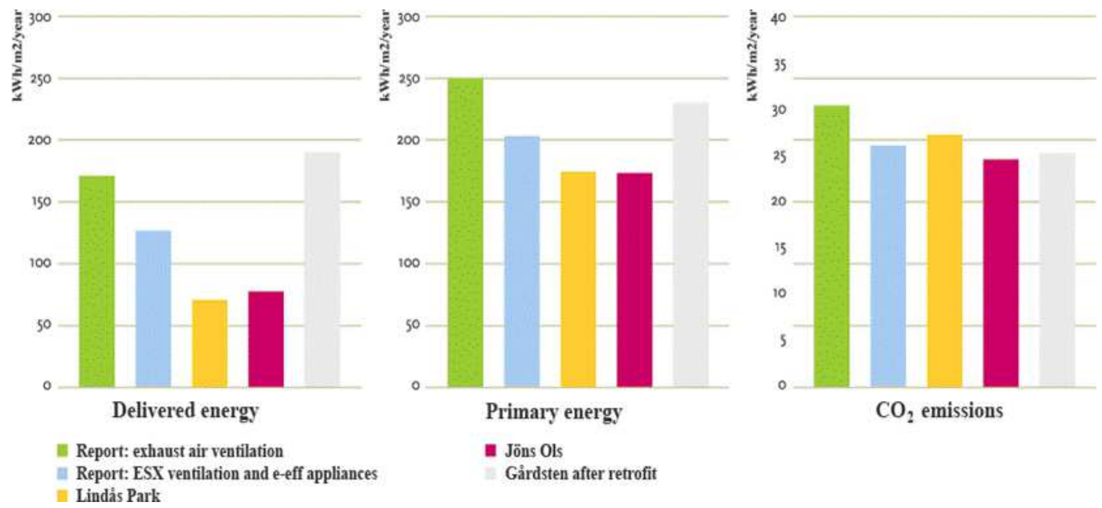

Figure 5. Comparison on delivered energy, primary energy consumption and primary CO_2 emissions between the studied residential building, Lindås Park passive house, the Jöns Ols residential building (Lund) and an existing renovated residential multi-family building in Gothenburg.

2.3 *How much lower must the energy end use for heating be to balance the use of incremental kWh electricity?*

The necessary reduction of heating energy demand to balance the environmental impact of the use of incremental kWh electricity depends on what energy supply system the comparison is based on. In this study the supply system base line is the Swedish District Heating Association's forecast on average mix of energy sources for 2010 and European marginal electricity production has been used as baseline in this study. With this supply system scenario a reduction of 3 kWh heat is needed to balance each added kWh in terms of electricity primary energy consumption. The corresponding number for primary CO_2 emissions is 5.6. The 2010 district heating forecast includes a certain share of CHP. Should the CHP produced district heating increase compared to the 2010 forecast, an even larger reduction of heat demand is necessary to balance each kWh increase in electricity demand.

In the short term perspective it is reasonable to assume that it is environmentally sound to invest in measures reducing heat demand in accordance with the ratios 3:1 between heat and electricity demand when discussing primary energy consumption, and 5.6:1 when it comes to primary CO_2 emissions. In a longer term perspective a new forecast of the district heating mix has to be made. Given the current Swedish development it is probable that such a forecast would include a larger share of CHP.

The general conclusion from the study is that to reach a sustainable energy system, it is not sufficient to focus on delivered energy only. There has to be a shift of focus towards CO_2 emissions and primary energy consumption, over the whole chain from excavation of energy sources to end use.

3 CONCLUSIONS

The main conclusions from the study are:

Primary energy consumption of heat pump solutions with an average coefficient of performance (COP) of 2.5 exceed the primary energy consumption of most solutions with exhaust air ventilation systems without heat recovery as well as systems with ESX ventilation (e.g. exhaust air heat pumps and ground heat pumps). To achieve lower primary CO_2 emissions the heat pump's COP has to exceed 2.5.

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