Energy Usage and Conservation in Surfacing Lines

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Abstract

This paper deals with energy usage and conservation for a surfacing line in a carpentry factory. In this line, wood panels are coated with paint in a highly automated fashion. The products vary in shapes, and the way they shall be coated, and therefore a number of machines are present in the line which is of about a 100 m length. Sanding machines, roller coaters, dryers etc. are installed and all machinery use electricity for their operation. There are, however, other equipment coupled to the line. One example is the wood dust transportation system, another is the steam system used for heating purposes. By use of a number of electricity meters, monitoring ventilation flow rates etc. it has been possible to analyze how much energy that is used in the surfacing line and also to propose measures to reduce this amount.

INTRODUCTION

The carpentry industry in Sweden is seldom subject of academic interest. To a part this is the result of a very low number of employees with an academic background. The Employers' Association of the Swedish Wood-Products Industry, ARBIO, wanted to change this state of things and 1992 they financed part of a new division at our institute which educates students and post graduates in wood technology. Among the other divisions one deals with energy systems and, therefore, it was natural to start investigations of such systems within carpentry factories. The first study dealt with a factory for staircases and the main result was that about 25 % of the electricity cost could be avoided if the machinery were operated in an artful way, Reference [1]. The latest studies, References [2] and [3] deal with a small furniture factory where different equipment are examined in order to find suitable load management measures.

CASE STUDY

This paper deals with Totebo Ltd. which manufactures furniture for the Swedish and European market. One of their largest customers is IKEA but other companies are represented as well, such as Martela Morgana and Kinnarps. The factory is sited in a small village, Totebo, about 350 km south of Stockholm. It was established 1911 and has now about 150 employees. The reason for choosing Totebo for siting the company, was a small river or stream where it was possible to find power for the wood working equipment. Still, the stream is utilized in the form of a small hydro power station where part of the electricity is produced. Nowadays, this stream cannot provide but a small part of the electricity and the company therefore bought about 4.5 GWh electricity from Sydkraft Ltd. The cost for this was about 2 MSEK for 1997. A duration graph, i. e. the electricity use each hour has been sorted due to its magnitude, is presented in Figure 1.

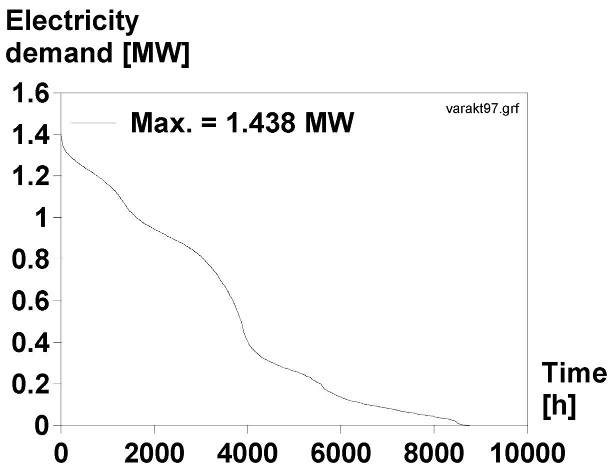

Figure 1: Purchased electricity by Totebo Ltd. in the form of a duration graph, 1997.

THE SURFACING LINE

At Totebo Ltd. book shelves, tables, cabinets and so on are manufactured. These products consist of a number of different panels which must be "painted". Some times only clear lacquer is used while pigmented paint is used otherwise. Other products are stained and then lacquer is applied. A panel finishing line must be able to provide all these treatments. Because of environmental reasons the clear lacquer used is of a UV-setting type, i. e. light in the ultra-violet wavelength is used for polymerization. When a pigmented lacquer is used the pigment prevents the setting process and therefore ordinary drying must be applied.

Sanding machine

The line, however, starts with a sanding machine, type Tagliabue T122, where the surfaces of the panels are treated. The sanding machine has to be coupled not only to the electricity grid but also to the wood dust transportation and the compressed air systems, see Figure 2.

