IMPROVEMENTS IN ENERGY AND WATER CONSUMPTION PERFORMANCES OF A TEXTILE MILL AFTER BAT APPLICATIONS

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ABSTRACT

IMPROVEMENTS IN ENERGY AND WATER CONSUMPTION
PERFORMANCES OF A TEXTILE MILL AFTER BAT APPLICATIONS

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European Union's Integrated Pollution Prevention and Control (IPPC) Directive forms a comprehensive framework for industries mentioned in the Annex 1 of the Directive concentrating on the reduction of the environmental impacts of the industrial activities which can be implemented by the BREF Documents that provide guidelines for each sector. Among those industries, textile is a water and energy intensive one. In the present study, gains in terms of energy and water consumptions were assessed in a denim producing textile mill following the adaptation of related BAT measures.In this respect, installation of flow meters, use of semi-counter current rinsing applications; minimization of wash waters in the water softening plant, reuse of concentrate stream from reverse osmosis plant and compressor cooling waters resulted in reduction from 6,000 to 4,850 tone/day of total water consumption in the period of January'05-December'07. Consequently, specific water consumption in the mill was decreased from 78 to 55 L/kg textile by 29.5% which is close to lower limit of the range suggested in BREF Textile Document (i.e. 50-100 L/kg fabric). Use of waste heat from finishing wastewater streams in heating up the washing waters, heat-insulation and maintenance applications in addition to BAT measures taken for water minimization reduced specific energy consumption from 0.0100 to 0.0091 Gcal/kg textile resulting in 9% reduction in the period of January'05-December'07, although, energy consumption was increased from 786 to 804 Gcal/day. This achieved level of specific energy consumption was in the reference range mentioned in BREF Textile Document (i.e. 8-20 kWh/kg fabric).

Keywords: BAT, Best Available Techniques, Energy consumption, IPPC Directive, Textile industry, Water consumption

ÖZ

TEKSTİL ENDÜSTRİSİNDE BAT UYGULAMALARI SONRASINDA SU VE ENERJİ KULLANIMI PERFORMANSI DEĞERLENDİRMESİ

Kocabaş, Ayşe Merve
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Şubat 2008, 152 sayfa

Avrupa Birliği Entegre Kirlilik Önleme Direktifi, Ek-1 kısmında yer alan endüstrilerin çevresel etkilerini azaltmaya yönelik uygulamaları teşvik eden, kapsamlı bir direktiftir. Her endüstri için hazırlanmış "Mevcut En İyi Teknikler" Referans Dökümanları bu uygulamalara kılavuzluk etmektedir. Bu endüstriler içinde, tekstil, su ve enerji yoğun endüstrilerden biridir. Bu çalışmada, denim üreten bir tekstil fabrikasında "Mevcut En İyi Teknikler" in uygulanmasından sonra enerji ve su tüketimindeki kazançlar incelenmiştir. Bu kapsamda, debimetrelerin takılması, ters yıkama prensibinin uygulanması, su yumuşatma tesisinde rejenerasyon suyunun azaltılması, ters osmos ünitesinden çıkan atık suların ve kompresör soğutma sularının yeniden kullanılması ile toplam su tüketimi Ocak'05-Aralık'07 döneminde 6000 ton/günden 4850 ton/güne düşmüştür. Sonuç olarak, fabrikadaki spesifik su tüketimi 78 L/kg kumaştan 55 L/kg kumaşa düşerek %29.5 azalmıştır. Böylelikle, "Mevcut En İyi Teknikler" Referans Dökümanında belirtilen spesifik su tüketimi aralığının alt limitine (50-100 L/kg kumaş) yaklaşmıştır. Terbiye sıcak atıksularının süreçlerde kullanılacak yıkama sularını ısıtmak amacıyla kullanılması, yeterli olmayan bölgelerde izolasyonun iyileştirilmesi, ısıtma sistemlerine ve ramözlere periyodik olarak bakım uygulamalarının enerji tüketiminin azaltılmasında etkili olduğu söylenebilir. Bunların yanı sıra, su tüketiminin azaltılması amacıyla uygulanan kompresör soğutma sularının geri kullanımı ve ters yıkama prensibinin uygulanması da e-

nerji tüketimini azaltıcı önlemler olarak sayılabilir. Ocak'05-Aralık'07 döneminde, toplam enerji tüketiminin 786 Gcal/günden 804 Gcal/güne yükselmesine rağmen, yukarıda belirtilen uygulamalar sonucunda spesifik enerji tüketiminin 0.0100 Gcal/kg kumaştan 0.0091 Gcal/kg kumaşa düşerek %9 azaldığı gözlemlenmiştir. Ulaşılan spesifik enerji tüketimi değeri, "Mevcut En İyi Teknikler" Referans Dökümanında belirtilen aralığa (8-20 kWh/kg kumaş) tekabül etmektedir.

Anahtar Kelimeler: BAT, Mevcut En İyi Teknikler, Enerji tüketimi, IPPC Direktifi, Tekstil endüstrisi, Su tüketimi

To my beloved grandfather...

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LIST OF ABBREVIATIONS

BAT	Best Available Techniques
BREF	BAT Reference Document
CHP	Combined Heat and Power
EU	European Union
IPPC	Integrated Pollution Prevention and Control
KASKİ	Kayseri Water and Sewerage Directorate
METU	Middle East Technical University
MoEF	Ministry of Environment and Forestry
SPO	State Planning Organization
UNEP	United Nations Environment Programme
USA	United States of America
USEPA	United States Environmental Protection Agency

CHAPTER 1

INTRODUCTION

In the European Union (EU) countries, industrial pollution has been managed by "integrated" approach taking into account emissions to water, air and soil as a whole. This approach deals with pollution rising from industrial activities by considering the production phases rather than setting limit values for the discharges or emissions. In other words, the approach adopts 'pollution prevention' rather than 'end-of-pipe' concept. Integrated Pollution Prevention and Control (IPPC) Directive (96/61/EC), published in 1996 by EU, covers legal arrangements and requires the inspecting authorities to give permits to the industrial facilities and to monitor their environmental performances within this general approach. In short, the IPPC Directive requires an integrated approach to the environmental protection of air, water and land, through the application of Best Available Techniques (BAT), establishing operating conditions and emission limit values in permits for industry.

According to the Directive "certain measures designed to prevent or, where that is not practicable, to reduce emissions in the air, water and land from the activities listed in Annex I, including measures concerning waste are taken in order to achieve a high level of protection of the environment taken as a whole" [9]. In view of that, BAT Reference (BREF) Documents, published by European IPPC Bureau, are considered to be strong guidance documents to implement the requirements of the Directive. The BREF Documents present operating conditions for industrial activities to improve control of industrial processes while ensuring that environmental impacts of the industrial activities are prevented or minimized as possible.

Operators of industrial installations where one or more activities listed in Annex I of the IPPC Directive are carried out are required to obtain an authorisation (environmental permit) from the authorities. A wide range of polluting activities which are categorized into six are listed in Annex I: energy production, production and processing of metals, minerals, chemicals, waste management and others among which textile manufacturing is listed in 'others' [9].

Textile industry, being one of the most complicated and oldest industries, plays a major role in Turkish economy as any other developing countries. Exporting almost two thirds of the textiles produced, textile industry has a share of 6 – 7% in total Turkish export. In this share, EU market of Turkey is enlarged every year since Customs Union came into effect and is in the front rank with 44.5% in Turkish textile exports [1]. Therefore, EU countries are the most important Turkish textiles importers. Taking into account the share of textile industry in the Turkish economy, EU export of Turkish textiles is one of the most significant economical tools in Turkey.

Turkey being a candidate country for full membership to the EU is in the period of adopting legal requirements and sanctions of the Union. Among many other Directives, the IPPC Directive is of priority as manufacturing industry is wide spread in Turkey and its implementation requires heavy investment. Meanwhile, throughout the EU, environmental concerns in manufacturing industry have increased recently since the IPPC Directive was published. For that reason, many countries that import Turkish textiles (EU and the USA being the first) require quality tests, covering environmental aspects, before, during and after the production processes. Besides, those concerns are even declared as 'non-tariff barriers' in terms of exports in manufacturing industry nowadays [10]. Moreover, as water shortage is experienced and energy sources and raw materials are expensive recently, raw materials, energy and water consumptions are to be minimized by utilizing technologies which enable recovery in textiles industry in Turkey. In this respect, Textile and Apparel Specialist Commission Report of 8th Five Year Development Plan of State Planning Organization (SPO) stated that the current water consumption for textile industry being 131 litres of water per kilogram finished textile should be reduced to 80 litres of water per kilogram finished textile by using energy and water saving technologies [11]. In the same report, the significance of energy consumption and related expenses in textile industry are also emphasized. Additionally, target energy consumption is stated as 40,000 kilojoules per kilogram fabric. Therefore, the adoption of the IPPC Directive in guidance of BREF Documents to textile industry is of priority among other industries in Turkey. For this purpose, Ministry of Environment and Forestry (MoEF) has been conducting several projects for the adaptation and implementation of the Directive. Additionally, BREF Document for textile manufacturing has been fully translated into Turkish by the Turkish Textile Finishing Manufacturers Association.

In the BREF Document, textile industry is stated as one of the most water and energy intensive industries among others. Instead of covering all of the textile manufacturing processes, BREF Document for textile manufacturing specifies the activities to be covered as “plants for pre-treatment (operations such as washing, bleaching, and mercerisation) or dyeing of fibres or textiles where the treatment capacity exceeds 10 tones per day”.

The main environmental concern in the textile industry is about the amount of water discharged and the chemical load it carries. Other important issues are energy consumption, air emissions, solid wastes and odours, which can be a significant nuisance in certain treatments [6]. In BREF Document, for textile manufacturing, many techniques are suggested related to process modifications, pollution prevention opportunities, use and optimization of water and chemicals, control of raw materials, recovery, reuse and recycle options which in turn are experienced to result in significant reductions in terms of chemicals, water and energy without distorting the final product quality and hence improve production efficiency.

1.1 Objective and Scope of the Study

The major goal of this study is to assess the water and energy consumption performances of a textile mill in Turkey after the application of appropriate BAT measures for minimization of water and energy consumption. The study is carried out as a part of the project titled “Adaptation of IPPC Directive to a Textile Mill in Turkey” which is conducted by Environmental Engineering Department of Middle East Technical University (METU) in cooperation with the Ministry of Environment and Forestry. The project is the first implementation of the IPPC Directive and BREF Document to an industrial facility in Turkey. In the project, all the aspects of IPPC Directive including application of appropriate preventive measures against pollution, waste management, energy efficiency, prevention of accidents and risks and emissions to water, air and land have been studied. Hence, assessing water and energy consumption performances in this study is a part of the abovementioned project.

For the purpose of the project, a denim production mill has been selected. The selected mill, one of the worlds and EU’s leading denim cloth producers is in the scope of the IPPC Directive with a production capacity of 75 tones per day. Considering the environmental impacts of textile industry, performance assessment in the selected mill in terms of water and energy consumptions is vital. Additionally, reduction in water and energy consumptions which are indispensable in terms of both technical and economical aspects are analysed in the selected mill.

Within this framework, the application of the preventive measures included in sector specific BREF Document is essential in order to implement water and energy management in the selected mill. To this purpose, initially, production processes were analysed in detail by the project team. Then a set of preventive measures was suggested to the industrial facility. The facility adapted the appropriate BAT measures suggested which were considered to be technically and economically feasible. Subsequently, in the present study water and energy consumptions of the mill are analysed in order to investigate the effects of the applied BAT measures that were determined in cooperation with the managerial authorities of the mill.

According to the initial results from the studies conducted in the mill, water and energy consumptions were observed to mainly stem from dyeing and finishing processes with a portion of more than 50%. Moreover, the wastewater originating from those two processes were found to compose 80% of the total wastewater directed to the on site wastewater treatment plant in the mill. Additionally, water consumption and wastewater generation result in energy consumption which proves that energy consumption is also highest in those two processes in the selected mill [6].

Consequently, water and energy consumption performances of the selected mill were analysed and assessed after the application of appropriate BAT options in the selected mill concentrating on the mentioned processes. During the study, water and energy consumptions for the factory specific processes, are analysed. By considering the BAT options applied beforehand, the effects of the application of the BATs in terms of water and energy consumptions were assessed. In this respect, these assessments were made not only for dyeing and finishing processes but also for the whole plant.

CHAPTER 2

TEXTILE INDUSTRY

Textile industry is one of the oldest industries around the world. It is also one of the most complicated and longest industries among all manufacturing industries. The process chain and types vary according to the desired final product (e.g. synthetic fibres, woven/knitted fabric) which can be classified as clothing, home furnishing and industrial use (e.g. carpets, jeans, bedclothes etc.) [12, 6]. Generally, the textile process chain composes of pre-treatment, dyeing and finishing processes. However, there is a variety of sub-sectors included in textile industry which require different process chains. Besides, as fashion trends change according to the public demand, manufacturing techniques are continuously changing. Therefore, the process chain of different end products cannot be generalized whereas, the industry is quite complicated in general [6, 13, 14].

Throughout the process chain of different end products of textile industry, a considerable amount of water, energy and chemicals are consumed in process baths. Furthermore, for certain processes, elevated temperatures are required for the quality of the product. Therefore, the environmental impacts of the industry are inevitable [6, 13, 14].

Water and energy is consumed in nearly every step of the process chain of textile manufacturing. However, the majority of those resources are utilized in wet processes such as dyeing, sizing and finishing in general. In pre-treatment of raw material, a considerable amount of water in scouring and energy in spinning is consumed. Dyeing process is carried out by saturation of the material via dye baths where huge amounts of water is consumed with chemicals, dyestuffs and auxiliaries no matter what the process mode is (semi-continuous/continuous or batch). Sizing and finishing processes also require hot water baths saturated with different chemicals. Plus, heat and electricity requirements are also of concern. Furthermore, the resulting wastewater from all those process baths is environmentally intensive as wastewater includes dyestuffs, detergents, auxiliaries and a variety of chemicals [6, 13, 14]. Due to the reasons mentioned above, the environmental impacts of the textile industry are obvious and considered by industrial environments due to the strict regulations set by the governments. Hence, it can be considered that most of the countries shall put effort to deal with the environmental impacts of a variety of industries.

2.1 Textile Industry in Turkey

Textile manufacturing is one of the major industries that develop Turkish economy like in any other developing countries. Textile is also one of the first industries established in Turkey. The development of Textile manufacturing grew rapidly after the collapse of Ottoman Empire and started exporting textile products in 1960s by the incentive measures applied. Especially, Turkish Textile Industry became one of the leading worldwide, after 1980 economic reforms due to export oriented economic policies and supports introduced for the import of machinery equipment, mainly. Today, Turkish Textile Industry uses modern technology and can compete in international markets. In 2002, the manufacturing production share of textiles and clothing industry was 21.5% in which 44% was exported [15, 16].

In recent years, textile industry has a share of 6 – 7% in total Turkish export. According to one of the most recent reports, the export share of textiles in total export of Turkey remained almost the same with 6.6% in 2005-2006 periods. On the other hand, the export of Turkish Textile Industry improved by 14.7% in 2006 when compared to the previous year by reaching 5.6 billions of $. Table 2.1 represents the details of the data mentioned above [1].

In textiles export of Turkey, cotton textile goods occupy a share of 21.8% while knitted fabrics' share is 16.9%. Additionally, textiles goods with man-made fibres and staples develop 16.9% and 16.8% of textile export, respectively. Additionally, textile industry outpaced apparel industry in which export share has increased by 2.1% in 2006 compared to 2005 [1].

The so called traditional EU market of Turkey in terms of textiles is in the front rank with 44.5% in Turkish textile export. The textile export share of 25 importing EU countries, Italy being the first, is reported to reach 2.5 billions of $ in the same period mentioned above. Another significant importer of Turkish textiles is OECD countries. However, export share of Turkey has reduced in 2006 in OECD countries because of the reduction in export to the USA

Table 2.1: Textiles and raw materials share in total export [1]

Unit: 1000$	**2005**	**2006**	**Change in 2005/2006** (%)
Total Export	$73,444,821$	$85,761,134$	16.8
Textiles and Raw Materials Export	$4,860,887$	$5,576,097$	14.7
Textiles and Raw Materials Export Share (%)	6.6	6.5	
Industrial Export	$62,691,423$	$73,908,460$	17.9
Textiles and Raw Materials Share in Industrial Export (%)	7.8	7.5	

by 9.6%. The export shares of Turkish textiles in the abovementioned countries and other countries are presented in Table 2.2 [1].

In Turkey, textile industry composes 6 – 7% of the total export in which EU and the USA are the most significant importers of Turkish textile products with 80% and 14% respectively. Especially by EU-Turkey customs union that entered into force in 1996, EU's textile imports characteristics were changed with the sharp increase in Turkey's market share [8].

Moreover, according to Nordas, the greatest textile supplier to EU was Turkey with a share of 10% and 16% in 1995 and 2002, respectively [8]. The data in Figure 2.1 represent the situation [8]. Consequently, EU countries are the most important Turkish textiles importers. Hence, EU export of Turkish textile industry is one of the most significant economical tools in Turkey.

Table 2.2: Turkish textile export record in 2006 [1]

Unit: 1000$	**2005**	**2006**	**Change in 2005/2006** (%)
EU Countries	2,047,832	2,482,093	21.2
Other OECD Countries (USA, Canada, Switzerland etc.)	280,492	272,682	−2.8
Other EU Countries (Romania, Bulgaria etc.)	507,288	597,316	17.8
Former Soviet Union Countries (Russian Fed., Azerbaijan etc.) (%)	510,585	636,974	24.8
Middle East Countries (S. Arabia, Israel etc.)	347,280	365,485	5.2
African Countries (Egypt, Tunisia etc.)	285,215	349,753	22.6
Other Asian Countries (China, India, Malaysia etc.)	183,643	202,107	10.1

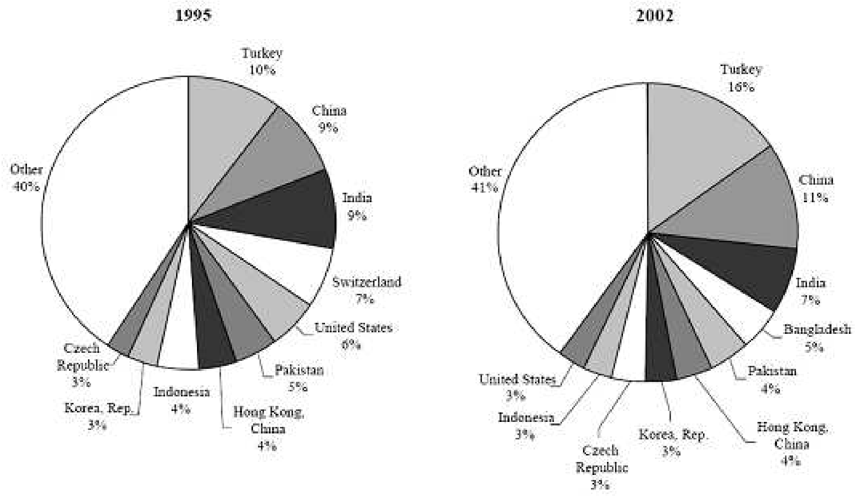

Figure 2.1: Sources of imports of textiles to the EU [8]

CHAPTER 3

LITERATURE SURVEY

3.1 Integrated Pollution Prevention and Control

Industrial Revolution introduced by Britain in 1700s, brought increase in industrial productivity by mechanization as well as lower costs for manufactured products and an increase in the standard of living. For job opportunities that industrialization offered, people tend to move from rural to urban areas which in turn brought urbanization. The rapid growth of mechanical production also pushed increasing demand of energy, raw materials and natural resources. Increase in productivity in common areas and urbanization resulted in severe stress on the environment by the wastes generated. For that reason, a new industrial "waste management philosophy" was developed stressing elimination/minimization of waste production at the source in the industry's production area. This paradigm became known by several names including 'waste minimization', 'source reduction', 'waste reduction', 'green engineering' and 'sustainable engineering' or 'pollution prevention' [17].

The concept of waste minimization was introduced by the U.S. Environmental Protection Agency (USEPA) in 1988 after it is realized that industrial wastes should be managed other than the conventional methods. In this respect, waste minimization has always been a challenge in all of the industrial activities in terms of both environmental and economical means. Although, pollution prevention and waste minimization terms are used interchangeably, waste minimization is a broader concept than pollution prevention. Waste minimization is generally defined as a systematic reduction of *(i)* raw material consumption, *(ii)* water and energy use, *(iii)* emissions to air, land and water and *(iv)* direct use of materials and services [18].

Waste prevention approach and its techniques are defined as on-site reduction, source reduction of waste by changes of input raw materials, technology changes, good operating practices and product changes. Off-site recycling techniques are also of concern in waste minimization techniques; however, those techniques are lower in priority when compared to on-site prevention or minimization of waste [19].

Waste minimization techniques are variable depending on the type of the process, equipment utilized, desired end product or raw material processed. There are a number of methods to reduce waste in households, industries, laboratories and businesses, the applications are available online. Additionally, waste minimization technologies mentioned above can provide immediate or short term payback while others may payback in several years. Furthermore, capital, operational and maintenance costs of techniques are variable. Good housekeeping practices are generally low while technology changes in production processes can be higher in terms of initial cost [20].

Waste minimization favours the industrial activities in terms of both economic and business sense. In this respect, waste minimization applications provide reductions in:

- The quantity and toxicity of hazardous and solid waste generation;
- Raw material and product losses;
- Raw material purchase costs;
- Waste management recordkeeping and paperwork burden;
- Waste management costs;
- Workplace accidents and worker exposure;
- Compliance violations; and
- Environmental liability.

Additionally, "waste minimization applications improve production efficiency, profits, good community relations, employee participation morale, product quality and overall environmental performance of the businesses and industrial activities" [20]. Hence, it is apprehended that waste minimization approaches can be applied to all pollution-generating activities, including those found in the energy, agriculture, federal, consumer, as well as industrial sectors [21].

In this respect, industrial activities and resulting pollutions in EU countries are managed by "integrated pollution management" approach. This approach is based on management of waste streams with the production processes instead of enforcing discharge standards promoting end-of-pipe treatment technologies. Within this framework, waste prevention/minimization techniques are considered in all production phases to minimize the emissions to air, water and land as a whole. For that purpose, EU's IPPC Directive (96/61/EC) was published in 1996. The Directive covers legal arrangements and requires the inspecting authorities to give permits to the industrial facilities and to monitor their environmental performances within this general approach. The purpose of the Directive is "to achieve integrated prevention and control of pollution arising from the industrial activities". Moreover, IPPC Directive lays down measures designed to prevent or, where that is not practicable, to reduce emissions in the air, water and land from the abovementioned activities, including measures concerning waste, in order to achieve a high level of protection of the environment taken as a whole" [9].

Furthermore, the Directive was published in 1996 and is now in force for all of the EU countries since October 2007. This approach points out the flexibility of the Directive. Additionally, the permit given by the Directive takes the operating conditions and geographical status of the facilities into account while setting emission limit values. Therefore, permits consider individual characteristics of the facilities covering IPPC Directive [9].

The permit can be given to new installations as well as existing ones, on condition that the operating installation's emission limit values are inline with the values set by the permit. The Directive indicates that the environmental quality standards set are achievable by the use of BATs. 'Best Available Techniques' shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole [9].

Another characteristic of the Directive is the public participation. According to the IPPC Directive, "Member States shall take the necessary measures to ensure that applications for permits for new installations or for substantial changes are made available for an appropriate period of time to the public, to enable it to comment on them before the competent authority reaches its decision" [9].

According to the Directive, “Member States shall take the necessary measures to provide that the competent authorities ensure that installations are operated in such a way that *(a)* all the appropriate preventive measures are taken against pollution, in particular through application of the best available techniques; *(b)* no significant pollution is caused; *(c)* waste production is avoided; where waste is produced, it is recovered or, where that is technically and economically impossible, it is disposed of while avoiding or reducing any impact on the environment; *(d)* energy is used efficiently; *(e)* the necessary measures are taken to prevent accidents and limit their consequences; *(f)* the necessary measures are taken upon definitive cessation of activities to avoid any pollution risk and return the site of operation to a satisfactory state” [9].

In short, the IPPC Directive requires an integrated approach to the environmental protection of air, water and land, through the application of BATs, establishing operating conditions and emission limit values in permits for industry. Integrated approach emphasizes the significance of covering waste management with production process, as the ultimate aim is to reduce the pollution generated by industrial activities without distorting the quality of the product [9].

In this respect, industrial activities are categorized in six groups as energy industries, production and processing of metals, mineral industry, chemical industry, waste management and other activities in section 6.2 of Annex I of the Directive in which textile industry is covered under ‘others’ heading . For textile industry, the Directive indicates that “plants for pre-treatment (operations such as washing, bleaching, and mercerisation) or dyeing of fibres or textiles where the treatment capacity exceeds 10 tones per day” are to take the permit regulated by the Directive for operation [9].

3.2 Water Consumption in Textile Industry

In textile industry, known to be water intensive, the main environmental concern is the amount of water discharged and the chemical load it carries. Other important issues are energy consumption, air emissions, solid wastes and odours, which can be a significant nuisance in certain treatments. The fact that production of textiles affords a great variety of processing steps requiring use of large amounts of water and chemicals has put efforts on minimization of use of, and where applicable reuse of raw materials and water within the production steps

[6]. In this respect, the stringent environmental regulations for discharge today are forcing the dyers and finishers in the textile industry to examine the potential for recycling the water from the waste stream by new technologies [22].

According to Beckmann and Pflug [23], the average water consumption in a textile mill was 150 to 200 m^3 per metric tone of finished goods in 1980 resulting in costs for water supply and wastewater treatment accounted for 4.3% of the total wet processing costs. Likewise, water consumption of textile industry in France is reported to be from 100 up to 150 m^3 per tone of fabric as shown in Table 3.1 [2] while in German textile finishing industry, water consumption is between 20 to 350 m^3 per tone of fabric [24, 25, 26]. A similar study indicates that water consumption in German textile industry is variable in sub-sectors as shown in Table 3.2 [3].

Table 3.1: Water consumption during finishing [2]

Substrate	**Water consumption (m^3/tone of fabric)**	
	Average[1]	Maximum
Cotton	100-150 (250-350)	200
Wool (piece)	50-100 (200-300)	150
Polyamide (piece)	50-100 (125-150)	150
Polyester (piece)	50-100 (100-200)	150
Acrylic (piece)	50-100 (100-220)	150

[1] Figures in parenthesis are reported from [27] for water consumption during finishing

Table 3.2: Specific water consumption of different types of textile finishing industries in Germany [3]

Type of textile finishing industry	**1988**		**1992**		**1996**	
	Average (L/kg)	Range (L/kg)	Average (L/kg)	Range (L/kg)	Average (L/kg)	Range (L/kg)
Flocs/yarn	79	18-151	67	31-124	69	10-185
Knit Fabric	168	100-313	139	54-250	97	20-133
Woven Fabric	118	29-190	146	90-302	103	38-280
Textile Printing	194	56-375	179	65-330	179	70-229

Table 3.3 indicates water consumption values in the USA, according to the report "Development Document for Effluent Limitations Guidelines and Standards for the Textile Mills" published by the USEPA. A comparison of values presented in Table 3.2 with those given in Table 3.3 indicates that water consumption values are similar in those two countries.

Table 3.3: Water consumptions and wastewater discharge volumes in Textile Industry [4]

Mills finishing Woven fabric	**Water Usage (L/kg product)**			**Discharge (median mill) (m^3/day)**	**# of mills studied**
	Minimum	**Median**	**Maximum**		
Simple processing	12.5	78.4	275.2	636	48
Complex processing	10.8	86.7	276.9	1,533	39
Complex processing plus de-sizing	5.0	113.4	507.9	636	50

Moreover, Rosi et al. [28] reported that the biggest impact of textile industry on the environment is related to primary water consumption with 80-100 m^3 per tone of finished textile and wastewater discharge with 115-175 kg of COD per tone of finished textile.

Additionally, water uses in industrial sectors in California are reported in the report of Pacific Institute [5] as indicated in Table 3.4. As can be seen from Table 3.4, specific water consumptions ranges in textile sub-sectors in California are quite high.

Van Veldhuisen [29] grouped in-plant control applications under four headings: *(i)* water minimization (water conservation); *(ii)* wastewater recovery and reuse; *(iii)* chemical substitution and *(iv)* recovery of valuable substances (material reclamation). Significant reductions in water use can be achieved by preventing the unnecessary water consumption practices in textile mills. From this point of view, Dulkadiroglu et al. [30] pointed out the importance of the implementation of in-plant control techniques for textile industries for achieving significant reductions in water use, raw material and energy consumption, wastewater production and in some cases even wastewater load. At this level, it should be noted that energy consumption in textile industry is directly related to water consumption as most of the energy required is to heat up process baths. Therefore, reduction in water consumption results in energy consumption also [6, 4, 13].

In terms of ‘general good management practices’ monitoring and recording water consumption at machine and process level is reported as vital in BREF Textile document. Therefore, controlling water consumption is stated as one of the key implementations for optimizing water consumption. Additionally, reducing water consumption by improved working practices such as “well documented production procedures and training of the staff” and by reducing liquor ratio in dyeing process is declared to be quite important. Improving washing efficiency in both batch and continuous dyeing is reported as another way to reduce water consumption. By combining processes in a single step where applicable is indicated as another way to reduce specific water consumption in the facilities. Moreover, reuse of water is stated as the third method to optimize water consumption in textile mills. Some examples of implementation of abovementioned measures are mentioned to result in 50-100 litres of water per kilogram of fabric produced in mills finishing of woven fabric consisting mainly of cellulosic fibres in BREF Textile Document [6].

Another method to optimize water consumption is the application of counter current washing systems. The counter-current principle is explained as “reuse of the least contaminated water from the final wash for the next-to-last wash and so on until the water reaches the first wash stage, after which it is discharged” in BREF Textile document [6]. The technique is called as “relatively straightforward and inexpensive and applicable for washing after continuous

Table 3.4: Water use by processing category in textile industry in California [5]

Processing category	**Minimum (L/kg)**	**Median (L/kg)**	**Maximum (L/kg)**
Wool	110.8	284.2	657.5
Woven	5	113.3	507.5
Knit	20	83.3	376.7
Carpet	8.3	46.7	162.5
Stock/yarn	3.3	100	557.5
Non-woven	3.3	40	82.5
Felted fabrics	33.3	212.5	931.2

de-sizing, scouring, bleaching, dyeing or printing" [6]. The achievable specific water consumption values are as low as listed in Table 3.5 for continuous washing processes during finishing of woven fabric.

However, it should be noted that in addition to the methods to optimize-minimize water consumption explained above, many other techniques, generally complex in nature, are described in BREF Textile Document of EU. It is also pointed out in BREF Textile Document that, except investment in new equipments and major structural modifications (especially in segregating waste streams) the abovementioned principles are applicable with low cost. [6]

Table 3.5: Achievable specific water consumption values in finishing process [6]

	Water Consumption (L/kg textile)	
	Total	**of which hot water**
Pre-treatment processes		
Washing for de-sizing	3-4	3-4
Washing after scouring	4-5	4-5
Washing after bleaching	4-5	4-5
Washing after cold bleaching	4-6	4-6
Washing after mercerization		
→ Washing to remove NaOH	4-5 (hot)	4-5
→ Neutralisation without drying	1-2 (cold)	N/A
→ Neutralisation and drying	1-2 (warm)	< 1
Washing after dyeing		
Reactive dyestuffs	10-15	4-8
Vat dyestuffs	8-12	3-7

Likewise, Smith [31] claimed that, by the application of appropriate water reuse and recovery options, a 10% to 30% reduction in water use can be achieved without major investments in textile industry. Henningsson [32] also studied waste minimization approaches in food industry in UK and reported that procedural changes and good housekeeping measures to reduce water use and effluent generation were fairly successful with more than £15,000 saved without any significant capital cost.

Similar to Smith, another study from the USA, Gleick et al. [5] indicated that "the process water savings in textile industry can range from 20 – 50% in continuous dyeing by taking simple measures such as counter-current washing techniques and use of automatic shut-off valves" in the report of Pacific Institute. The results of the study are presented in Table 3.6.

Table 3.6: Process water saving in textile industry [5]

End Use	**Type**	**Technology**	**Savings**
Continuous Dyeing	Recycling	Counter-current washing	20 – 50% of dyeing water use
	Efficiency	Use of automatic shut-off valves	20% of dyeing water use
	Reuse	Reuse of rinse water from dyeing for dye bath makeup	50%

In his study, Fresner [33] pointed out that, 10% of process water could be saved by reusing cooling water as process water. He also mentioned the water savings by applying counter flow principle to the washing step. Additionally, he declared that 20% of water usage could be avoided by optimizing the use of water through better process control, mainly in washing process (e.g. switching off the water supply when the equipment is not used) in a textile mill applying mainly de-sizing [33]. Consequently, Fresner [33] resulted in a 30% reduction in the total water use. Likewise, Rosi et al. [28] predicted a saving of 50% of fresh water consumption by the application of water reuse where applicable after suitable membrane treatment processes.

Ciliz et al. [7] emphasized the significance of water minimization options such as reducing the liquor ratio of dyeing machines, reusing of treated wastewater in certain processes (such as pre-washing of printing screens) and optimization in the regeneration process for back-washing of the resins for the softening of raw water in a textile mill. In the study Ciliz et al. [7] claimed that with the latter water minimization method, 6 m^3 of water could be saved per day. Likewise Ciliz et al., Tanapongpipat et al. [34] studied the process modification in scouring process of textile industry by reducing the tank number to rinse the de-sizing agent from the fabric and achieved a reduction of approximately 20% in wastewater discharged from the process.

Alvarez et al. [35] also studied minimization-optimization of water use in chemical industry. An initial water balance is conducted in order to ascertain the water use in different steps of production process. Later on, they have developed approaches to minimize the water consumption in the process of cleaning reactors and cleaning containers processes. They have achieved a reduction of 60% and 90% in water consumption in cleaning the reactors and containers, respectively [35].

Gumbo et al. [36] reported a reduction of 17% in wire galvanising industry via recycling hot quench water through a cooling system. In addition, they have achieved a reduction of 5% in water consumption through recycling filter-backwash water via water treatment in soft drink manufacturing industry. In the study the significance of the direct reuse of non-contaminated process water, cascading of process water used on a high quality process to requiring only low quality water, applying counter-current flow and treatment of wastewater from one source for reuse in another process in the process were emphasized [36].

Consequently, in water intensive textile industry, there are various methods to optimize-minimize water consumption achieving up to 50% savings with no significant cost.

3.3 Energy Consumption in Textile Industry

In addition to water consumption issue being the initial consideration, energy consumption is the third most significant environmental consideration in textile industry [6]. Energy efficiency is reported to be "closely linked to waste minimization as the measures to avoid or reduce waste often save energy" [37]. BREF Textile document also reveals that energy consumption in textile industry is directly related to water consumption, as the majority of the energy is required to heat up process baths. Therefore, energy efficiency is as significant as water minimization in textile industry. The major difference between the two waste minimization approaches is that "energy saving measures in any facility relate to staff awareness and attention as small measures that can collectively make a big difference due to the fact that heating and lighting energy requirements can be reduced through the sensible conservation measures" [37].

In his study, Ozturk [38] pointed out the inefficient consumption of energy in textile industry in Turkey. He also mentioned the rapid growth of energy consumption in industries and its severe effects on the country economy. Hepbasli et al. [39] also reported development of energy efficiency and management implementation in the Turkish industrial sector. In this respect, Ozturk [38] indicated the significance of tracking the energy consumption for a textile firm "to understand and control the usage of electrical and heat energy". According to the study of Hepbasli et al. [39], textile sector is the third energy intensive industry after iron/steel and cement industries in Turkey. This consideration is also confirmed by the Eighth Five Years Development Plan of State Planning Organization (SPO) [11], indicating that the cost of energy in textile processing is presented as 12% of total cost. In the study of Ogulata [40] as well, it is pointed out that the cost of energy consumption is growing. In his study, the significance of recovering energy by heat recovery systems was also indicated.

In terms of energy efficiency, various studies are implemented. According to studies conducted in eight different mills, used for the development of BREF Textile Document, total specific energy consumption is in the range of 8-20 kWh/kg in textile industry. The higher value is for mills also having spinning, twisting and coning sections. The consumption of electricity is specifically stated as between 0.5-1.5 kWh/kg [6].

In the study of Ciliz et al. [7], the overall energy consumption at the enterprise described was calculated as 1.5-1.7 kWh/kg finished textile. The energy consumption distribution in the mill is presented in Table 3.7. In the work of Ciliz et al. [7] it is claimed that 0.3-0.4 kWh/kg finished textile could be saved by utilization of water-to-water heat exchanger for process wastewater from bleach and dye wastewater with a pay-back period of one year.

Table 3.7: Some cotton fabric processes mentioned in the study of Ciliz et al. [7]

Cotton Treatment Options	**Consumption of Energy (kWh/kg finished textile)**
Scouring/washing	1.4-3.6
Bleaching/washing/drying	2.2-9.2
Bleaching/dyeing/washing/drying	2.8-9.8
Dyeing/finishing/drying	2.2-5.0
Finishing	1.7-3.4

In BREF Textile Document, under the heading of ‘general good management practices’, heat insulation of high temperature machines is also included in terms of energy efficiency. By the application of this method, insulation of pipes, valves, tanks and machines, 9% reduction of total energy requirement is reported to be achievable in wet processes by the Energy Efficiency Office UK [41]. Moreover, for the sake of energy efficiency in finishing process, minimization of energy consumption in stenter frames are reported to be an important method. Energy in stenter frames are reduced by several methods categorized in 6 groups as: optimising exhaust airflow through the oven, heat recovery, insulation, heating systems, burner technology and miscellaneous. Optimising exhaust airflow through the oven is achieved by reducing the water content of the incoming fabric and exhaust airflow within the oven. Energy savings of the two methods are reported as reduction of moisture content of the fabric from 60% to 50% before it enters the stenter, up to 15% energy saving is achievable. Moreover, a reduction of fresh air consumption from 10-5 kg fresh air per kilogram of fabric is reported to reduce energy consumption by 57%. Additionally, by the use of air-to-water, or air-to-air where necessary, heat exchangers up to 70% of energy can be saved. Plus, insulation of stenters is reported to save 20% of energy [6]. Despite the methods explained above, it should be kept in mind that, there are more techniques related to energy efficiency in BREF Textile document.

Besides BREF Textile Document, Fresner [33] studied energy consumption in the selected mill in his work. He claimed that electricity consumption was reduced by 30% by changing lighting system in addition to the savings by controlling blowers in the dryers and the air-conditioning system frequently. Likewise, Palanichamy and Babu [42] studied energy conservation measures like equipment operational changes, building structural modifications, changes in machinery accessory and steam heating in place of electrical heating in a textile processing mill. Their studies have shown that a reduction of 171.1 kWh/tone of the textile product is achievable.

Kalliala and Talvenmaa [43] performed studies regarding textile wet processing mills in Finland, as well. Kalliala and Talvenmaa [43] have studied in six mills in which two of them are more water intensive and hence consume more energy. They have suggested BAT options of effective use of production machinery and recycling and monitoring of process water and energy consumption to achieve a reduction of 30% as was the case in one of the mills they have studied. Similarly, Ogulata [40] also declared in his study that, significant reduction in energy consumption of textile mills is achievable by changing the conventional dryer system with drying machinery with heat recovery system.

Apart from examining water and energy saving studies separately, Department of Environment and Natural Resources in North Carolina [44] presents a case study covering environmental impacts of both aspects. In the study, a textile dyeing and finishing mill, where several minimization measures were applied, is analysed in the USA. Accordingly, it is stated that water is conserved during the scouring process through the use of counter-flow washing procedure. Additionally, cooling water is used to cool the jet dyeing machines during the dyeing process. After passing through heat exchangers, the heated water is used in initial baths and washing in other stages of the process, thus reducing heating fuel consumption. Moreover, instrumentation and process controls for the dyeing process were upgraded from manual to computer control. The controlled time of the wash after dyeing has significantly reduced fuel heat consumption and water usage. According to the report, the computerized automation system on the dyeing process has resulted in a 28% reduction in water consumption and a 15.9% reduction in fuel consumption per yard produced [44].

Consequently, textile industry is accepted as water and energy intensive by various authorities. For that reason, energy and water saving is a significant consideration in industrial activities. As the abovementioned studies indicate, there are a lot of techniques applicable to save water and energy despite varying percentages of savings. In this study, effects of several water and energy minimization techniques on the consumption performances are assessed, by being another application of waste minimization.

CHAPTER 4

METHODOLOGY

4.1 Study Approach

BREF Textile document indicates the significance of “collection of information on the installation and the volumes of water consumed in various processes in the installation studied”. This step of auditing is called as “a part of a wider programme involving the collection of information types, quantities, composition and sources of all waste streams”. It is also indicated that “although data at site level is a good indicator for benchmarking and a baseline to measure the improvements, a process specific analysis is fundamental for setting priorities in identifying potential pollution prevention options”. Also, “monitoring process inputs and outputs is the starting point for identifying options and priorities for improving environmental and economic performance ” [6]. In this respect, Babuna et al. [45] also emphasized the significance of performing mass balance analysis in selecting reusable waste streams.

Furthermore, since “the production may vary widely not only during a year (because of seasonal changes and fashion) but even over a single day (according to the production programme), the resulting emissions are even more difficult to standardise and compare”. The ideal approach is stated to be “a systematic analysis of the specific processes”. However, the tackle of the approach is declared as “lack of data availability” due to the fact that “legal requirements have tended to focus on the final effluent rather than on the specific processes”, mainly [6].

