ENVIRONMENTAL MANAGEMENT ASPECTS FOR ENERGY SAVING IN NATURAL STONE QUARRIES

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Abstract (Times New Roman Font, Size 11pt, Bold Face)
Greek marble, and particularly the marble of the island of Thassos, is known worldwide and forms the primary type of exported natural stone from Greece. More than 4,000 enterprises, mainly SMEs, are engaged in quarrying, cutting or/and processing, manufacture of art works, ecclesiastical elements and memorials, in the trade of marble blocks and products in home and foreign markets, installation and applications. The Sector has realized important investments and exports have been constantly increasing since 1991. In 2002 and 2003, the annual production was ca 2.100.000 tons, or 3% of the world ornamental stone production. Today, the quarry production in rough blocks, despite the various problems concerning the environmental impact, has been stabilized at 0.8-0.9 million tons.
Considering the above situation and in order to prepare the Greek natural stone sector for the implementation of the EC directives for building products and for energy efficiency in buildings, the paper investigates the implementation of the environmental management system (EMS) of ISO 14001 and related energy saving potentials, in a typical medium sized operational marble quarry in the North of Greece (island of Thassos), producing white calcitic and dolomitic marble. The selected test case examines a typical, as far as equipment, quarrying methods and economic size are concerned, small to midium-sized enterprise with respect to the international scene. The systematic record of energy flows at the selected quarry can act as a prototype guideline for the energy overview of similar middle-sized quarries. On the basis of electrical and thermal energy balances and water flows, potentials for energy savings are identified and expected cost savings are calculated. Considering the structure and the operational functions of the selected quarry, the environmental impact of each independent action is evaluated. The general layout of the EMS is described according to the structure and principles of ISO 14001.

Keywords: Territory planning, Energy auditing, Environmental management system, Dolomitic marble quarries

1. Introduccion

Natural stones, such as marble, granite, limestone etc are minerals that constitute an important source of international economic wealth not only due to their inexhaustible reserves, but also thanks to their durability, flexibility and high aesthetic content. These major characteristics have guaranteed a long-lasting presence of natural stones in the international scene and generate a growing interest in their use in contemporary urban architecture, since they contribute in retaining the traditional appearance of old and in preserving the character of buildings.

The international natural stone quarry production sums up to ca. 68.7 million tonnes per annum (Laskaridis, 2008) and is characterised as a low-tech, traditional sector with fragmented commercial activities and small size of companies. More than 89% of the international quarrying activity is concentrated in nine countries, each producing more than 2 million tonnes of natural – ornamental stones per annum, namely China, Italy, India, Iran, Spain, Turkey, Brazil, Greece and Portugal. The non-European countries are relatively new comers in the international scene, with developing economies that impose stringent competition rules to the traditional economies, mainly due to the very low production costs of the former. The majority of quarrying activities worldwide are performed by SMEs, necessarily located close to the natural stone producing areas, very often in remote, mountainous areas that are not connected to the electricity supply grid.

The current work has been motivated by the competitive international economic scene and environmental legislation that necessitate rationalization of production costs, as well as by recent developments in energy production via the exploitation of local biomass and renewable energy resources. Furthermore, the implementation of the EC directives for building products and for energy efficiency in buildings impose the requirement for evaluation of the energy consumption in stone quarries and processing plants and proposal of measures that could lead to reduction of the energy consumed during exraction, processing, transporation, nstallation of a natural stone. As a first step towads this towrds this dieraction the current work investigates the potentials for energy reduction in a quarry. The selected test case is a typical SME, with quarrying activities in the North of Greece. It should be noted that there are no previous studies to be found in the open literature regarding the potentials of energy management in marble quarries.