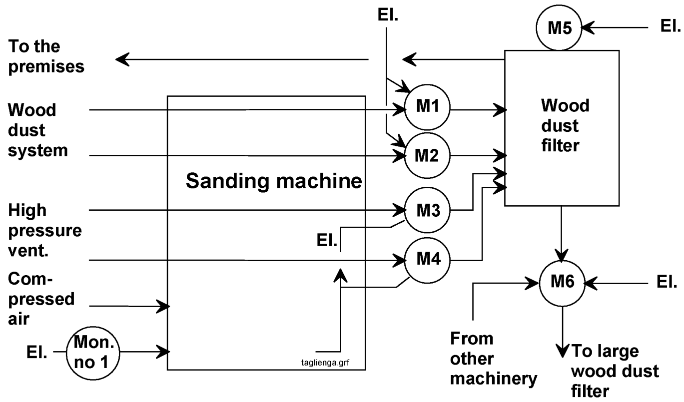

Figure 2: Principal view of a sanding machine.

The transportation system use an air stream as a working fluid. This air stream is provided by two fans driven by the motors M1 and M2 in Figure 2. When the motors operate they use a current, I, of about 33 A respectively. Using

$$P = V \times I \times cos\varphi \times 3^{0.5} \ ,$$

see Reference [4] page 252, where V equals 400 V and $cos\varphi$ equals 0.9, this lead to demands of about 20 kW, which also was monitored in our Watt meter. The motors, therefore, operate in a proper way.

The air used for transportation comes from the premises, passes through the sanding machine, the fans and the filter and is during winter time led back to the factory. This in order to save some energy. During winter the returning air naturally will be somewhat colder than the indoor factory temperature because the pipes and the filter located outdoors are uninsulated. This is however, assumed to be of minor importance compared to other heat losses. The air velocity in the pipes is supposed to be 20 - 25 m/s and our monitoring showed that about 30 m/s is present in the three pipes with a diameter of 0.4, 0.4 and 0.2 m respectively. Information from the manufacturers representative says that the sanding machine should use about 15,000 m^3/h but here about 30,000 m^3/h was monitored.

There is also a so called high pressure ventilation system. This is used for keeping the panels steady during the sanding process by use of vacuum. The two motors M3 and M4 gets their current via the electricity meter, Mon. no 1 in Figure 2. The motors are marked 9.2 kW but instead the demand was only 5.0 and 3.4 kW respectively. They are therefore not used efficiently. The air becomes polluted with wood dust and therefore it is led to the filter and the flow has been measured to about 1,600 m^3/h which is slightly less than the flow recommended by the manufacturer, 2,000 m^3/h.

Motor M5, size about 1 kW, drives a screw for the filtered saw dust. The actual need was only 0.26 kW, $cos\varphi = 0.26$, while motor M6, size 37 kW, operates a big fan which via air transports the dust to another large filter. The M6 motor had a real demand of 15.2 kW. M6 is, however, used also for other machines than the Tagliabue. The air flow between the fan coupled to M6 transports wood dust from the sanding machine filter and a large filter on the roof of the factory. This air stream, monitored to 1,700 m^3/h use outdoor air. We have also monitored $cos\varphi$ for the sanding machine as a total and found it to be 0.49. The motors inside the machine therefore seems to be too big compared to the actual need. The electricity used for the sanding machine has been monitored by use of a modern electricity meter which sends pulses to a computer where they are stored each minute. In Figure 3 the electricity use is shown for eight hours starting 00.00 June 29, 1998.

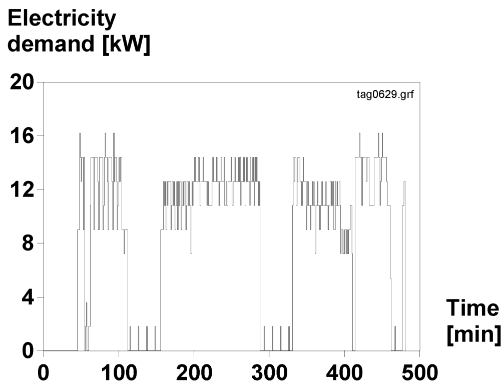

Figure 3: Electricity demand by the Tagliabue sanding machine. Based on minutes.