Within this framework, prior to the studies, a site visit was implemented. The purpose of the site visit was to get familiar with the processes involved in the production chain with types, production amounts, the major waste streams and recipes by a walk through in the plant with the accompany of the company officials of the selected mill. During the walk-through in the mill; machines, chemicals and auxiliaries used in the processes were analysed. Additionally, some site specific information was gathered from the company officials. Most importantly, water and energy consumption values, applied BAT options with dates applied were discussed with the company officials for the purpose of the study. At this level, the cooperation of the management of the factory was vital as "information gathering is highly dependent on the commitment and organizational skill of the management" [6]. In short, the initial phase of the study was completed by collecting necessary data. A description of the selected mill can be summarized as in the following section, while processes are described in Chapter 5 in detail.

4.2 Selected Mill

The selected mill in this study is one of the worlds leading denim cloth producers. The company was established in 1953 in Middle Anatolia of Turkey as a fibre manufacturing and weaving factory and was restructured in 1986 to produce 100% cotton denim. In the factory, yarn manufacturing, dyeing and finishing processes are fully integrated. The factory, having denim production capacity of 45 millions of meters per year, is established on a 156,000 m^2 area and currently has 900 employees. Wet processes in the mill are carried out via groundwater in the area and average water consumption is 5000-7000 tones/day. In the mill over 140 different types of chemicals, dyestuffs and auxiliaries are stored and used in the processes.

Additionally, the facility has its own wastewater treatment plant consisting of an activated sludge treatment system in which process wastewaters are treated before discharged to the sewer system of Kayseri Water and Sewerage Authority (KASKİ). The necessary energy, in terms of electricity and steam, to be used in the processes are provided from cogeneration and boiler house units in the facility campus.

Generally, in the mill, different types of cottons are *pre-treated* and yarns are manufactured. The manufactured yarns then pass through *dyeing* and *sizing* processes. Dyed yarns are then *weaved* and processed in *finishing* line to be displayed for the customers. Although, the sequence of the major processes is stable during production line, sequence of sub-processes may differ according to the desired end use of the final product.

4.3 Studies Conducted in the Selected Mill

After the initial site visit, not only retrospective yearly and monthly consumptions but also specific water and energy consumptions were analysed. (e.g. liter of water consumption/ kg processed textiles, Gcal of energy consumption/kg processed textiles) At this level, only overall consumptions could be analysed as the factory records were covering only the consumptions that were considered as expenses. Hence, process and machine specific data was not available before the project implementation. Therefore, it was necessary to conduct more site visits to collect data periodically. From this point of view it is evident that data collection was not a single phase but a continuing period.

The purpose of data collection was not only to analyse the effect of BAT measures taken but also to develop water and energy balances in the mill. During data collection, incorrect information was provided which resulted in significant changes in calculations and results. Moreover, in the mid-phases of the study, it was found out that overall water consumption of the selected mill was much higher than it was claimed. Additionally, process and machine specific data belonging prior to 2006 was not reliable and were estimated roughly. Therefore, it was decided to analyse data of the years 2006 and 2007.

During collection of both water and energy consumptions data, it was found out that consumption data was not monitored by a single department or team but spread over different process departments. Water consumption of dyeing process was monitored by the dyeing process team while water consumption of finishing process was obtained from the department involved in technical issues of the mill. Additionally, overall energy consumption data was monitored by this same department despite the fact that there was an energy team concerning issues related to energy efficiency of the mill. In addition, energy consumption of dyeing process was monitored by the dyeing process department while energy consumption of finishing process was monitored by the department involved in technical issues of the mill. Data regarding different energy sources consumed were also spread in different departments of the mill. For instance, natural gas and steam consumption data was obtained from the technical department mentioned while electricity consumption data was monitored by the energy team of the selected mill. In short, there were many obstacles faced with during data collection.

During data collection, daily, monthly and annual consumptions were analysed. However, specific consumptions were more significant for the sake of the study as specific consumptions eliminate the effect of amount of textile production. Although specific consumptions are dependent on many factors (i.e. different recipes applied), specific consumption values allow comparison with other similar sites and processes. Additionally, they are significant when development of a baseline to track changes in consumption levels is of concern. Therefore, specific consumptions on overall, process and machine basis were calculated by dividing consumption amounts with the amount of fabric processed.

In terms of both water and energy consumptions, annual data at site level is significant when benchmarking is of concern. This approach was beneficial to understand the level of the site specific studies in terms of water and energy. Afterwards, by considering the application schedules of BAT options suggested to the mill, monthly average water and energy consumptions and product amounts were analysed and effect of BAT measures were assessed.

From this information, most water intensive processes were identified by process specific monthly water and energy consumption data. Accordingly, dyeing and finishing processes were selected for further analysis. For that purpose, process specific analysis was conducted by monitoring and recording consumptions at machine/process level. This approach allows not only "an initial rough comparison of consumption and emission factors of the mills within the same category", but also "assessment of consumption values after implementation of BAT measures", in other words monitoring [6].

CHAPTER 5

SELECTED MILL

The processes involved in production chain of the selected mill are quite complicated varying due to many factors affecting the end product and its properties. In this section, the processes involved in the selected denim producing mill are described.

5.1 Fibre preparation

Prior to yarn manufacturing, cottons coming from different parts of the world and cities of Turkey are analyzed to determine whether the cotton is appropriate for yarn manufacturing or not. After separation of cottons that are appropriate for manufacturing, they are stored in a 7500 m^2 warehouse before putting into production. This warehouse has a capacity of 6000 tones. Basic fibrous raw materials arrive on site generally in press-packed bales and are stored in a covered warehouse in the campus.

5.2 Yarn Manufacturing

In yarn manufacturing, *blending* process within which the major purpose is to mix and combine different types of cottons to obtain a unique and homogeneous type of fibre is the first step. Another feature of blending is that, impurities in cotton lumps are eliminated. Afterwards, the fibres are prepared in parallel in *carding* machine. After combing process, paralleled fibres are combined and lead to *drawing* machine where thick wicks are formed. Those are then lead to *roving* machine where drawings are made thinner and turned into thinner wicks. And as a last step in yarn manufacturing, the drawings are then submitted to spinning process to finalize the thicknesses of the drawings which can be called as yarn anymore. Then yarns are rolled onto bobbins to be stocked in the warehouse. However, yarns rolled onto bobbins should be *topped* before directed to other processes by warping creel equipment.

Prior to further processing throughout the facility, fixation process is applied to the yarns in order to protect the yarn from mechanical stresses and to impart polish. Fixation process is applied under a certain pressure and temperature for a certain period of time. In the fixation process, water vapour which is 0.90 mbars at 85-90 ^{o}C is applied onto the yarns. Thus, the moisture content of the yarns increases from 5-6% to 7.5-8%.

5.3 Dyeing

Dyeing is a method for colouring a textile material in which a dye is applied to the substrate in a uniform manner to obtain an even shade with a performance and fastness appropriate to its final use [6]. Dyeing is the first wet process in the facility after yarn manufacturing processes. The major steps in dyeing process are pre-treatment, washing, dyeing, softening and drying. The dyeing unit of the facility is composed of four dyeing machines that all include pre-treatment, pre-rinsing, indigo dyeing, topping, post-rinsing and softening becks with the rollers to decrease the water content of the warp yarns and dry them up as the last step in the dyeing process.

The incoming warp yarns are directed to the dyeing machines depending on the recipe that will be applied. The number of rinsing and dyeing becks is not the same for each machine. For the same dyeing machine, total number of becks used may change with the recipe applied. Thus, there are different rope guides regarding the final product. The maximum capacity of each dyeing machine is 20,000 meters. The speed of dyeing is a significant parameter during the process, since the time that the warp yarns are dyed determines the shade of them. That is mainly due to the time that the warp yarns stay in the dyeing beck. If the speed of dyeing is high, a lighter colour is obtained since the yarn stays for a short time in the beck.

Dyeing process is performed in continuous mode which is advantageous in terms of water consumption and thus economics in the facility. Though, it is predicted that one of the most water intensive processes is dyeing by utilization of hot water baths. The temperature of the processes in each beck is regulated by water-vapour pipes at the bottom of the becks. On the other hand, in two of the dyeing machines, temperature of the processes is regulated by heat exchangers. The details of the subsequent processes involved in dyeing will be explained in detail in further sections.

5.3.1 Pre-treatment

The purpose of the pre-treatment process is to remove foreign materials in order to obtain the homogeneity of the fibres for uniformity in hydrophilic characteristics and affinity for dyeing and finishing processes [6]. The process is applied at the head of the dyeing machine prior to pre-rinsing step.

The pre-treatment in the facility is performed via two different techniques: classical pre-treatment and pre-treatment with mercerization depending on the preferences of the client. Classical pre-treatment is carried out with wetting agent, complexing agent and caustic (NaOH), whereas, in mercerized pre-treatment, a wetting agent other than the one used in classical pre-treatment with a higher concentration in process and caustic is applied.

In the pre-treatment process, softened water at 60^oC is used. The temperature of the soft water is regulated by the vapour supplied from cogeneration unit. The chemical mixture used in the process is prepared in the chemical preparation unit with soft water and then the prepared mixture is sent to the pre-treatment beck. The incoming warps to the dyeing machine are dry and absorb pre-treatment liquid at 60^oC as much as 65% of their weight after the process. The warps that are pre-treated are squeezed by rollers under 100 psi pressure prior to the pre-rinsing process. The volumes of the pre-treatment becks are variable. However, as pre-treatment is a batch process, the generated wastewater is discharged to the wastewater drainage channel at the end of each process cycle. Additionally, if the prepared dyeing liquor is not suitable for the recipe applied, this so called wastewater is also discharged to the same channel.

5.3.2 Pre-rinsing

The purpose of this process is to remove the chemicals remaining on the warp yarns after the pre-treatment process [6]. In the mill, for this process, both hard and soft water are continuously applied resulting in continuous wastewater generation. Depending on the dyeing recipe applied the flow rate of pre-rinsing water changes and thus the flow rate of the wastewater generated. The volumes of the pre-rinsing becks vary between 1000-1600 L depending on the dyeing machine utilized. The temperatures in the pre-rinsing becks vary according to the dyeing temperatures that will be applied in the next steps of dyeing process.

5.3.3 Dyeing

Process of colouring textiles as a whole is called dyeing [13]. In the facility, dyeing process is applied in continuous mode. However, the sequence of the process steps does not change regarding the process mode. Instead, all dyeing processes include preparation of dye, dyeing, fixation, washing and drying steps [6].

In continuous dyeing, the dye liquor is applied to the textile by impregnation (by means of foulards). Accordingly, the textiles are fed continuously in an open width through a dip trough with dye liquor. Therefore, the textile absorbs a certain amount of dye solution through the dip before leaving the trough. Applied dyeing recipes in the facility are determined according to the customer requirements.

5.3.4 Post-rinsing

The purpose of this process is to remove dyestuff and chemicals remaining on the warp yarns after the dyeing process. In the mill, for this process, both hard and soft water is consumed. The volumes of the post-rinsing becks vary between 1,000-1,600 L depending on the dyeing machine utilized. As in the case of pre-rinsing, the wastewater generation is continuous and the flow rate depends on the recipe applied.

5.3.5 Softening

Softening may be considered as a subsequent batch washing bath [6]. After dyeing, the warps are to be softened in order to favour the process in warping creel. Softening is a batch process and hence wastewater from this process is discontinuous with discharging 1000 L of water a week. In this process, softening agent and citric acid for pH adjustment are used.

5.3.6 Drying

The purpose of drying process is to reduce or eliminate the water content of the yarns after dyeing, rinsing and softening processes [6]. In the selected mill, drying process is applied via contact driers at a temperature of 140^{o}C in order to reduce the water content of the yarn from 68% to 7-8% after the softening process.

5.4 Sizing

In sizing process, a starch based solution is applied to the yarns in order to lubricate and protect the warp yarn in the weaving process. In the selected mill, there are two machines operating in sizing process. Both of the machines include two becks, to pre-wetting and to size, respectively. Pre-moisturizing is applied with soft water under 90^oC in order to favour penetration of sizing agents into the warp yarns. After sizing, warps are dried by reducing temperature to the desired moisture content level. Dried warps are then combed in drawing process in which the warps are prepared for weaving.

In sizing, starch, which is generally derived from either potatoes or corn, is commonly used. In the selected mill, potatoes or corn based starch that is easily biodegredable is used as the sizing agent. As starch is decomposed for the sake of the process, it cannot be recovered and is responsible for most of the COD load in the finishing effluents. Additionally, some auxiliary chemicals such as polyacrylates, carboxymethyl cellulose (CMC) and vegetable oils are utilized in order to favour sizing operation. Polyacrylate is a derivative of petroleum and is generally used in order to reduce the amount of starch in sizing process. CMC is another widely preferred additive of the process to improve the adhesion of starch sizes for the cotton although it cannot be degraded easily. Lastly, vegetable oil is used in order to reduce the friction.

5.5 Weaving

Weaving process is assembling yarns on a loom and the production of fabrics [6]. There are two types of yarns weaved, dyed and non-dyed. Weaving is included in dry processes and requires only electricity. However, in order to favour the process, a certain level of moisture is required which is supplied by air-conditioners utilized during the process.

5.6 Finishing

Finishing process includes different types of treatment techniques in order to form the textile with the desired end-use properties which can be visual effects, handle and special characteristics (i.e. non-flammability, water-proofing, and shrink resistance) [6]. Finishing treatment takes place as a separate process after dyeing and weaving, hence, fabric finishing is in question.

The processes included in the finishing line of the selected mill are classified into two as wet and dry finishing processes. Dry finishing processes are categorized as mechanical processes which enhance further wet processes via calendaring, anti-shrink finishing, shearing, emery and raising and require only energy consumption. Wet processes, being both energy and water intensive, are carried out in eight different machines. The reason for having different types of finishing machines is due to the customer oriented end use properties of the product. Wet processes carried out in eight different machines are differing in terms of water and energy use as the different desired end use properties of the fabric require highly variable consumption of water, chemicals and energy.

5.6.1 Pre-treatment

The processes applied to weaved fabric in order to prepare the fabric for dyeing and printing processes are called pre-treatment processes [6]. Cotton fabrics are pre-treated in order to remove impurities remaining from previous processes, to obtain a proper whiteness and expanded fibres of the fabric, and to wet the fabric for improvement of its absorbability.

Singeing : The purpose of this process is to remove surface fibres by contacting the fabric with a gas flame [6]. Singeing can be applied only when the fabric is dry, therefore in the selected mill, singeing is the first process applied to the fabric as a pre-treatment process. Another reason for singeing as the first process applied is that the fabric may turn yellow in colour which can be recovered in the bleaching process which is applied after singeing.

De-sizing: De-sizing is the first wet finishing process applied to the woven fabric in order to remove remaining sizing agents which are not water soluble and hydrophobic and hence reduce the absorbability of the fabric [6]. De-sizing techniques differ according to the type of the sizing agent used. In the selected mill, starch based solution is applied in order to size the yarns. In order to de-size the woven fabric in finishing, either catalytic action with an enzyme (catalytic degradation) or other chemical treatment should be applied to convert starch-based sizes into a soluble form. Chemical degradation is applicable by either enzymatic or oxidative de-sizing. Enzymatic de-sizing which is a common application is used to remove starch by amylases. The major advantage of using amylase is that starches are decomposed without damaging cellulose fibre.

Kier boiling : Natural fibres include impurities such as fat, waxes and pectin. Those cellulosic impurities are to be removed since impurities bring on hydrophobic character to the fibres which subsequently result in difficulties in wet processes. Therefore, this process is carried out in order to make the fabric more hydrophilic.

Bleaching : The natural cotton includes coloured impurities and is generally yellowish in colour. Moreover, some chemical treatments can also cause colours on the fabric that is not desired and should be removed. Therefore, bleaching process is applied for the removal of this undesired colour on the fabric. In the selected mill, bleaching is applied by oxidizing agents such as hydrogen peroxide (H_2O_2), sodium chlorite ($NaClO_2$) and sodium hypochlorite ($NaClO$) in the bleaching bath. Generally, this process is carried out in combination with kier boiling.

Mercerization : Mercerization is carried out by application of a strong basic solution of caustic in order to improve tensile strength of the cotton [6].

5.6.2 Colouring

The colouring of the fabrics in the selected mill is carried out in continuous colouring machine. There are two types of colouring techniques in this machine: pad-dry and pad-steam. In pad-dry technique, dye and alkali are padded to the material at the same time and then it is dried and thermo fixed. The second technique is pad steam in which steam is applied to the material after passing through colouring beck. The fabric is always washed after colouring by applying either of the techniques explained above in order to remove the colorant.

5.6.3 Denim finishing

This process is carried out in order to obtain better quality in easy-care and other end use properties. The purpose of this process is to form the denim fabric with the desired final end use properties. Denim finishing can be applied in two different methods:

Chemical denim finishing : Chemical denim finishing processes are applied by saturation of fabric with the chemical agents. Addition of chemical agents increases the weight of the fabric. The chemical agents leak immediately after the application during washing since the affinity of finishing agents to the fabric is low.

Mechanical denim finishing : After chemical treatment, some mechanical denim finishing processes, also called dry finishing, are carried out. Those processes are applied in order to improve the easy-care and appearance properties. The processes included in mechanical denim finishing are: calendaring, anti-shrink finishing, shearing, emery and raising. Additionally, in order to stabilize the size of the fabric, sanforizing process is applied. Sanforizing is carried out by mechanical shrinking with four sanforizing machines in finishing line. Moreover, stenter frames are required for full drying of the fabric in the mill. During drying, hot current of air is blown across the fabric to promote evaporation of the moisture.

CHAPTER 6

RESULTS OF ANALYSIS

The results of the study are presented in two sections as water and energy consumptions. The results will be assessed based on total consumption amounts on monthly and annual basis in addition to specific consumptions which is based on production amounts. Additionally, BAT measures which are suggested and implemented during the project period will be taken into consideration throughout the performance assessment. For that purpose, both water and energy consumption analyses are carried out within the context of the schedule of BAT applications. In the following sections, consumptions, related BAT measures and data analyses will be presented.

6.1 Water Consumption

In this section, as the major focus is water consumption, wet production processes are of concern. In any sub-sector of the textile industry, there are different types of wet processes applied which are using extensive amounts of water [6]. Moreover, almost all dye stuffs, auxiliaries and other chemicals are applied to textiles via dye baths. Therefore, water is consumed at nearly every production process regardless of the type of end use of the textiles. In the textile industry, generally, yarn manufacturing, dyeing, printing, scouring and finishing processes are responsible for the consumption of large amounts of water during production. Therefore, the highest water consumptions are predicted in those processes [6]. Additionally, water consumption is highly variable according to the complexity of the process and machinery used. Furthermore, type of dye used, weight of the product, washing and rinsing procedures are considerably effective on the variation of water consumption [13]. Hendrickx [14] also pointed out that, the amount of water used per pound of fabric will vary with the weight of the fabric, process, equipment type and dyestuff. Consequently, water consumption in a textile mill is considerably high and may show wide variation due to several reasons.

In the selected mill, being a large and complex plant, high water consumptions in the production processes were observed during the initial assessment. Before the project, the daily average water consumption in the mill was reported to be changing between 5000-7000 tones/day. The mill extracts its water from the wells and uses both hard and soft water during the production processes. In the mill, hard water is generally required for cleaning purposes; whereas, the majority of the processes are carried out by softened water. Thus, a portion of the extracted groundwater is softened in ion exchangers. The softened water from the ion exchangers is diverted to the processes. In addition to this, almost $40 - 50\%$ of softened water from ion exchangers is transferred to the reverse osmosis system to produce deionised ultra pure water to be utilized in the cogeneration plant for steam generation. Softened water diverted to the processes is mostly used in dyeing, sizing and finishing processes which are accepted as wet processes. As can be seen from Figure 6.1, the majority of water is consumed in dyeing and finishing processes which subsequently produce highest amount of wastewater in the mill. Dyeing and finishing processes, continuous in principle produce almost 80% of the wastewater treated in the treatment facility. Wastewaters from sizing process are also directed to wastewater treatment facility however, as sizing is a batch process, wastewater stream of sizing process is not continuous. Additionally, wastewaters from other processes are also directed to wastewater treatment plant however, the contribution of those waters to wastewater characteristics is much less than the dyeing, finishing and sizing processes. On the other hand, wastewaters originating from company dwellings and staff canteen are directed to sewer line without any treatment applied. Production line and water flow in the mill can be seen in Figure 6.1. Figure 6.1 represents the average daily water consumptions in the selected mill before the project implementation. As the available data was not sufficient to develop the actual water balance before project implementation in 2005, estimated data is used in the water flow diagram of the selected mill.

6.1.1 Suggested/Applied BAT Measures

At the beginning of the study, an initial screening of the possible applicable BAT options was made for the water consumption in the production processes in the project period. It appeared

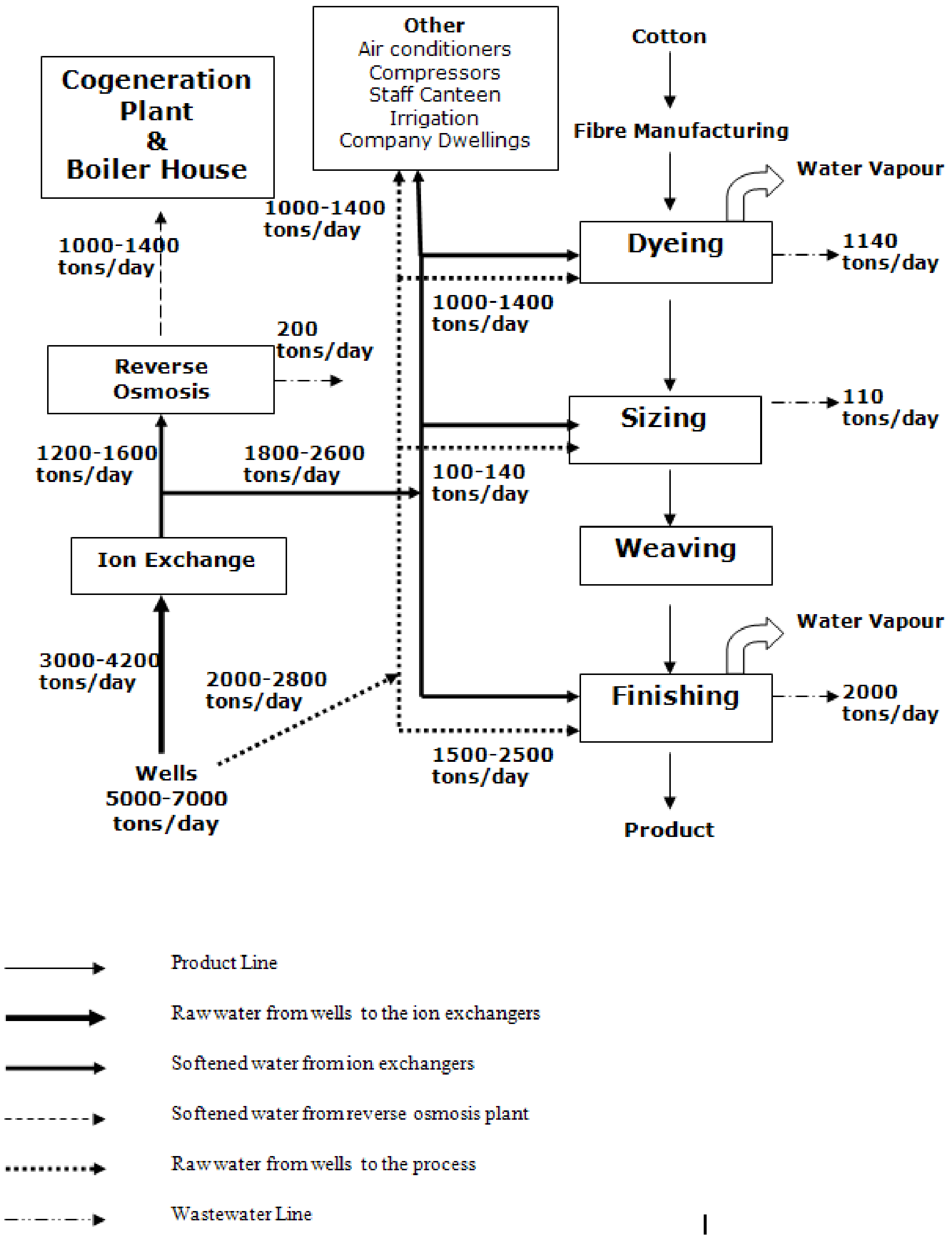

Figure 6.1: Water flow in the selected mill (as of 2005)

that a number of BAT options were applicable to the facility. However, the applicability of each BAT option was discussed with the plant management for their possible realization at the plant scale. As a result of this evaluation, some BAT options were eliminated due to their inapplicability at the plant scale. Furthermore, additional water minimization strategies that were not covered by the BREF Textile Document were developed by the mill staff considering their technical and economical viability. As a result, the selected BAT measures are as follows:

1. *Installation of flow meters in dyeing and finishing processes* – installation of flow meters on the individual machines utilized in different processes enables flow control in processes. Furthermore; flow meters are utilized in order to document water use and evaluate improvements and hence help monitoring of water consumption.

2. *Semi-counter current rinsing in dyeing and finishing processes* – reuse of the least contaminated wash waters in final wash until the water reaches the first wash stage quality, after reaching this quality stage the water is discharged. This application improves washing efficiency.

3. *Reuse of dyeing and finishing wash waters after a treatment scheme (advanced oxidation, membrane filtration etc.)* – wash waters with chemicals and dyestuffs are treated in order to remove the impurities; and, if reuse criteria for textile industry are met, these waters are reused in the processes and hence minimize total water consumed by eliminating the extraction of water from the wells.

4. *Recovery and reuse of sodium hydroxide from mercerization wash waters in the finishing process* – after sodium hydroxide recovery from wash waters of mercerization, water is re-circulated into the process to be reused and hence washing efficiency is improved along with reduced chemical cost.

5. *Reuse of concentrate stream of reverse osmosis plant* – the use of concentrate stream for cleaning purposes (e.g. toilets) in the mill improves the total water consumption performance of the mill by eliminating the extraction of water for cleaning purposes.

6. *Minimization of wash water consumption in the water softening plant (reuse of wash waters from regeneration of ion exchangers)* – elimination of excess water consumption in regeneration of ion exchangers improve water consumption performance of the mill, reducing the amount of total extracted water.

7. *Reuse of compressor cooling waters in production processes* – reuse of softened cooling waters of compressors in production processes reduces the amount of water extracted from the wells and thus increase total water consumption performance of the mill.

Among BAT measures listed above, 1, 2, 5, 6 and 7 are implemented during the project period. Installation of flow meters on process and machine basis was completed by April'06 which is currently reported. Additionally, semi-counter current rinsing systems in dyeing and finishing processes were completed by April'06 and August'06, respectively. Meanwhile, concentrate reject streams of reverse osmosis process have been reused in the processes since mid-2006. Furthermore, water consumed for rinsing after regeneration of ion exchangers is reduced nearly at the same time. Compressor cooling waters are also reused in the processes since July'06.

6.1.2 Water Consumption Analysis

Initially, in order to get a picture about the overall water consumption in the mill, annual water consumptions were analyzed. Table 6.1 summarizes the water consumption in the mill for the period 2002-2007.

Table 6.1: Water consumption pattern of the selected mill

Year	**Fabric production (m)**	**Total Water consumption (tone/year)**	**Daily Average water consumption (tone/day)**	**Specific Water consumption (L/kg fabric*)**
2002	38,532,438	2,484,906	6,903	106
2003	35,700,419	2,191,956	6,089	101
2004	48,761,165	2,670,865	7,419	90
2005**	46,345,755	2,185,229	6,070	78±7.0
2006	40,454,056	1,732,756	4,813	71±11.7
2007	52,310,712	1,744,320	4,845	55±5.4
2006-2007 Average	46,382,384	1,738,538	4,829	63±12.0

* 1 m fabric is 0.61 kg [46] ** Start of the project

For comparisons sake, specific water consumption is believed to be a better indicator to assess the performance of the water consumption pattern in the mill. This is because; the specific water consumption takes into the amount of fabric production and the recipe effect on the overall water consumption account. Otherwise, these effects cannot be distinguished. The term specific water consumption simply identifies the amount of water consumed while producing a certain amount of textiles (i.e. litres of water consumption per kilograms of fabric production). Therefore, performance assessment is carried out by considering specific water consumptions during the water consumption analysis. Accordingly, specific water consumptions in 2005, 2006 and 2007, which represent the project implementation period, are estimated as 78, 71 and 55 litres of water per kg of fabric, respectively. Totally, the reduction in specific water consumption is 29.5% in the period of 2005-2007 which is considered to be due to above-mentioned BAT measures applied. Additionally, Table 6.1 presents the annual total water consumptions, fabric production amounts, daily average water consumptions and annual specific water consumptions from the year 2001 to 2007. Accordingly, water consumption varies between 1.7-2.5 millions of tones per year. Moreover, fabric production amount is highly variable between 35 to 52 millions of meters.

Monthly fabric productions and total water consumptions of the selected mill can also be analyzed in Figure 6.2 for the period 2005-2007. As can be seen from Figures 6.2 and 6.3, total water consumption and specific water consumptions in the period of 2005-2007 reduce gradually despite the fact that fabric production increases during the same period. May'06 is the start of the pattern that fabric production increases while water consumption decreases. This also results in the sharp decrease observed in overall specific water consumption of the mill in Figure 6.3. At this point it should be emphasized that BAT measures taken for water minimization were nearly completed by May'06. On average, specific water consumption was 63 ± 12 L/kg fabric in the period of 2006-2007 therefore, reduction in specific water consumption is not a coincidence but a consequence of the applied BAT measures. Figures 6.2 and 6.3 therefore indicate that applied BAT measures were effective on total water consumption pattern of the mill. Data for Figures 6.2 and 6.3 are provided in Table A.1 Appendix A.

As is presented in Table 6.1, fabric production and water consumption values are highly variable for the period 2002-2007. For that reason, in evaluating the water consumption performance of the processes, this fact is taken into consideration by using specific water consumption values. As water consumption is also affected by the type of production, fibre type, fabric

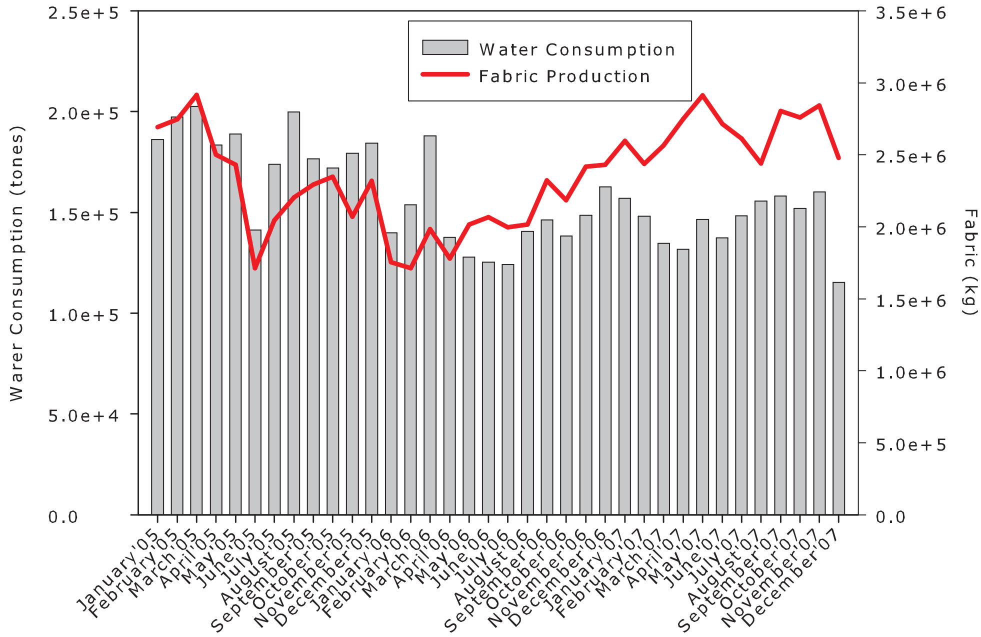

Figure 6.2: Water consumption and fabric production patterns in the mill

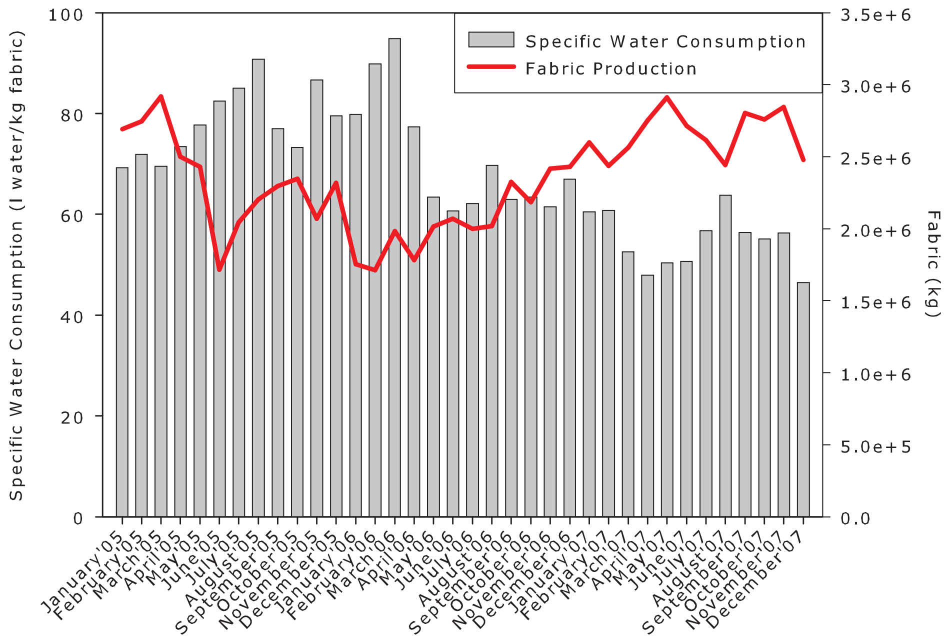

Figure 6.3: Specific water consumption and fabric production patterns in the mill

type, dying recipe and end use properties of the fabric, it is crucial to conduct a detailed water consumption analysis for each major wet process in the mill.

For this purpose, water consumptions in processes are identified regarding detailed process analysis. In this context, data presented in Table 6.2 differentiates water consumptions in processes. As can be seen from Table 6.2, dyeing and finishing processes are responsible for nearly 50% of the total water consumption in the mill.

In Table 6.2, the details of water consumption in supplementary facilities, water softening processes and other facilities are not given in detail as they are not among the production processes. Supplementary facilities and water softening processes do not consume water but produce steam and electricity and soft water to be consumed during production, respectively. The only water consumption in those facilities is in terms of hard water from wells for cleaning purposes.

Furthermore; hard water is consumed in staff canteen, company dwellings and for irrigation purposes that are classified as "others". This indicates that there are other water demanding points independent from fabric production. Additionally, wastewater originating from those sources is discharged to the municipal sewer line. However, water consumption of those sources is also covered in overall water consumption analysis. On the other hand, water consumption performance of those sources is not monitored as they are not related to production amounts. Likewise, water consumption in staff canteen, company dwellings and for irrigation purposes are not taken into consideration during the water consumption analysis.

Because of the reasons mentioned above, only *wet processes* in the production chain are considered during the initial assessment. As can be seen from Table 6.2, the highest amount of water was consumed in the year 2005. Additionally, total water consumption remained almost the same with 1.7 millions of tones in the last two years while fabric production increased from 46 to 52 millions of meters as denoted before. It is clear that, dyeing and finishing processes are consuming the majority of the water, being responsible for nearly 50% of the total water consumption. On the other hand, water consumption for dyeing and finishing processes are decreasing despite the increase in fabric production. Additionally, this reduction is also observed from the percent changes in water consumption of the wet processes indicated. Consequently, being the two major wet processes, detailed water consumption analysis was carried out for these processes. At this level it should be pointed out that the automated flow control system was installed in January'06, however the system was completed in January 2007. Since then, water flow control of the selected mill was fully automated with water consumption values in processes separately. Report of the flow control system is presented in Table A.2 in Appendix A. Therefore, process and machine specific data was more accurate in the period of 2006-2007 than it was in the year 2005. In the proceeding sections of this chapter, dyeing and finishing processes will be analyzed in terms of water consumption in the selected mill.

Table 6.2: Water consumption in wet processes in the production chain

Annual Water Consumptions in Wet Processes								
Process	**2005**		**2006**		**2007**		**Average**	
	tone	%	**tone**	%	**tone**	%	**tone**	%
Sizing	45,712	2.1	51,199	2.9	67,769	3.9	**55,893**	**2.9**
Dyeing	419,288	19.2	459,850	26.5	367,359	21.1	**415,499**	**22.0**
Finishing	653,758	30	430,044	24.8	453,303	26.0	**512,368**	**27.1**
TOTAL (tone/year)	2,185,229		1,732,755		1,744,320		**1,887,435**	
TOTAL (tone/day)	6,070		4,813		4,845		**5,243**	

As can be seen from Table 6.2, the highest amount of water consumed was in the year 2005. Additionally, total water consumption remains almost the same with 1.7 millions of tones in the last two years while fabric production increases from 46 to 52 millions of meters as denoted before. It is clear that, dyeing and finishing processes are consuming the majority of the water, being responsible for nearly 50% of the total water consumption. On the other hand, water consumption for dyeing and finishing processes are decreasing despite the increase in fabric production. Additionally, this reduction is also observed from the percent changes in water consumption of the wet processes indicated. Consequently, being the two major wet processes, detailed water consumption analysis was carried out for these processes.

6.1.2.1 Dyeing

BREF Textile Document highlights the fact that dyeing process is one of the highest water consuming processes in the textile production chain. This fact was also confirmed by the initial investigations carried out in the selected mill.

In the mill, dyeing is applied to the non-weaved products, i.e. yarn dyeing is taking place. A small portion of the water is consumed in dye preparation kitchens; whereas, the majority of water is consumed in dyeing baths with a variety of dyestuffs and chemicals throughout the process. In the dyeing line of the selected mill, there are four dyeing machines which are composed of pre-treatment, pre-rinsing, dyeing, post-rinsing, softening and drying processes. The details of those processes are provided in Chapter 4. Both soft and hard water can be used for the rinsing operations. In the kitchens, for the preparation of the recipes, softened water is being used. Hard water is used for cleaning purposes. As of July'06, due to the reuse of compressor cooling waters within the mill, generally soft water is being used for rinsing operations.

As dyeing is one of the major water intensive processes in the textile industry, BAT measures implemented in the dyeing process are considered to have a major effect on the overall water consumption in the mill. Although it is indicated that there are four different dyeing machines in the dyeing line, machine specific water consumptions are not taken into consideration separately. Among BAT options suggested for the selected mill, measures for the dyeing process specifically are the first two measures (i.e. 1 and 2) in Section 6.1.1.

By the beginning of 2006, flow control of the dyeing process was fully automated. The studies regarding semi-counter current washing also started in the beginning of 2006 and in April'06 this system was implemented in three dyeing machines. Studies regarding the implementation of a full scale membrane system for the reuse of wash waters from dyeing process are underway.

For the evaluation of the water consumption performance of the dyeing process, initially, the general water consumption patterns were analyzed. Table 6.3 summarizes the data regarding the dyeing process for the period 2006-2007. According to Table 6.3, the amount of dyed yarn increased from 1.2 million to 1.4 million kilograms on monthly average throughout the implementation period of BAT options. On the other hand, total water consumption seems to be slightly decreasing during this period. However, most importantly, it is observed that average specific water consumption decreased from 27 to 21 litres of water per kg of dyed yarn which corresponds to 22.2% reduction. Detailed data on monthly basis of dyeing process is provided in Table A.3 in Appendix A.

Table 6.3: Water consumption pattern in dyeing process

	Dyed Yarn (kg)	**Total Water Consumed (tone)**	**Specific Water Consumption (L/kg yarn)**	**Dyeing (%)**
2006	1,218,830	31,942	27±5.4	6.3
2007	1,446,598	30,767	21±1.2	7.0
Average	1,332,714	31,355	24±4.7	6.6

At this point, it should be noted that, for evaluating the performance of water consumption in the dyeing process, the recipe effects should also be taken into consideration. This is because, dyeing of darker shades require consumption of more water during the process. Thus, this effect should also be reflected in the overall water consumption. For this purpose, the parameter "% dyeing" is used. It is the ratio of the dye stuff utilized to the amount of yarn dyed [46]. When Table 6.3 is analyzed, it is seen that, although the % dyeing is increased in the year 2007 as compared to 2006, the specific water consumption has decreased. This clearly highlights the fact that although darker shades were used in the year 2007, water consumption did not increase, although it should be higher, as compared to 2006. This is due to the BAT measures taken within the process which optimizes the water consumption in the process.

Figure 6.4 clearly shows this fact. In the figure, it is observed that water consumption is high in the initial months of 2006 relative to the proceeding months. During initial months of the year 2006, water consumption varied while amount of yarn dyed increased gradually. On the other hand, amount of dyed yarn and water consumption followed the same pattern in 2007. In order to see the actual consumption pattern, specific water consumptions were considered on monthly basis.