Greek marble, and particularly the marble of the island of Thassos, is known worldwide and forms the primary type of exported stone. More than 4,000 enterprises, mainly SMEs, are engaged in quarrying, cutting or/and processing, manufacture of art works, ecclesiastical elements and memorials, trade of marble blocks and products in home and foreign markets, installation and applications. The marble quarry production, despite fluctuations, has increased during the last 40 years. In 2002 and 2003, the annual production was ca. 2,100,000 tonnes, or 3% of the world ornamental stone production. In 2004, the annual production decreased to 1,400,000 tonnes or 1.8% of the world ornamental stone production. Today the quarry production in rough blocks, despite the various problems concerning the environmental legislation and the growing bureaucracy for new quarrying licenses, has been stabilized at 0,8-0,9 million tons (Laskaridis et al. 2000, National Statistics of Greece, 2003, Laskaridis, 2008).

The selected test case examines a typical, as far as equipment, quarrying methods and economic size are concerned, small to midium-sized enterprise with respect to the international scene. The systematic record of energy flows at the selected quarry can act as a prototype guideline for the energy overview of similar sized quarries.

2. Description of Selected Test Case - Quarry Overview

The selected quarry is located on the island of Thassos, at an amphitheatric location of 440 - 530m altitude, with abrupt topographic variations and covering a total area of about 47,800 m^2. It operates since 1977, as an "open pit" quarry with several fronts and seven beds, each 6m high. It specializes in the quarrying of white dolomitic marble "THASSOS LIMENAS WHITE", marketed with the patented commercial name "PRINOS". The quarry implements EN 12440:2000. The annual productivity is ca. 3.000 m^3 in rough blocks, from 2 m^3 up to 8 m^3 according to customers' orders, and 5.000 m^3 of irregular small sized blocks with a market value ranging from 350 to 700 €/m^3. The quarry has 20 employees and can operate (due to climatic conditions) for about 10 months per year. A significant percentage of the production is exported in various European countries, China, Saudi Arabia, the U.S.A., and Singapore and is used in large buildings mainly for facings with slabs.

Quarrying operations basically involve isolating blocks from the parent ledge by cutting it free on all sides perpendicular to each other. The isolated stone block has dimensions suitable for sale and processing or it may be much larger so that further subdivision into smaller blocks may be required. The basic quarrying sequence includes pre-production operations, primary cuts, secondary cuts and finishing of blocks, removal and haulage of blocks.

One DORMAN Diesel engine of nominal power 450kVA and one PERKINS engine 2000 series of nominal power 250kVA are used to operate the mechanical equipment of the quarry that includes two air-compressors (one diesel-powered Atlas COPCO XA146 and one electric INGERSSOL Rand SSR ML-110) eight BENETTI diamond wire saws (seven of which are model Alpha 840 and one is model VIP 910) two drill machines, three pneumatic top-hammers. There exist auxiliary drilling equipment such as short plugs, hydraulic jacks, air pillows and others. In addition, the quarry uses various vehicles such as excavators and loaders, truck/dumpers, cars and jeeps. All the equipment is property of the quarry.

The advantage of using diamond wire saws for stone cutting is demonstrated by reduced manpower (3 – 4 workers only), increased cutting speed (up to 10 - 12 m^2/hour) and easy installation (Milano et Al. 2004).

3. Economic Overview of the Quarry

A typical energy audit procedure has been adopted in order to collect the necessary economic and technical data. Cost analysis indicated that for the year 2008 (Figure 1), the energy costs for the quarry mechanical equipment were 13.7% of the total operational costs. Figure 2 indicates that the annual mean volume of sales was about 200 m^3 per month. Considerable fluctuations are observed for the months of December and February, associated with the halt of quarry operations due to weather conditions. During these months productivity is very low or zero. The recorded sales (Figure 2) result from selling during these months, blocks already in stock from the summer months.