The maximum demand for the machine was monitored to 16.2 kW. The project started in spring 1998 and now it is possible to show graphs for one full year, from May 31, 1998 to May 30, 1999. The electricity consumption via meter no. 1 in the sanding machine is shown in Figure 4.

It must be noted here that our monitoring system was out of order for two periods, about 10 days in September 1998 and 9 days in February 1999. The missing values have been replaced by values from the same type of days in later weeks. There were also other periods when the system malfunctioned but they were much shorter. Therefore, values for about 500 hours, out of 8,760, have been copied and added to the original data file. The monitored annual electricity consumption in the sanding machine, therefore, adds up to 24.3 MWh. There are also the motors which are not registered by the meter. The power demand has been monitored to about 56 kW which is used whenever the sanding machine operates. Motor number M6 has been included here even though it is used for other equipment as well. During the monitored year the sanding machine was used 3,686 hours according to the electricity meter. The motors, therefore, use about 206.4 MWh for one year and the total sanding process in the Tagliabue

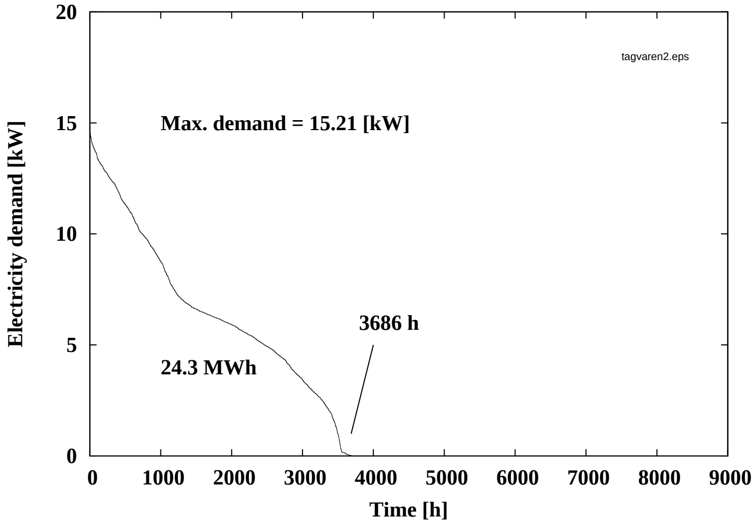

Figure 4: Electricity consumption in the sanding machine for one full year. Based on hours.

machine 230.7 MWh. The fact that the air stream which originates from the inside of the premises is lead back into the building makes it difficult to save more energy in the form of heat in a profitable way. As is shown later in this paper, heat is produced by fireing wood chips to a cost of approximately 0.05 SEK/kWh. (One US $ equals about 9 SEK.) Some of the motors in the sanding machine operate with a low efficiency but it is not cheap to rebuild the machine in order to improve the situation. Hence, profitable energy conservation does not seem to be possible for this machine.

A compressed air system is used for blowing dust away from the panels. This system is coupled also to other processes in the factory and is therefore not dealt with in detail here.

Staining machines

The second machine in the line is a so called staining machine, type Bürkle CAL/B1300. The pigmented stain is applied by a soft moos rubber roller. Even if no stain is applied the machine at least to a part must operate just for transportation of the panels. The electricity use in the machine is relatively low and during our monitoring period the highest value was 0.65 kW. The electricity used in June 1998 added up to 106 kWh or about 1.2 MWh each year. Because of the relatively low electricity demand no duration graph for the full year is presented.

A roller coater, type Bürkle DAL also used for staining, comes next in the process. The finishing line includes ten machines of similar construction and one of them has been monitored by use of an electricity meter. The other nine machines are used for applying UV-lacquer and UV-sealing. The electricity meter never registered a higher demand than 0.9 kW in this type of machine. Some of these roller coater machines have ventilation hubs but none of them were operating during the studied period. The motors coupled to the hub fans are relatively small, about 0.3 kW. The electricity use in one DAL machine has been monitored to 151 kWh for June and, hence, 1.6 MWh is assumed to be used for one full year.