Figure 6.5 presents the specific water consumption in the dyeing process for the period 2006-

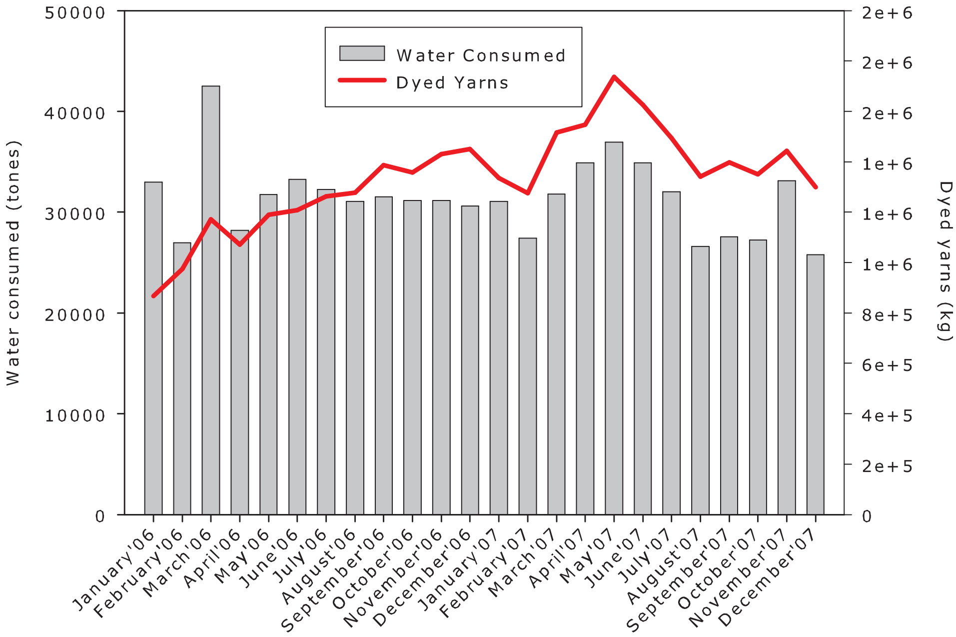

Figure 6.4: Water consumption and dyed yarns patterns in the dyeing process

2007. In the mill, specific water consumption reduced from around 40 to 20 litres of water per kg of dyed yarn from the beginning of 2006 to the last months of 2007, respectively. Moreover, in this period, % dyeing increased from 5.7 to 8. This variation is simply based on different recipes applied to the yarns to obtain different shades of end products throughout the specified period.

As can be seen from Table 6.3, 22.2% reduction was achieved in the specific water consumption for the period January'06-December'07, as a result of the BAT measures taken in the dyeing process regardless of increase in the % dyeing in this period. Consequently, in the year 2007, uniform and lower water consumption was achieved in the dyeing process. Adoption of BAT measures regarding the reuse of wash waters is underway. This measure, once applied, will definitely result in high amounts of savings in the water consumption of the dyeing process.

6.1.2.2 Finishing

As indicated in BREF Textile document, finishing is another major water consuming processes in sector. This fact has also been confirmed by the overall water consumption analysis.

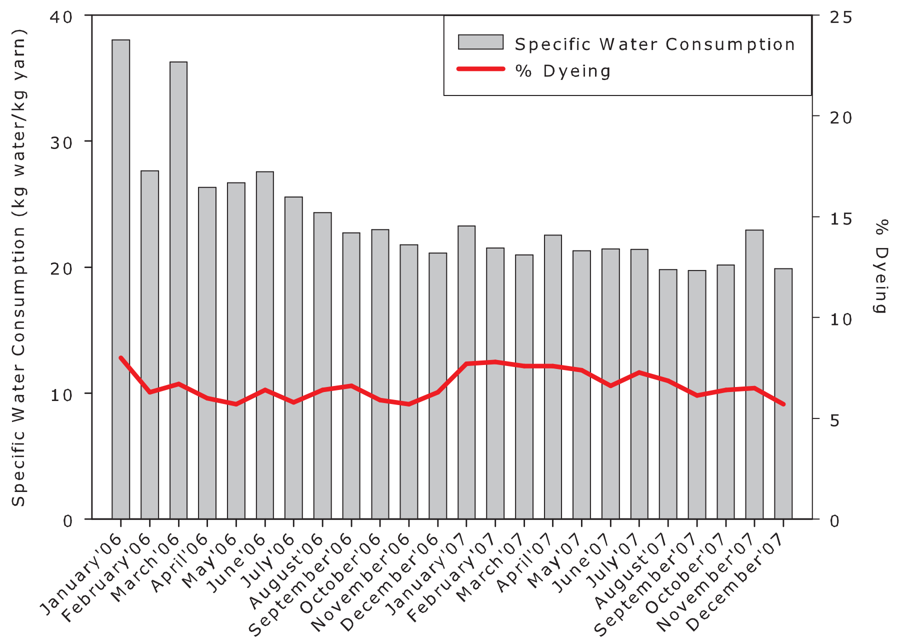

Figure 6.5: Specific water consumption and % patterns in the dyeing process

In the selected mill, different types of finishing processes, dry or wet, can be applied to the woven fabric. As dry processes are generally applied by mechanical or physical means wet processes which are applied by hot water baths saturated with various chemicals are of concern in water consumption analysis. Throughout the process, softened water is consumed as hard water is only consumed for cleaning purposes. Wet finishing processes have chemical treatment and rinsing stages requiring use of large quantities of chemicals and water. However, regarding different recipes being applied, the utilization of machines and chemicals vary widely. Hence, average production amounts of machines vary also.

There are 8 different machines utilized for wet processing in the finishing line. Table 6.4 designates the average amount of textiles processed in each machine in the finishing line on monthly basis. Accordingly, highest amount of fabric was processed in Machine 1, Machine 6, Machine 7 and Machine 8 with 1.7, 1.6, 1.5 and 1.2 millions of meters per month on average, respectively.

As finishing is one of the major water intensive processes in the textile industry, the implementation of BAT options in finishing is expected to have a major effect on the overall water consumption in the mill. Therefore, the BAT options suggested in finishing process which are the 1^{st},2^{nd} and 4^{th} measures mentioned in Section 6.1.1 are considered to have a major effect on reducing overall water consumption.

By April'06, fully automated flow control system was implemented in the finishing process. Additionally, at the same time, semi-counter current rinsing system was installed in Machine 6. Afterwards, the same system was installed to Machine 7 in August'06. Furthermore, a pilot scale membrane system was installed in August'07, after optimization of the treatment scheme at lab scale. Studies on further optimization of the pilot membrane system are ongoing. This application is expected to further reduce water consumption by reusing the rinsing waters and also reduce the chemical cost by reusing the recovered caustic in the process.

For the evaluation of the water consumption performance of the finishing process, initially, the water consumption patterns of wet processes were analyzed. Table 6.5 summarizes the data regarding the eight machines utilized in finishing process for the period of 2006-2007. According to Table 6.5, the amount of water consumed increased in M1, M2, M3, M4 and M7 on monthly average throughout the implementation period of BAT measures. On the other hand, water consumption in M5, M6 and M8 seems to be slightly decreased during this period. Table 6.5 also designates the distribution of total water consumed in finishing line. Accordingly, M6 and M7 are responsible for almost 45% of the total water consumed in finishing line. On the other hand, M2 and M3 are the least water intensive ones. Detailed water consumption data for each machine of finishing process is provided in Tables A.4, A.5,

Table 6.4: Fabric production of 8 machines in finishing process

	Amount of fabric processed (meter/month)				
	2005	**2006**	**2007**	**Average**	%
Machine 1 (M1)	1,702,378	1,296,159	2,107,790	1,702,109	20.11
Machine 2 (M2)	240,093	499,434	462,840	400,789	4.74
Machine 3 (M3)	99,673	339,975	527,537	322,395	3.81
Machine 4 (M4)	483,542	407,612	1,224,894	705,349	8.34
Machine 5 (M5)	955,198	956,492	1,075,931	995,874	11.77
Machine 6 (M6)	1,491,853	1,645,854	1,726,757	1,621,488	19.16
Machine 7 (M7)	1,370,550	1,297,740	1,868,365	1,512,218	17.87
Machine 8 (M8)	1,194,353	1,149,038	1,261,647	1,201,680	14.20
TOTAL	7,537,640	7,592,304	10,255,762	8,461,902	

A.6, A.7, A.8,A.9, A.10, A.11 in Appendix A.

Table 6.5: Monthly average water consumption pattern in 8 machines of finishing

Machine	**Water Consumption (tones/month)**			
No.	**2006**	**2007**	**Average**	%
M1	4,712	4,946	4,829	**13.5**
M2	1,874	2,315	2,095	**5.8**
M3	1,544	2,737	2,141	**5.9**
M4	2,893	7,257	5,075	**14.1**
M5	3,792	2,764	3,278	**9.1**
M6	10,017	9,318	9,668	**26.9**
M7	5,442	6,267	5,855	**16.3**
M8	3,772	2,138	2,955	**8.2**
TOTAL	**34,047**	**37,742**	**35,896**	

Furthermore, by considering fabric productions and water consumptions of the machines separately, machine specific water consumptions are evaluated on monthly basis. Therefore, for each machine, specific water consumptions during the years of 2006 and 2007 are summarized in Table 6.6 on monthly basis. As seen, M6 and M7 are responsible for highest amount of water consumed in finishing. For that reason, the effect of BAT options applied in those machines is expected to be more effective than the others in overall water consumption performance of the finishing line.

As can be seen from Table 6.6, specific water consumptions of all the machines have reduced when compared with the consumptions in the previous year. However, so as to summarize the specific water consumptions, the percent changes of specific water consumption in each machine are also summarized in Table 6.6. Accordingly, the highest reduction is observed in M8 with 48.9% and the least is observed in M3 with 5.7%. However, as the most water intensive machines are M6 and M7, percent changes in specific water consumptions in those machines are more effective on total water consumption of finishing process when compared to the others. As can be seen from Table 6.6, reductions in specific water consumption of M6 and M7 are 13.7% and 21.1%, respectively.

Table 6.6: Water consumption patterns of the machines in finishing process

Machine No.	Year	Fabric Production (kg)	Water Consumption (ton)	Specific Water Production (L/kg fabric)	% change
M1	2006	790,657	4,712	6.26	-38.2
	2007	1,285,751	4,946	3.87	
M2	2006	304,655	1,593	6.43	+26.7
	2007	282,333	2,315	8.15	
M3	2006	207,385	1,544	10.02	-5.7
	2007	321,798	2,737	9.45	
M4	2006	248,643	2,696	14.66	-34.0
	2007	747,185	7,257	9.68	
M5	2006	583,460	3,792	6.53	-35.5
	2007	656,318	2,764	4.21	
M6	2006	1,003,971	10,017	10.26	-13.7
	2007	1,053,321	9,318	8.85	
M7	2006	791,621	5,442	7.00	-21.1
	2007	1,139,703	6,267	5.52	
M8	2006	700,913	3,772	5.40	-48.9
	2007	769,605	2,138	2.76	
Overall Finishing	2006	2,056,414	34,047	16.87	-15.8
	2007	2,659,128	37,742	14.20	

Another indication of Table 6.6 is the increase in specific water consumption in M2. However, increase in specific water consumption of M2 is not considered to have a major effect on the total specific water consumption of finishing as, both fabric production and water consumption of this machine were the lowest when compared to the other finishing machines. This is also confirmed by 15.8% reduction achieved in total specific water consumption of finishing line, as presented in Table 6.6.

As can be seen from Table 6.6, installation of flow meters provided significant reductions in the machines utilized during finishing process. However, M6 and M7, comprising almost 45% of total water consumed in finishing line, are exceptions in this context since semi-counter current washing systems were applied only for those two machines. In this context, machine specific data was analysed for those two machines.

M6, being the most water intensive machine in finishing line consumes almost 27.04% of water and produces almost 19.16% of total fabric in the process. As indicated in Table 6.6, average specific water consumption of M6 has reduced from 10.26 to 9.03 litres of water per kg of fabric, on monthly average. Water consumption pattern of M6 is provided in Figure A.1 in Appendix A. Figure 6.6 summarizes the detailed data on monthly basis of M6. As can be seen from Figure 6.6, specific water consumption of this machine has reduced gradually from over 20 to around 8 litres of water per kilogram of fabric from the beginning of 2006 to the end of 2007. Especially after April'06, specific water consumption was almost uniform at around 9 litres of water per kilogram of fabric. This also indicates that the effect of BAT measures implemented for water minimization in finishing machine M6 is observed by May'06 in which fully automation of flow control and semi-counter current systems were completed.

Abovementioned BAT measures were also implemented in M7, the second water intensive machine in finishing line. M7 machine is responsible for 15.3% of total water consumed and 17.87% of total fabric produced in finishing process.

As indicated in Table 6.6, specific water consumption of M7 reduced from 7 to 5.52 litres of water per kilogram of fabric on monthly average. Figure 6.7 summarizes the detailed data of M7 on monthly basis. Water consumption pattern of M7 is also provided in Figure A.2 in Appendix A. As can be seen from Figure 6.7, specific water consumption reduced from over 9 to 5 litres of water per kilogram fabric during the implementation period. The change in specific water consumption of M7 is clearly observed by the reduction after August'06 in

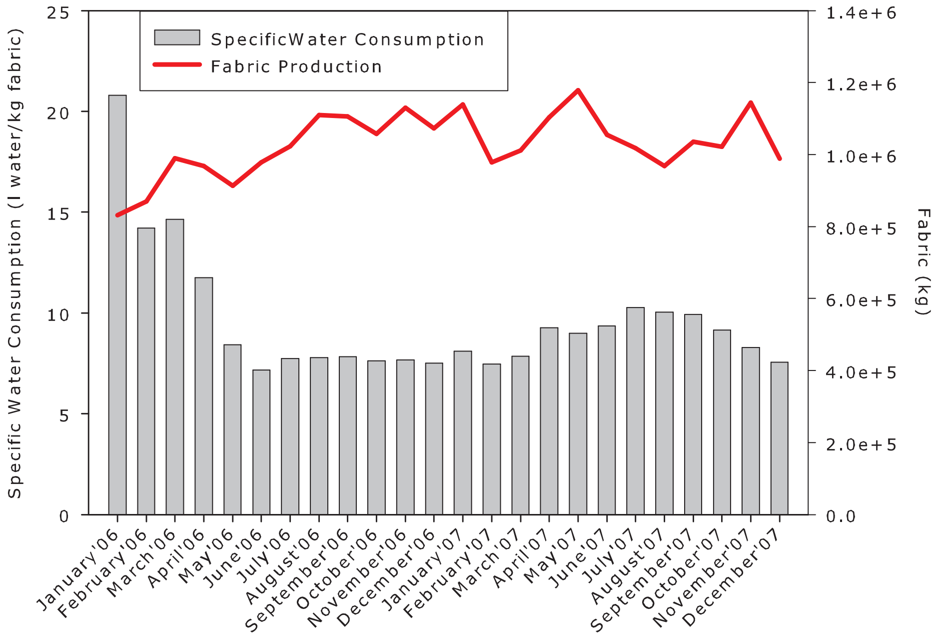

Figure 6.6: Specific water consumption and fabric production patterns in M6

which semi-counter current rinsing system was fully adapted. Consequently, a lower and more uniform water consumption pattern was achieved in finishing machine M7 by August'06.

The consumption patterns of other machines mentioned above (i.e. M1, M2, M3, M4, M5 and M8) are designated in Figures A.3, A.4, A.5, A.6, A.7, A.8, A.9, A.10, A.11, A.12, A.13 in Appendix A, respectively.

On the other hand, M1 should be considered as an exception than others as this machine contributes to fabric production most when compared to the others. As indicated in Table 6.4, fabric production from M1 composes 20% of total fabric production in finishing process. Additionally, M1 consumes considerable amount of total water consumed in finishing line with 13.5%. Therefore, reduction in specific water consumption of M1 is considered to have a major effect on overall specific water consumption of finishing line. In this respect, specific water consumption of M1 has reduced from 6.26 to 3.87 litres of water per kilograms of fabric produced that resulted in 38.2% reduction. The reduction is clearly observed in Figure 6.8. As can be seen from Figure 6.8, specific water consumption was highly variable until the end of 2006. However, specific water consumption pattern followed a more uniform and lower trend by the end of 2006 and during 2007.

Furthermore, as most water intensive finishing machines, M6 and M7, are considered apart

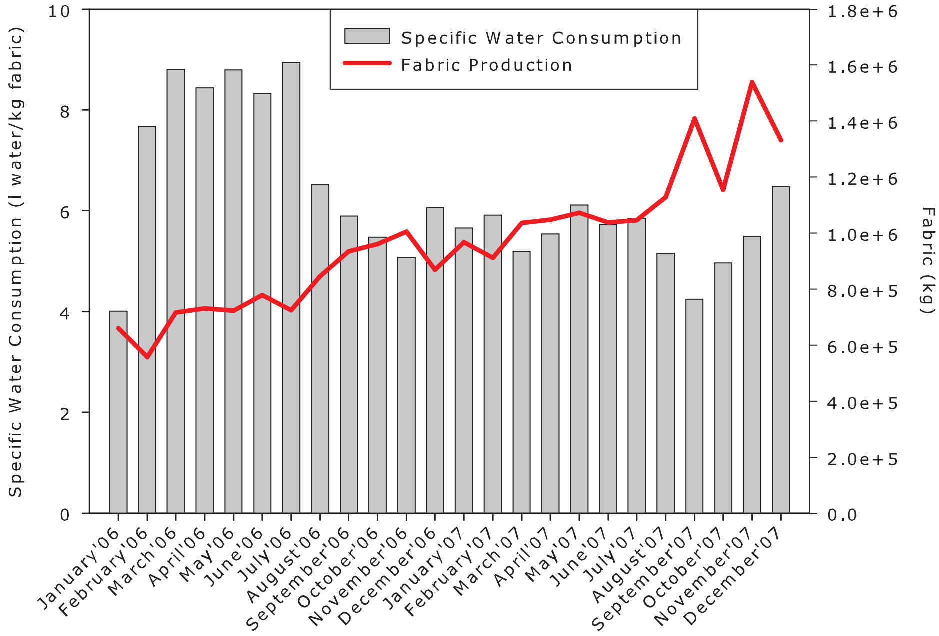

Figure 6.7: Specific water consumption and fabric production patterns in M7

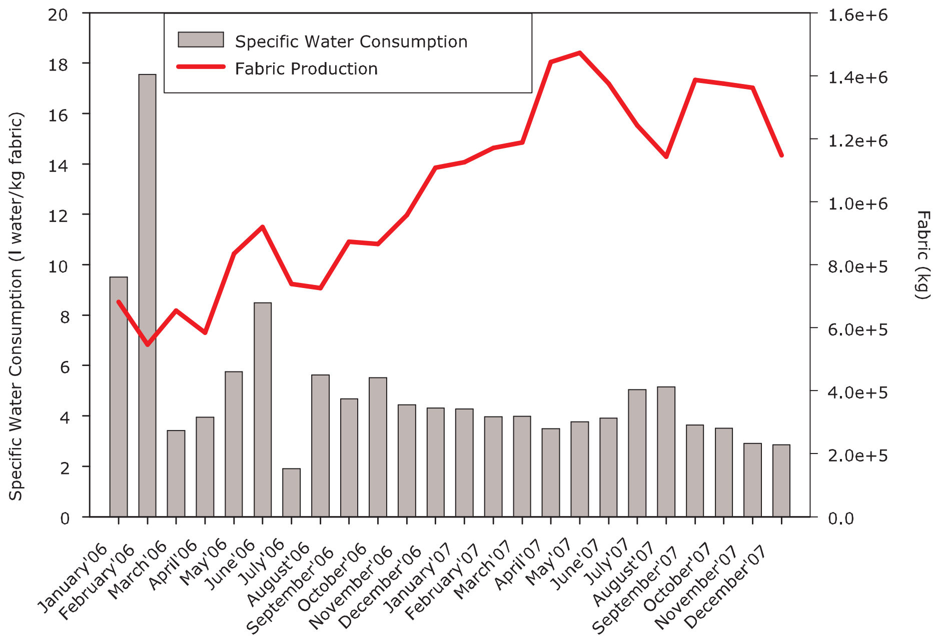

Figure 6.8: Specific water consumption and fabric production patterns in M1

from others and another analysis is conducted for those two machines. Another reason for this analysis is that, those two machines are the ones that additional process specific BAT measures were applied. Therefore, combination of water consumptions of finishing machines M6 and M7 were analyzed separately from other finishing machines. The results of the analysis are presented in Table 6.7. During implementation period of BAT measures, total fabric production of M6 and M7 has increased by 22% while water consumption of those machines has reduced by 0.82% in total. Most importantly, a significant reduction was achieved in specific water consumption of M6 and M7 by 19.5%.

Table 6.7: Water consumption pattern in machines M6 and M7

	Fabric Production (m)	**Fabric Production (kg)***	**Water Consumption (ton)**	**Specific Water Consumption (L /kg fabric)****
2006	2,943,594	1,795,592	15,459	8.84
2007	3,595,122	2,193,024	15,585	7.12
% **change**	**+22.0**		**-0.82**	**-19.5**
Average	**3,269,358**	**1,994,308**	**15,522**	**7.98**

* 1 m of fabric is 0.61 kg, ** 1 kg of water is 1 litre

Another representation of water consumption pattern of finishing machines M6 and M7 machines is seen in Figure 6.9. Accordingly, total water consumption and fabric production followed almost the same pattern since June'06. However, most importantly, specific water consumption pattern of finishing machines M6 and M7 designated in Figure 6.9 indicates that reduction in specific water consumption was followed by increase in fabric production since May'06 in which fully automated system for flow control was completely in operation. On the other hand, slight variations in specific water consumptions were also observed in Figure 6.10. This is considered to be due to the fact that the suggested BAT options for those two machines were applied in different schedules. This has resulted in such a pattern of specific water consumption of combination for M6 and M7. However, as a result, 19.5% reduction was achieved during the indicated period.

Another assessment of water consumption pattern of finishing line can be carried out by con-

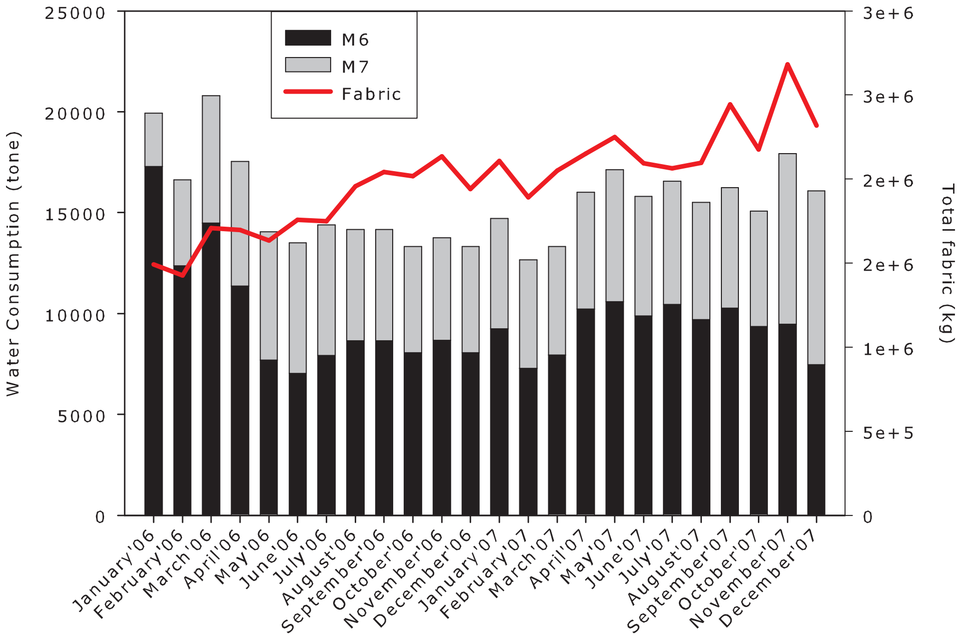

Figure 6.9: Water consumption pattern in machines M6 and M7

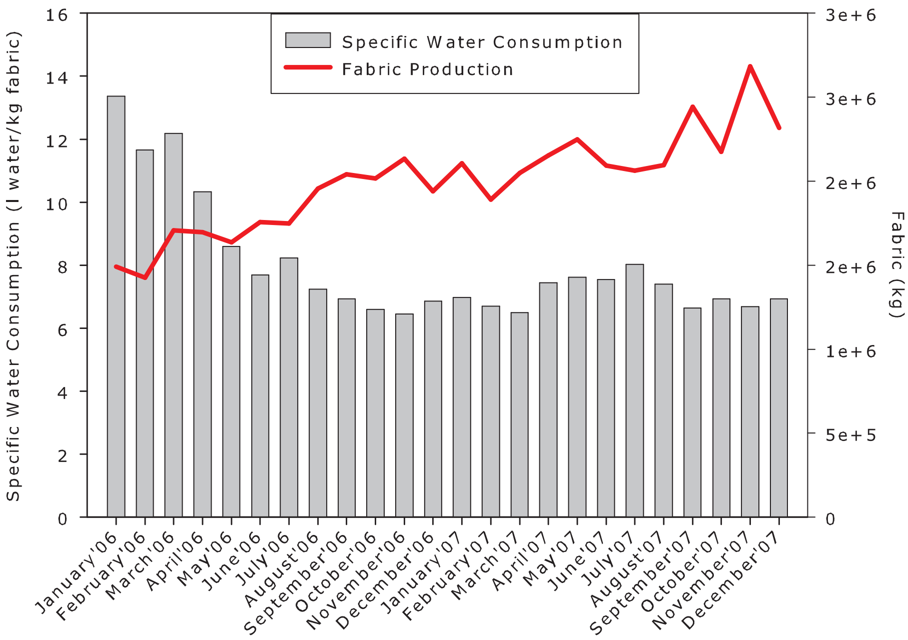

Figure 6.10: Specific water consumption pattern in M6 and M7

sidering the machines which contribute most to the total fabric production amount in finishing line. Therefore, by taking Table 6.4 into consideration, M1, M6 and M7 should be involved in this analysis. The applied BAT measures for those three machines were explained before. In this context, combination of water consumption patterns of those three machines is analyzed in Table 6.8.

Table 6.8: Combination of water consumption pattern of M1, M6 and M7

	Fabric Production (m)	**Fabric Production (kg)***	**Water Consumption (ton)**	**Specific Water Consumption (L /kg fabric)****
2006	4,239,752	2,586,249	20,514	6.06
2007	5,702,911	3,478,776	20,531	5.92
% **change**	+34.5		+1.8	-2.3
Average	**4,971,332**	**3,032,512**	**20,351**	**5.99**

* 1 m of fabric is 0.61 kg, ** 1 kg of water is 1 litre

As can be seen from Table 6.8, total fabric production of M1, M6 and M7 increased by 34.5% from 2006 to 2007. As a consequence of increase in fabric production, total water consumption slightly increased. However, annual specific water consumption of those three machines reduced by almost 2.3% which is expected to result reduction in total water consumption of total finishing line. Figure 6.11 is another representation of water consumption pattern of combination of M1, M6 and M7.

More importantly, as Figure 6.12 indicates, specific water consumption of those three machines reduced gradually during the indicated period. According to Figure 6.12, specific water consumption reduced to around 6 from 14 litres of water per kg fabric. Additionally, specific water consumption of those three machines was more uniform and lower after August'06 in which all of the BAT measures (i.e. application of fully automated flow control and semi-counter current rinsing systems) were fully adapted.

After analyzing machine specific water consumption data in eight machines in finishing, total water consumption of finishing line should be taken into consideration. For that purpose,

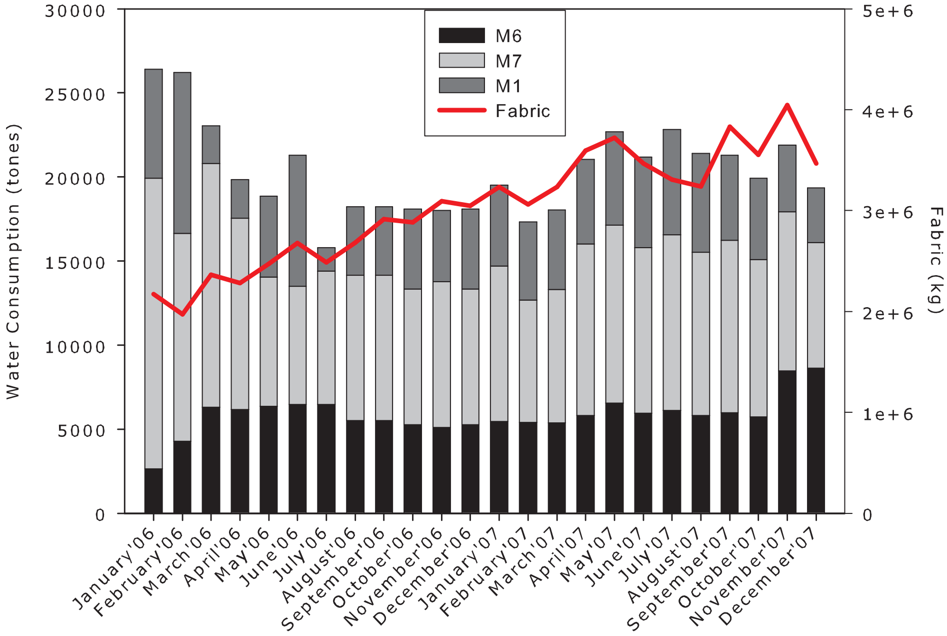

Figure 6.11: Combined water consumption and fabric production patterns of M1, M6 and M7

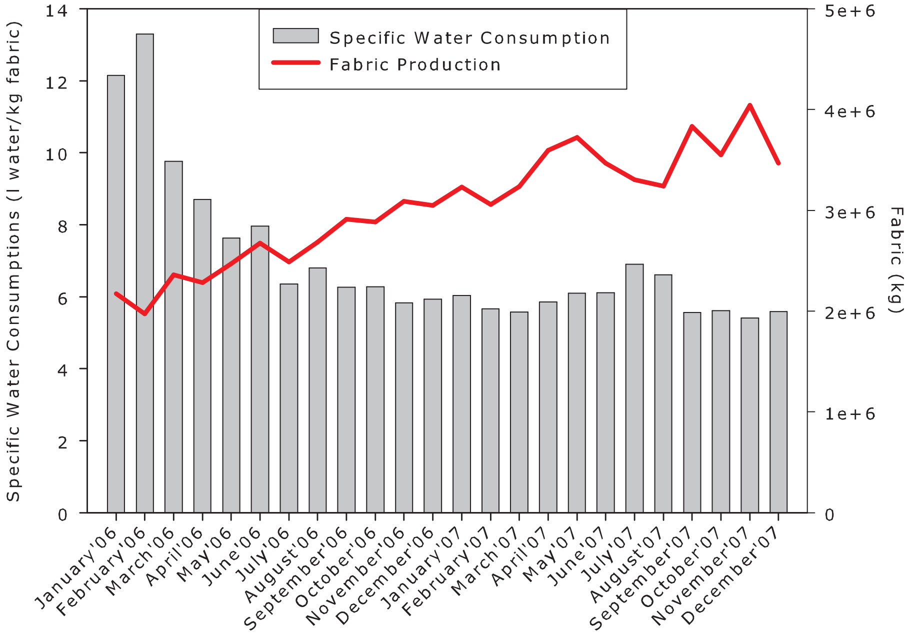

Figure 6.12: Specific water consumption and fabric production patterns of M1, M6 and M7

total water consumption and fabric production of the finishing line are analyzed and specific water consumptions are calculated. Table 6.9 summarizes the monthly averages of parameters mentioned above.

Table 6.9: Monthly average total water consumption pattern in finishing process

	Fabric Production (m)	**Fabric Production (kg)***	**Water Consumption (ton)**	**Specific Water Consumption (L /kg fabric)**
2006	3,371,171	2,056,414	34,047	16.87±3.6
2007	4,359,226	2,659,128	37,742	14.20±0.8
% **change**	+29.3		+10.9	-15.8
Average	**8,924,032**	**5,443,659**	**35,894**	**15.54±2.9**

* 1 m of fabric is 0.61 kg [46]

As can be seen from Table 6.9, fabric production increased with almost 30% while total water consumption increased only 10.9% during the indicated period. Therefore, as a performance indicator, specific water consumption was taken into consideration. According to the analysis of specific water consumption of finishing process, almost 16% reduction was achieved in overall. In Figure 6.13, the details of water consumption of total finishing process are presented.

As can be seen from Figure 6.13, total water consumption was highly variable during the period of January'06-December'07. Although monthly water consumption seemed to be increasing in proceeding months of 2007, fabric production also increased. For instance, in March'06 and June'07 almost same amount of water was consumed. However, fabric production increased from around 2.0 to 2.7 millions of kilograms indicating that water was consumed more efficiently in the process. Moreover, total water consumption and fabric production data on monthly basis followed almost the same pattern since December'06. Furthermore, specific water consumptions indicated a steadier trend in the indicated period. The results can be seen in Figure 6.14.

In Figure 6.14, it is observed that specific water consumption reduced sharply by May'06

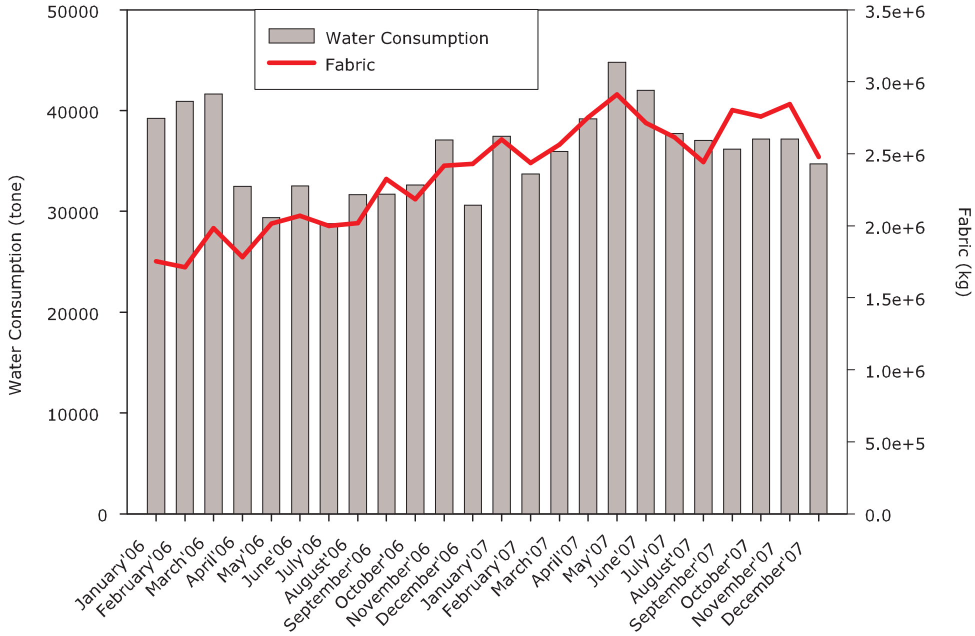

Figure 6.13: Overall water consumption and fabric production patterns in finishing process

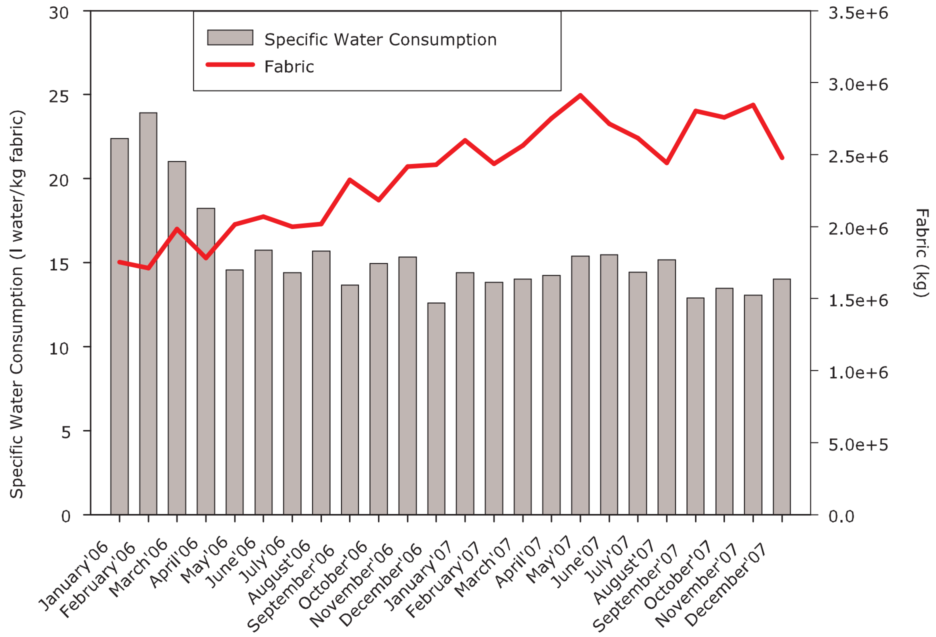

Figure 6.14: Overall specific water consumption and fabric production patterns in finishing process

despite the continuous increase in fabric production. Additionally, water was consumed more efficiently during the indicated period as specific water consumption reduced more while fabric production increased over 6 millions of kilograms. Consequently, specific water consumption of finishing process reduced from 16.87 to 14.20 litres of water per kilogram of fabric, resulting in 15.8% reduction in total with a lower and more uniform water consumption trend. Therefore, the initial effects of BAT measures taken for water minimization have been effective on overall water consumption pattern of finishing process by May'06. Specific water consumption reduced further in the proceeding months of the indicated period meaning that the effects of taken measures were ongoing. If it is considered that finishing process is responsible for 27% of total water consumption in the selected mill, 15.8% reduction of water consumption in finishing line is much more effective than other processes.

6.2 Energy Consumption

Energy is essential in all of the industrial activities, as it is one of the major resources utilized during production processes. Energy is necessary to run machinery equipment, heat up process baths and spaces and additionally for lightening, cooling and temperature controlling systems and etc. In most of the industries the major energy forms consumed are natural gas, electricity, steam, fuel-oil, coal and LPG. Industrial activities in terms of energy consumption and energy efficiency are emphasized in the IPPC Directive. The Directive states that 'Member States shall take the necessary measures to provide that the competent authorities ensure that installations are operated in such a way that energy is used efficiently' besides the other requirements of the Directive [9].

In this context, when industrial activities are considered in terms of energy consumption, textile industry is considered to be one of the most significant one. Actually, environmental concern in terms of energy consumption and efficiency is the third consideration after water consumption and wastewater generation with heavy loads of chemicals in textile industry. Therefore, textile industry is accepted as one of the energy intensive industries by the BREF Textile document [6].

In textile industry, the major energy sources are fuel-oil, natural gas, electricity, LPG, steam and coal. As the end use products require a considerable amount of machinery during the process chain, electricity is one of the most significant resources. Additionally, some of the process baths are heated up by electricity. Furthermore, LPG, natural gas and similar fuels are consumed in drying and singeing processes while steam is utilized for heating purposes generally. Another significant evidence about energy consumption in textile industry is that energy consumption is directly related to water consumption in the production processes since the majority of the energy is consumed in heating up the process baths as indicated before [6].

Evidently, a detailed energy balance analysis is necessary for monitoring energy consumption in addition to the assessment of energy consumption performance in the mill. To conduct an energy balance analysis in the selected mill, initially energy sources required are identified. In this respect, the major energy source required is natural gas in the selected mill. Natural gas is consumed in cogeneration unit which produces electricity and steam to be directed to the processes and to be used for other purposes in the mill campus. Furthermore, natural gas is required in some processes such as singeing and drying. On the other hand, apart from production processes, natural gas is also consumed for heating purposes in company dwellings and staff canteen. Another energy source required in the mill is electricity. Although cogeneration unit produces required electricity in the mill, the amount of necessary electricity cannot be predicted exactly. Therefore, electricity production is sometimes insufficient and sometimes in excessive amounts. For that reason, electricity is purchased from or sold to central electricity network when necessary.

In addition to electricity and natural gas, steam is also a significant energy source required in the production processes. Steam is produced in cogeneration unit and boilers then directed to processes and to be consumed for other purposes. Steam is an essential energy source consumed as the majority of steam is consumed in wet processes for heating up the process baths as is discussed in the coming sections.

As explained above, natural gas and electricity are the major energy sources required in the mill. Natural gas is consumed in cogeneration unit to produce steam and electricity to be used in the processes. Additionally, boilers also provide steam to be used in the facility campus by consuming natural gas whenever steam production in cogeneration unit is not sufficient. In this respect, the majority of energy requirement in the facility is met by the cogeneration unit.