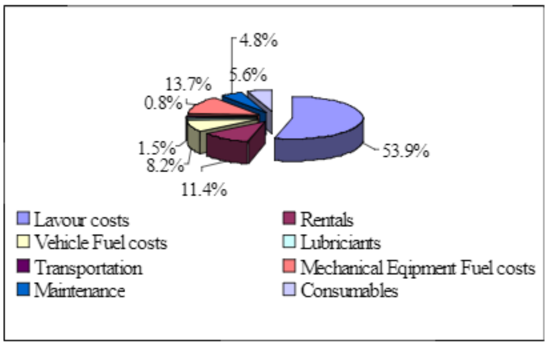

Figure 1: Typical expenses in a medium sized quarry

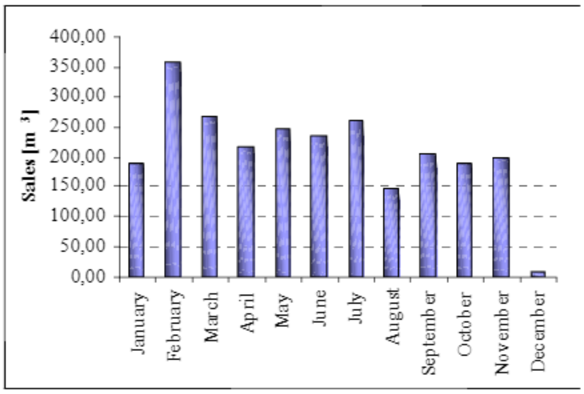

Figure 2: Mean values of monthly volume of sales

4. Overview of Energy Flows

The two diesel-powered generators cover the electric power requirements of the quarry (Table 1). The local electric energy network, driven by the two generators, comprises eight diamond wire saws, an electric air compressor and a water drill pump. In particular, the DORMAN generator supplies the eight diamond wire saws and the water drill pump. The PERKINS generator supplies only the electric air-compressor.

Compressed air is used for the operation of the drilling equipment and it is produced with the help of two air-compressors. In specific, the INGERSOLL Rand compressor supplies air to the two drilling machines, whereas the Atlas COPCO compressor supplies the three pneumatic top-hammers. In case only one of the two drills is in operation, the diesel-powered compressor stops and the electric one (INGERSOLL Rand) supplies the one drill and the three pneumatic top-hammers.

Significant amounts of water, about 80m^3, are consumed daily at the quarry in order to cool and clean the diamond saw wires and for the drilling procedure. The water originates either from dams located on the mountain at a higher altitude than the quarry, or from a water-drill, especially during the summer months. Water is stored in three overflow-tanks with dimensions 6m x 3m x 2m, where from water is supplied to the quarry under free-fall flow.

5. Energy Balances – Evaluation of Energy Consumption

The energy balance has been calculated taking into account the technical characteristics of the available equipment and the energy flows. It indicated that 35.8% of produced energy remains unexploited, since both generators are over-dimensioned. The Dorman and Perkins generators produce, respectively, 41.8% and 25.0% more energy than the current consumption requirements. This is the result of non-optimal organization of the local electric power network as well as the absence of energy management.

Further analysis of available data demonstrated that the diesel oil consumption is ca. 33.4% higher than the theoretically expected one. This fact is in agreement and supports the above initial finding of non-optimal energy management at the quarry.

The energy saving potential is limited due to the fact that the two generators produce the amount of power that it is approximately required for the current operation. However, the operation of the quarry at its optimum energy consumption point, requires the reduction of power production by 6.6% and the resulting maximum energy saving would be only 4.5%. Consequently, the anticipated saving in expenditure is calculated equal to 5,975€, and corresponds to 6.1% of operational costs for the year 2008.

The above analysis indicates that for the examined case, medium or high capital cost energy saving measures will lead to solutions that are not financially viable.

6. Overview of Environmental Management System

The implementation of an Environmental Management System (EMS) in natural stone quarries is a step towards the achievement of low environmental impact and enhancement of public acceptance. The EMS (Ofori, G. et al. 2001, Von Ahsen et al. 2001) can become a powerful tool in the hands of enterprises that wish to evaluate the environmental impacts of their activities, set the basis for rational re-arrangement of internal structure, adopt workers' training and improve their economic competitiveness, although the cost for its application is considerable. It should be noted that the enterprise, additionally to the EMS, must introduce a regular Environmental Audit System which is a systematic and documented verification process of objectively obtaining and evaluating evidence to determine whether the organization's EMS conforms to audit criteria and for communication of the results of this process to management.