Between all the machines there are roller conveyors. The monitored total electricity demand for all such conveyors was about 2.2 kW according to our electricity meter and for June 632 kWh were registered. The annual use is therefore expected to be 6.7 MWh. The electricity amount used in the roller coaters and conveyors is too small if profitable reconstruction is considered. They should therefore be left as they are.

After staining the panels must be dried. This is achieved in a jet air drying tunnel, type Finnrose Fodo-10-1. The heat is provided in the form of steam from the wood chip fired boiler. A fan provides the necessary air stream through the jet nozzles. Some 7,000 m^3/h, according to the manufacturer's representative, circulates and about 1,000 m^3/h of the air should be vented to the outside of the factory, see Figure 5.

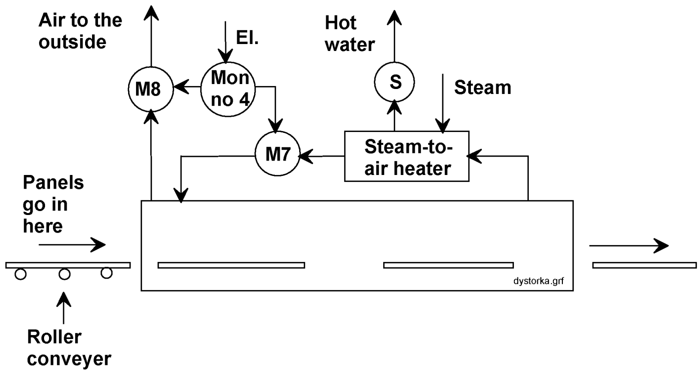

Figure 5: Jet air drying tunnel.

The air stream led to the outside has been monitored by use of a so called wing anemometer and the capacity was found to be 1,350 m^3/h, i. e. slightly more than expected. The temperature inside the dryer is about 70 °C and subsequently this is also the temperature of the air led to the outside. One problem here is to monitor the heat provided by the steam. Steam flow meters are expensive and they are difficult to install in an existing system. Instead, the weigh bucket method in Reference [5] page 181, has been used. The inlet steam temperature, 146 °C, and the outgoing water temperature, 97 °C, have been monitored. The steam trap, S in Figure 5, therefore seems to operate properly.

The hot water is led to a basin in the basement of the factory where from it is pumped into the boiler. By disconnecting the pipe it was possible to measure the amount of water passing the steam trap which was 950 ml/minute or 57 l/h, June 17, 1998. Steam with a temperature of 146 °C has an enthalpy of 2.12 $\times$ 106 J/kg, see Reference [6] page 837. Some calculations revealed that the demand was about 33 kW. Information from the manufacturer shows a maximum demand of 60,000 kCal/h which equals about 70 kW and hence about half of the available capacity was used. Two fans operate by use of the motors M7 and M8 in Figure 5 with a marked demand of 10 and 1 kW respectively. The electricity consumption has been monitored by meter no. 4. The dryer is only in use when stained products pass. The conveyers, however, must operate whenever any type of panels are treated. In Figure 6, values from the electricity meter are shown.

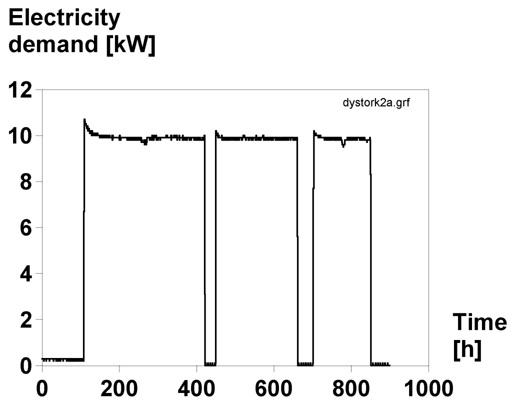

Figure 6: Electricity consumption in the jet air dryer during 15 hours, June 29 1998.