Cogeneration units, also known as Combined Heat and Power (CHP), produce electricity and heat in one single process by consuming fuels. The efficiency of CHP systems can reach up

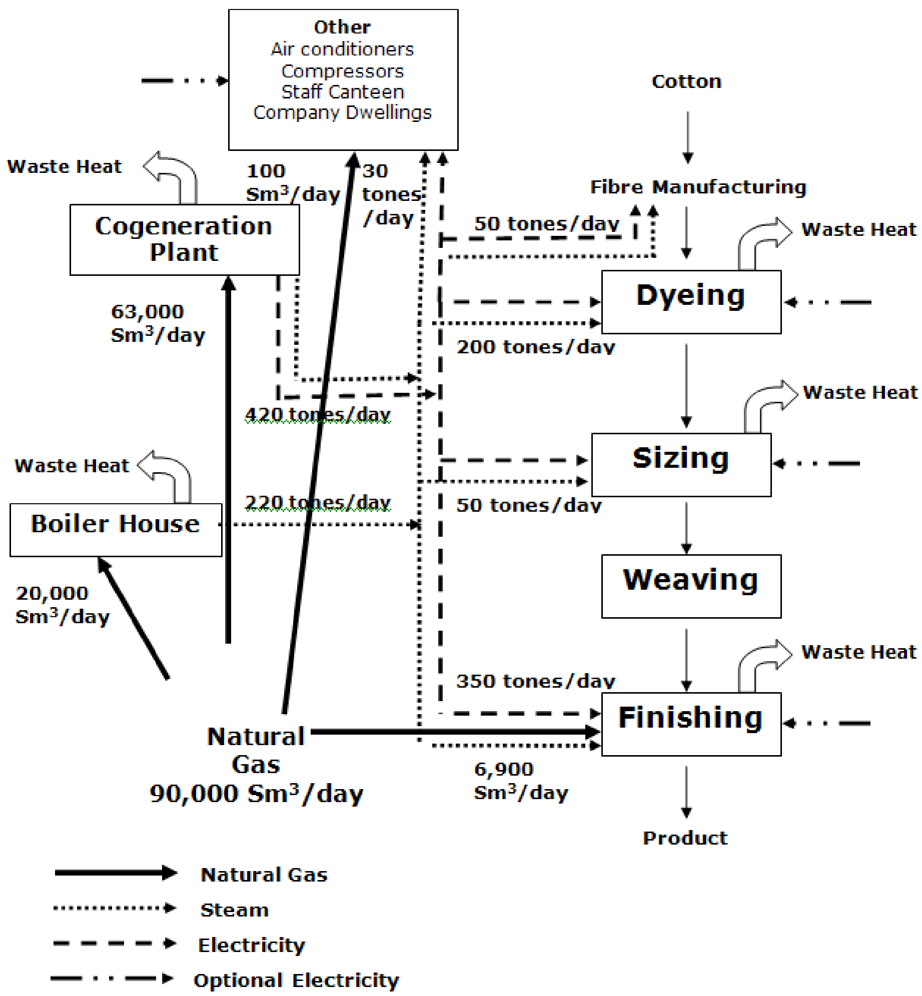

Figure 6.15: Energy flow in the mill (as of 2005)

to 90% which cannot be underestimated as most advanced conventional electricity generation systems can convert 55% of fuel into useful energy. The system saves 15 – 40% of energy when compared with the separate production of electricity and heat. Moreover, cogeneration reduces CO_2 emissions significantly. Although the initial investment cost of cogeneration is relatively high, the pay-back period is 3-5 years depending on the fuel and electricity prices. Cogeneration has become a very popular alternative for energy production recently as the system proposes a wide range of applications including process industries (pharmaceuticals, paper and board, brewing, ceramics, brick, cement, food, textile, minerals etc.), commercial and public sector buildings (hotels, hospitals, leisure centres, swimming pools, universities, airports, offices, barracks, etc.) and district heating schemes. In cogeneration systems, steam turbines, gas turbines, combined cycle (gas and steam turbines) and Diesel and Otto engines are the most popular technologies to be used [47].

Heat generated by CHP systems can be delivered through various mediums, including warm water (e.g., for space heating and hot water systems), steam or hot air (e.g., for commercial and industrial uses). For that purpose, those facilities are usually sited close to the heat demanding points to meet the demand as efficiently as possible. The electricity production is also very efficient reaching up to 55% in combined systems. Generally, electricity is produced more than needed. Therefore, surplus electricity can be sold to the electricity grid via the distribution system [47].

In the selected mill, CHP system includes two steam turbines with a capacity of 5 megawatts. In the cogeneration unit, natural gas is consumed to produce electricity and steam to be utilized in campus. In general, the electrical and overall efficiency of the steam turbines are 7-20% and 60-80%, respectively [47]. In cogeneration unit, natural gas and water enters into the steam turbines and electricity is produced. The resulting steam at a temperature of 500^oC is directed to the by-pass stacks. However, an economizer system is present in order to recover the steam and send to the processes to be consumed. Therefore, the temperature of the flue gas is reduced to 130-140^{o}C. On the other hand, if economizer system is not utilized (i.e. when production is much less) flue gas is wasted at nearly 500^{o}C.

In addition to cogeneration unit, boilers also provide steam for the processes. In boiler house, a conventional system to produce steam, natural gas is consumed. The system is put into service whenever steam production in cogeneration facility is not sufficient to assure the demand.

In the mill, there are three steam boilers with a capacity of 15 tones.

As Figure 6.15 indicates, steam and electricity produced in cogeneration unit and boilers are directed to the facility campus for production processes and demands in company dwellings and staff canteen. Additionally, natural gas is also required in staff canteen and in finishing process to be directly used in certain machines. Although natural gas and steam requirements in different processes could be distinguished by the available data, process specific electricity requirement for different purposes could not be distinguished in the mill and hence, general electricity requirement of the processes could not be determined. Therefore, in Figure 6.15 only steam and natural gas consumptions are presented. As depicted in Figure 6.15, the majority of steam was consumed in dyeing and finishing processes demanding more than 75% of total steam production. Additionally, it should be noted that Figure 6.15 indicates energy consumption of the mill in 2005, before the project implementation.

6.2.1 Suggested/Applied BAT Measures

The possible BAT options for the minimization of energy consumption were identified based on comparison with the BREF Textile Document. The applicability of these options at the plant scale was discussed and evaluated with the factory administration. The identified BAT options were:

1. *Use of waste heat from finishing and dyeing wastewater streams in heating up the washing waters*: Instead of consuming energy to heat up process baths, heat of wastewater streams originating from finishing machines is recovered by specifically designed heat exchangers. This reduces the total energy consumption of the specific machine.

2. *Heat-insulation of pipes, valves, tanks, machines*: Heat insulation is the general principle of good housekeeping practice that should be applied at the general level in all processes. Heat insulation of the machinery equipment eliminates losses in energy streams and can save up to 9% of energy consumed [6].

3. *Maintenance of heating systems and stenters*: Periodical maintenance of the heating systems and stenters eliminates losses to a considerable extent.

4. *Heat recovery from hot air discharges in finishing line*: Additionally, exhaust heat can

be recovered by air-to-water heat exchangers to be used in dyeing or finishing processes. Those measures result in reduction in total energy consumption of the mill.

5. *Optimization of stenter frames*: If the water content of the incoming fabric is minimized by using mechanical dewatering equipment, considerable amount of energy saving can be achieved.

By the end of the year 2005, waste heat from finishing hot wastewater streams were recovered by heat-exchanger systems in M6 and M7 in finishing process. On the other hand, heat insulation and maintenance applications could not be scheduled as those measures are applied periodically during the project period. Additionally, studies for items 3 and 4 in the list above are underway and hence they are not implemented yet. On the other hand, BAT measures implemented for water minimization are considered to be as effective as BAT measures taken for energy minimization. By the application of semi-counter current rinsing system, as wasted wash waters with relatively high temperatures are reused, it is not necessary to increase the temperature of wash waters for next washing cycle and hence, energy is saved. Additionally, reusing compressor cooling waters which are higher in temperature than groundwater provides energy savings as energy is not required to increase the temperature of process waters as much as it was before implementation of this measure. As a result, BAT measures taken for water minimization are considered to have a major effect on energy minimization also.

6.2.2 Energy Consumption Analysis

As a consequence, the major energy resources incoming to the selected mill are determined as natural gas which is then converted to electricity and steam by cogeneration unit and electricity by the initial step of the energy balance analysis in the mill. The second issue that is pointed out is the distribution of the energy resources utilized in the mill. In this respect, the major energy resource consumed in the plant was determined as natural gas with a 98.1% in average of the indicated period in Table 6.10. As a result, for the sake of monitoring total energy requirement of the mill, natural gas and electricity requirements were considered with fabric production in order to assess the performance of the mill.

Similarly, Table 6.10 designates monthly average natural gas consumptions in terms of Sm^3 and Gcal and fabric productions in terms of meters and kg, besides specific energy consumptions during the implementation period of BATs for the whole facility. As can be depicted from Table 6.10, overall energy consumption has slightly increased from 786 to 804 Gcal/day while specific energy consumption for the whole facility decreased from 10 to 9.1 Mcal on monthly basis up to date. The details of the data are provided in Table B.1 in Appendix B.

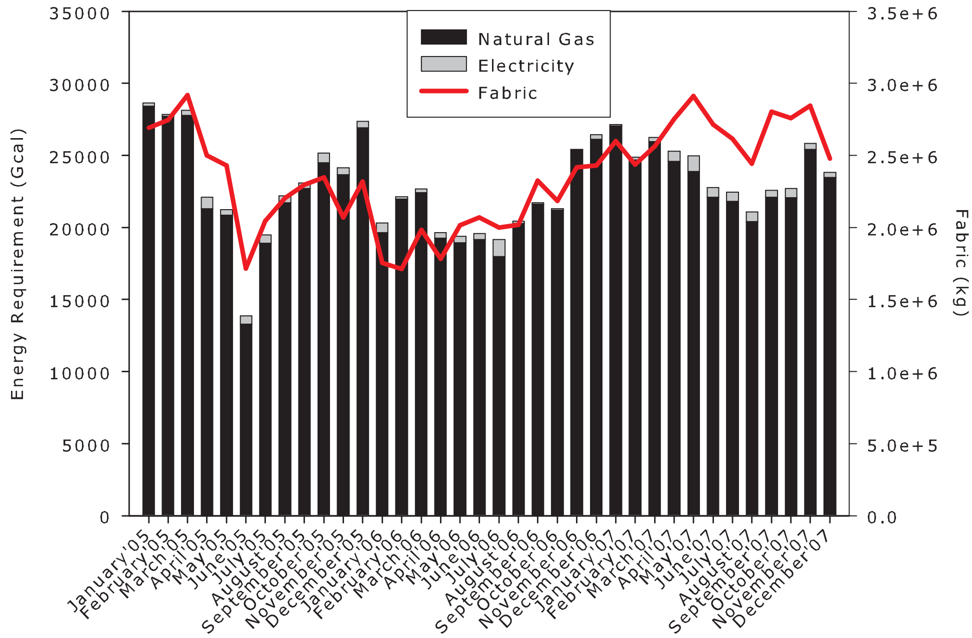

Figure 6.16: Incoming energy into the mill

As can also be seen from Figure 6.16, natural gas is the major energy source utilized in the selected mill. Moreover, incoming energy trend of the mill followed almost the same pattern with the fabric production in the indicated period. A significant note that is to be pointed out, energy has been consumed more efficiently in the last year of the indicated period. As an example, in March'05 and May'07, fabric productions were nearly same whereas, energy consumption in May'07 was much less than it was in March'05. The same trend was also observed in the proceeding months of 2007. The reduction is also confirmed by the pattern observed in Figure 6.17 which shows incoming specific energy of the mill on monthly basis. In Figure 6.17, it was seen that specific energy requirement reduced gradually, in three stages during the indicated period. The first significant reduction was observed by mid-2005. However, as seen from Figure 6.17, fabric production also decreased in the same period. Moreover, as project implementation period covers after October 2005, the reduction in 2005 was not of concern. The second significant reduction was observed in the initial months of the year 2006 despite the fact that fabric production increased in the same period. This reduction

Table 6.10: Monthly average incoming energy and production pattern in the mill

	Natural gas		Electricity		Total Energy		Fabric Production		Specific Energy
	Sm^3	**Gcal***	**kWh**	**Gcal****	**Gcal**	**Gcal/day**	**m**	**kg*****	**Gcal/kg**
2005	2,690,808	23,141	530,221	456	23,597	786	3,862,146	2,355,909	0.0100±0.0011
2006	2,460,523	21,160	409,831	352	21,513	717	3,371,171	2,056,414	0.0105±0.0011
2007	2,746,648	23,621	599,886	516	24,137	804	4,359,226	2,659,128	0.0091±0.0008
Average	**2,632,660**	**22,641**	**513,313**	**441**	**23,082**	**755**	**3,864,181**	**2,357,150**	
%	**98.1**		**1.9**						
2006-2007 Average	**2,603,586**	**22,390**	**504,859**	**434**	**22,825**	**761**	**3,865,199**	**2,357,771**	**0.0098±0.0011**

* 1 Sm^3 Natural Gas = 0.0086 Gcal ** 1 kWh = 0.00086 Gcal *** 1 meter of fabric = 0.61 kg [46]

could be related to the implemented BAT measures for water minimization. Specific energy requirement of the mill reduced further in the year 2007 while fabric production continuously increased. This third stage of reduction could also be associated with BAT measures implemented to minimize energy consumption directly. On average, specific energy consumption was 0.0098±0.0011 Gcal/kg fabric in the period of 2006-2007 indicating that BAT measures taken are effective on overall specific energy consumption. However, in order to distinguish the effects of BAT measures taken, a detailed energy balance analysis was necessary. Therefore, energy consumption analysis for specific processes were performed, the results of which are presented in the following sections.

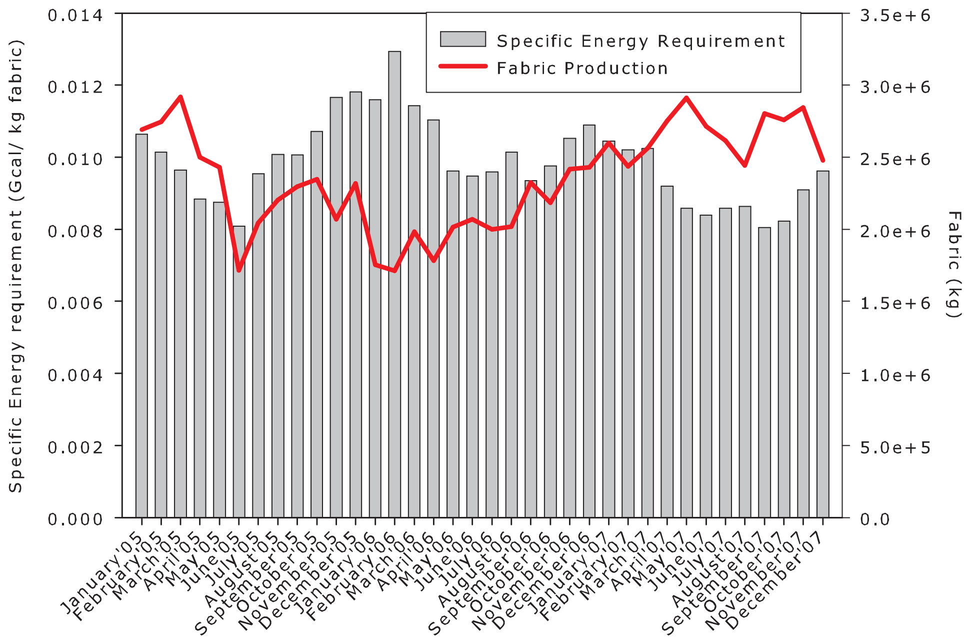

Figure 6.17: Specific energy requirement pattern of the mill

At this point, after determination of the major energy sources utilized and specific energy consumption in the mill in general, the processes in which the main energy consumption occurred were selected by the energy balance analysis. The detailed energy balance analysis was also attempted to indicate the effects of the BAT options applied in specific processes as mentioned before.

As indicated in 6.2, energy requirement of the facility is met by the cogeneration facility and boiler house as the production of steam and electricity is provided by those two units. For that reason, energy balance analyses for those two units were conducted. For that purpose, the overall energy consumption and production of the cogeneration unit in the mill is presented, initially in Table 6.11. The detailed data is available in Table B.2 in Appendix B.

As can be seen from Table 6.11, energy production of the cogeneration unit increased as fabric production increased. Only exception was observed in 2006 in which energy loss was also high when compared to the other years. On the other hand, although fabric production increased almost 29%, energy consumption of the cogeneration unit increased slightly with 7.6% in the period of 2006-2007. Therefore, energy loss per one kilogram of fabric has decreased from 1.7 to 1.1 Mcal resulting in 35% reduction in the indicated period.

In addition to cogeneration unit, energy consumption and production of boiler house was also analyzed as depicted in Table 6.12. The detailed data is included in Table B.3 in Appendix B.

As can be seen from Table 6.12, natural gas consumption seemed to be directly related to fabric production in the indicated period. However, natural gas consumption in 2007 was less than it was in 2005 despite the fact that fabric production increased. On the other hand, losses in boilers also seemed to be related to fabric production whereas; this pattern was broken in 2007 as energy loss decreased although fabric production increased when compared to the previous years proving that energy efficiency has increased in boilers. Therefore, energy loss per one kilogram of fabric has decreased from 320 to 230 Kcal resulting in 28.1% reduction.

Although energy loss per kilogram of fabric produced in cogeneration unit and boilers reduced significantly throughout the project period, average energy loss from those units is considered to be a substantial amount still. Accordingly, as indicated in Tables 6.11 and 6.12 energy losses from cogeneration unit and boilers due to exhaust gases are around 3250 and 625 Gcal on monthly average, respectively. This amount of wasted heat from cogeneration unit and boilers in total is estimated to heat up around 52,000 tones of water from 15^{o}C to 90^{o}C according to the Equation 6.1. In calculation of value of wasted energy, the specific heat (i.e. Cp) is taken as 1 cal/gr^{o}C.

$$Q = m \cdot C_p \cdot \Delta T \tag{6.1}$$

This amount of water corresponds to over 30% of water consumed per month. Therefore, this amount of wasted energy can be appraisable to heat up water to be used in the processes by an appropriate heat exchanger system. However, it should be pointed out that energy losses in

Table 6.11: Energy balance of the cogeneration unit

	Natural gas Consumption		Steam Production		Electricity Production		Fabric Production		LOSS	
	Sm^3	**Gcal***	**Tone**	**Gcal****	**kWh**	**Gcal*****	**m**	**kg******	**Gcal**	**Gcal/kg fabric**
2005	1,883,717	16,200	12,446	8,239	5,438,987	4,678	3,862,146	2,355,909	3,283	0.0014
2006	1,909,941	16,425	12,398	8,207	5,578,937	4,798	3,371,171	2,056,414	3,420	0.0017
2007	2,015,716	17,335	13,761	9,110	6,060,959	5,212	4,359,226	2,659,128	3,013	0.0011

* 1 Sm^3 Natural Gas = 0.0086 Gcal ** 1 tone of steam = 0.662 Gcal *** 1 kWh = 0.00086 Gcal **** 1 meter of fabric = 0.61 kg [46]

heat transfer in heat exchanger systems should be considered in addition to the losses during the transfer of exhaust gases from the emission point to the distance where wasted heat will be used for an actual calculation. Therefore, substantial amount of energy is still wasted in cogeneration unit and boilers. This evidently confirms that wasted energy from cogeneration unit and boilers is profitable.

In the detailed energy balance analysis, the initial step is to determine the amount of energy required in the production processes. As indicated before, electricity and steam generated by cogeneration unit and boilers, and a small amount of natural gas is consumed in the processes. Although, the majority of electricity and steam is consumed in production processes, consumption for other purposes (i.e. company dwellings, staff canteen etc.) should also be taken into consideration during overall energy balance analysis. However, as energy consumptions

Table 6.12: Energy balance of boilers

	Natural gas consumption		**Steam Production**		**Fabric Production**		**LOSS**	
	Sm^3	**Gcal***	**Tone**	**Gcal****	**m**	**kg*****	**Gcal**	**Gcal/kg fabric**
2005	597,778	5,141	6,601	4,370	3,862,146	2,355,909	771	0.00032
2006	388,902	3,345	4,294	2,843	3,371,171	2,056,414	502	0.00025
2007	474,317	4,079	5,238	3,467	4,359,226	2,659,128	612	0.00023

* 1 Sm^3 Natural Gas = 0.0086 Gcal ** 1 tone of steam = 0.662 Gcal *** 1 meter of fabric = 0.61 kg [46]

Table 6.13: Steam consumption distribution in the mill

	2005	**2006**	**2007**	**Average**	%
	tone/year				
Warehouse	775	865	650	763	0.35
Yarn manufacturing	11,976	8,370	7,737	9,361	4.27
Sizing	17,432	16,765	17,438	17,212	7.86
Weaving	1,100	700	2,926	1,575	0.72
Dyeing	59,780	66,607	61,294	62,560	28.56
Finishing	128,951	106,381	104,172	113,168	51.66
Grinding	4,593	4,238	5,010	4,614	2.11
Others	4,391	6,175	18,903	9,823	4.48

except steam and natural gas of only processes were not monitored, energy requirement for other purposes could not be presented. Therefore, only steam requirement in different processes are indicated in Table 6.13. Additionally, energy source distribution in the facility can be represented in Table 6.14 which covers energy requirement of the whole facility. The details of Table 6.14 are provided in Table B.4 in Appendix B.

As expected, steam is dominant over other energy sources consumed in terms of calorific value in the facility as can be seen from Table 6.14. Similarly, in Table 6.15, the percentages of the energy resources are provided and it is observed that steam consumed has a share of 63.7% of the total energy requirement, in the mill. In Table 6.14 it was observed that although, fabric production increased from 2.3 to 2.7 millions of kilograms (17% increase), specific energy consumption remained almost the same with 2.4% reduction during the period of 2005-2007. However, specific energy consumption decreased by 8% from the year 2006 to 2007.

Figure 6.18 is another representation of the energy consumption trend in the production processes of the mill. Steam is the dominant energy source with an average of 13,000 Gcal per month as indicated in Figure 6.18. However, the highest variability was also observed in steam requirement. Additionally, electricity requirement of the processes was almost stable during the indicated period with 5,000 Gcal on monthly average basis. On the other hand, natural gas requirement was also variable throughout the indicated period. In general, although energy requirement of the processes seem to be increasing, it was observed from Figure 6.18 that this increase was mainly due to increase in fabric production. This is also confirmed by Figure 6.19 which indicates the reduction in specific energy requirement of the mill by December'06. In Figure 6.19, it was also observed that specific energy requirement of the mill increased in summer season of 2007. However, this slight increase did not change the general pattern of energy requirement of the mill as the average specific energy requirement of the mill decreased. On the other hand, a more detailed energy balance analysis was necessary to complete the gaps in the overall energy consumption of the mill. However, it should be kept in mind that energy balance analysis can be completed by considering inputs, outputs and losses. Although energy requirements of the processes that are covered to complete energy balance analysis are known, energy losses and consumptions cannot be estimated specifically in machines. Therefore, in the coming sections, energy requirements of the processes mentioned are of concern.

Table 6.14: Monthly average overall energy requirement pattern of the facility

	Fabric production	**Electricity**			**Steam**			**Natural gas**			**Specific energy**
	kg	kWh	Gcal*	kWh/kg fabric	Ton	Gcal**	tone/kg fabric	Sm^3	Gcal***	Sm^3/kg fabric	Gcal/kg fabric
2005	2,355,909	5,956,711	5,131	2.53	19,083	12,633	0.0081	209,313	1,800	0.088	**0.0083**
2006	2,056,414	5,987,576	5,149	2.91	17,508	11,591	0.0085	161,684	1,390	0.078	**0.0088**
2007	2,659,128	6,659,491	5,727	2.50	20,352	13,473	0.0076	256,614	2,207	0.096	**0.0081**
Ave.	2,357,150	6,201,259	5,336	2.63	18,981	12,566	0.0081	209,204	1,799	0.089	**0.0084**

* 1 kWh=0.00086 Gcal, ** 1 ton steam= 0.662 Gcal, *** 1 Sm^3 Natural gas = 0.0086 Gcal

Table 6.15: Energy consumption percentages in the selected mill (based on monthly averages)

	Electricity	Steam	Natural gas
2005	27	64	9
2006	29	64	8
2007	27	63	10
Average	**27.7**	**63.7**	**9**

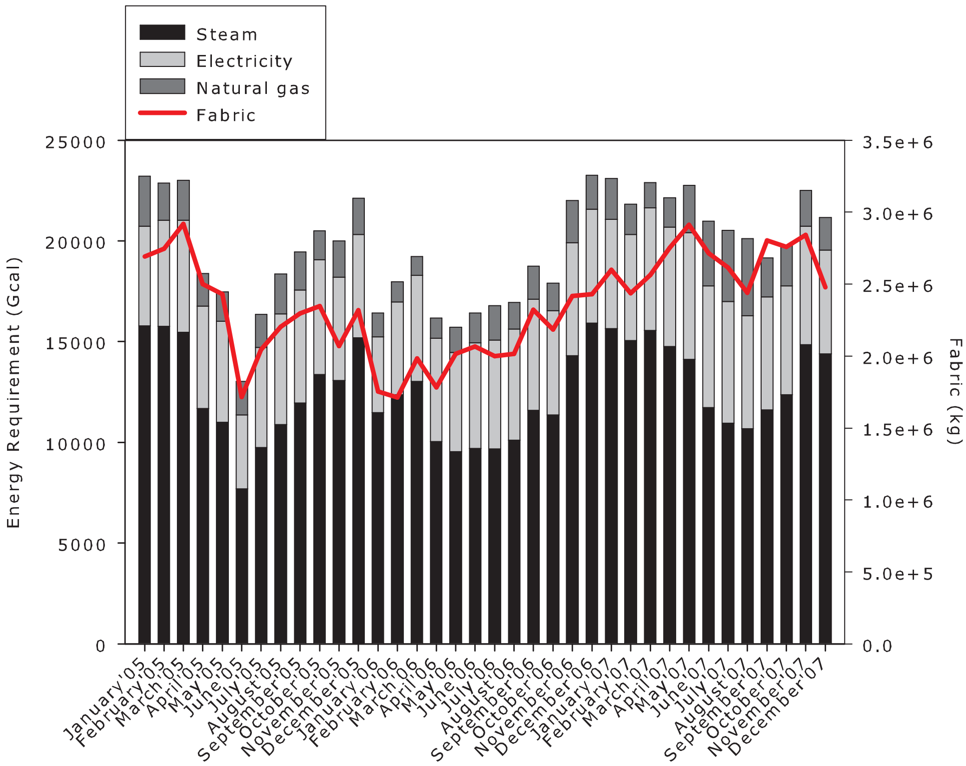

Figure 6.18: Energy consumption pattern in production processes

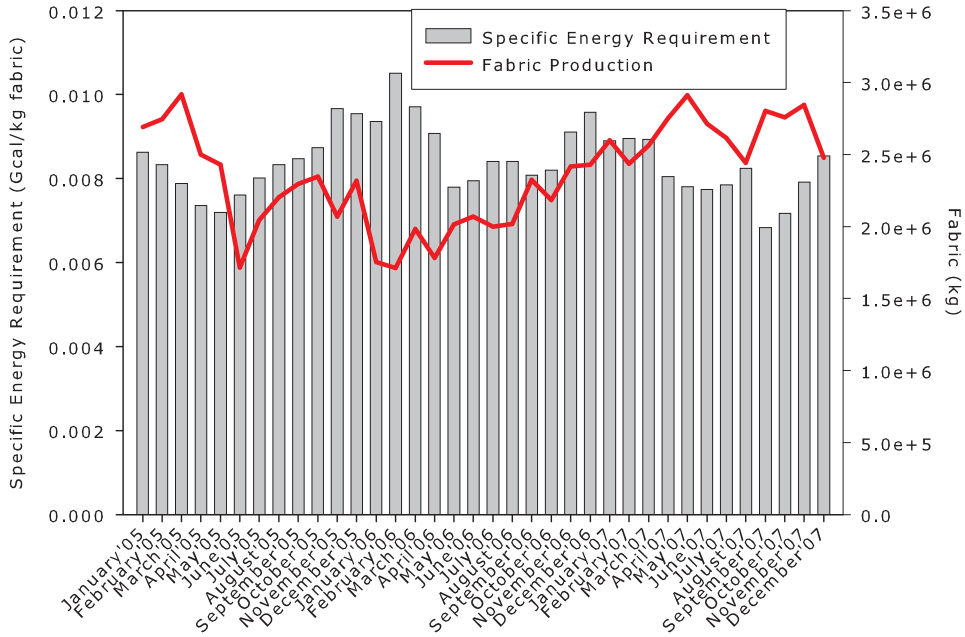

Figure 6.19: Total specific energy consumed in the mill

Consequently, steam is the dominant energy source required in production processes of the selected mill. Furthermore, steam is generally consumed in wet processes as presented in Table 6.13. This consideration is also confirmed by the fact that 'the majority of energy is consumed in heating up the process baths' indicated in the BREF Textile Document [6]. In this respect, in detailed energy balance analysis most water intensive and hence most energy intensive processes were selected which are dyeing and finishing. For that reason, among BAT measures suggested for energy minimization, some applications were specific to mentioned processes. Although, spinning operation, in which considerable amount of electricity is required is another consideration during energy balance analysis, the corresponding heating value of electricity is low. Because of this consideration, electricity requirement of spinning operation is negligible when compared to the energy consumption in terms of steam. Therefore, the focus of the energy balance analysis is now dyeing and finishing processes.

6.2.2.1 Dyeing

As dyeing is a water intensive process in textile industry, energy requirement of this process is one of the major concerns in detailed energy balance analysis. In general, dyes are applied to the warp yarns within baths saturated with chemicals.

In dyeing process, the major energy sources required are steam and electricity. Electricity is consumed in order to run four dyeing machines in process plus for lightening and air conditioning. Furthermore, in rope openers where warp yarns are folded onto, electricity is required. Additionally, steam is required in order to heat up the process baths.

Therefore, BAT measures for energy minimization that were applied in dyeing process are considered to be effective on reducing energy requirement of the process. The BAT measures selected for energy minimization explained in Section 6.2.1 as well as measures for water minimization, are expected to result in reductions in energy requirement of the process. In dyeing process, heat insulation of pipes, tanks and machines and maintenance of heating systems were realized in terms of energy minimization in addition to the measures taken for water minimization. The energy consumption pattern of the dyeing process can be seen from Table 6.16

In order to evaluate the energy requirement of the dyeing process, it was necessary to compare average specific energy requirements in project period. In Table 6.16, steam and electricity requirements and specific energy requirements are indicated in terms of tone, kWh and Gcal/kg warp yarn, respectively. As can be seen from Table 6.16, steam requirement decreased slightly whereas electricity requirement increased with nearly 9.4%. However, specific energy requirement of the process decreased by 25%. This confirms that the increase in energy requirement was due to increase in warp yarn production. The detailed data is presented in Table B.5 in Appendix B. Additionally, change in electricity and steam requirements with dyed yarn can be seen from Figures 6.20 and 6.21, respectively.

Another representation of steam requirement can be seen in Figure 6.22. From this figure, one can observe that specific steam requirement reduced gradually by mid-2006. This is considered to be mainly due to the applied BAT measures for water minimization which were completed at nearly the same times in addition to maintenance and insulation applications with the reduction observed in steam requirement of dyeing process.

Additionally, specific electricity requirement in dyeing process is represented in Figure 6.23. As can be seen from Figure 6.23, specific electricity requirement remained almost the same during the indicated period. As electricity is required only to run the machinery equipment and for air-conditioning in dyeing process, specific electricity requirement remaining the same was not unexpected.

Table 6.16: Monthly average energy requirement of dyeing process

Monthly Average	**Dyed Yarn**	**Steam Requirement**		**Electricity Requirement**		**Total Energy**	**Specific Energy Requirement**
	kg	**ton**	**Gcal***	**kWh**	**Gcal****	**Gcal**	**(Gcal/kg yarn)**
2006	1,218,830	5,386	3,565	346,696	298	3,863	0.0033±0.0010
2007	1,446,598	4,882	3,232	379,358	326	3,558	0.0024±0.0007
Average	1,333,464	5,134	3,398	363,027	312	3,711	0.0029±0.00097
% Change	+18.5	-9.4		+9.4		-7.9	-27

* 1 ton steam= 0.662 Gcal, ** 1 kWh=0.00086 Gcal

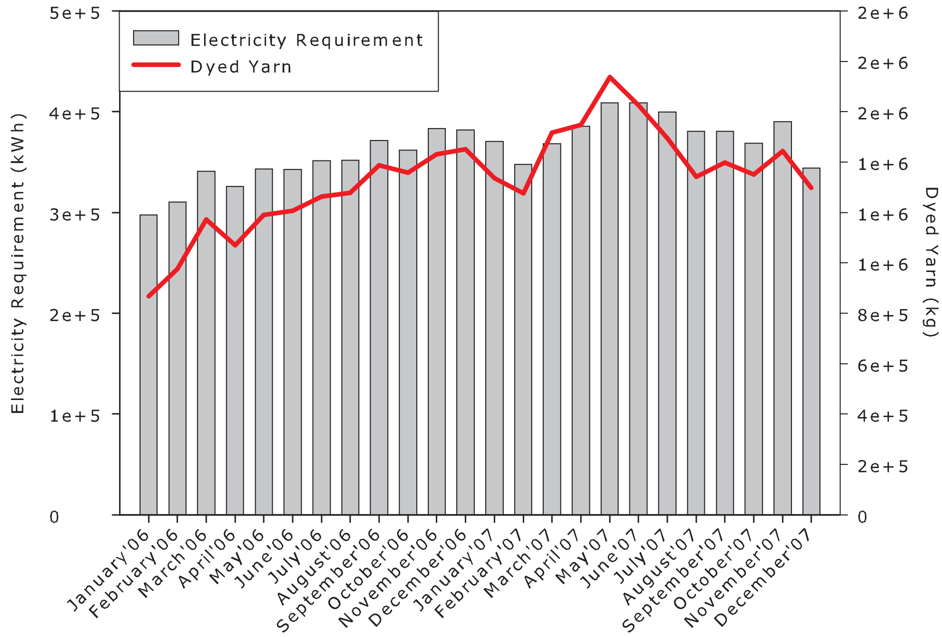

Figure 6.20: Electricity requirement in dyeing process

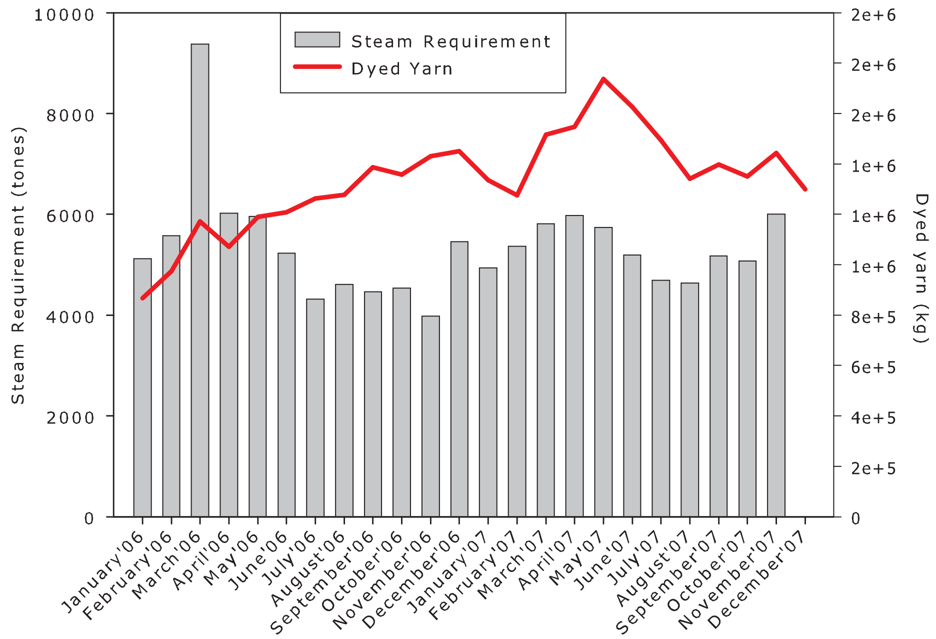

Figure 6.21: Steam requirement in dyeing process

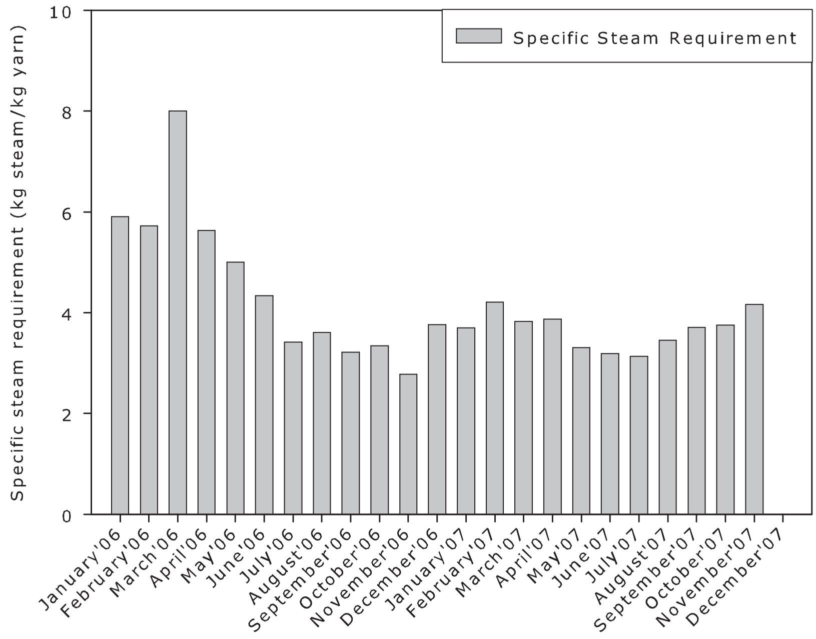

Figure 6.22: Specific steam requirement in dyeing process

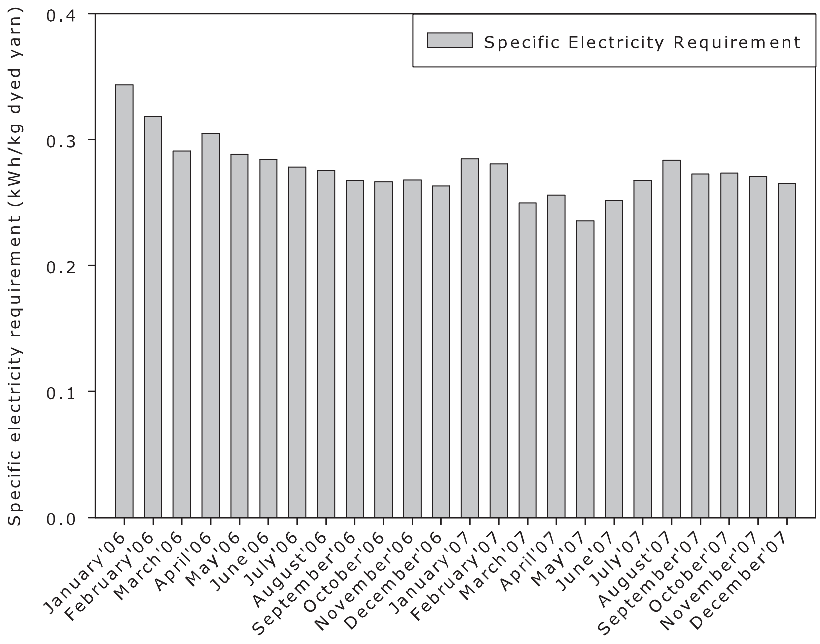

Figure 6.23: Specific electricity requirement in dyeing process

From this point of view, the distribution of required energy sources in dyeing process could be distinguished. As can be seen from Figure 6.24, steam is the dominant energy source required in dyeing process. Furthermore, as shown in Figure 6.24, energy requirement of dyeing process increased in the year 2007 with increased fabric production.

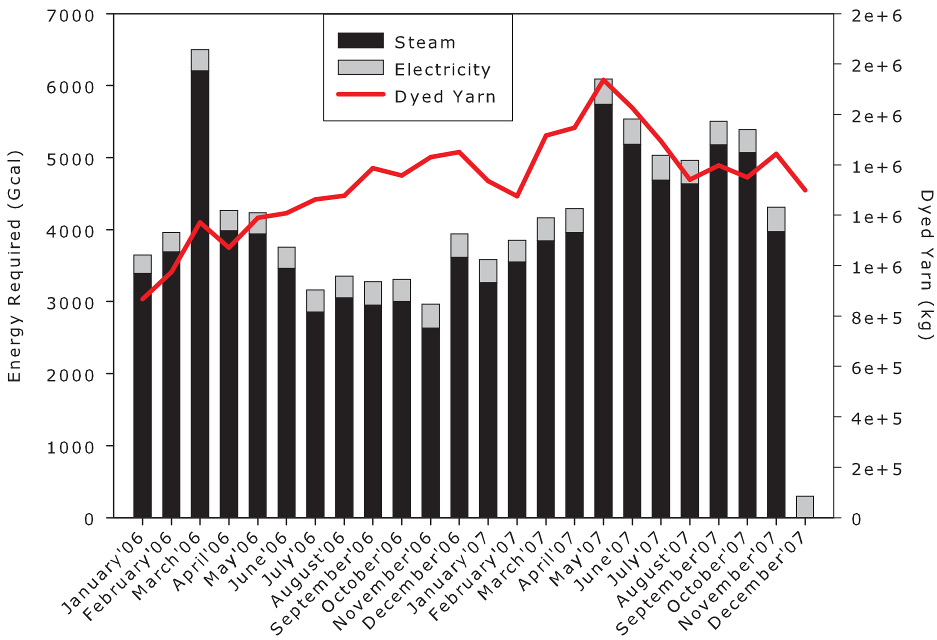

Figure 6.24: Energy source distribution in dyeing process

In order to develop the energy balance analysis in dyeing process, specific energy requirements are of concern. In this respect, Figure 6.25 indicates specific energy requirements based on monthly basis. As can be seen from Figure 6.25, specific energy requirements reduced whereas warp yarn production increased gradually in the indicated period. Especially by April'06 it is seen that specific energy requirement reduced whereas production of warp yarn increased. As indicated in Section 6.1.1, application of semi-counter current rinsing (April'06) in dyeing process and reuse of compressor cooling waters (July'06) in addition to maintenance and insulation applications resulted in the reductions observed.