ISO 14001 constitutes the most widely approved environmental management standard. It was first released in September 1996 and consists of specifications and guidelines that can be objectively evaluated from an independent bureau of standardization. It does not demand specific environmental achievement. Recent trends regarding the implementation of ISO 14001 focus on formulating specified guidelines on products or services, namely the Product Category Rules (PCRs). The PCRs establish "common and harmonized" rules when estimating the environmental impact of a category of products. As considers the marble sector, the PCR entitled "Marble and other calcareous stone, granite sandstone and other monumental or building stone" is under preparation under the product category of "Non-metallic mineral products" (http://www.environdec.com).

For a marble quarry, like the one described above, the typical structure of ISO 14001 is the following:

6.1 Commitments and Policy

The commitment of the management of the quarry for pollution prevention, continuous improvement of environmental performance, intention to comply with legislation should be included in the company's mission statement and policy. This policy involves all personnel, workers and managers in order to assure the integrated implementation of the standard.

6.2 Evaluation of environmental impacts

In order to apply ISO 14001, it is necessary to identify operations or actions that interfere with the environment, assess their impacts and evaluate their significance (Table 1).

Table 1: Summary of environmental assessment

Action	Environmental impact	Current practise
Production of electric power	Pollutant emission from fossil fuel combustion	-
Production of electric power	Excess energy production impacts pollutant emission	-
Quarrying – cutting/stone block removal	Waste-stone production	Removal from operation site – disposal in vicinity of quarry
Hole drilling – block cutting	Liquid sludge	-
Quarrying - cutting	Dust production	Protective masks for personnel
Hole frilling - quarrying – cutting – block removal	Noise from machinery operation	Protective head-sets for personnel
Drilling - cutting	Vibrations	-
Vehicle operation	Pollutant emission for fuel combustion	-
Vehicle operation	Dust from ground	Protective masks for personnel

Environmental consequences may stem from solid wastes - that are mainly the non-usable pieces of quarried stones - from liquid wastes - principally the sludge produced from the cutting operations using water-cooled diamond saws - and from air-borne pollution, which is linked to the fuel consumption by the generators and vehicles.

The most important environmental issue of quarrying, drilling and block cutting-removal operations is the management of produced quarry "wastes" (low quality, irregular sized and shaped, faulty blocks).

Although quarry solid wastes are inorganic and non-hazardous, their local, continuous and long-term deposition and accumulation may change the ecological profile. For the examined quarry, it has been estimated that only ca. 30% of marble excavated is of high quality, sold in the market as top-class product.

A further 20-30% of the production enters the market as low-quality product, whereas the rest is deposited at the quarry as waste material. The implementation of modern non-intrusive diagnostic methods for deposit quality recognition can reduce the amount of low quality production but it is currently restricted due to cost and lack of experience. Installation of a mobile crushing-grinding-pulverisation unit at the quarry premises can offer a permanent solution for the exploitation of small size wastes. The latter, after achieving an appropriate size, may be used as aggregates in construction applications (e.g. in roads, bridges, harbours), in cement and concrete production or as filler or whitener in paper, plastics, paints, or pharmaceutical products, depending on their mineralogical, physico-mechanical and aesthetic properties.

Liquid wastes and gaseous pollutants from quarries have a lower environmental impact. Non-hazardous liquid sludge (water plus stone power plus earth) results from the water-cooling of drills and diamonds-saws. Sprinkling of water on the diamond-saw blades and on the drills reduces significantly the amount of dry-dust, which would have otherwise floated on the air, with possible effects on the respiratory system of operators. Despite the significant amounts of water consumed (approximate consumption: $80m^3$ for 12.5 m^3 production per day), collection and recycling of sludge is not possible due to the nature of the operations. Another source of dust are the vehicles (trucks, loaders, excavators etc) needed for the quarry operations. It is also easily and regularly managed via wetting the ground.