6.2.2.2 Finishing

As mentioned before, finishing is the process where the desired end use properties of the textile are given. For this purpose, dry or wet processes are applied to the textile. As mentioned

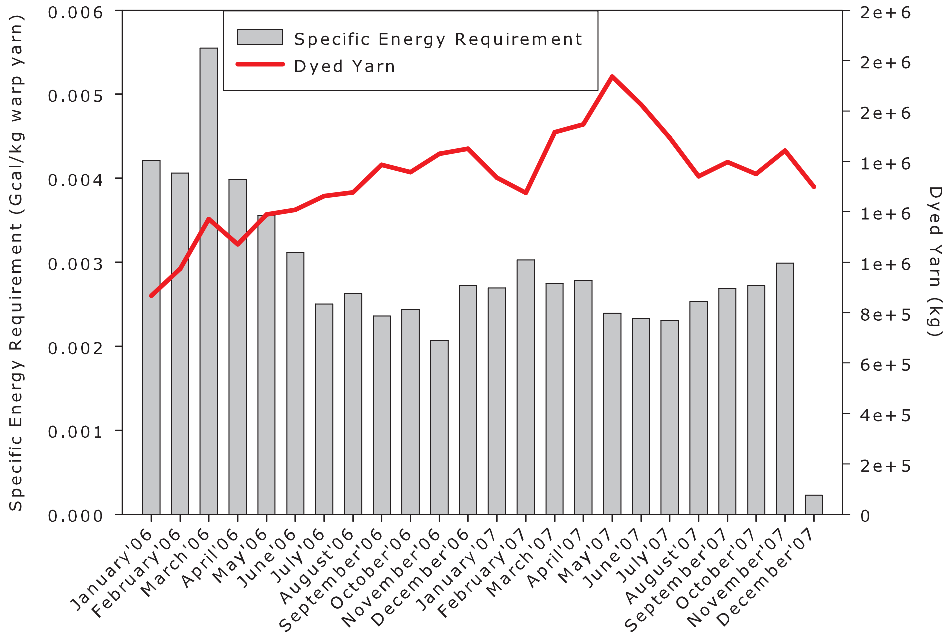

Figure 6.25: Specific energy requirement in dyeing process

in Section 6.1, wet processes of finishing are the most water intensive processes in the sector and in the selected mill. For that reason, energy requirement of wet processes are considered to be significant for energy consumption analysis. Furthermore, dry processes are of concern in the selected mill as dry processes are generally applied by mechanical or physical means which consume considerable amounts of energy. Therefore, energy requirement of finishing process is considered to be one of the major concerns in total energy consumption of the selected mill.

In finishing process of the selected mill, the energy sources consumed are steam, natural gas and electricity. In finishing line, electricity is consumed in order to run finishing machinery equipment in process plus for lightening and air conditioning purposes. On the other hand, steam is consumed to heat up process baths. Natural gas is directly utilized in some machines for processing. The distribution of those energy sources are indicated in Table 6.17. As can be seen, steam is the dominant energy source required in finishing process. Details of Table 6.17 are provided in Table B.6 in Appendix B. Overall energy requirement in finishing process is also analyzed in Figures 6.26 and 6.27.

As can be seen in Figure 6.26, total energy requirement and fabric production both increased during the period of 2006-2007. On the other hand, specific energy requirement decreased

Table 6.17: Energy requirement of finishing line (monthly average)

Monthly	**Natural Gas**		**Steam**		**Electricity**		**Total**	**Fabric**	**Specific**
average	**Sm^3**	**Gcal***	**Tone**	**Gcal****	**kWh**	**Gcal*****	**Energy (Gcal)**	**Production (kg)**	**Energy (Gcal/kg fabric)**
2006	157,233	1,352	8,729	5,779	274,673	236	7,367	2,056,414	0.0036±0.0005
2007	254,789	2,191	10,140	6,713	343,794	296	9,200	2,659,128	0.0035±0.0003
Average	206,011	1,772	9,435	6,246	309,234	266	8,284	2,357,771	0.00355±0.00044

* 1 Sm^3 Natural gas = 0.0086 Gcal, ** 1 ton steam= 0.662 Gcal, *** 1 kWh=0.00086 Gcal

although with a slight change of 2.8%.

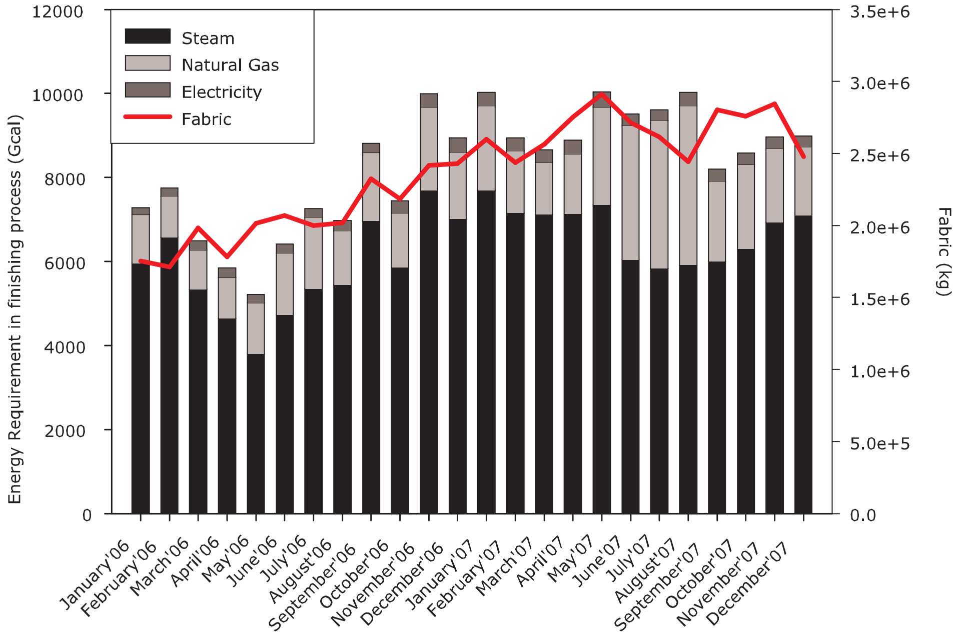

Figure 6.26: Energy source distribution in finishing process

In Figure 6.26, energy source distribution is also observed clearly as steam is required more than natural gas and electricity. However, as specific energy requirement is a performance indicator, analysis of Figure 6.27 provides a better assessment. As Figure 6.27 indicates, specific energy requirement was variable during the period of 2006-2007 despite the fact that annual average specific energy requirement of finishing process decreased by 2.8%.

In assessing specific energy requirement of finishing line, energy source requirements should be handled separately as natural gas, electricity and steam are not required in every machine. In this respect, natural gas requirement is presented in Table 6.16. As presented in Table 6.18, natural gas consumption has increased from 2006 to 2007 in six machines in finishing process. It should be noted that a new machine requiring natural gas for processing is introduced in addition to the wet processing machines in finishing. According to Table 6.18, natural gas requirement has increased in every machine except M2 presented in the table from 2006 to 2007. On the other hand, fabric production has also increased by almost 72% during the indicated period whereas; specific natural gas requirement of finishing process remained almost the same. Similarly, in Figure 6.28, specific natural gas requirement distribution in finishing process is presented in which specific natural gas requirement indicates variability.

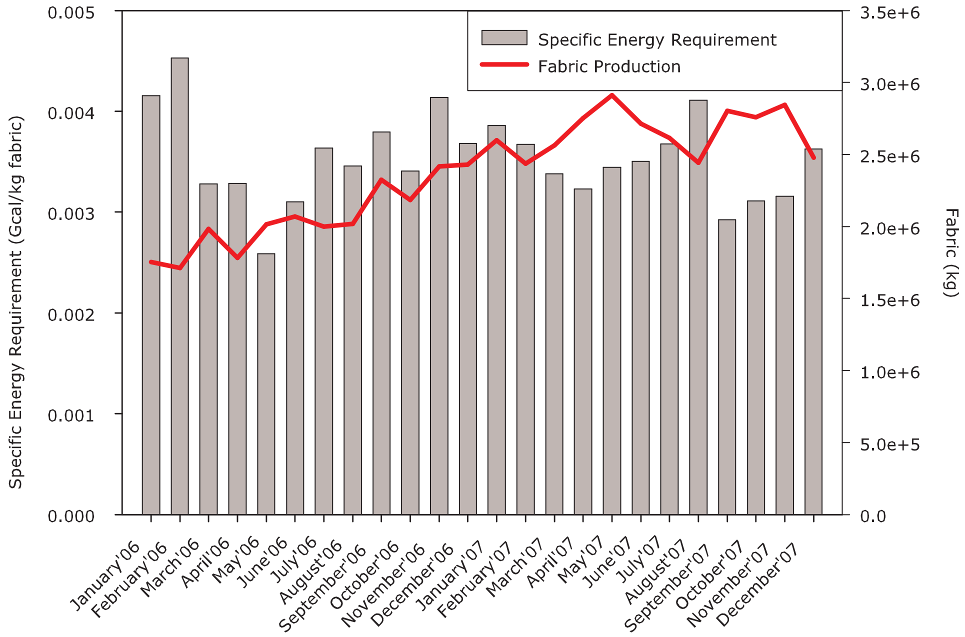

Figure 6.27: Specific energy requirement pattern in finishing process

However, except the summer season in 2007, specific natural gas requirements were less than in 2006 which is also confirmed by the reduction in specific natural gas requirement in terms of Sm^3 per kilograms fabric in 6.18. The reduction is considered to be due to insulation and maintenance applications in finishing line as no other BAT measures for energy minimization in terms of natural gas consumption is taken in those machines in the project period.

Another energy source required in finishing process is steam. The machine specific steam requirement data is presented in Table 6.19. According to Table 6.19, steam requirements of machines were variable on monthly average during the period of 2006-2007. On the other hand, fabric production has increased by 33% and has resulted in a reduction of 8.3% in specific steam requirement of the finishing process. Similarly, in Figure 6.29, specific steam requirement distribution in finishing process is presented. As can be seen from Figure 6.29, specific steam requirement reduced gradually in the indicated period. The reductions observed in specific steam requirement of finishing process are considered to be due to BAT measures taken for water minimization as steam is mostly utilized to heat up process baths. This is confirmed by the fact that the significant reduction in Figure 6.29 is observed in mid-2006 in which semi-counter current rinsing system was completed and compressor cooling waters were being reused.

Table 6.18: Natural gas requirement of finishing process (monthly average)

Natural Gas (Gcal)	**2006**	**2007**
M1	357	570
M2	84	44
M7	3	131
M4	165	263
M6	289	460
M9	454	723
TOTAL	1,352	2,191
Fabric Production (kg)	3,415,746	5,879,244
Specific Natural Gas Requirement (Gcal/kg fabric)	**0.0004**	**0.0004**
Specific Natural Gas Requirement (Sm^3/kg fabric)	**0.0484**	**0.0435**

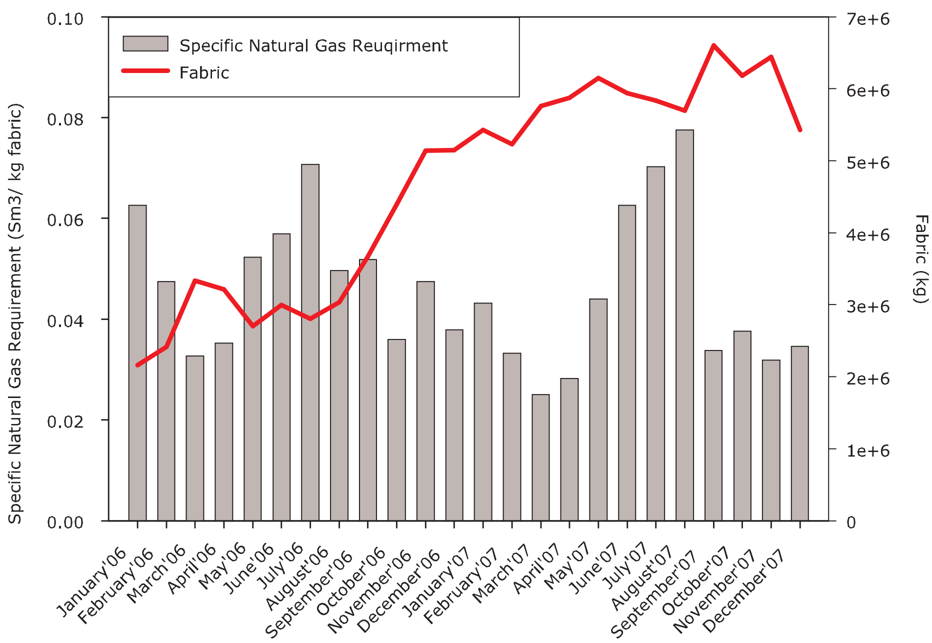

Figure 6.28: Specific natural gas requirement pattern in finishing process

Table 6.19: Steam requirement of finishing process (monthly average)

Steam (Gcal)	**2006**	**2007**
M1	569	493
M2	752	959
M3	314	352
M4	612	1,066
M5	541	501
M6	1,585	1,634
M7	798	1,066
M8	608	642
TOTAL	5,779	6,7132
Fabric Production (kg)	4,706,251	6,256,014
Specific Steam Requirement (Gcal/kg fabric)	**0.0012**	**0.0011**
Specific Steam Requirement (tone/kg fabric)	**0.0019**	**0.0016**

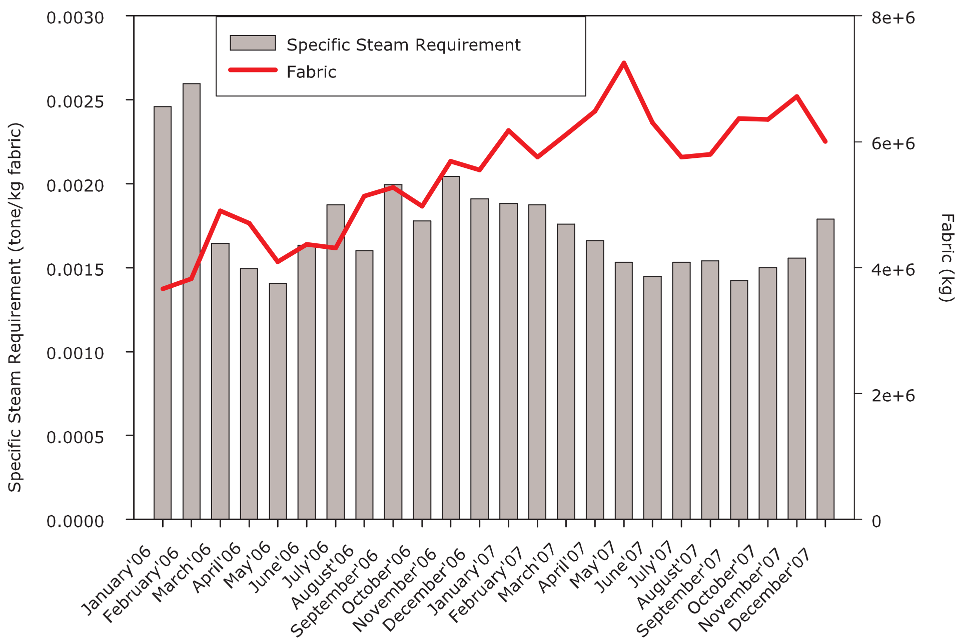

Figure 6.29: Specific steam requirement pattern in finishing process

The last energy source to be mentioned is electricity. The machine specific electricity requirements in finishing line are presented in Table 6.20. According to Table 6.20, electricity requirements of machines were variable on monthly average during the period of 2006-2007. On the other hand, fabric production has increased by 40% and has resulted in a reduction of 10.4% in total specific electricity requirement of the finishing process. Additionally, Figure 6.30 indicates electricity requirement distribution in finishing process. In Figure 6.30, a slight decrease is observed in proceeding months of 2007.

Table 6.20: Electricity requirement of finishing process (monthly average)

Electricity (Gcal)	**2006**	**2007**
M1	24	29
M2	9	13
M3	14	26
M4	16	35
M5	12	11
M6	28	29
M7	24	29
M8	11	5
M9	99	119
TOTAL	236	296
Fabric Production (kg)	5,463,143	7,626,964
Specific Electricity Requirement (Gcal/kg fabric)	**$4.31*10^{-5}$**	**$3.86*10^{-5}$**
Specific Electricity Requirement (kWh/kg fabric)	**0.0501**	**0.0452**

As seen from Tables 6.18, 6.19 and 6.20; total specific energy requirements in terms of steam, natural gas and electricity of finishing process have changed during the indicated period. Although reasons for the reductions are mentioned in the previous parts of this section, in order to complete energy consumption analysis and see the effects of BAT measures on machine basis, machine specific data is also analyzed. For that purpose, energy consumptions of M1, 2, 3, 4, 5, 6, 7, 8 and 9 are presented below.

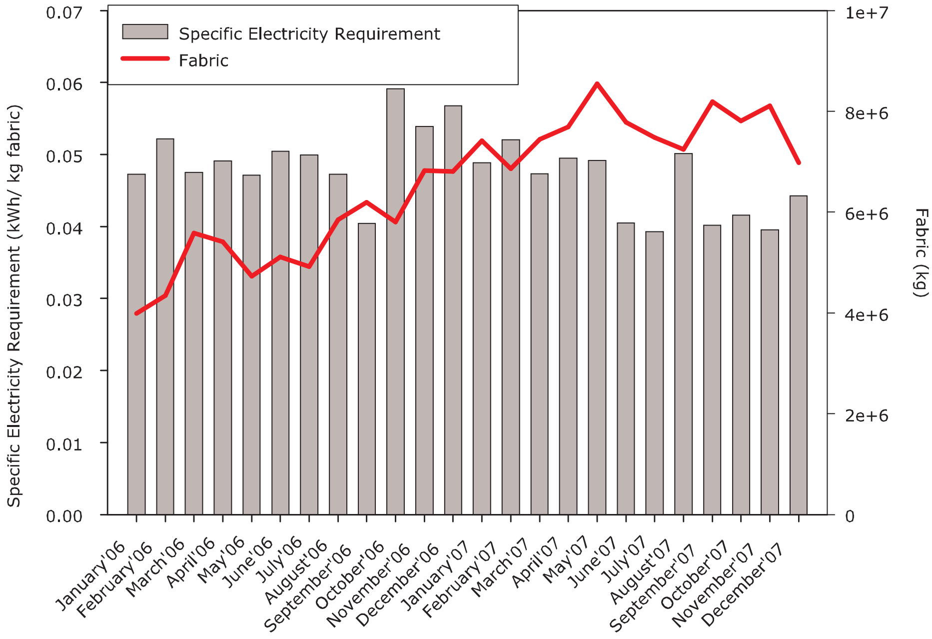

Figure 6.30: Specific electricity requirement pattern in finishing process

As can be seen from Table 6.21, M1 requires steam, natural gas and electricity for processing textiles. Steam requirement is more than the other energy source requirements. Although, energy requirement of M1 in terms of natural gas and electricity increased, steam requirement decreased during the indicated period. On the other hand, specific energy requirement of M1 has reduced from $1.3 * 10^{-3}$ to $9.0 * 10^{-4}$ Gcal/kg fabric processed resulting in a reduction of 30.8% in terms of specific energy requirement of the machine.

Figure 6.31 is another representation of energy requirement of M1. From Figure 6.31, it is observed that steam and natural gas are dominant energy sources required in M1. Moreover, total energy requirement increased during the period of 2006-2007. However, fabric production also increased by almost 63% and Figure 6.31 does not represent the specific energy requirements of M1. Therefore, in order to determine specific energy requirement trend of M1, Figure 6.32 was analyzed.

According to Figure 6.32, monthly specific energy requirement of M1 remained almost the same until May'07. Although an increase is observed in summer months of 2007, specific energy consumption has decreased by the end of 2007. This increase however, was not considered to be significant as average specific energy reduced from the year 2006 to 2007.

In M2, steam, natural gas and electricity is required for processing textiles. As M1, steam

Table 6.21: Energy requirement in M1*

		2006	2007
Steam	**tone**	860	744
	Gcal**	569	493
Natural Gas	**Sm^3**	41,563	66,245
	Gcal***	357	570
Electricity	**kWh**	28,160	33,201
	Gcal****	24	29
Fabric	**m**	1,296,159	2,107,789
Production	**kg**	790,657	1,285,751
Total Energy	**Gcal**	951	1,091
Specific Energy	**Gcal/kg fabric**	$1.3*10^{-3}$	$9.0*10^{-4}$

* Details given in Table B.7 in Appendix B,

** 1 ton steam= 0.662 Gcal, *** 1 Sm^3 Natural gas = 0.0086 Gcal, **** 1 kWh=0.00086 Gcal

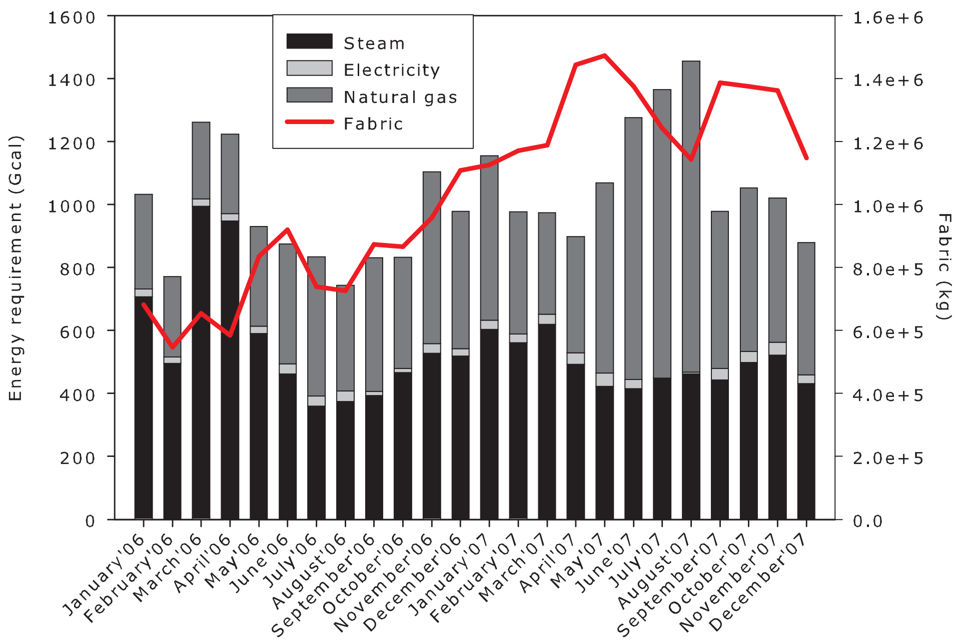

Figure 6.31: Energy requirement in M1

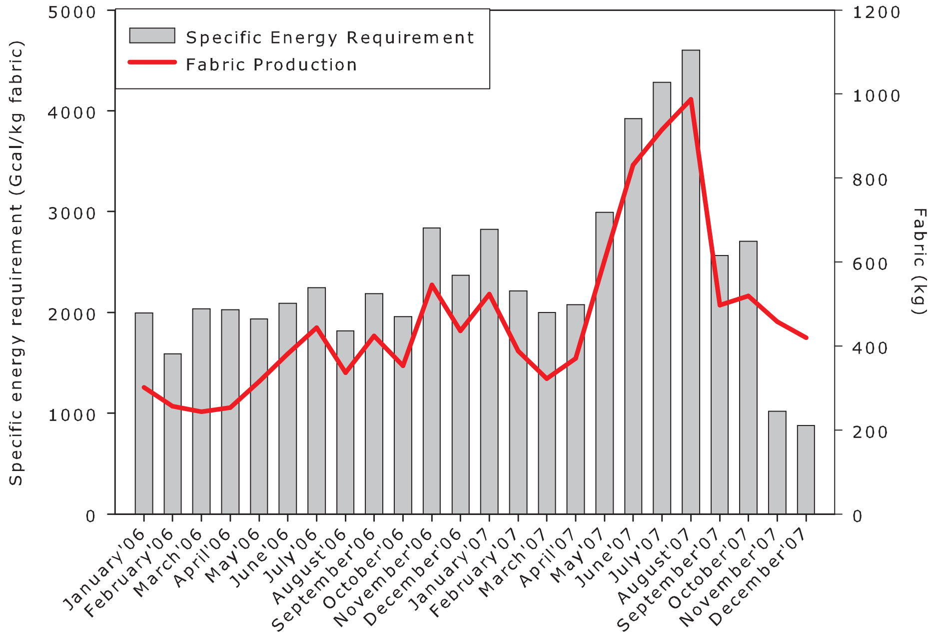

Figure 6.32: Specific energy requirements in M1

requirement is more than the other energy source requirements. As can be seen from Table 6.22, energy requirement of M2 in terms of steam and electricity increased, whereas, natural gas requirement decreased during the indicated period. On the other hand, specific energy requirement of M2 has increased from 0.0028 to 0.0036 Gcal/kg fabric processed. This increase was not considered to be significant as processing of textiles in M2 is less when compared to other machines.

Figure 6.33 represents total energy requirement of M2 on monthly basis. As can be seen from Figure 6.33, energy requirement and fabric production of M2 is highly variable during the indicated period. Although, energy requirement and fabric production trends seem to be following the same pattern, a more reliable analysis was done by analyzing specific energy requirements of M2 in Figure 6.34. Despite that fact that monthly average specific energy requirement of M2 increased, uniform energy requirement pattern is observed in Figure 6.34.

In M3, steam and electricity is required for processing textiles. As can be seen from Table 6.23, energy requirements of M3 in terms of steam and electricity increased during the indicated period. On the other hand, specific energy requirement of M3 has reduced from 0.0016 to 0.0012 Gcal/kg fabric processed, resulting in 31% reduction in specific energy requirement of M3.

Table 6.22: Energy requirement of M2*

		2006	2007
Steam	**tone**	1,135	1,449
	Gcal**	752	959
Natural Gas	**Sm^3**	9,805	5,096
	Gcal***	84	44
Electricity	**kWh**	9,900	14,995
	Gcal****	9	13
Fabric	**m**	499,434	462,841
Production	**kg**	304,655	282,333
Total Energy	**Gcal**	844	1,016
Specific Energy	**Gcal/kg fabric**	$2.8*10^{-3}$	$3.6*10^{-3}$

* Details given in Table B.8 in Appendix B,

** 1 ton steam= 0.662 Gcal, *** 1 Sm^3 Natural gas = 0.0086 Gcal, **** 1 kWh=0.00086 Gcal

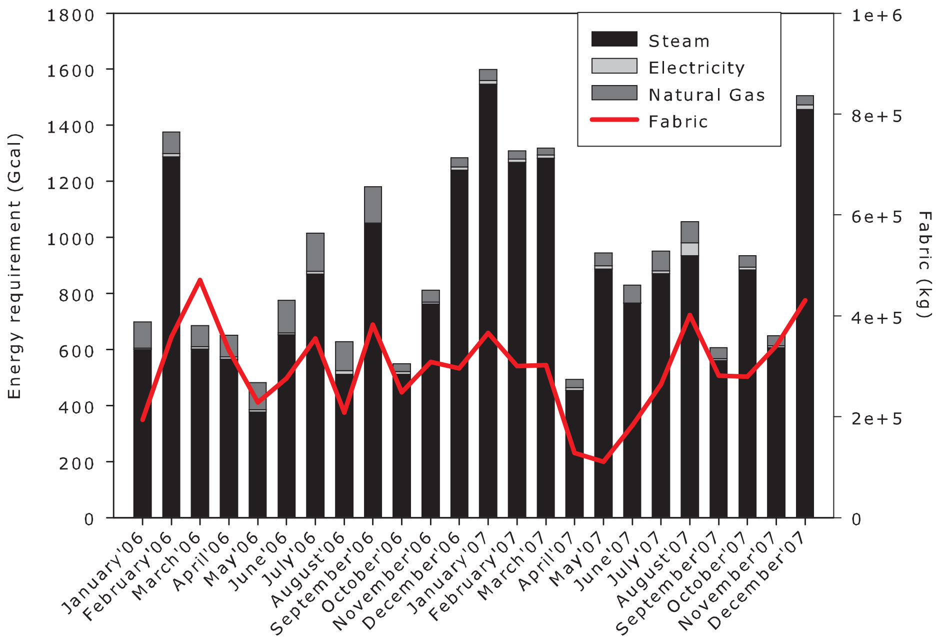

Figure 6.33: Energy requirement in M2

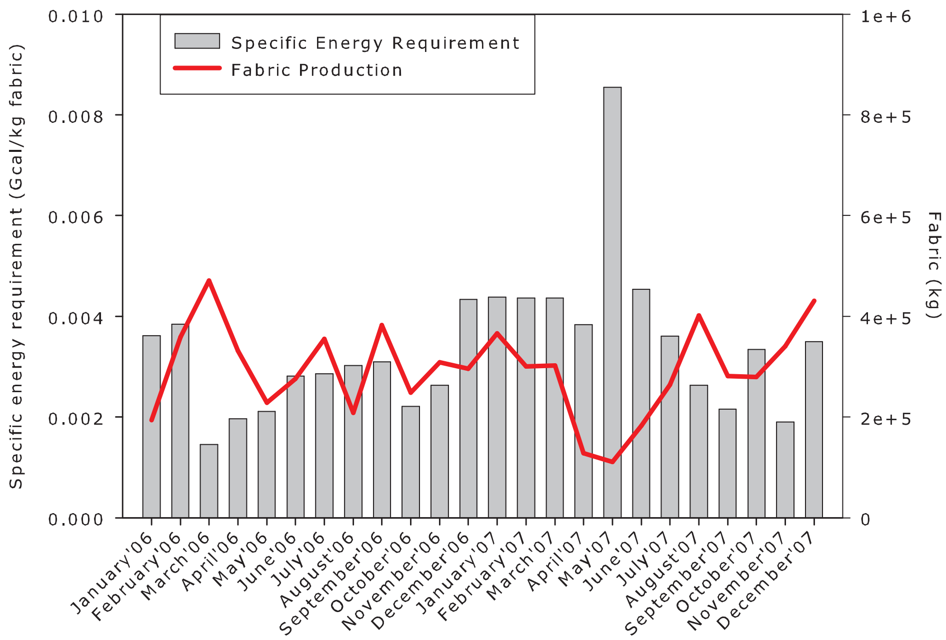

Figure 6.34: Specific energy requirement in M2

Table 6.23: Energy requirement of M3*

		2006	2007
Steam	**tone**	474	532
	Gcal**	314	352
Electricity	**kWh**	16,537	30,426
	Gcal***	14	26
Fabric	**m**	339,975	527,538
Production	**kg**	207,385	321,798
Total Energy	**Gcal**	328	378
Specific Energy	**Gcal/kg fabric**	**0.0016**	**0.0012**

* Details given in Table B.9 in Appendix B,

** 1 ton steam= 0.662 Gcal, *** 1 kWh=0.00086 Gcal

From Table 6.23 and Figure 6.35 it is observed that M3 is one of the least energy intensive machines in finishing line. Figure 6.35 indicates that total energy requirement of M3 varies between 600-100 Gcal on monthly basis. In this respect, although peaks in total energy requirement are also observed in Figure 6.35, the effect of those peaks on specific energy requirement is considered to be minor. This consideration is also confirmed by Figure 6.36 indicating monthly specific energy requirements of M3 were more uniform in 2007 when compared to the previous year.

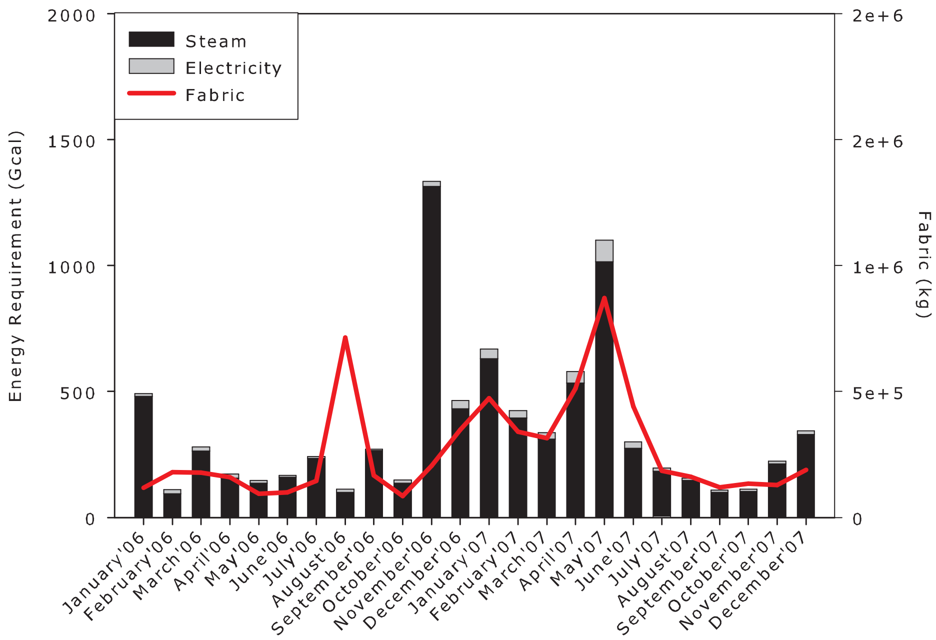

Figure 6.35: Energy requirement in M3

In M4, steam, natural gas and electricity are required for processing textiles. As can be seen from Table 6.24, energy requirements of M4 in terms of steam, natural gas and electricity increased during the indicated period. On the other hand, specific energy requirement of M4 has reduced from 0.0040 to 0.0019 Gcal/kg fabric processed, resulting in 53% reduction in specific energy requirement of M4.

Figure 6.37 is another form of indicating total energy requirement of M4. Accordingly, energy requirement of M4 was highly variable between 300-2000 Gcal per month. Although, it is seen that efficiency of energy consumption in M4 was very low in initial months of 2006, fabric production followed almost the same pattern with energy requirement after April'06.

This consideration is also confirmed by Figure 6.38. As Figure 6.38 indicates, specific energy

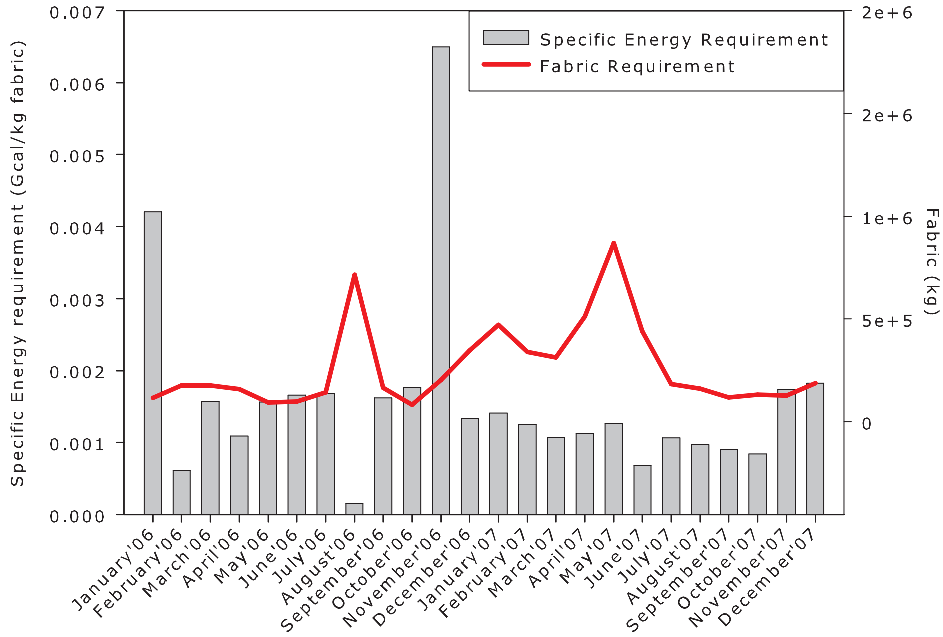

Figure 6.36: Specific energy requirement in M3

Table 6.24: Energy requirement of M4*

		2006	**2007**
Steam	**tone**	925	1,611
	Gcal**	612	1,066
Natural Gas	**Sm^3**	19,183	30,575
	Gcal***	165	263
Electricity	**kWh**	18,423	41,076
	Gcal****	16	35
Fabric	**m**	530,474	1,245,308
Production	**kg**	323,589	747,185
Total Energy	**Gcal**	793	1,365
Specific Energy	**Gcal/kg fabric**	**0.0040**	**0,0019**

* Details given in Table B.10 in Appendix B,

** 1 ton steam= 0.662 Gcal, *** 1 Sm^3 Natural gas = 0.0086 Gcal, **** 1 kWh=0.00086 Gcal

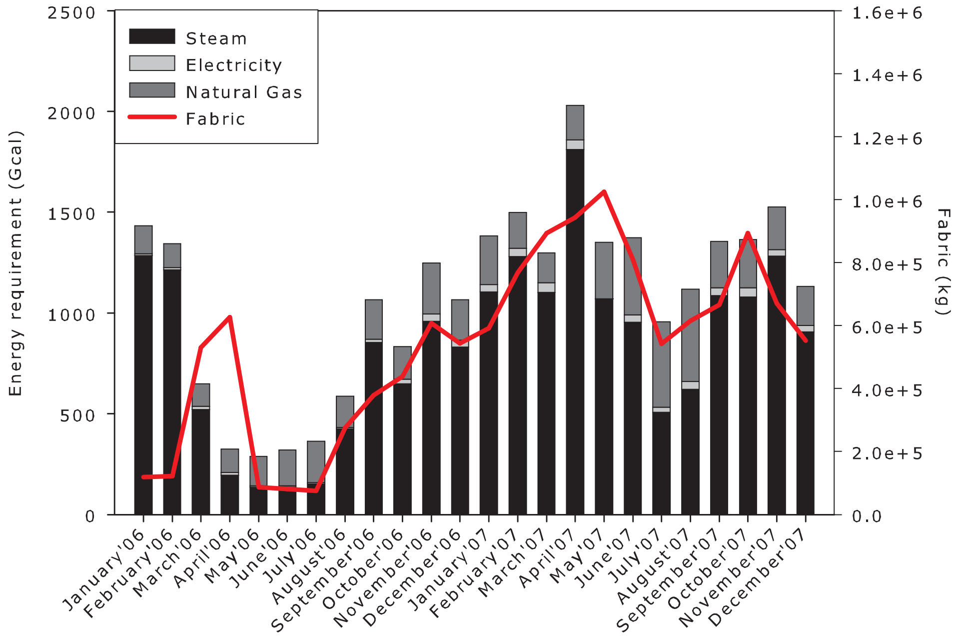

Figure 6.37: Energy requirement in M4

requirement of M4 was lower and more uniform in 2007 when compared to 2006 despite the increase in fabric production.

In M5, steam and electricity is required for processing textiles. As expected, steam requirement is more than electricity requirement. As can be seen from Table 6.25, energy requirement of M5 in terms of both steam and electricity decreased during the indicated period although amount of fabric processed increased. Hence, specific energy requirement of M5 has reduced from 0.0009 to 0.0008 Gcal/kg fabric processed, resulting in 11% reduction in specific energy requirement of M5.

Figure 6.39 indicates the variability in energy requirement of M5 in 2006. This pattern however, changed in 2007 by a lower energy requirement pattern. Although, the sharp reduction from over 800 to 500 Gcal and more uniform energy requirement in 2007 can easily be seen from Figure 6.39, specific energy requirements are more significant performance indicators and hence should be examined carefully.

As can be seen from Figure 6.40, specific energy requirement was also variable and relatively more independent from fabric production in 2006 when compared to 2007. In 2007, the specific energy requirement was lower and more uniform despite the fact that fabric production was still variable.

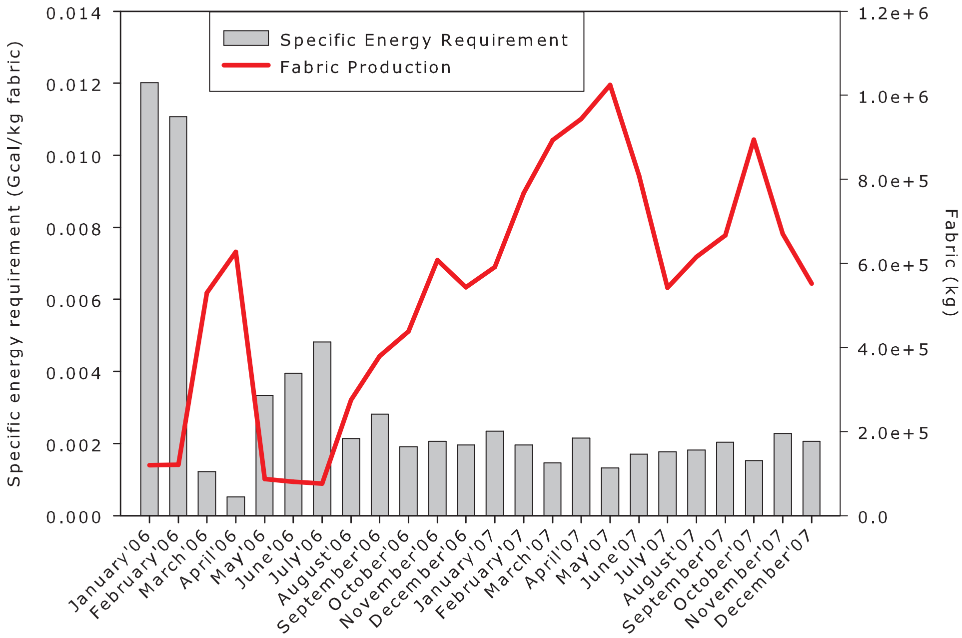

Figure 6.38: Specific energy requirement in M4

Table 6.25: Energy requirement of M5*

		2006	2007
Steam	**tone**	817	756
	Gcal**	541	501
Electricity	**kWh**	13,373	12,842
	Gcal***	12	11
Fabric Production	**m**	956,491	1,075,931
	kg	583,460	656,318
Total Energy	**Gcal**	552	512
Specific Energy	**Gcal/kg fabric**	**0.0009**	**0.0008**

* Details given in Table B.11 in Appendix B,

** 1 ton steam= 0.662 Gcal, *** 1 kWh=0.00086 Gcal

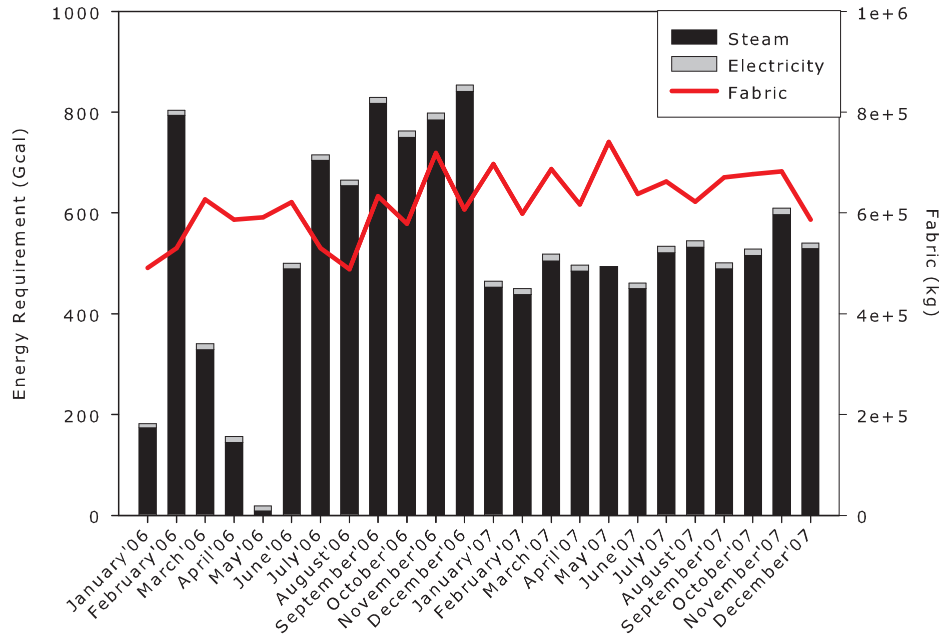

Figure 6.39: Energy requirement in M5

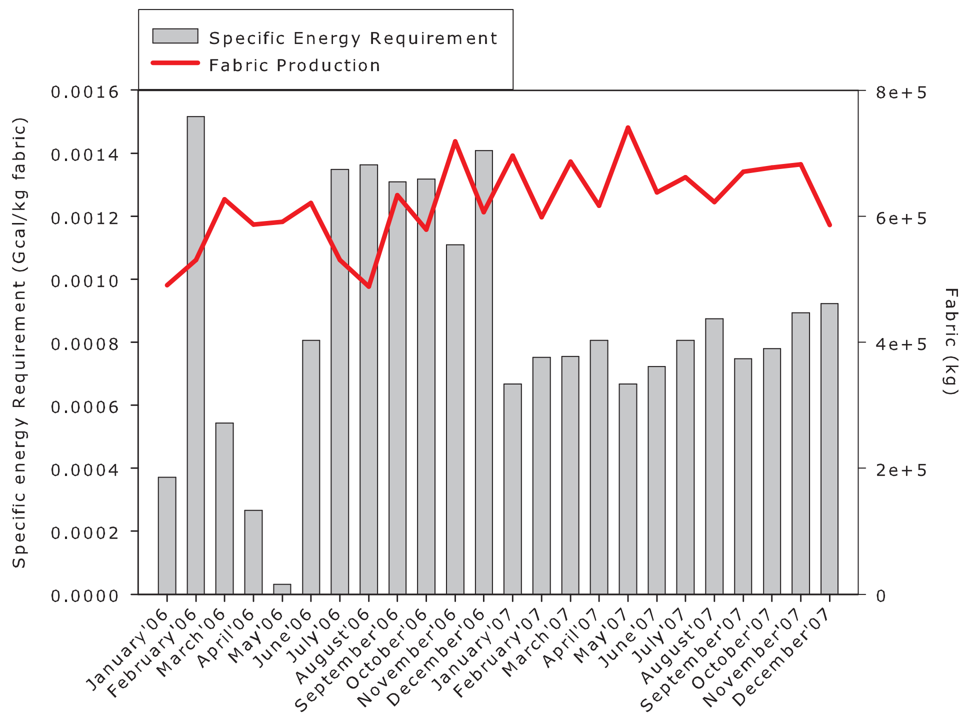

Figure 6.40: Specific energy requirement in M5

In M6, steam, natural gas and electricity are required for processing textiles. In this machine, energy requirements were variable during the indicated period. As can be seen from Table 6.26, energy requirement of M6 in terms of steam, natural gas and electricity increased during the indicated period. On the other hand, specific energy requirement of M6 remained almost the same with a slight increase from 0.0019 to 0.0020 Gcal/kg fabric processed. This is considered to be due to the fact that the application of use of waste heat from wastewater discharges of M6 was initiated in 2005 before project implementation period. Therefore, the reduction as a result of the measure taken is not noticable.

Table 6.26: Energy requirement of M6*

		2006	2007
Steam	**tone**	2,394	2,468
	Gcal**	1,585	1,634
Natural Gas	**Sm^3**	33,583	53,506
	Gcal***	289	460
Electricity	**kWh**	32,393	34,292
	Gcal****	28	29
Fabric Production	**m**	1,645,854	1,726,756
	kg	1,003,971	1,053,321
Total Energy	**Gcal**	1,902	2,124
Specific Energy	**Gcal/kg fabric**	**0.0019**	**0.0020**

* Details given in Table B.12 in Appendix B,

** 1 ton steam= 0.662 Gcal, *** 1 Sm^3 Natural gas = 0.0086 Gcal, **** 1 kWh=0.00086 Gcal

In Figure 6.41, it is seen that the energy requirement of M6 is variable but around 2,000 Gcal during the indicated period. On the other hand, energy requirement increased in the proceeding months of the period while fabric production varied between 8-1.2 millions of kilograms. Additionally, it should be noted that energy requirement trend follows the same pattern with the fabric production if minor deviations are omitted.

Alternatively, monthly specific energy requirements were more uniform when compared to the total energy requirement. As can be seen from Figure 6.42, specific energy requirement of M6 was almost uniform with small variations in the indicated period.

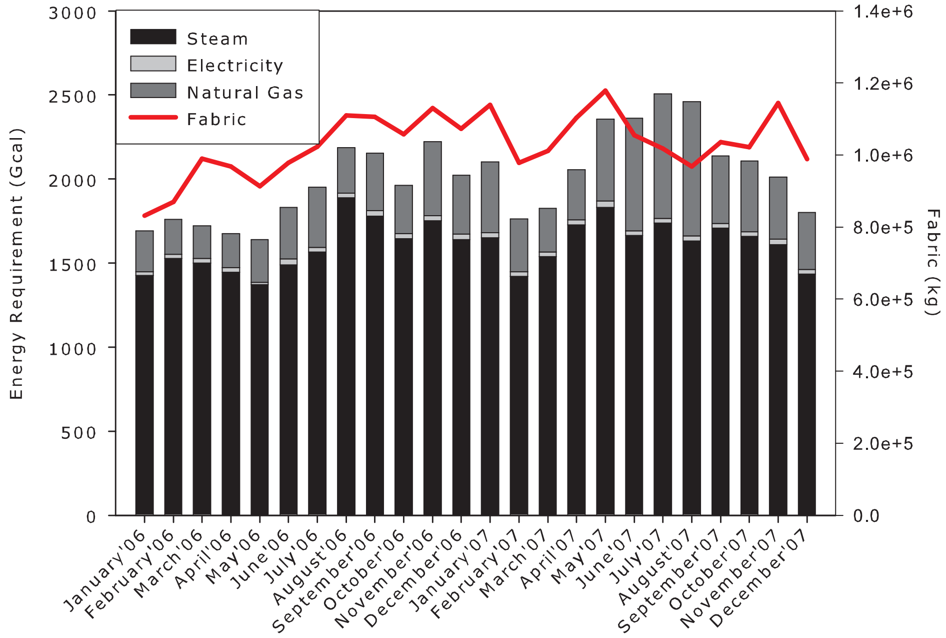

Figure 6.41: Energy requirement in M6

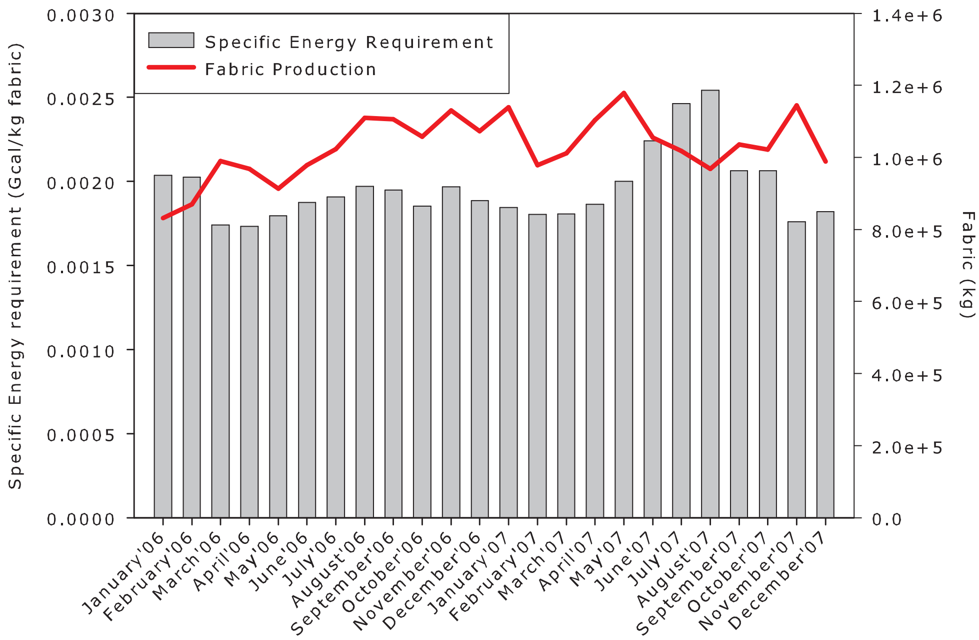

Figure 6.42: Specific energy requirement in M6

In M7, steam, natural gas and electricity is required for processing textiles. As can be seen from Table 6.27, energy requirement of M7 in terms of steam, natural gas and electricity increased during the indicated period. It should be noted that, natural gas was not a required energy source until October'06 in M7. Therefore, increase in natural gas requirement in the period of 2006-2007 is apprehensible. On the other hand, specific energy requirement of M7 remained the same.

Table 6.27: Energy requirement of M7*

		2006	2007
Steam	**tone**	1,206	1,610
	Gcal**	798	1,066
Natural Gas	**Sm^3**	2,984	15,291
	Gcal***	26	131
Electricity	**kWh**	27,587	33,561
	Gcal****	24	29
Fabric Production	**m**	1,297,739	1,899,505
	kg	791,621	1,139,703
Total Energy	**Gcal**	848	1,226
Specific Energy	**Gcal/kg fabric**	**0.0011**	**0.0011**

* Details given in Table B.13 in Appendix B,
** 1 ton steam= 0.662 Gcal, *** 1 Sm^3 Natural gas = 0.0086 Gcal, **** 1 kWh=0.00086 Gcal

In Figure 6.43, indicating monthly energy requirements vs. fabric production, the increase in energy requirement is confirmed. However, energy requirement increased with the increase in fabric production. Therefore, the major reason for the increase in energy requirement is considered to be due to the increase in fabric production. On the other hand, Figure 6.44 shows a stronger evidence for this consideration.

In Figure 6.44, specific energy requirements of M7 are presented on monthly basis. As can be seen from Figure 6.44, specific energy requirement was variable in the range of 0.0008-0.0012 Gcal/kg fabric during the year 2006. However, energy requirement of M7 gradually decreased and remained almost the same by March'07.

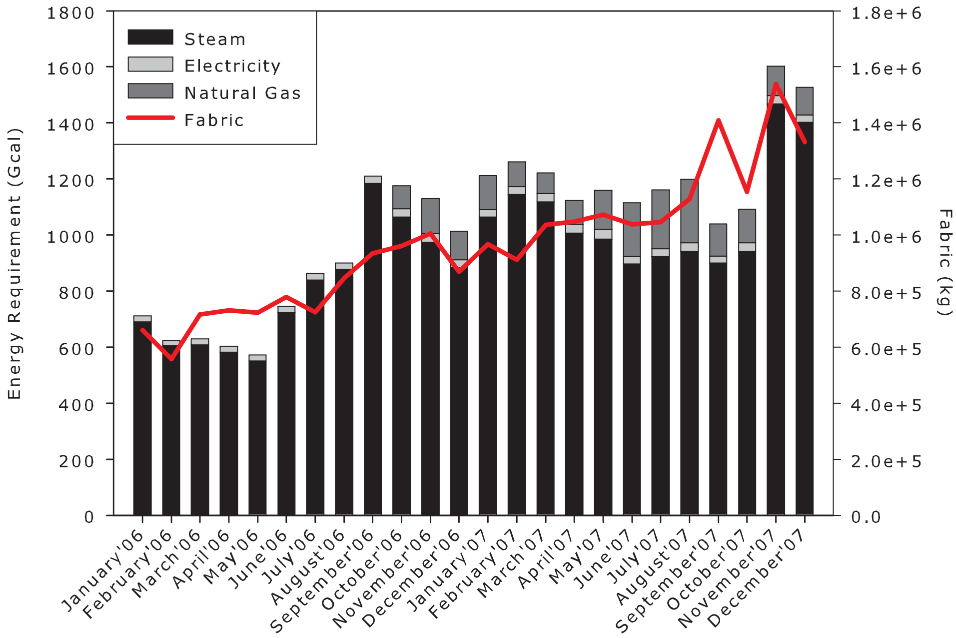

Figure 6.43: Energy requirement in M7

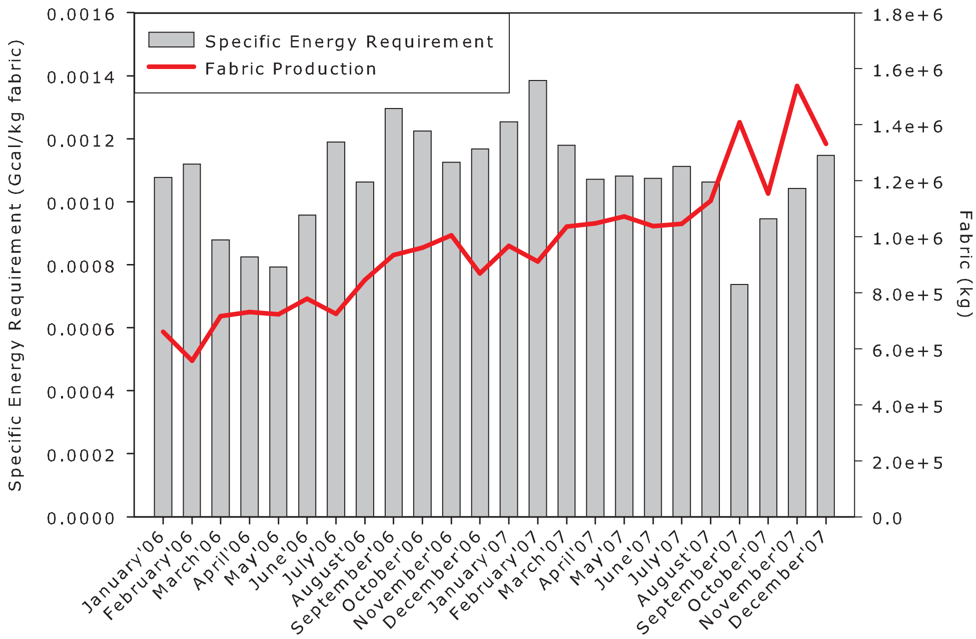

Figure 6.44: Energy requirement in Machine 7

In Machine 8, steam and electricity are required for processing textiles. As can be seen from Table 6.28, energy requirement of M8 in terms of steam increased while electricity requirement decreased during the indicated period. On the other hand, specific energy requirement of M8 has reduced from 0.9 to 0.8 Mcal per kilogram of fabric. Increase in energy requirement is considered to be due to the increase in fabric production which is also confirmed by Figure 6.45 and 6.46.

Table 6.28: Energy requirement of M8*

		2006	**2007**
Steam	**tone**	918	970
	Gcal**	608	642
Electricity	**kWh**	13,120	5,396
	Gcal***	11	5
Fabric Production	**m**	1,149,038	1,261,648
	kg	700,913	769,605
Total Energy	**Gcal**	619	647
Specific Energy	**Gcal/kg fabric**	**0.0009**	**0.0008**

* Details given in Table B.14 in Appendix B,

** 1 ton steam= 0.662 Gcal, *** 1 kWh=0.00086 Gcal

In M9, natural gas and electricity are required for processing of textiles. As can be seen from Table 6.29, energy requirement of M9 in terms of both electricity and natural gas increased during the indicated period. On the other hand, specific energy requirement of M9 has reduced from 0.0008 to 0.0006 Gcal/kg fabric processed, resulting in almost 25% reduction in specific energy requirement of M9. This reduction is considered to be due to maintenance and insulation applications.

As can be seen from Figure 6.47, natural gas requirement is higher than electricity requirement which remained almost the same during the period. Moreover, it is observed that energy requirement increased with increase in fabric production. Therefore, specific energy consumption trend is expected to be uniform in M9. As seen from Figure 6.48, specific energy consumption was almost uniform except minor changes.

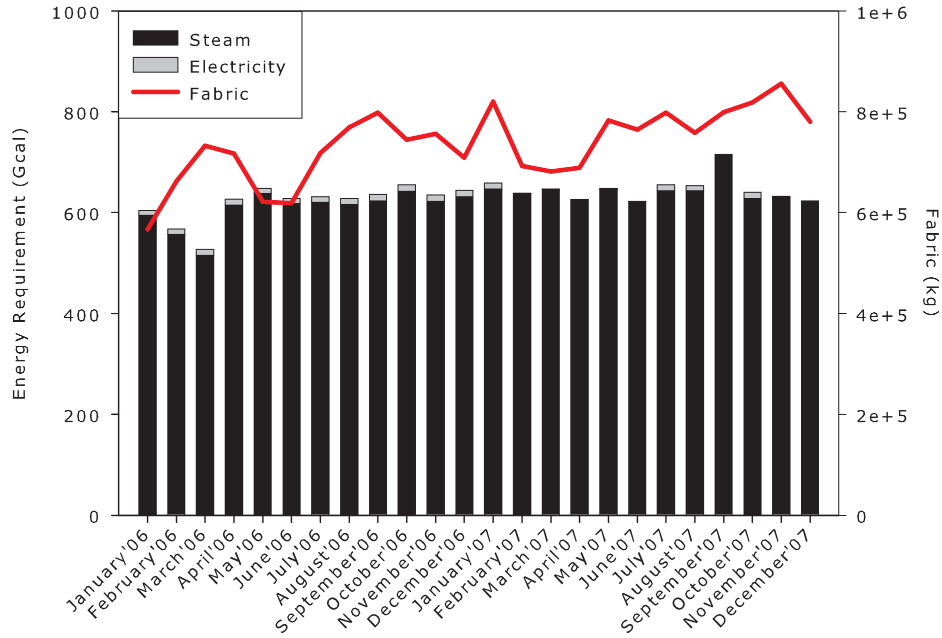

Figure 6.45: Energy requirement in M8

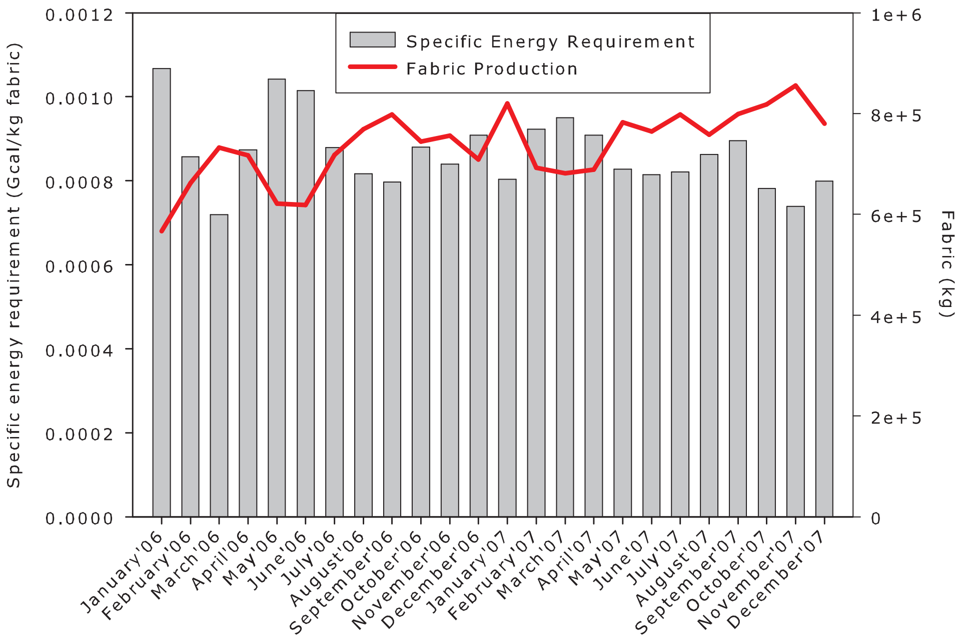

Figure 6.46: Specific energy requirement in M8

Table 6.29: Energy requirement of M9*

		2006	2007
Natural Gas	**Sm^3**	52,754	84,080
	Gcal**	454	723
Electricity	**kWh**	115,108	138,005
	Gcal***	99	119
Fabric	**m**	1,240,807	2,247,459
Production	**kg**	756,892	1,370,950
Total Energy	**Gcal**	553	842
Specific Energy	**Gcal/kg fabric**	**0.0008**	**0.0006**

* Details given in Table B.15 in Appendix B,

** 1 Sm^3 Natural gas = 0.0086 Gcal, *** 1 kWh=0.00086 Gcal

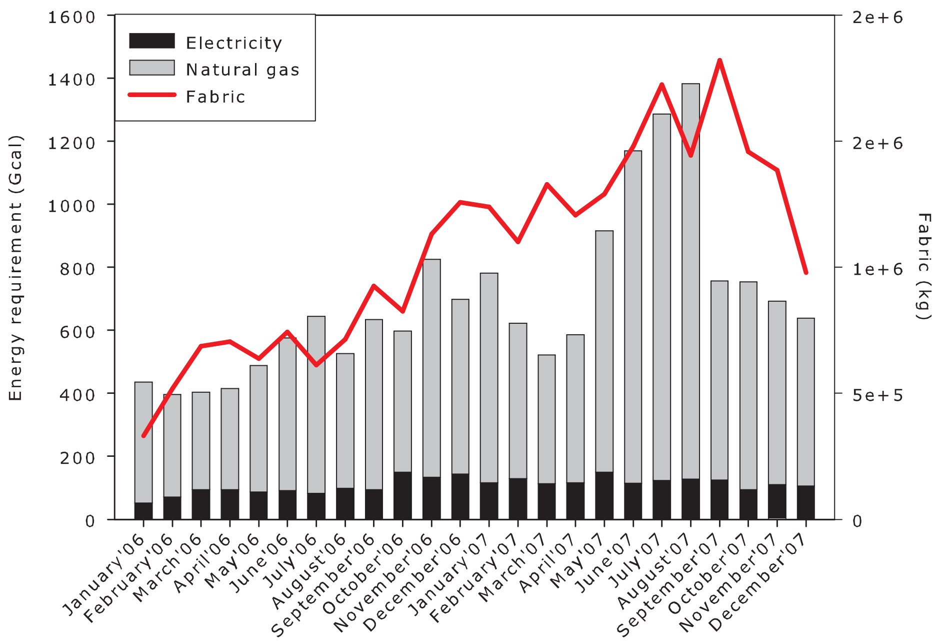

Figure 6.47: Energy requirement in M9

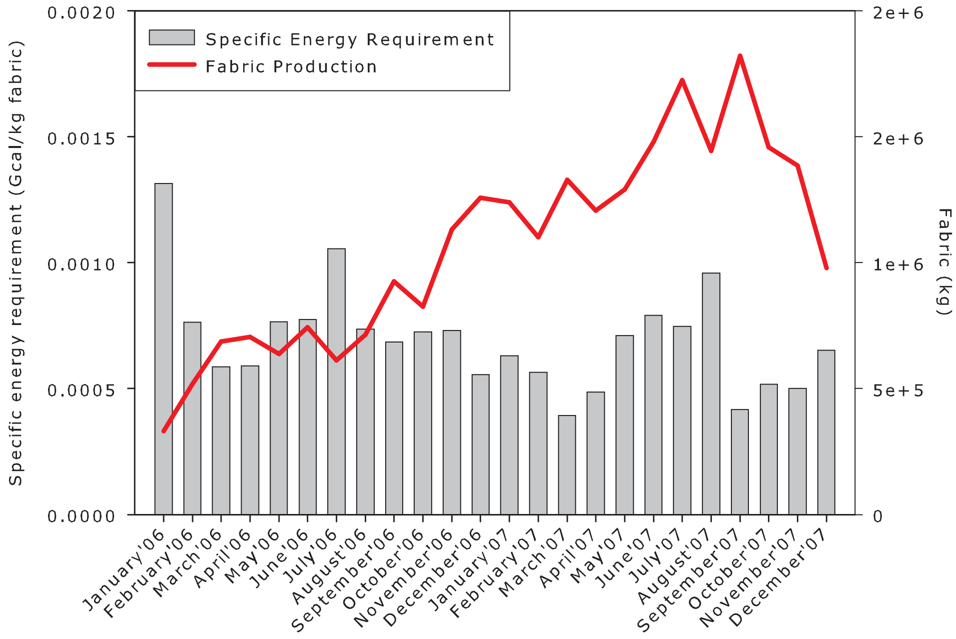

Figure 6.48: Specific energy requirement in M9

6.3 General Assessments

Water and energy consumption in textile industry has been a challenge for the sector. As mentioned throughout this study, IPPC Directive and BREF Textile Document provided a guideline to manage water and energy consumptions for EU countries. According to those guidelines, by the application of sector specific BAT measures, specific water consumption of mills finishing woven fabric consisting of mainly cellulosic fibres could be reduced to 50-100 litres of water per kilogram of fabric [6]. Bearing the fact that specific water consumption of the mill was reduced to 55 litres of water per kilogram of fabric in 2007 in mind, the achieved level of water consumption is close to the lower limit of the indicated range in BREF Textile Document. Moreover, it is also indicated in the BREF Textile Document that, application of insulation applications can provide up to 9% reduction in energy consumption in the textile mills [6]. In this study, by application of maintenance, insulation, reuse of waste heat from finishing wash waters and water minimization measures provided 9% reduction in total. In the mill, specific energy consumption was reduced to 0.0091 Gcal/kg of fabric which corresponds to 10.6 kWh/kg of fabric being in the stated range of BREF Textile Document (i.e. 8-20 kWh/kg fabric)[6]. Furthermore, specific electricity consumption was also indicated as 0.5-1.5 kWh/kg fabric based on the study on eight different mills [6]. In the mill, the achieved specific electricity consumption in 2007 was 2.5 kWh/kg fabric which barely exceeds the upper limit of the indicated range in BREF Textile Document. However, it should be kept in mind that, applied BAT measures for energy minimization were mostly effective on steam consumption.

Additionally, water and energy consumptions in textile industry were also spotlighted in 8th Five Year Development Plan which is published by SPO in Turkey [11]. In the Textile and Apparel Specialist Report, it is indicated that water consumption in textile industry should be reduced to 80 litres of water per kilogram fabric from 131 litres per kilogram of fabric from 2001 to 2006. As indicated before, by the application of appropriate BAT measures in terms of water minimization in the mill, specific water consumption was reduced from 78 litres of water per kilogram of fabric to 71 and 55 litres of water per kilogram of fabric in 2006 and 2007, respectively. Therefore, this study also proved that by the application of BAT measures, specific water consumption could be reduced by considerable extents and long-term targets of Turkish Textile Industry were achievable. Besides, specific energy consumption of textile finishing industry was also intended to be reduced to 40,000 kJ/kg fabric in the same report. In the selected mill, specific energy consumption achieved in 2007 was 0.0091 Gcal/kg fabric which corresponds to 38,160 kJ/kg fabric that falls below the target level indicated in the report.

In summary, water and energy consumptions of the mill selected in this study were compatible with reference levels indicated in the BREF Textile Document. Moreover, by this first application of BAT measures in Turkey, it is proved that long term target levels of water and energy consumptions in Turkish Textile Industry were achievable.

6.4 Economical Assessments

As mentioned in Sections 6.1 and 6.2 significant reductions were achieved in overall and in water and energy intensive wet processes, finishing and dyeing. To evaluate the benefits, savings were estimated in terms of monetary amounts. For that estimation, unit costs were considered for water pumping and purchased energy.

In terms of water, according to the rough assessment mentioned, the amount of saving achieved in operational costs is calculated to be 632,000 YTL on annual basis by assuming that the extraction cost of 1 tone of water is 1 YTL [46]. This calculation is based on the fact that water consumption has reduced from 78 to 55 litres of water per kilogram of fabric in the period of January'05-December'07. Reduction of 23 litres of water per kilogram of fabric is then converted to annual average water consumption savings by considering the fact that annual average fabric production is 45,000,000 of meters (i.e. 27,450,000 kilograms). The amount of water saved per year is estimated to be nearly 632,000 tones according to the abovementioned calculation. Then, the amount of savings is calculated by multiplying the extraction cost of water which is 1 YTL per tone of water. The calculation can also be seen from Table 6.30. However, it should be kept in mind that this is a rough estimation. There are some other cost items to be considered for net savings. For example, the initial consideration in such a detailed cost analysis should be investment costs as flow control devices are purchased for a better water management in the mill. Secondly, as water consumption has decreased, wastewater generation also decreased. The reduction in water consumption not only reduced the payments for discharge of wastewaters, but should also change the operational costs of the wastewater treatment plant. Therefore, the actual savings can be evaluated by a detailed cost analysis. However, as the necessary data could not be obtained from the managerial authorities of the selected mill, a detailed cost analysis to estimate savings in terms of water minimization could not be carried out in this study.

Table 6.30: Savings achieved in terms of water and energy minimization

	Reduction	Unit cost	Savings (YTL/year)	Total Savings (YTL/year)
Water	78-55 L/kg fabric	1 YTL/tone of water	632,000	2,082,000
Energy	10-9.1 Mcal/kg fabric	0.5 YTL/Sm^3 of natural gas	1,450,000	

Similarly, the amount of savings in terms of energy costs are calculated to be almost 1,450,000 YTL on annual basis by assuming that the cost of 1 Sm^3 of natural gas is 0.5 YTL [46]. This estimation is based on the fact that energy requirement of the mill has reduced from 10 to 9.1 Mcal per kilogram of fabric produced in the period of January'05-December'07. The reduction in energy requirement in terms of Mcal corresponds to 0.104 Sm^3 per kilogram of fabric considering the fact that 1 Sm^3 of natural gas is 0.0086 Gcal. This amount of reduction is then converted to total amount of natural gas saved which is 2,854,800 Sm^3 on annual basis by considering the fabric production which is 45,000,000 of meters (i.e. 27,450,000 kilograms) per annum. The amount of savings in terms of energy costs is then calculated by multiplying the unit cost of natural gas with the total amount of natural gas saved on annual basis. The details of this calculation can be seen from Table 6.30 However, as mentioned above, investment costs including payments for heat exchanger systems, isolation and maintenance applications should be taken into consideration for a better estimation of net savings provided. Additionally, energy efficiency is expected to improve more when the waste heat from cogeneration unit and boiler house is recovered and used for certain purposes in future.

CHAPTER 7

CONCLUSIONS

In the study, a denim producing plant was selected in order to assess water and energy consumption performances after the application of site specific BAT measures taken. The goal of the study was realized by developing water and energy balance analyses for the implementation period of selected BAT measures in the mill. For this purpose, detailed data analysis was carried out immediately after first site visit. Visits to the plant were repeated several times to update the water and energy balance analyses. During the study, specific water and energy consumptions were assessed on daily, monthly and annual basis. In addition to the overall water and energy consumptions, process specific and machine specific consumptions were also analyzed and assessed in order to observe the effects of BAT measures taken. In this respect, most water intensive processes were determined to be finishing and dyeing processes. The same processes were determined to be the most energy intensive ones as energy consumption is directly related to water consumption[6].

The results of the analyses indicated that severe reductions were obtained in terms of both water and energy consumptions by application of selected BAT measures which are also low in cost when compared to the other measures suggested in BREF Textile Document. The adaptation of the BAT options to the selected mill caused significant changes in terms of water and energy consumption as listed below:

1. Water

   In the selected mill, 15.8% and 22.2% reductions in terms of water consumption were achieved in finishing and dyeing processes in the period of 2006-2007, respectively. These reductions in turn resulted in 29.5% reduction in overall specific water consumption in the period of January'05 - December'07. Moreover, savings achieved in water consumption in terms of monetary amounts are calculated to be 635,000 YTL on annual basis regardless of expenses for wastewater reduction and investment costs.

As a consequence, overall specific water consumption of the selected mill is reduced to 55 from 78 litres of water per kilogram of fabric production in the period of 2005-2007. By achieving this level, specific water consumption was reduced to reference range mentioned in BREF Textile Document (i.e. 50-100 litres of water per kilogram of fabric produced in mills) Additionally, this achieved level is also below the target specific water consumption level which is 80 litres of water per kilogram fabric finished mentioned in the Textile and Apparel Specialist Commission Report of SPO [11]. In this respect, this study is a strong evidence that Turkish textile manufacturing industry can not only reach the long-term target levels stated in Turkish development plans but also satisfy the achievable levels mentioned in BREF Textile Document of EU in terms of water consumption.

2. Energy

In the selected mill, 27% and 2.8% reductions in terms of energy consumption were achieved in finishing and dyeing processes in the period of 2006-2007, respectively. These achieved reductions resulted in 9% reduction in overall specific energy requirement of the selected mill in the period of January'05 - December'07. Similar to savings calculated in water minimization, energy savings in terms of monetary amounts are calculated to be 1,500,000 YTL on annual basis.

As a consequence, incoming specific energy requirement of the mill is reduced to 0.0091 Gcal per kilogram fabric produced in the year 2007. This level corresponds to 10.6 kWh per kilogram of fabric produced which is in the range of stated range (i.e.8-10 kWh/kg fabric) in BREF Textile Document [6]. This value, also corresponding to 38,160 kJ per kilogram of fabric, is also below the target levels stated in Textile and Apparel Specialist Commission Report of SPO [11]. Additionally, specific electricity consumption in the selected mill is reduced to 2.5 kWh per kilogram of fabric produced in the year 2007 which barely exceeds the range stated in BREF Textile Document (i.e. 0.5-1.5 kWh per kilograms of fabric produced) [6]. However, as the electricity consumption range indicated in BREF Textile Document is based on analyses of eight mills finishing woven fabric consisting mainly of cellulosic fibres, this slight exceeding is considered to be minor. Yet, similar to water consumption this study proves that Turkish textile manufacturing industry can not only reach the long-term target levels stated in Turkish development plans but also can satisfy the achievable levels mentioned in BREF Textile Document of EU in terms of energy consumption.

CHAPTER 8

RECOMMENDATIONS

This study was carried out in order to assess water and energy consumption performances in a selected textile manufacturing plant. The results of the study were based on available data obtained from the managerial authorities in the plant. Although the staff of the selected mill was ready to adopt the requirements of the IPPC Directive by carrying out monitoring in certain processes and willing to implement the study, available data was limited as the current legal requirements of Turkey are based on 'end-of-pipe' approach. Additionally, available data was mainly based on the processes in which expenditures are of consideration. Therefore, the most significant limitation for a more comprehensive energy and water balance analysis was the lack of data. In this respect, to complete the study, machine specific data in terms of both water and energy consumptions should be monitored. In order to implement this task, the 'integrated approach' should be penetrated into the operating authorities in the mill.

During the study, available data collection was the most stressful limitation as monitoring task is not assigned to a single authority in the mill. Monitoring was carried out arbitrarily. Although water consumption monitoring by automated system was completed in the recent period of the study, energy consumption monitoring is still not accurate. For that purpose, energy management should be studied and implemented by the energy team in the selected mill. In addition to the abovementioned recommendations, a few more considerations should be pointed out for water and energy consumption performance monitoring:

Energy requirement of the mill should be further improved despite the increase in production efficiency in the mill. In this respect, energy monitoring should be completed by including energy requirement and consumption of every machine. As energy consumptions of the machines and processes could not be determined without emission values, energy balance analysis could not be developed properly. However, as energy efficiency concept is partially dependent on the sensitivity and cooperativeness of the staff, the awareness in concept should be increased. At this point, energy team of the selected mill should step in.

In the selected mill, energy efficiency was increased to a considerable extent by the application of certain measures in some processes which were considered to be major points that energy is wasted. The certain energy losses were determined to be as follows:

i. Insufficient isolation

ii. Evaporation

iii. Exhaust gases originating from cogeneration unit and boiler house

iv. Hot discharges of cooling waters in compressors

v. Hot discharges of finishing and dyeing wash waters

By taking necessary measures, losses from *i*, *iv* and *v* were minimized and in overall, 9% reduction in energy requirement was achieved. Therefore, current major energy loss is due to the exhaust gases from cogeneration unit and boilers. As mentioned before, losses from cogeneration unit and boilers correspond to around 3,250 Gcal and 625 Gcal per month, respectively. According to a rough estimation carried out, wasted energy from cogeneration unit and boilers can heat up 52,000 tones of water from $15^{o}C$ to $90^{o}C$ which corresponds to almost 33% of water consumed per month. Therefore, it is clear that wasted energy from exhaust gases of cogeneration unit and boiler house is profitable.

From this point of view, it is considered that wasted energy can be used for caustic recovery. Caustic recovery process is carried out by using membrane systems. Although substantial amount of caustic is recovered, the density of caustic is not sufficient for reuse. Therefore, heat is necessary to obtain concentrate caustic which is reusable. The amount of heat necessary for that purpose can be supplied from the waste heat from cogeneration unit and boiler house by an appropriate heat exchanger unit.

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APPENDIX A

WATER CONSUMPTION PATTERNS IN THE SELECTED MILL

In Appendix A, data on water consumption of the selected mill are provided. In this respect, not only overall water consumption data but also process and machine specific consumption data of the selected mill are provided.