Fuel consumption by the quarry vehicles and for the production of energy is essentially linked to the formation of pollutants, such as CO_2, CO, NOx, soot emissions etc, and thereby contributes to the long-term climate change. In the case of the examined quarry, this effect is minimal for the local area, since it is located on a mountainous area of an island. However, the irrational use of energy has as a consequence the excessive consumption of an important fossil fuel (diesel) that has to be transported to the remote quarry area, generating further environmental impacts.

All types of quarrying operations generate noise and vibrations e.g. due to the movement of the trucks, the operation of wire saws, drills, power generators etc. It is also a fact that the operation of quarries in the vicinity of inhabited areas can have significant visual and noise impact for the local area. However, the examined quarry is not located in an area of specific residential or ecological interest.

Overall, the above-described environmental effects are of low intensity and concern only the quarry area. Waste management and visual impact are exemptions to abovementioned conclusion. The current practice including waste management is deficient, since legislation (Law 2939/2001 “alternative disposal of wastes and other packaging”) is not effective and there are doubts concerning the disposal.

6.3 Laws and regulations

There is a number of National and European Laws and Regulations related to quarry operation and environmental performance, such as: Law 669/77 concerning “quarry’ exploitation”, Law 1428/84 concerning “exploitation of quarries and other regulations”, Law 2939/2001 concerning “alternative disposal of wastes and other packaging” etc.

6.4 Objectives and Actions

Following the recognition of the activities that interfere with the environment a plan of objectives and actions to improve the environmental performance is compiled (Table 2).

Table 2: Objectives and Actions

Objectives	Actions
Solid waste reduction and sustainable waste management	Sell wastes directly as low quality stone or as aggregate, for gravel or filler production
	Installation of mobile crusher – grinder – pulveriser for local exploitation of wastes
	Use of contemporary technologies for deposit evaluation e.g. radars, ultrasonic methods
Noise and vibration reduction	Use of new equipment and of novel excavation technologies
	Replacement of electromechanical equipment
Minimisation of non utilized power	Regular energy audits
	Implementation of energy saving measures
	Usage of renewable energy sources
Reduction of pollutants production, dust and emissions	Implementation of recent anti-pollution measures in vehicles
	Sprinkle the ground with water
	Water the surface of the stone before drilling-cutting
Visual impact	Rehabilitation of environment through plants – architectural interventions

6.5 Environmental management system

The adoption of an environmental management system summarizes the environmental objectives and specifies the actions need in order to improve the environmental performance of the quarry. The personnel responsible for the implementation and supervision of ISO 14001 should be assigned (e.g operations or mineralogical engineer, chief operator of electromechanical equipment).

7. Conclusions

The paper investigated the energy saving potentials in a typical medium sized operational marble quarry in the North of Greece (island of Thassos) producing white dolomitic marble. It has been demonstrated that considerable amounts, up to 35.8%, of energy produced in the quarry remain unutilized. The analysis revealed the importance of re-arranging the local electric network distributing power to the various pieces of equipment of the quarry and optimizing the energy distribution network taking into account specific requirements of the quarrying process.

Consequently, the best practice for energy saving in the examined marble quarry is to create an action plan that consists of zero capital-cost saving measures. These actions focus on the optimization of the performance of the quarry by implementing training programs for the personnel, organizing audits, regular servicing and repairs of existing equipment.

As far as the implementation of ISO 14001 concerned, the benefits achieved are cost savings associated with rational management of raw materials (power and water), reduction and exploitation of wastes produced, acquisition of competitive benefit, improvement of personnel and workers, rearrangement of internal structure and compliance with legislation.

The work sets the basis for the introduction of new technologies in the tradition natural stone sector that will impact work organization, corporate profitability and employment and will enhance the economic growth of the Sector.

The investigated energy saving measures and energy production scenarios as well as the perspectives for implementation of ISO 14001, although not directly profitable for small, isolated businesses, they may by easily applicable in medium and big size businesses and in cooperatives in countries such as Spain, Italy, etc. where several quarries are located in the same area and the short distance between facilitates collaboration in the field of energy production, water and waste management.

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