Table A.1: Monthly average specific water consumption patterns of machines in finishing process

		Fabric Production (m)	Fabric Production (kg)	Water Consumption (tones)	Specific Water Consumption (l water / kg fabric)
2005	January	4,412,820	2,691,820	186,210	69.18
	February	4,499,852	2,744,910	197,289	71.87
	March	4,780,439	2,916,068	202,566	69.47
	April	4,098,403	2,500,026	183,455	73.38
	May	3,983,340	2,429,838	188,847	77.72
	June	2,808,655	1,713,280	141,310	82.48
	July	3,349,197	2,043,010	173,719	85.03
	August	3,612,179	2,203,429	199,916	90.73
	September	3,761,169	2,294,313	176,527	76.94
	October	3,848,407	2,347,528	171,916	73.23
	November	3,392,445	2,069,391	179,241	86.62
	December	3,798,847	2,317,297	184,233	79.50
	TOTAL	46,345,755	28,270,910	2,185,229	936
	Average	3,862,146	2,355,909	182,102	78.01
2006	January	2,873,954	1,753,112	139,907	79.80
	February	2,805,721	1,711,490	153,737	89.83
	March	3,249,331	1,982,092	187,967	94.83
	April	2,918,885	1,780,520	137,667	77.32
	May	3,304,644	2,015,833	127,828	63.41
	June	3,389,267	2,067,453	125,340	60.63
	July	3,274,575	1,997,491	124,034	62.10
	August	3,306,228	2,016,799	140,542	69.69
	September	3,807,591	2,322,630	146,220	62.95
	October	3,579,961	2,183,776	138,351	63.35
	November	3,961,924	2,416,774	148,598	61.49
	December	3,981,975	2,429,005	162,565	66.93
	TOTAL	40,454,056	24,676,974	1,732,755	852
	Average	3,371,171	2,056,414	144,396	71.03
2007	January	4,258,240	2,597,526	157,030	60.45
	February	3,993,233	2,435,872	148,001	60.76
	March	4,203,263	2,563,991	134,673	52.52
	April	4,509,133	2,750,571	131,692	47.88
	May	4,774,197	2,912,260	146,559	50.32
	June	4,449,715	2,714,326	137,294	50.58
	July	4,284,045	2,613,267	148,230	56.72
	August	4,000,434	2,440,264	155,580	63.76
	September	4,594,766	2,802,807	158,068	56.40
	October	4,521,757	2,758,272	151,943	55.09
	November	4,659,457	2,842,269	160,107	56.33
	December	4,062,473	2,478,109	115,143	46.46
	TOTAL	52,310,712	31,909,534	1,744,320	657
	Average	4,359,226	2,659,128	145,360	54.77

Table A.2: Report of fully automated flow control system

2007	Sizing	Dyeing	Finishing	Pumped	TOTAL	Rinsing	R/O	WW
January	4,658	30,390	37,424	157,030	72,472	9,519	5,379	84,613
February	4,331	27,406	33,685	148,001	65,423	6,833	5,090	87,247
March	5,175	31,799	35,951	134,673	72,925	9,259	5,727	86,653
April	5,267	34,856	39,184	131,692	79,307	8,736	5,082	79,560
May	5,935	36,937	45,141	146,559	88,013	9,196	5,970	87,447
June	5,762	34,865	42,002	137,294	82,630	11,489	4,858	85,025
July	6,261	32,000	37,703	148,230	75,964	10,993	5,958	88,288
August	5,759	27,773	37,010	155,580	70,543	15,559	5,382	86,980
September	7,725	26,251	36,161	158,068	70,138	10,298	4,968	73,483
October	6,229	27,245	37,187	151,943	70,661	9,399	4,119	71,815

Table A.3: Monthly average specific water consumption patterns of dyeing process

		Dyed Yarn (kg)	**Water Consumed (tone)**	**Specific Water Consumption (l water/kg yarn)**	% **Dyeing**
2006	**January**	867,000	32,984	38	8.0
	February	974,051	26,939	28	6.3
	March	1,171,087	42,475	36	6.7
	April	1,070,213	28,191	26	6.0
	May	1,189,832	31,736	27	5.7
	June	1,206,885	33,242	28	6.4
	July	1,263,283	32,270	26	5.8
	August	1,276,925	31,030	24	6.4
	September	1,386,960	31,524	23	6.6
	October	1,357,105	31,148	23	5.9
	November	1,430,204	31,146	22	5.7
	December	1,450,418	30,617	21	6.3
	Monthly Average	1,218,830	31,942	27	6.3
2007	**January**	1,335,000	31,065	23	7.7
	February	1,275,109	27,406	21	7.8
	March	1,515,686	31,799	21	7.6
	April	1,546,704	34,865	23	7.6
	May	1,736,500	36,937	21	7.4
	June	1,625,900	34,865	21	6.6
	July	1,494,500	31,999	21	7.3
	August	1,341,300	26,579	20	6.8
	September	1,397,600	27,563	20	6.1
	October	1,350,200	27,244	20	6.4
	November	1,442,414	33,101	23	6.5
	December	1,298,259	25,783	20	5.7
	Monthly Average	1,446,598	30,767	21	7.0

Table A.4: Monthly average specific water consumption and fabric production patterns of M1

		Machine 1			
		Fabric Production (m)	Fabric Production (kg)	Water Consumption (tone)	Specific Water Consumption (L/kg fabric)
2006	January	1,117,570	681,718	6,475	9.50
	February	895,470	546,237	9,580	17.54
	March	1,071,237	653,455	2,229	3.41
	April	958,438	584,647	2,311	3.95
	May	1,369,445	835,361	4,800	5.75
	June	1,507,077	919,317	7,800	8.48
	July	1,211,136	738,793	1,402	1.90
	August	1,190,563	726,243	4,078	5.62
	September	1,430,184	872,412	4,078	4.67
	October	1,418,579	865,333	4,772	5.51
	November	1,568,797	956,966	4,245	4.44
	December	1,815,407	1,107,398	4,772	4.31
	TOTAL	15,553,903	9,487,881	56,542	75
	Monthly Average	1,296,159	790,657	4,712	6.26
2007	January	1,844,616	1,125,216	4,814	4.28
	February	1,919,213	1,170,720	4,642	3.97
	March	1,947,338	1,187,876	4,718	3.97
	April	2,365,079	1,442,698	5,021	3.48
	May	2,413,780	1,472,406	5,549	3.77
	June	2,252,941	1,374,294	5,366	3.90
	July	2,035,993	1,241,956	6,253	5.03
	August	1,874,081	1,143,189	5,893	5.15
	September	2,273,395	1,386,771	5,036	3.63
	October	2,253,920	1,374,891	4,831	3.51
	November	2,231,979	1,361,507	3,954	2.90
	December	1,881,132	1,147,491	3,278	2.86
	TOTAL	25,293,467	15,429,015	59,355	46
	Monthly Average	2,107,789	1,285,751	4,946	3.87

Table A.5: Monthly average specific water consumption and fabric production patterns of M2

		Machine 2			
		Fabric Production (m)	**Fabric Production (kg)**	**Water Consumption (tone)**	**Specific Water Consumption (L/kg fabric)**
2006	**January**	316,916	193,319	3,371	17.43
	February	588,040	358,704	3,115	8.68
	March	771,457	470,589	3,418	7.26
	April	542,953	331,201	1,640	4.95
	May	374,125	228,216	1,146	5.02
	June	451,923	275,673	1,392	5.05
	July	582,205	355,145	1,898	5.34
	August	340,911	207,956	1,131	5.44
	September	626,404	382,106	1,131	2.96
	October	406,823	248,162	1,341	5.40
	November	505,984	308,650	1,567	5.08
	December	485,465	296,134	1,341	4.53
	TOTAL	5,993,206	3,655,856	19,120	77
	Monthly Average	499,434	304,655	1,593	6.43
2007	**January**	599,458	365,669	2,120	5.80
	February	492,026	300,136	1,790	5.967
	March	495,925	302,514	2,517	8.32
	April	210,729	128,545	726	5.65
	May	181,025	110,425	962	8.71
	June	300,114	183,070	1,476	8.06
	July	432,290	263,697	2,775	10.52
	August	658,843	401,894	3,486	8.67
	September	460,653	280,998	2,252	8.01
	October	458,542	279,711	2,956	10.57
	November	558,447	340,653	3,123	9.17
	December	706,031	430,679	3,600	8.36
	TOTAL	5,554,083	3,387,991	27,783	98
	Monthly Average	462,840	282,333	2,315	8.15

Table A.6: Monthly average specific water consumption and fabric production patterns of M3

		Machine 3			
		Fabric Production (m)	**Fabric Production (kg)**	**Water Consumption (tone)**	**Specific Water Consumption (L/kg fabric)**
2006	**January**	191,327	116,709	1737	14.88
	February	292,336	178,325	1,970	11.05
	March	292,066	178,160	3,078	17.28
	April	259,761	158,454	1,620	10.22
	May	154,160	94,038	985	10.48
	June	163,932	99,999	1,135	11.35
	July	236,902	144,510	1,674	11.58
	August	1,170,875	714,234	881	1.23
	September	274,267	167,303	881	5.27
	October	137,842	84,084	928	11.04
	November	336,296	205,141	2,714	13.23
	December	569,937	347,662	928	2.67
	TOTAL	4,079,701	2,488,618	18,531	
	Monthly Average	339,975	207,384	1,544	10.02
2007	**January**	775,401	472,995	4,912	10.38
	February	555,593	338,912	2,820	8.32
	March	513,625	313,311	2,572	8.21
	April	838,026	511,196	3,498	6.84
	May	1,426,342	870,069	5,809	6.68
	June	721,153	439,903	3,260	7.41
	July	301,673	184,021	1,913	10.40
	August	263,457	160,709	1,862	11.59
	September	196,020	119,572	1,262	10.55
	October	218,925	133,544	1,468	10.99
	November	210,651	128,497	1,444	11.24
	December	309,582	188,845	2,028	10.74
	TOTAL	6,330,448	3,861,573	32,848	113
	Monthly Average	527,537	321,798	2,737	9.45

Table A.7: Monthly average specific water consumption and fabric production patterns of M4

		Machine 4			
		Fabric Production (m)	**Fabric Production (kg)**	**Water Consumption (tone)**	**Specific Water Consumption (L/kg fabric)**
2006	**January**	195,453	119,226	2,362	33.02
	February	198,900	121,329	2,378	19.60
	March	224,568	136,986	3,078	22.47
	April	198,320	120,975	1,627	13.45
	May	141,642	86,402	624	7.22
	June	132,375	80,749	815	10.09
	July	123,800	75,518	1,441	19.08
	August	450,232	274,642	3,521	12.82
	September	621,129	378,889	3,521	9.29
	October	718,218	438,113	4,380	10.00
	November	996,196	607,680	6,591	10.85
	December	890,509	543,210	4,380	8.06
	TOTAL	4,891,342	2,983,719	32,356	
	Monthly Average	407,612	248,643	2,696	14.66
2007	**January**	969,214	591,221	6,376	10.78
	February	1,257,720	767,209	8,649	11.27
	March	1,464,412	893,291	9,027	10.11
	April	1,546,035	943,081	9,939	10.54
	May	1,679,205	1,024,315	9,866	9.63
	June	1,326,023	808,874	7,695	9.51
	July	888,129	541,759	5,201	9.60
	August	1,007,899	614,818	5,604	9.11
	September	1,092,106	666,185	6,357	9.54
	October	1,464,801	893,529	7,840	8.77
	November	1,098,888	670,322	5,580	8.32
	December	904,296	551,621	4,945	8.96
	TOTAL	14,698,728	8,966,224	87,079	116
	Monthly Average	1,224,894	747,185	7,257	9.68

Table A.8: Monthly average specific water consumption and fabric production patterns of M5

		Machine 5			
		Fabric Production (m)	**Fabric Production (kg)**	**Water Consumption (tone)**	**Specific Water Consumption (L/kg fabric)**
2006	**January**	803,805	490,321	2,551	5.20
	February	869,442	530,360	3,534	6.66
	March	1,027,785	626,949	4,990	7.96
	April	962,007	586,824	4,039	6.88
	May	968,436	590,746	3,700	6.26
	June	1,017,494	620,671	3,900	6.28
	July	869,529	530,413	3,965	7.48
	August	800,482	488,294	3,900	7.99
	September	1,038,160	633,278	3,900	6.16
	October	948,395	578,521	3,900	6.74
	November	1,178,455	718,858	3,900	5.43
	December	993,917	606,289	3,230	5.33
	TOTAL	11,477,907	7,001,523	45,509	78
	Monthly Average	956,492	583,460	3,792	6.53
2007	**January**	1,141,697	696,435	3,027	4.35
	February	981,146	598,499	2,003	3.35
	March	1,125,188	686,365	2,306	3.36
	April	1,010,424	616,359	2,186	3.55
	May	1,213,615	740,305	3,250	4.39
	June	1,045,584	637,806	5,953	9.33
	July	1,085,279	662,020	2,248	3.40
	August	1,020,119	622,273	2,257	3.63
	September	1,099,259	670,548	2,461	3.67
	October	1,109,941	677,064	2,614	3.86
	November	1,117,935	681,940	2,601	3.81
	December	960,984	586,200	2,258	3.85
	TOTAL	12,911,171	7,875,814	33,164	51
	Monthly Average	1,075,931	656,318	2,764	4.21

Table A.9: Monthly average specific water consumption and fabric production patterns of M6

		Machine 6			
		Fabric Production (m)	**Fabric Production (kg)**	**Water Consumption (tone)**	**Specific Water Consumption (L/kg fabric)**
2006	**January**	1,362,361	831,040	17,284	20.80
	February	1,425,143	869,337	12,362	14.22
	March	1,623,440	990,298	14,489	14.63
	April	1,585,779	967,325	11,370	11.75
	May	1,496,986	913,161	7,693	8.42
	June	1,603,052	977,862	7,019	7.18
	July	1,676,310	1,022,549	7,908	7.73
	August	1,819,633	1,109,976	8,647	7.79
	September	1,813,172	1,106,035	8,647	7.82
	October	1,733,391	1,057,369	8,056	7.62
	November	1,852,413	1,129,972	8,672	7.67
	December	1,758,565	1,072,725	8,056	7.51
	TOTAL	19,750,245	12,047,649	120,204	123
	Monthly Average	1,645,854	1,003,971	10,017	10.26
2007	**January**	1,868,105	1,139,544	9,234	8.10
	February	1,602,895	977,766	7,286	7.45
	March	1,658,641	1,011,771	7,929	7.84
	April	1,809,458	1,103,769	10,212	9.25
	May	1,931,306	1,178,097	10,591	8.99
	June	1,728,651	1,054,477	9,865	9.36
	July	1,668,387	1,017,716	10,445	10.26
	August	1,586,568	967,806	9,703	10.03
	September	1,698,145	1,035,868	10,270	9.91
	October	1,674,255	1,021,296	9,350	9.16
	November	1,874,858	1,143,663	9,470	8.28
	December	1,619,809	988,083	7,464	7.55
	TOTAL	20,721,078	12,639,858	111,819	106
	Monthly Average	1,726,757	1,053,321	9,318	8.85

Table A.10: Monthly average specific water consumption and fabric production patterns of M7

		Machine 7			
		Fabric Production (m)	Fabric Production (kg)	Water Consumption (tone)	Specific Water Consumption (L/kg fabric)
2006	**January**	1,081,446	659,682	2,640	4.00
	February	911,715	556,146	4,268	7.67
	March	1,174,739	716,591	6,310	8.81
	April	1,197,602	730,537	6,163	8.44
	May	1,182,983	721,620	6,347	8.80
	June	1,275,250	777,903	6,478	8.33
	July	1,188,191	724,797	6,477	8.94
	August	1,387,229	846,210	5,509	6.51
	September	1,531,423	934,168	5,509	5.90
	October	1,573,895	960,076	5,257	5.48
	November	1,645,861	1,003,975	5,089	5.07
	December	1,422,545	867,752	5,257	6.06
	TOTAL	15,572,879	9,499,456	65,305	
	Monthly Average	1,297,740	791,621	5,442	7.00
2007	**January**	1,081,446	659,682	5,468	8.29
	February	1,494,095	911,398	5,383	5.91
	March	1,698,344	1,035,990	5,380	5.19
	April	1,717,786	1,047,849	5,805	5.54
	May	1,756,500	1,071,465	6,544	6.11
	June	1,701,454	1,037,887	5,935	5.72
	July	1,713,163	1,045,029	6,111	5.85
	August	1,849,187	1,128,004	5,808	5.15
	September	2,308,905	1,408,432	5,971	4.24
	October	1,892,980	1,154,718	5,727	4.96
	November	2,521,931	1,538,378	8,452	5.49
	December	2,181,127	1,330,487	8,618	6.48
	TOTAL	22,420,384	13,676,434	75,202	66
	Monthly Average	1,868,365	1,139,703	6,267	5.52

Table A.11: Monthly average specific water consumption and fabric production patterns of M8

		Machine 8			
		Fabric Production (m)	**Fabric Production (kg)**	**Water Consumption (tone)**	**Specific Water Consumption (L/kg fabric)**
2006	**January**	927,871	566,001	2,810	4.96
	February	1,085,968	662,440	3,711	5.60
	March	1,200,773	732,472	4,060	5.54
	April	1,174,880	716,677	3,696	5.16
	May	1,019,044	621,617	4,058	6.53
	June	1,013,929	618,497	3,980	6.43
	July	1,176,135	717,442	4,009	5.59
	August	1,260,186	768,713	3,978	5.17
	September	1,307,985	797,871	4,027	5.05
	October	1,220,287	744,375	3,990	5.36
	November	1,239,514	756,104	4,293	5.68
	December	1,161,887	708,751	2,651	3.74
	TOTAL	13,788,459	8,410,960	45,263	65
	Monthly Average	1,149,038	700,913	3,772	5.40
2007	**January**	1,343,828	819,735	1,469	1.79
	February	1,134,374	691,968	1,108	1.60
	March	1,116,825	681,263	1,498	2.20
	April	1,129,403	688,936	1,792	2.60
	May	1,282,468	782,305	2,206	2.82
	June	1,252,171	763,824	2,448	3.20
	July	1,307,374	797,498	2,752	3.45
	August	1,241,707	757,441	2,392	3.16
	September	1,309,152	798,583	2,548	3.19
	October	1,341,224	818,147	2,397	2.93
	November	1,402,769	855,689	2,526	2.95
	December	1,278,469	779,866	2,514	3.22
	TOTAL	15,139,764	9,235,256	25,650	33
	Monthly Average	1,261,647	769,605	2,138	2.76

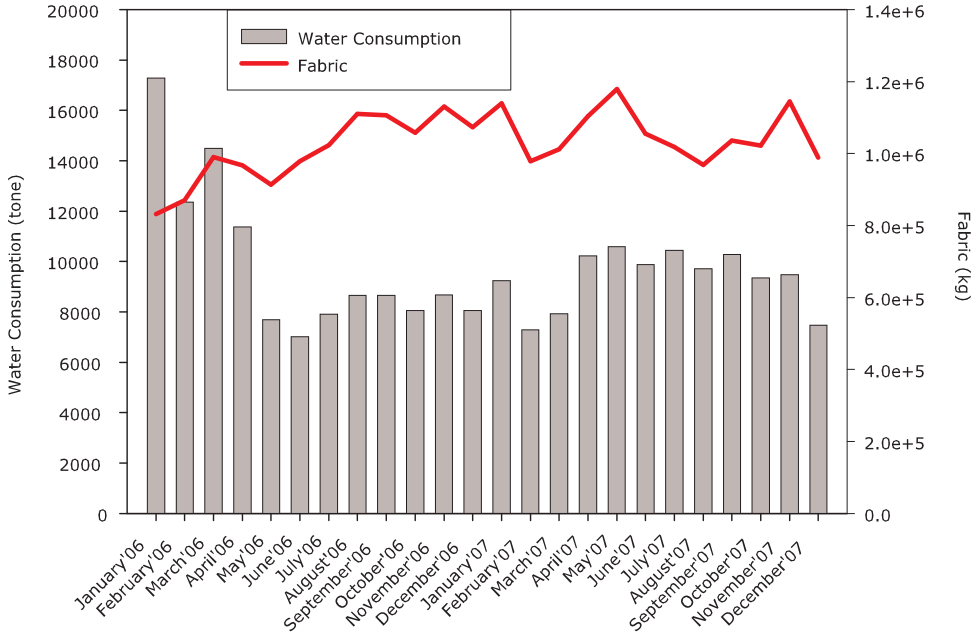

Figure A.1: Water consumption and fabric production patterns of M6

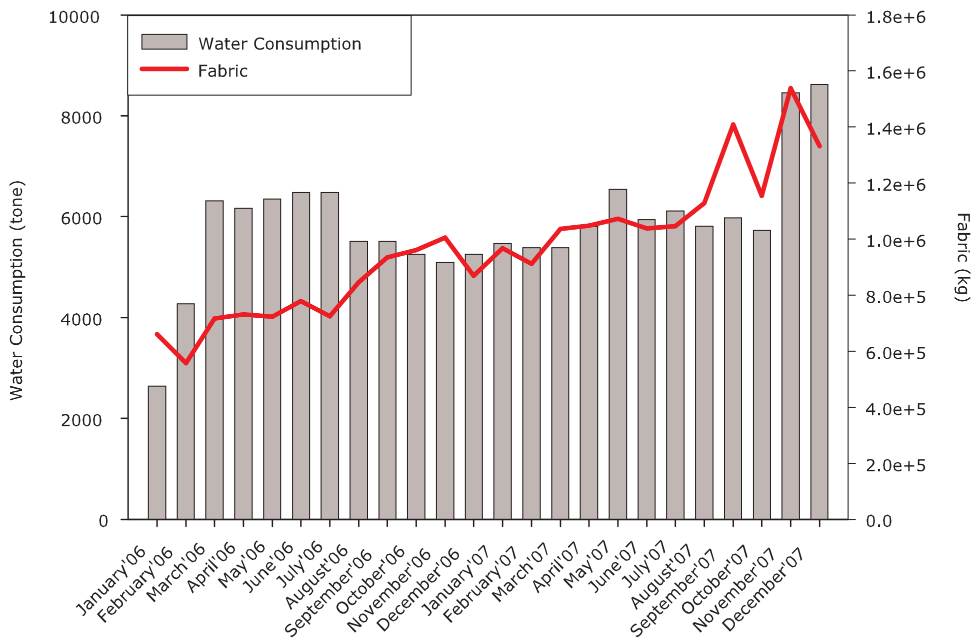

Figure A.2: Water consumption and fabric production patterns of M7

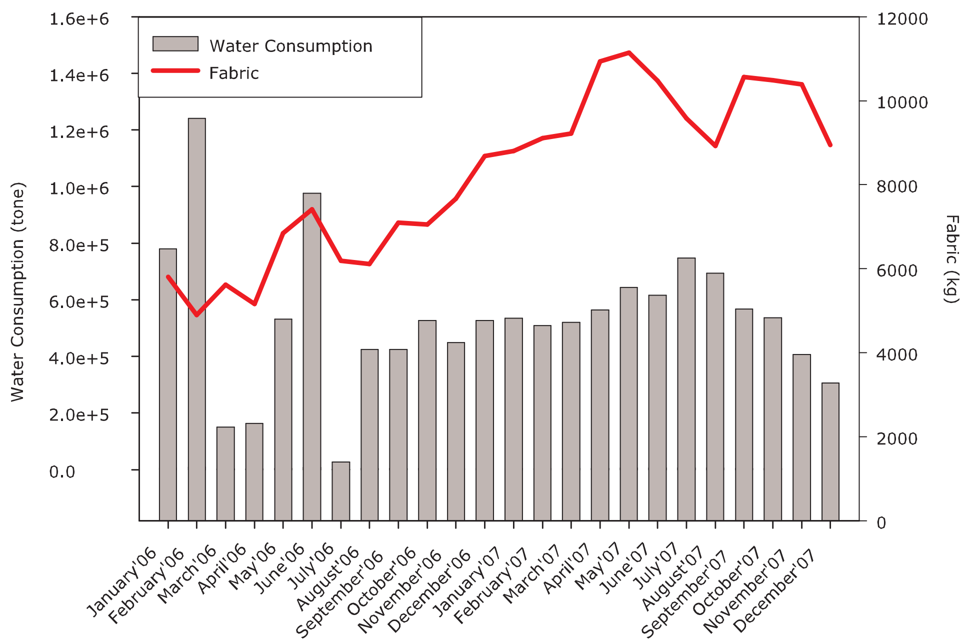

Figure A.3: Water consumption and fabric production patterns of M1

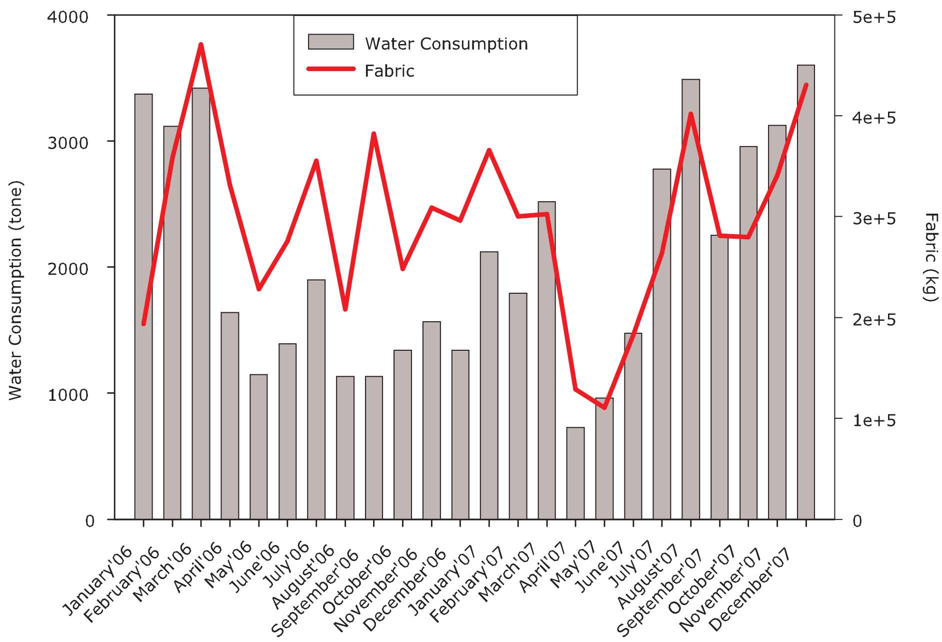

Figure A.4: Water consumption and fabric production patterns of M2

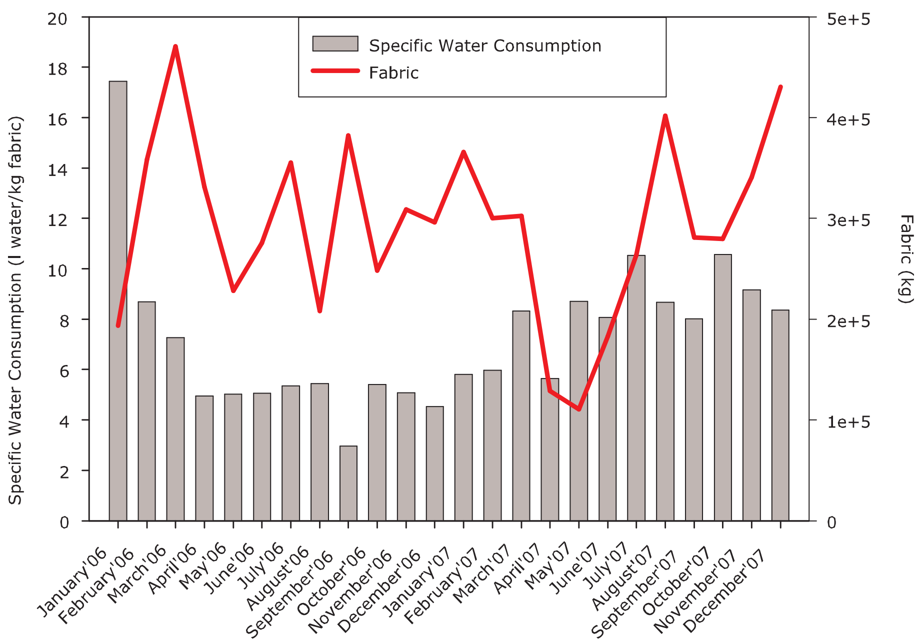

Figure A.5: Specific eater consumption and fabric production patterns of M2

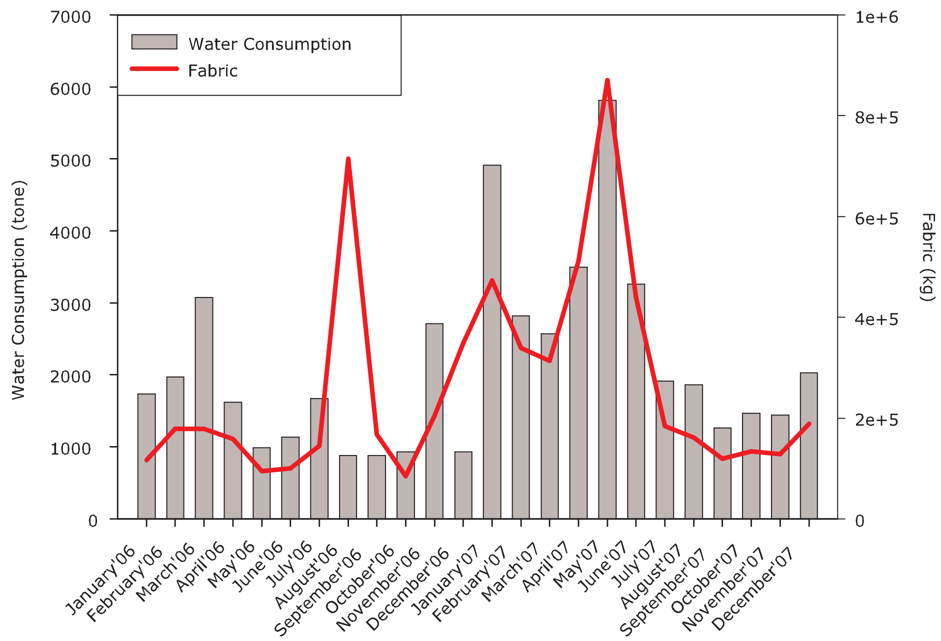

Figure A.6: Water consumption and fabric production patterns of M3

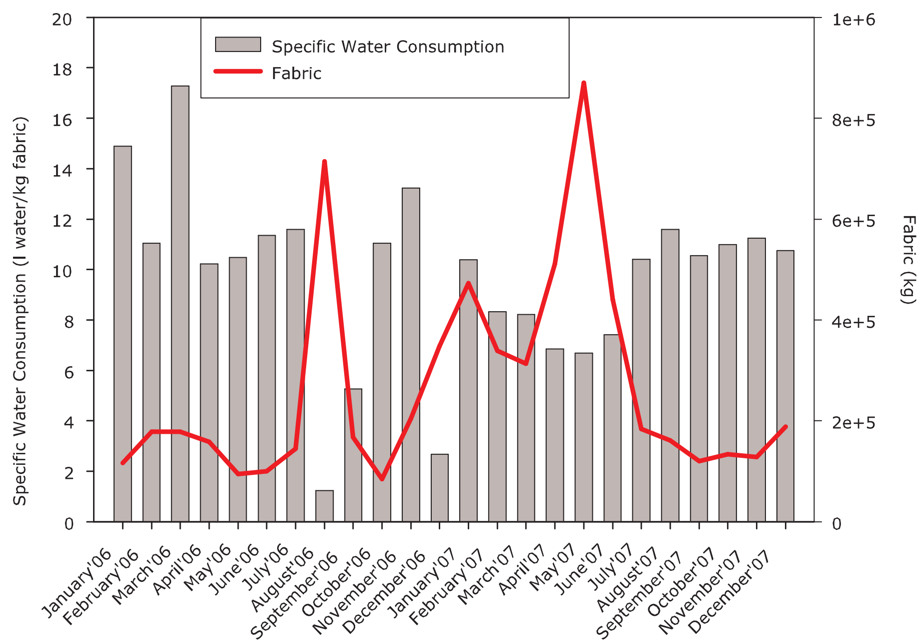

Figure A.7: Specific water consumption and fabric production patterns of M3

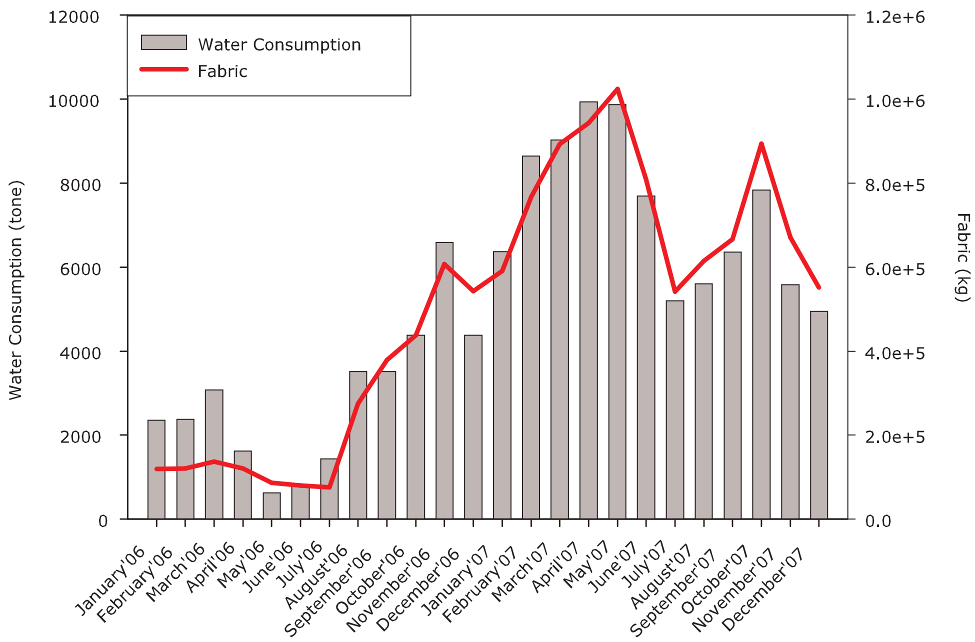

Figure A.8: Water consumption and fabric production patterns of M4

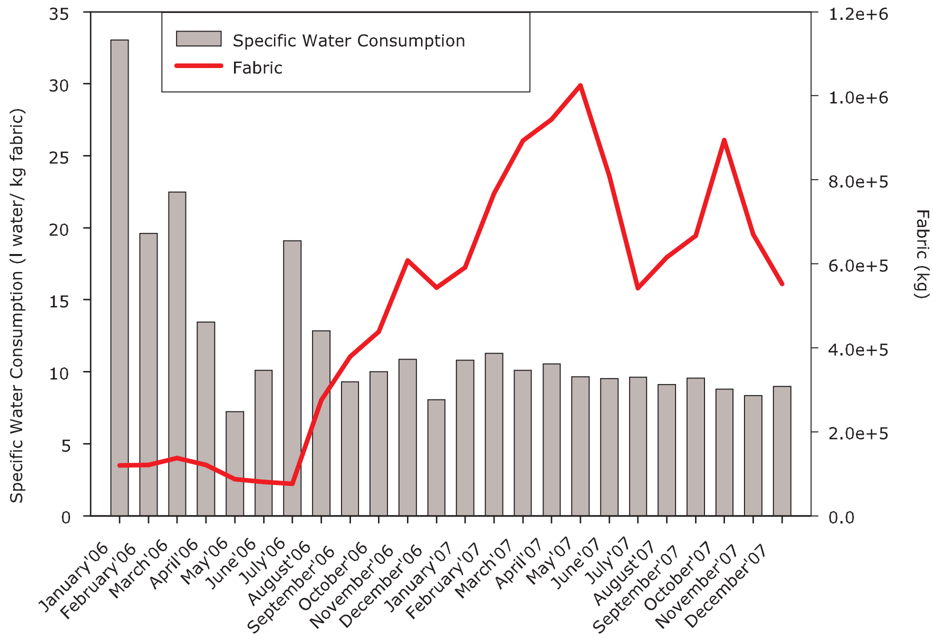

Figure A.9: Specific water consumption and fabric production patterns of M4

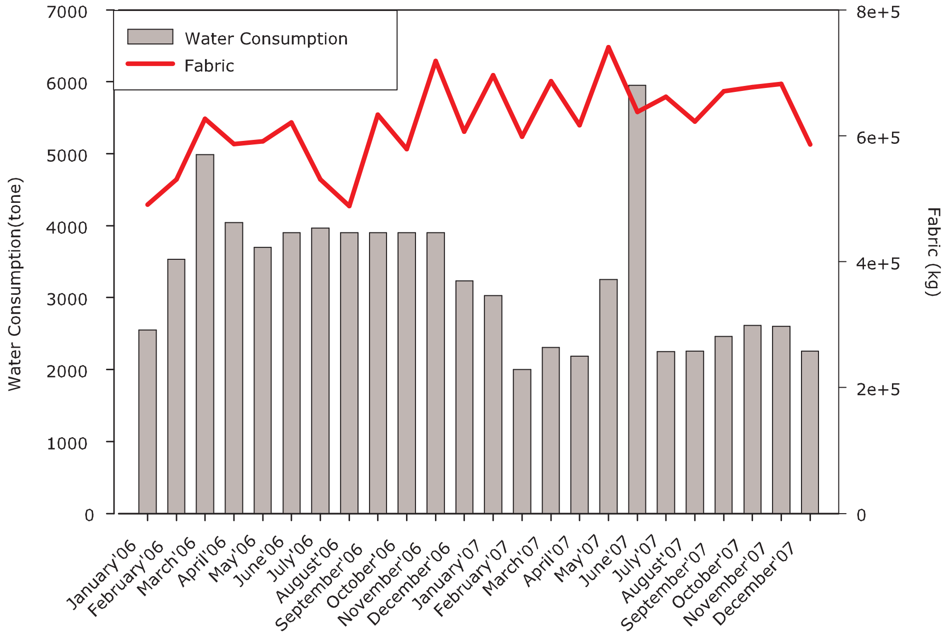

Figure A.10: Water consumption and fabric production patterns of M5

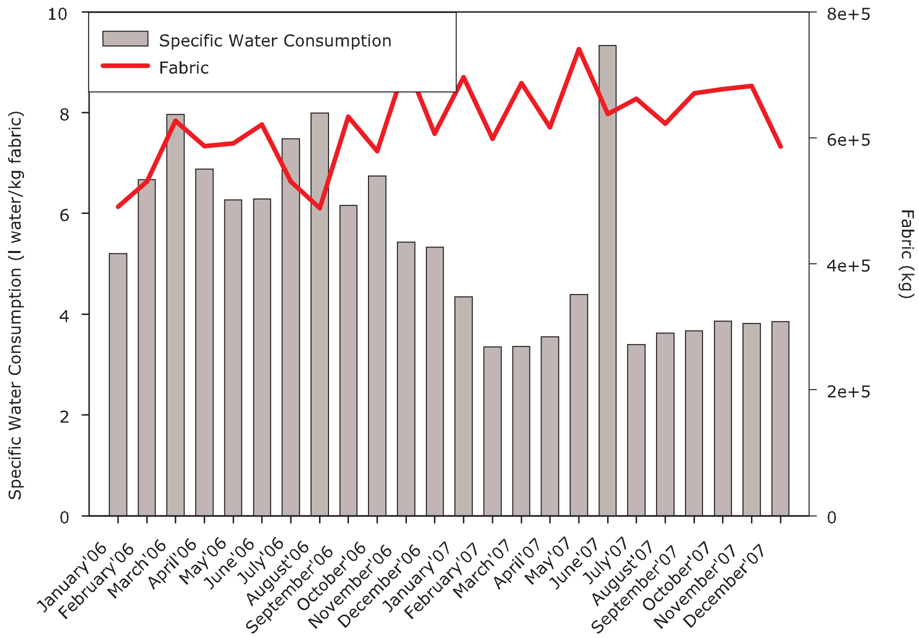

Figure A.11: Water consumption and fabric production patterns of M5

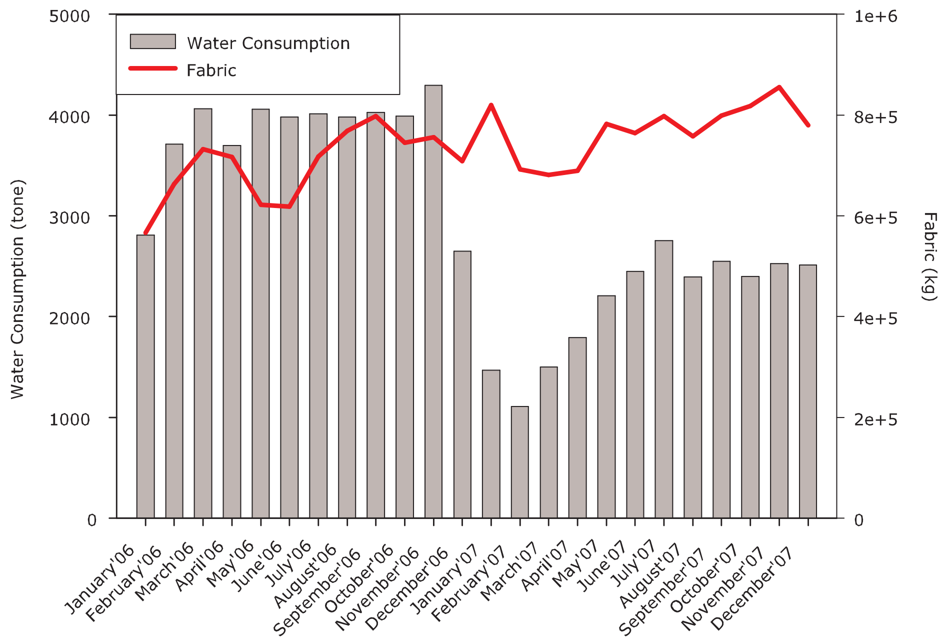

Figure A.12: Water consumption and fabric production patterns of M8

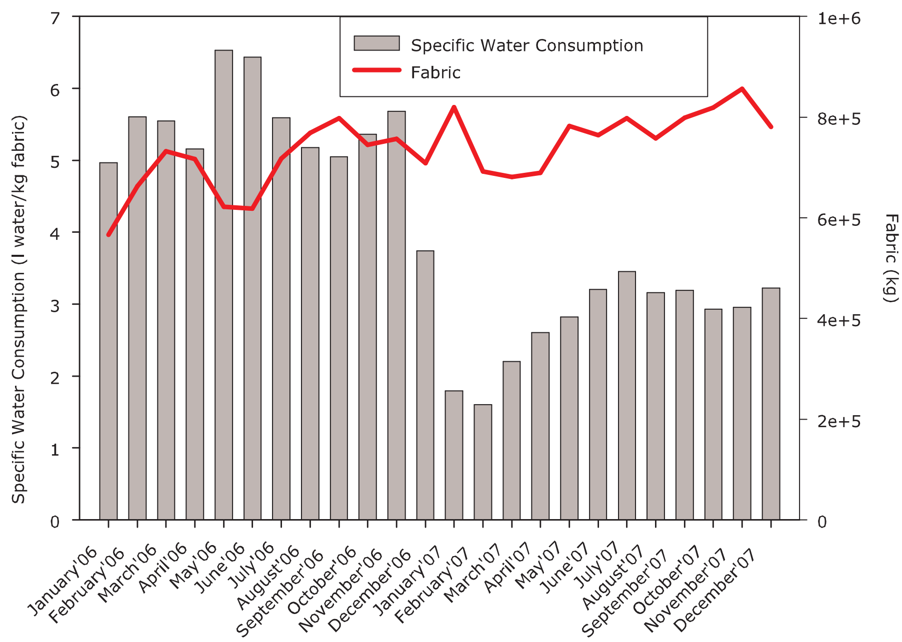

Figure A.13: Specific water consumption and fabric production patterns of M8

APPENDIX B

ENERGY CONSUMPTION PATTERNS IN THE SELECTED MILL

In Appendix B, data on energy consumption of the selected mill are provided. In this respect, not only overall energy consumption data but also process and machine specific energy consumption data of the selected mill are provided.

Table B.1: Overall energy requirement of the mill

		Electricity		Natural Gas		Total Energy	Fabric Production	Incoming Specific Energy
		(kWh)	(Gcal)	(Sm^3)	(Gcal)	(Gcal)	(kg)	(Gcal/kg fabric)
2005	**January**	268,002	230	3,303,652	28,411	28,642	2,691,820	0.0106
	February	158,760	137	3,220,763	27,699	27,835	2,744,910	0.0101
	March	388,584	334	3,229,973	27,778	28,112	2,916,068	0.0096
	April	931,392	801	2,477,426	21,306	22,107	2,500,026	0.0088
	May	448,875	386	2,424,961	20,855	21,241	2,429,838	0.0087
	June	649,026	558	1,544,404	13,282	13,840	1,713,280	0.0081
	July	654,318	563	2,199,472	18,915	19,478	2,043,010	0.0095
	August	580,041	499	2,523,362	21,701	22,200	2,203,429	0.0101
	September	451,899	389	2,638,975	22,695	23,084	2,294,313	0.0101
	October	771,309	663	2,846,387	24,479	25,142	2,347,528	0.0107
	November	530,221	456	2,751,959	23,667	24,123	2,069,391	0.0117
	December	530,221	456	3,128,359	26,904	27,360	2,317,297	0.0118
	TOTAL	6,362,647	5,472	32,289,692	277,691	283,163	28,270,910	0.1199
	Average	530,221	456	2,690,808	23,141	23,597	2,355,909	0.0100
2006	**January**	806,085	693	2,281,930	19,625	20,318	1,753,112	0.0116
	February	202,608	174	2,552,973	21,956	22,130	1,711,490	0.0129
	March	293,139	252	2,604,825	22,401	22,654	1,982,092	0.0114
	April	450,198	387	2,238,213	19,249	19,636	1,780,520	0.0110
	May	489,132	421	2,203,427	18,949	19,370	2,015,833	0.0096
	June	485,730	418	2,227,876	19,160	19,577	2,067,453	0.0095
	July	1,375,164	1,183	2,091,155	17,984	19,167	1,997,491	0.0096
	August	185,409	159	2,358,727	20,285	20,445	2,016,799	0.0101
	September	104,706	90	2,512,577	21,608	21,698	2,322,630	0.0093
	October	124,362	107	2,463,633	21,187	21,294	2,183,776	0.0098
	November	3,780	3	2,955,183	25,415	25,418	2,416,774	0.0105
	December	397,656	342	3,035,759	26,108	26,450	2,429,005	0.0109
	TOTAL	4,917,969	4,229	29,526,278	253,926	258,155	24,676,974	0.1263
	Average	409,831	352	2,460,523	21,160	21,513	2,056,414	0.0105
2007	**January**	121,338	104	3,142,954	27,029	27,134	2,597,526	0.0104
	February	205,254	177	2,870,169	24,683	24,860	2,435,872	0.0102
	March	335,475	289	3,018,712	25,961	26,249	2,563,991	0.0102
	April	820,638	706	2,857,675	24,576	25,282	2,750,571	0.0092
	May	1,269,135	1,091	2,777,243	23,884	24,976	2,912,260	0.0086
	June	779,814	671	2,569,056	22,094	22,765	2,714,326	0.0084
	July	714,420	614	2,537,207	21,820	22,434	2,613,267	0.0086
	August	756,567	651	2,372,771	20,406	21,056	2,440,264	0.0086
	September	545,832	469	2,568,311	22,087	22,557	2,802,807	0.0080
	October	745,038	641	2,562,860	22,041	22,681	2,758,272	0.0082
	November	471,933	406	2,955,708	25,419	25,825	2,842,269	0.0091
	December	433,188	373	2,727,104	23,453	23,826	2,478,109	0.0096
	TOTAL	7,198,632	6,191	32,959,770	283,454	289,645	31,909,534	0.1092
	Average	599,886	516	2 ,746,648	23,621	24,137	2,659,128	0.0091

Table B.2: Energy consumption and production of cogeneration unit

		Natural Gas Consumption (Sm^3)	Natural Gas Consumption (Gcal)	Steam Production (tone)	Steam Production (Gcal)	Electricity Production (kWh)	Electricity Production (Gcal)	Fabric Production (m)	Energy Loss (Gcal)	Energy Loss (Gcal/kg fabric)
2005	**January**	1,942,445	16,705	12,070	7,990	5,476,447	4,710	4,412,820	4,005	0.0015
	February	2,041,623	17,558	13,179	8,724	5,982,934	5,145	4,499,852	3,688	0.0013
	March	2,122,426	18,253	13,704	9,072	6,073,631	5,223	4,780,439	3,957	0.0014
	April	1,728,982	14,869	11,484	7,602	4,992,046	4,293	4,098,403	2,974	0.0012
	May	1,860,352	15,999	12,268	8,121	5,387,957	4,634	3,983,340	3,244	0.0013
	June	1,052,663	9,053	8,354	5,530	3,614,221	3,108	2,808,655	414	0.0002
	July	1,748,241	15,035	11,861	7,852	5,123,780	4,406	3,349,197	2,776	0.0014
	August	2,029,847	17,457	13,530	8,957	5,807,850	4,995	3,612,179	3,505	0.0016
	September	2,040,202	17,546	13,869	9,181	6,078,800	5,228	3,761,169	3,137	0.0014
	October	2,050,996	17,639	13,302	8,806	5,852,200	5,033	3,848,407	3,800	0.0016
	November	1,870,003	16,082	12,010	7,951	5,438,987	4,678	3,392,445	3,454	0.0017
	December	2,116,823	18,205	13,724	9,085	5,438,987	4,678	3,798,847	4,442	0.0019
	TOTAL	22,604,603	194,400	149,355	98,873	65,267,839	56,130	46,345,755	39,396	0.0165
	Average	1,883,717	16,200	12,446	8,239	5,438,987	4,678	3,862,146	3,283	0.0014
2006	**January**	1,306,730	11,238	7,691	5,091	3,577,106	3,076	2,873,954	3,070	0.0018
	February	1,810,051	15,566	11,449	7,579	5,180,504	4,455	2,805,721	3,532	0.0021
	March	2,034,628	17,498	13,198	8,737	5,820,405	5,006	3,249,331	3,755	0.0019
	April	1,870,749	16,088	11,654	7,715	5,520,931	4,748	2,918,885	3,625	0.0020
	May	1,879,659	16,165	11,890	7,871	5,253,900	4,518	3,304,644	3,776	0.0019
	June	1,915,681	16,475	12,713	8,416	5,610,692	4,825	3,389,267	3,234	0.0016
	July	1,608,548	13,834	10,707	7,088	4,889,113	4,205	3,274,575	2,541	0.0013
	August	2,112,854	18,171	13,964	9,244	6,244,175	5,370	3,306,228	3,556	0.0018
	September	2,089,697	17,971	14,301	9,467	6,299,984	5,418	3,807,591	3,086	0.0013
	October	2,029,409	17,453	13,374	8,854	5,898,847	5,073	3,579,961	3,526	0.0016
	November	2,192,295	18,854	14,403	9,535	6,476,102	5,569	3,961,924	3,750	0.0016
	December	2,068,986	17,793	13,432	8,892	6,175,489	5,311	3,981,975	3,590	0.0015
	TOTAL	22,919,287	197,106	148,776	98,490	66,947,248	57,575	40,454,056	41,042	0.0202
	Average	1,909,941	16,425	12,398	8,207	5,578,937	4,798	3,371,171	3,420	0.0017

Table B.2 (continued)

		Natural Gas Consumption		Steam Production		Electricity Production		Fabric Production	Energy Loss	
		(Sm^3)	(Gcal)	(tone)	(Gcal)	(kWh)	(Gcal)	(m)	(Gcal)	(Gcal/kg fabric)
2007	**January**	2,174,188	18,698	13,509	8,943	6,195,337	5,328	4,258,240	4,427	0.0017
	February	2,005,085	17,244	13,139	8,698	5,917,573	5,089	3,993,233	3,457	0.0014
	March	2,274,969	19,565	15,244	10,092	6,741,930	5,798	4,203,263	3,675	0.0014
	April	2,073,316	17,831	13,760	9,109	6,068,216	5,219	4,509,133	3,503	0.0013
	May	1,989,709	17,111	14,193	9,396	6,038,164	5,193	4,774,197	2,523	0.0009
	June	1,967,513	16,921	14,536	9,623	6,264,170	5,387	4,449,715	1,911	0.0007
	July	1,969,576	16,938	14,395	9,529	6,302,970	5,421	4,284,045	1,988	0.0008
	August	1,722,286	14,812	13,252	8,773	5,763,760	4,957	4,000,434	1,082	0.0004
	September	2,076,101	17,854	13,783	9,124	5,986,850	5,149	4,594,766	3,581	0.0013
	October	1,900,417	16,344	12,684	8,397	5,540,173	4,765	4,521,757	3,182	0.0012
	November	2,167,925	18,644	14,316	9,477	6,349,046	5,460	4,659,457	3,707	0.0013
	December	1,867,511	16,061	12,324	8,158	5,563,321	4,784	4,062,473	3,118	0.0013
	TOTAL	24,188,596	208,022	165,135	109,319	72,731,510	62,549	52,310,712	36,153	0.0136
	Average	2,015,716	17,335	13,761	9,110	6,060,959	5,212	4,359,226	3,013	0.0011

Table B.3: Energy consumption and production of boilers

		Natural Gas Consumption		Steam Production		Fabric Production	Energy Loss	
		(Sm^3)	(Gcal)	(tone)	(Gcal)	(kg)	(Gcal)	(Gcal/kg fabric)
2005	January	1,070,908	9,210	11,825	7,828	2,691,820	1,381	0.00051
	February	964,858	8,298	10,654	7,053	2,744,910	1,245	0.00045
	March	879,171	7,561	9,708	6,427	2,916,068	1,134	0.00039
	April	558,838	4,806	6,171	4,085	2,500,026	721	0.00029
	May	395,765	3,404	4,370	2,893	2,429,838	511	0.00021
	June	296,958	2,554	3,279	2,171	1,713,280	383	0.00022
	July	260,221	2,238	2,873	1,902	2,043,010	336	0.00016
	August	265,387	2,282	2,930	1,940	2,203,429	342	0.00016
	September	379,339	3,262	4,189	2,773	2,294,313	489	0.00021
	October	627,036	5,393	6,924	4,584	2,347,528	809	0.00034
	November	672,668	5,785	7,428	4,917	2,069,391	868	0.00042
	December	802,188	6,899	8,858	5,864	2,317,297	1,035	0.00045
	TOTAL	7,173,337	61,691	79,210	52,437	28,270,910	9,254	0.00382
	Average	597,778	5,141	6,601	4,370	2,355,909	771	0.00032
2006	January	838,379	7,210	9,258	6,129	1,753,112	1,082	0.00062
	February	626,685	5,389	6,920	4,581	1,711,490	808	0.00047
	March	459,518	3,952	5,074	3,359	1,982,092	593	0.00030
	April	252,598	2,172	2,789	1,846	1,780,520	326	0.00018
	May	180,722	1,554	1,996	1,321	2,015,833	233	0.00012
	June	139,773	1,202	1,543	1,022	2,067,453	180	0.00009
	July	282,523	2,430	3,120	2,065	1,997,491	364	0.00018
	August	93,680	806	1,034	685	2,016,799	121	0.00006
	September	231,310	1,989	2,554	1,691	2,322,630	298	0.00013
	October	274,359	2,359	3,030	2,006	2,183,776	354	0.00016
	November	517,355	4,449	5,713	3,782	2,416,774	667	0.00028
	December	769,919	6,621	8,502	5,628	2,429,005	993	0.00041
	TOTAL	4,666,821	40,135	51,532	34,114	24,676,974	6,020	0.00299
	Average	388,902	3,345	4,294	2,843	2,056,414	502	0.00025
2007	January	732,848	6,302	8,092	5,357	2,597,526	945	0.00036
	February	689,915	5,933	7,618	5,043	2,435,872	890	0.00037
	March	597,905	5,142	6,602	4,371	2,563,991	771	0.00030
	April	617,065	5,307	6,814	4,511	2,750,571	796	0.00029
	May	515,475	4,433	5,692	3,768	2,912,260	665	0.00023
	June	228,001	1,961	2,518	1,667	2,714,326	294	0.00011
	July	156,245	1,344	1,725	1,142	2,613,267	202	0.00008
	August	206,880	1,779	2,284	1,512	2,440,264	267	0.00011
	September	267,832	2,303	2,957	1,958	2,802,807	346	0.00012
	October	428,333	3,684	4,730	3,131	2,758,272	553	0.00020
	November	581,156	4,998	6,417	4,248	2,842,269	750	0.00026
	December	670,153	5,763	7,400	4,899	2,478,109	864	0.00035
	TOTAL	5,691,808	48,950	62,851	41,607	31,909,534	7,342	0.00278
	Average	474,317	4,079	5,238	3,467	2,659,128	612	0.00023

Table B.4: Energy requirement in the mill

		Electricity Consumption (kWh)	(Gcal)	Steam Consumption (tone)	(Gcal)	Natural Gas Consumption (Sm^3)	(Gcal)	Total Energy (Gcal)	Fabric Production (kg)	Specific Energy (Gcal/kg fabric)
2005	**January**	5,738,968	4,936	23,850	15,789	290,299	2,497	23,221	2,691,820	0.0086
	February	6,137,158	5,278	23,792	15,751	214,282	1,843	22,871	2,744,910	0.0083
	March	6,459,947	5,556	23,375	15,474	228,376	1,964	22,994	2,916,068	0.0079
	April	5,917,957	5,089	17,631	11,672	189,606	1,631	18,392	2,500,026	0.0074
	May	5,833,241	5,017	16,621	11,003	168,844	1,452	17,472	2,429,838	0.0072
	June	4,260,412	3,664	11,620	7,693	194,783	1,675	13,032	1,713,280	0.0076
	July	5,776,208	4,968	14,723	9,747	191,010	1,643	16,357	2,043,010	0.0080
	August	6,385,812	5,492	16,449	10,889	228,128	1,962	18,343	2,203,429	0.0083
	September	6,527,864	5,614	18,042	11,944	219,434	1,887	19,445	2,294,313	0.0085
	October	6,619,540	5,693	20,199	13,372	168,355	1,448	20,513	2,347,528	0.0087
	November	5,965,711	5,131	19,746	13,072	209,288	1,800	20,002	2,069,391	0.0097
	December	5,965,711	5,131	22,949	15,192	209,348	1,800	22,123	2,317,297	0.0095
	TOTAL	71,588,528	61,566	228,998	151,597	2,511,752	21,601	234,764	28,270,910	0.0998
	Average	5,965,711	5,131	19,083	12,633	209,313	1,800	19,564	2,355,909	0.0083
2006	**January**	4,373,363	3,761	17,332	11,474	136,821	1,177	16,412	1,753,112	0.0094
	February	5,376,875	4,624	18,656	12,350	116,237	1,000	17,974	1,711,490	0.0105
	March	6,107,307	5,252	19,680	13,028	110,679	952	19,232	1,982,092	0.0097
	April	5,967,034	5,132	15,163	10,038	114,866	988	16,157	1,780,520	0.0091
	May	5,736,039	4,933	14,407	9,537	143,046	1,230	15,700	2,015,833	0.0078
	June	6,093,965	5,241	14,652	9,699	172,422	1,483	16,423	2,067,453	0.0079
	July	6,260,119	5,384	14,629	9,684	200,084	1,721	16,789	1,997,491	0.0084
	August	6,428,261	5,528	15,263	10,104	152,193	1,309	16,941	2,016,799	0.0084
	September	6,402,800	5,506	17,520	11,598	191,570	1,648	18,752	2,322,630	0.0081
	October	6,020,941	5,178	17,156	11,357	159,865	1,375	17,910	2,183,776	0.0082
	November	6,513,524	5,602	21,594	14,295	245,573	2,112	22,009	2,416,774	0.0091
	December	6,570,688	5,651	24,049	15,920	196,855	1,693	23,264	2,429,005	0.0096
	TOTAL	71,850,916	61,792	210,100	139,086	1,940,211	16,686	217,564	24,676,974	0.1061
	Average	5,987,576	5,149	17,508	11,591	161,684	1,390	18,130	2,056,414	0.0088

Table B.4 (continued)

		Electricity Consumption		Steam Consumption		Natural Gas Consumption		Total Energy	Fabric Production	Specific Energy
		(kWh)	**(Gcal)**	**(tone)**	**(Gcal)**	(Sm^3)	**(Gcal)**	**(Gcal)**	**(kg)**	**(Gcal/kg fabric)**
2007	**January**	6,303,640	5,421	23,649	15,656	235,918	2,029	23,106	2,597,526	0.0089
	February	6,121,693	5,265	22,726	15,045	175,169	1,506	21,816	2,435,872	0.0090
	March	7,077,027	6,086	23,486	15,548	145,838	1,254	22,888	2,563,991	0.0089
	April	6,888,098	5,924	22,306	14,767	167,294	1,439	22,129	2,750,571	0.0080
	May	7,306,921	6,284	21,331	14,121	272,059	2,340	22,745	2,912,260	0.0078
	June	7,043,795	6,058	17,701	11,718	373,542	3,212	20,988	2,714,326	0.0077
	July	7,017,390	6,035	16,544	10,952	411,386	3,538	20,525	2,613,267	0.0079
	August	6,520,327	5,607	16,134	10,681	443,605	3,815	20,103	2,440,264	0.0082
	September	6,532,115	5,618	17,524	11,601	224,378	1,930	19,148	2,802,807	0.0068
	October	6,284,266	5,404	18,669	12,359	234,110	2,013	19,777	2,758,272	0.0072
	November	6,820,979	5,866	22,436	14,853	206,627	1,777	22,496	2,842,269	0.0079
	December	5,997,643	5,158	21,721	14,379	189,440	1,629	21,166	2,478,109	0.0085
	TOTAL	79,913,894	68,726	244,227	161,678	3,079,366	26,483	256,887	31,909,534	0.0969
	Average	6,709,527	5,770	20,007	13,245	268,330	2,308	21,322	2,658,916	0.0080

Table B.5: Energy requirement of dyeing process

		Dyed Yarn (kg)	Steam Requirement (tone)	Steam Requirement (Gcal)	Electricity Requirement (kWh)	Electricity Requirement (Gcal)	Total Energy Requirement (Gcal)	Specific Energy Requirement (Gcal/kg yarn)
2006	**January**	867,000	5,121	3,390	297,641	256	3,646	0.0042
	February	974,051	5,574	3,690	310,007	267	3,957	0.0041
	March	1,171,087	9,372	6,204	340,697	293	6,497	0.0055
	April	1,070,213	6,022	3,987	325,877	280	4,267	0.0040
	May	1,189,832	5,952	3,940	342,909	295	4,235	0.0036
	June	1,206,885	5,231	3,463	342,783	295	3,758	0.0031
	July	1,263,283	4,316	2,857	351,043	302	3,159	0.0025
	August	1,276,925	4,608	3,050	351,592	302	3,353	0.0026
	September	1,386,960	4,462	2,954	371,204	319	3,273	0.0024
	October	1,357,105	4,531	3,000	361,634	311	3,311	0.0024
	November	1,430,204	3,977	2,633	383,272	330	2,962	0.0021
	December	1,450,418	5,460	3,615	328	3,943	0.0027	
	TOTAL	14,625,964	64,626	42,782	4,280,161	3,578	46,360	0.0392
	Monthly Average	1,220,330	5,386	3,565	346,696	298	3,863	0.0033
2007	**January**	1,335,000	4,932	3,265	370,186	318	3,583	0.0027
	February	1,275,109	5,365	3,552	347,746	299	3,851	0.0030
	March	1,515,686	5,807	3,844	368,027	317	4,161	0.0027
	April	1,546,704	5,980	3,959	385,436	331	4,290	0.0028
	May	1,736,500	5,739	3,799	408,531	351	4,151	0.0024
	June	1,625,900	5,186	3,433	408,624	351	3,785	0.0023
	July	1,494,500	4,687	3,103	399,826	344	3,447	0.0023
	August	1,341,300	4,636	3,069	380,376	327	3,396	0.0025
	September	1,397,600	5,176	3,427	380,647	327	3,754	0.0027
	October	1,350,200	5,069	3,356	368,776	317	3,673	0.0027
	November	1,442,414	6,001	3,973	390,207	336	4,308	0.0030
	December	1,298,259	0	0	343,921	296	296	0.0002
	TOTAL	17,359,172	58,578	38,779	4,552,302	3,915	42,694	0.0294
	Monthly Average	1,446,598	4,882	3,232	379,358	326	3,558	0.0024

Table B.6: Energy requirement in finishing process

		Steam		Electricity		Natural Gas		Total
		(Tone)	**(Gcal)**	**(kWh)**	**(Gcal)**	**(Sm^3)**	**(Gcal)**	**(Gcal)**
2006	**January**	8,996	5,955	188,434	162	134,961	1,161	7,278
	February	9,923	6,569	226,568	195	114,557	985	7,749
	March	8,054	5,332	265,523	228	108,819	936	6,496
	April	7,018	4,646	265,523	228	113,066	972	5,847
	May	5,748	3,805	222,803	192	141,186	1,214	5,211
	June	7,138	4,725	258,001	222	170,622	1,467	6,414
	July	8,070	5,342	245,771	211	198,224	1,705	7,258
	August	8,222	5,443	276,412	238	150,333	1,293	6,973
	September	10,515	6,961	250,589	216	189,770	1,632	8,808
	October	8,851	5,859	342,875	295	149,662	1,287	7,441
	November	11,618	7,691	367,338	316	230,902	1,986	9,993
	December	10,596	7,015	386,243	332	184,699	1,588	8,935
	TOTAL	104,748	69,343	3,296,081	2,835	1,886,801	16,226	88,404
	Average	8,729	5,779	274,673	236	157,233	1,352	7,367
2007	**January**	11,625	7,696	362,258	312	234,058	2,013	10,020
	February	10,789	7,142	356,834	307	173,489	1,492	8,941
	March	10,755	7,120	351,818	303	143,978	1,238	8,661
	April	10,773	7,132	380,757	327	165,494	1,423	8,883
	May	11,099	7,347	419,677	361	270,199	2,324	10,032
	June	9,123	6,039	314,902	271	371,742	3,197	9,507
	July	8,809	5,832	293,561	252	409,526	3,522	9,606
	August	8,927	5,910	362,531	312	441,745	3,799	10,020
	September	9,058	5,996	329,100	283	222,578	1,914	8,194
	October	9,524	6,305	324,660	279	232,250	1,997	8,581
	November	10,462	6,926	320,558	276	204,827	1,762	8,963
	December	10,738	7,109	308,875	266	187,580	1,613	8,987
	TOTAL	121,682	80,553	4,125,530	3,548	3,057,466	26,294	110,395
	Average	10,140	6,713	343,794	296	254,789	2,191	9,200

Table B.7: Energy requirement in Machine 1

		Steam		Electricity		Natural Gas		Total Energy	Specific Energy Requirement
		(Tone)	(Gcal)	(kWh)	(Gcal)	(Sm^3)	(Gcal)	(Gcal)	(Gcal/kg fabric)
2006	January	1,068 707	27,330	24	35,090	302	1,032	0.0015	
	February	748	495	23,033	20	29,785	256	771	0.0014
	March	1,502	994	27,217	23	28,293	243	1,261	0.0019
	April	1,430	947	27,217	23	29,397	253	1,223	0.0021
	May	892	590	27,471	24	36,708	316	929	0.0011
	June	697	461	36,562	31	44,362	382	874	0.0010
	July	542	359	37,199	32	51,538	443	834	0.0011
	August	565	374	38,208	33	39,087	336	743	0.0010
	September	593	393	16,313	14	49,340	424	831	0.0010
	October	704	466	14,210	12	41,081	353	832	0.0010
	November	796	527	36,238	31	63,381	545	1,103	0.0012
	December	784	519	26,920	23	50,699	436	978	0.0009
	TOTAL	10,322	6,833	337,919	291	498,761	4,289	11,413	0.0151
	Average	860	569	28,160	24	41,563	357	951	0.0013
2007	January	911	603	32,908	28	60,855	523	1,155	0.0010
	February	846	560	32,476	28	45,107	388	976	0.0008
	March	936	620	36,713	32	37,434	322	973	0.0008
	April	744	492	41,510	36	43,028	370	898	0.0006
	May	637	422	49,453	43	70,252	604	1,068	0.0007
	June	626	414	35,136	30	96,653	831	1,276	0.0009
	July	677	448	0	0	106,477	916	1,364	0.0011
	August	697	461	7,118	6	114,854	988	1,455	0.0013
	September	668	442	43,047	37	57,870	498	977	0.0007
	October	753	498	40,065	34	60,385	519	1,052	0.0008
	November	788	522	46,586	40	53,255	458	1,020	0.0007
	December	650	430	33,394	29	48,771	419	878	0.0008
	TOTAL	8,933	5,914	398,406	343	794,941	6,836	13,093	0.0103
	Average	744	493	33,201	29	66,245	570	1,091	0.0009

Table B.8: Energy requirement in Machine 2

		Steam		**Electricity**		**Natural Gas**		**Total Energy**	**Specific Energy Requirement**
		(Tone)	**(Gcal)**	**(kWh)**	**(Gcal)**	**($S\,m^3$)**	**(Gcal)**	**(Gcal)**	**(Gcal/kg fabric)**
2006	**January**	906	600	6,225	5	10,797	93	698	0.0036
	February	1,943	1,286	13,350	11	9,165	79	1,377	0.0038
	March	909	602	9,750	8	8,706	75	685	0.0015
	April	853	565	9,750	8	9,045	78	651	0.0020
	May	568	376	9,150	8	11,295	97	481	0.0021
	June	986	653	6,525	6	13,650	117	776	0.0028
	July	1,312	869	11,325	10	15,858	136	1,015	0.0029
	August	772	511	15,075	13	12,027	103	627	0.0030
	September	1,581	1,047	4,275	4	15,182	131	1,181	0.0031
	October	771	511	12,300	11	3,160	27	548	0.0022
	November	1,151	762	8,025	7	4,875	42	811	0.0026
	December	1,872	1,239	13,050	11	3,900	34	1,284	0.0043
	TOTAL	13,624	9,019	118,800	102	117,659	1,012	10,133	0.0339
	Average	1,135	752	9,900	9	9,805	84	844	0.0028
2007	**January**	2,335	1,546	16,275	14	4,681	40	1,600	0.0044
	February	1,915	1,268	13,350	11	3,470	30	1,309	0.0044
	March	1,937	1,282	13,500	12	2,880	25	1,318	0.0044
	April	685	453	12,720	11	3,310	28	493	0.0038
	May	1,339	887	12,720	11	5,404	46	944	0.0085
	June	1,156	765	900	1	7,435	64	830	0.0045
	July	1,315	871	11,250	10	8,191	70	951	0.0036
	August	1,412	935	52,800	45	8,835	76	1,056	0.0026
	September	847	561	7,425	6	4,452	38	605	0.0022
	October	1,335	884	11,700	10	4,645	40	934	0.0033
	November	916	606	8,025	7	4,097	35	649	0.0019
	December	2,200	1,456	19,275	17	3,752	32	1,505	0.0035
	TOTAL	17,391	11,513	179,940	155	61,149	526	12,194	0.0471
	Average	1,449	959	14,995	13	5,096	44	1,016	0.0039

Table B.9: Energy requirement in Machine 3

		Steam		Electricity		Total Energy	Specific Energy Requirement
		(Tone)	(Gcal)	(kWh)	(Gcal)	(Gcal)	(Gcal/kg fabric)
2006	**January**	725	480	12,780	11	491	0.0042
	February	140	93	19,170	16	109	0.0006
	March	398	263	18,815	16	280	0.0016
	April	236	156	18,815	16	172	0.0011
	May	205	135	13,135	11	147	0.0016
	June	240	159	8,520	7	166	0.0017
	July	353	233	10,118	9	242	0.0017
	August	149	99	14,555	13	111	0.0002
	September	401	265	6,568	6	271	0.0016
	October	205	136	15,088	13	149	0.0018
	November	1,983	1,313	23,075	20	1,333	0.0065
	December	652	432	37,808	33	464	0.0013
	TOTAL	5,686	3,764	198,445	171	3,935	0.0237
	Average	474	314	16,537	14	328	0.0016
2007	**January**	951	629	44,020	38	667	0.0014
	February	596	395	34,080	29	424	0.0013
	March	469	310	30,175	26	336	0.0011
	April	806	533	51,830	45	578	0.0011
	May	1,532	1,014	99,223	85	1,100	0.0013
	June	414	274	29,998	26	300	0.0007
	July	277	183	14,023	12	195	0.0011
	August	221	146	11,005	9	156	0.0010
	September	150	99	10,473	9	108	0.0009
	October	155	103	10,828	9	112	0.0008
	November	320	212	12,603	11	223	0.0017
	December	498	330	16,863	15	344	0.0018
	TOTAL	6,389	4,229	365,118	314	4,543	0.0141
	Average	532	352	30,426	26	379	0.0012

Table B.10: Energy requirement in Machine 4

		Steam		Electricity		Natural Gas		Total	Specific Energy
							Energy	Requirement	
		(Tone)	(Gcal)	(kWh)	(Gcal)	(Sm^3)	(Gcal)	(Gcal)	(Gcal/kg fabric)
2006	**January**	1,938	1,283	12,254	11	16,195	139	1,433	0.0120
	February	1,832	1,213	13,414	12	13,747	118	1,343	0.0111
	March	787	521	17,222	15	13,058	112	648	0.0012
	April	293	194	17,222	15	13,568	117	325	0.0005
	May	206	136	7,783	7	16,942	146	289	0.0033
	June	205	136	8,694	7	20,475	176	319	0.0040
	July	230	152	7,618	7	23,787	205	363	0.0048
	August	642	425	8,860	8	18,040	155	588	0.0021
	September	1,288	853	18,878	16	22,772	196	1,065	0.0028
	October	979	648	26,082	22	18,961	163	833	0.0019
	November	1,448	959	43,139	37	29,253	252	1,247	0.0021
	December	1,254	830	39,910	34	23,399	201	1,066	0.0020
	TOTAL	11,101	7,349	221,076	190	230,197	1,980	9,519	0.0478
	Average	925	612	18,423	16	19,183	165	793	0.0040
2007	**January**	1,667	1,104	42,228	36	28,087	242	1,381	0.0023
	February	1,932	1,279	47,113	41	20,819	179	1,499	0.0020
	March	1,665	1,102	54,648	47	17,277	149	1,298	0.0015
	April	2,735	1,811	54,400	47	19,859	171	2,028	0.0022
	May	1,616	1,070	248	0	32,424	279	1,349	0.0013
	June	1,439	953	42,311	36	44,609	384	1,373	0.0017
	July	764	506	31,133	27	49,143	423	955	0.0018
	August	939	622	45,292	39	53,009	456	1,116	0.0018
	September	1,638	1,084	46,451	40	26,709	230	1,354	0.0020
	October	1,630	1,079	53,240	46	27,870	240	1,365	0.0015
	November	1,935	1,281	37,591	32	24,579	211	1,525	0.0023
	December	1,368	906	38,254	33	22,510	194	1,132	0.0021
	TOTAL	19,329	12,796	492,908	424	366,896	3,155	16,375	0.0224
	Average	1,611	1,066	41,076	35	30,575	263	1,365	0.0019

Table B.11: Energy requirement in Machine 5

		Steam		Electricity		Total Energy	Specific Energy Requirement
		(Tone)	(Gcal)	(kWh)	(Gcal)	(Gcal)	(Gcal/kg fabric)
2006	**January**	262	173	10,096	9	182	0.0004
	February	1,198	793	12,546	11	804	0.0015
	March	496	328	13,866	12	340	0.0005
	April	218	144	13,866	12	156	0.0003
	May	13	9	11,225	10	18	0.0000
	June	739	489	12,780	11	500	0.0008
	July	1,063	704	13,291	11	715	0.0013
	August	988	654	13,376	12	665	0.0014
	September	1,234	817	13,760	12	829	0.0013
	October	1,132	749	15,208	13	762	0.0013
	November	1,185	784	15,123	13	797	0.0011
	December	1,270	841	15,336	13	854	0.0014
	TOTAL	9,798	6,486	160,474	138	6,624	0.0114
	Average	817	541	13,373	12	552	0.0009
2007	**January**	683	452	13,802	12	464	0.0007
	February	662	438	13,376	12	450	0.0008
	March	762	505	15,400	13	518	0.0008
	April	732	485	13,973	12	497	0.0008
	May	745	493	0	0	493	0.0007
	June	680	450	12,674	11	461	0.0007
	July	787	521	14,676	13	534	0.0008
	August	804	532	13,717	12	544	0.0009
	September	739	489	13,781	12	501	0.0007
	October	779	516	14,527	12	528	0.0008
	November	901	596	14,931	13	609	0.0009
	December	799	529	13,249	11	540	0.0009
	TOTAL	9,074	6,007	154,106	133	6,139	0.0094
	Average	756	501	12,842	11	512	0.0008

Table B.12: Energy requirement in Machine 6

		Steam		Electricity		Natural Gas		Total Energy	Specific Energy Requirement
		(Tone)	(Gcal)	(kWh)	(Gcal)	($S\,m^3$)	(Gcal)	(Gcal)	(Gcal/kg fabric)
2006	**January**	2,155	1,427	25,887	22	28,342	244	1,693	0.0020
	February	2,308	1,528	29,331	25	24,057	207	1,760	0.0020
	March	2,264	1,499	31,685	27	22,852	197	1,723	0.0017
	April	2,181	1,444	31,685	27	23,744	204	1,675	0.0017
	May	2,070	1,370	17,220	15	29,649	255	1,640	0.0018
	June	2,247	1,487	42,132	36	35,831	308	1,832	0.0019
	July	2,366	1,567	31,455	27	41,627	358	1,952	0.0019
	August	2,850	1,887	33,120	28	31,570	272	2,187	0.0020
	September	2,688	1,780	35,818	31	39,852	343	2,153	0.0019
	October	2,483	1,643	36,679	32	33,181	285	1,960	0.0019
	November	2,644	1,750	36,392	31	51,192	440	2,222	0.0020
	December	2,476	1,639	37,310	32	40,949	352	2,023	0.0019
	TOTAL	28,732	19,020	388,713	334	402,845	3,464	22,819	0.0227
	Average	2,394	1,585	32,393	28	33,570	289	1,902	0.0019
2007	**January**	2,493	1,651	33,923	29	49,152	423	2,102	0.0018
	February	2,146	1,421	32,144	28	36,433	313	1,762	0.0018
	March	2,323	1,538	33,349	29	30,235	260	1,827	0.0018
	April	2,607	1,726	35,473	31	34,754	299	2,055	0.0019
	May	2,766	1,831	42,993	37	56,742	488	2,356	0.0020
	June	2,515	1,665	29,963	26	78,066	671	2,362	0.0022
	July	2,625	1,738	32,201	28	86,000	740	2,505	0.0025
	August	2,462	1,630	36,506	31	92,766	798	2,459	0.0025
	September	2,580	1,708	32,144	28	46,741	402	2,138	0.0021
	October	2,503	1,657	34,038	29	48,773	419	2,106	0.0021
	November	2,432	1,610	37,023	32	43,014	370	2,012	0.0018
	December	2,165	1,433	31,742	27	39,392	339	1,799	0.0018
	TOTAL	29,618	19,607	411,501	354	642,068	5,522	25,483	0.0243
	Average	2,468	1,634	34,292	29	53,506	460	2,124	0.0020

Table B.13: Energy requirement in Machine 7

		Steam		**Electricity**		**Natural Gas**		**Total Energy**	**Specific Energy Requirement**
		(Tone)	**(Gcal)**	**(kWh)**	**(Gcal)**	**($S\,m^3$)**	**(Gcal)**	**(Gcal)**	**(Gcal/kg fabric)**
2006	**January**	1,043	690	23,443	20	0	0	711	0.0011
	February	913	604	20,602	18	0	0	622	0.0011
	March	919	608	24,982	21	0	0	630	0.0009
	April	878	581	24,982	21	0	0	603	0.0008
	May	832	551	24,331	21	0	0	572	0.0008
	June	1,092	723	25,515	22	0	0	745	0.0010
	July	1,267	839	27,114	23	0	0	862	0.0012
	August	1,325	877	25,574	22	0	0	899	0.0011
	September	1,788	1,184	30,784	26	0	0	1,210	0.0013
	October	1,607	1,064	34,987	30	9,480	82	1,175	0.0012
	November	1,471	974	35,638	31	14,626	126	1,130	0.0011
	December	1,335	884	33,093	28	11,700	101	1,013	0.0012
	TOTAL	14,470	9,579	331,046	285	35,806	308	10,172	0.0127
	Average	1,206	798	27,587	24	2,984	26	848	0.0011
2007	**January**	1,607	1,064	30,843	27	14,055	121	1,211	0.0013
	February	1,728	1,144	32,501	28	10,417	90	1,261	0.0014
	March	1,688	1,117	35,461	30	8,639	74	1,222	0.0012
	April	1,522	1,007	34,395	30	9,917	85	1,122	0.0011
	May	1,487	985	40,493	35	16,222	139	1,159	0.0011
	June	1,355	897	29,718	26	22,305	192	1,114	0.0011
	July	1,393	922	32,856	28	24,583	211	1,162	0.0011
	August	1,421	941	35,461	30	26,500	228	1,199	0.0011
	September	1,358	899	29,067	25	13,361	115	1,039	0.0007
	October	1,421	941	36,349	31	13,944	120	1,092	0.0009
	November	2,216	1,467	34,218	29	12,290	106	1,602	0.0010
	December	2,118	1,402	31,376	27	11,255	97	1,526	0.0011
	TOTAL	19,315	12,786	402,738	346	183,487	1,578	14,710	0.0131
	Average	1,610	1,066	33,561	29	15,291	131	1,226	0.0011

Table B.14: Energy requirement in Machine 8

		Steam		Electricity		Total Energy	Specific Energy Requirement
		(Tone)	**(Gcal)**	**(kWh)**	**(Gcal)**	**(Gcal)**	**(Gcal/kg fabric)**
2006	**January**	899	595	10,019	9	604	0.0011
	February	841	557	12,482	11	567	0.0009
	March	779	516	13,165	11	527	0.0007
	April	929	615	13,165	11	626	0.0009
	May	963	637	12,068	10	648	0.0010
	June	932	617	12,151	10	628	0.0010
	July	937	620	12,379	11	631	0.0009
	August	930	616	13,414	12	627	0.0008
	September	941	623	14,221	12	635	0.0008
	October	970	642	15,111	13	655	0.0009
	November	940	622	14,159	12	634	0.0008
	December	953	631	15,111	13	644	0.0009
	TOTAL	11,015	7,292	157,444	135	7,427	0.0107
	Average	918	608	13,120	11	619	0.0009
2007	**January**	977	647	13,207	11	658	0.0008
	February	963	638	1,304	1	639	0.0009
	March	976	646	1,304	1	647	0.0009
	April	943	624	1,346	1	625	0.0009
	May	975	646	1,635	1	647	0.0008
	June	938	621	1,221	1	622	0.0008
	July	971	643	14,324	12	655	0.0008
	August	971	643	12,151	10	653	0.0009
	September	1,078	714	1,366	1	715	0.0009
	October	948	628	14,117	12	640	0.0008
	November	954	631	1,449	1	632	0.0007
	December	940	622	1,325	1	623	0.0008
	TOTAL	11,634	7,702	64,750	56	7,757	0.0101
	Average	970	642	5,396	5	646	0.0008

Table B.15: Energy requirement in Machine 9

		Electricity		Natural Gas		Total Energy	Specific Energy Requirement
		(kWh)	(Gcal)	(Sm^3)	(Gcal)	(Gcal)	(Gcal/kg fabric)
2006	January	60,399	52	44,537	383	435	0.0013
	February	82,640	71	37,804	325	396	0.0008
	March	108,820	94	35,910	309	402	0.0006
	April	108,820	94	37,312	321	414	0.0006
	May	100,419	86	46,591	401	487	0.0008
	June	105,122	90	56,305	484	575	0.0008
	July	95,274	82	65,414	563	644	0.0011
	August	114,231	98	49,610	427	525	0.0007
	September	109,973	95	62,624	539	633	0.0007
	October	173,211	149	52,142	448	597	0.0007
	November	155,549	134	80,445	692	826	0.0007
	December	167,706	144	64,348	553	698	0.0006
	TOTAL	1,382,163	1,189	633,043	5,444	6,633	0.0093
	Average	115,180	99	52,754	454	553	0.0008
2007	January	135,052	116	77,239	664	780	0.0006
	February	150,489	129	57,251	492	622	0.0006
	March	131,268	113	47,513	409	522	0.0004
	April	135,111	116	54,613	470	586	0.0005
	May	172,912	149	89,166	767	916	0.0007
	June	132,982	114	122,675	1,055	1,169	0.0008
	July	143,098	123	135,144	1,162	1,285	0.0007
	August	148,481	128	145,776	1,254	1,381	0.0010
	September	145,346	125	73,451	632	757	0.0004
	October	109,796	94	76,643	659	754	0.0005
	November	128,132	110	67,593	581	691	0.0005
	December	123,398	106	61,901	532	638	0.0007
	TOTAL	1,656,064	1,424	1,008,964	8,677	10,101	0.0074
	Average	138,005	119	84,080	723	842	0.0006