From Figure 6 it is obvious that the demand is about 10 kW when the dryer is in operation. When only the roller conveyer is used, about 0.3 kW is used while the maximum need is about 10.7 kW. The motors in the dryer therefore seem to be of proper sizes. For the period May 31, 1998 to May 31, 1999, 5,979 kWh was used, see Figure 7.

The precise annual use of steam is not known but for the period the electricity meter registered higher loads than 1 kW for 630 hours. It is assumed that the steam system was used for that number of hours also. Above it was shown that about 30 kW were utilized which also is assumed to be constant when the dryer is used. The need for steam adds up to 18,900 kWh for a full year. Because of the low cost for heat only about 1,000 SEK each year could be saved. The pay back period seems to be at least five years if all the heat from the dryer is utilized e. g. for heating domestic hot water.

There is also a dryer, heated by infrared light, type Finnrose IRM10. IRM stands for medium wave infrared light, i. e. a wavelength of 2.3 to 3.4 μm. The electricity use has been monitored in our fifth meter. During the studied period this machine was only used as a transportation device and thus used only about 0.2 kW. One short test showed that about 6.5 kW was needed if the dryer was in full operation. The ventilation pipes were disconnected from the dryer and therefore it is assumed that this machine is not used as a dryer at all. The electricity consumption was only 572 kWh for one full year.

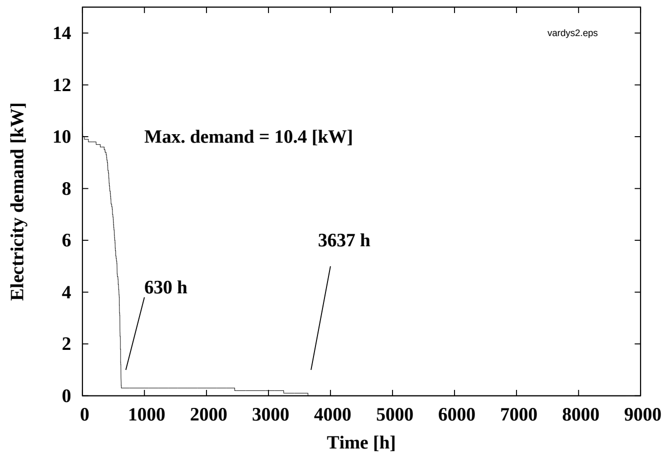

Figure 7: Electricity consumption in the air jet dryer for one full year.

Sealing machine

The next process is a UV sealing machine, type Bürkle SAS 1300. The sealer is cured by a so called UV-oven where light of a specific wavelength is used for polymerization. This, and two other UV-ovens, type Superfici, use electricity with a demand shown in Figure 8.

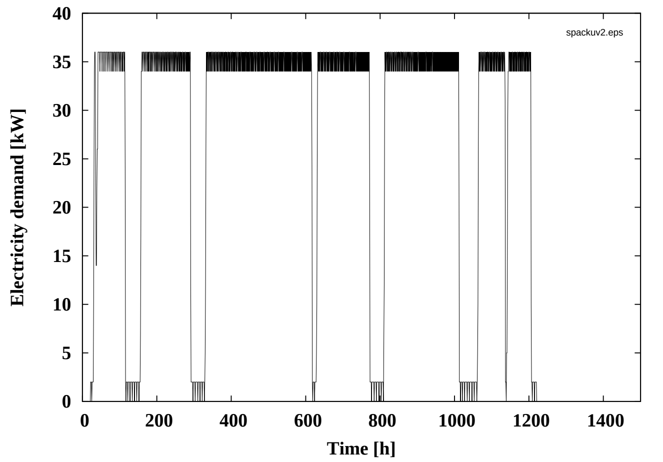

Figure 8: Electricity consumption in three UV-ovens, June 29, 1998.

Two UV-lamps are implemented in sequence and each device is ventilated by use of a small electric motor and a fan. The meter, however, also registers a third such oven located after the first base coating machine. Information from the manufacturer shows that UV-lamps demand about 10 kW/m length of the lamp, a value which is confirmed by our measurements, see Figure 9 where 37.5 kW is used as a maximum.

Each lamp is about 1.3 m. The sealing machine had an electricity use of 227

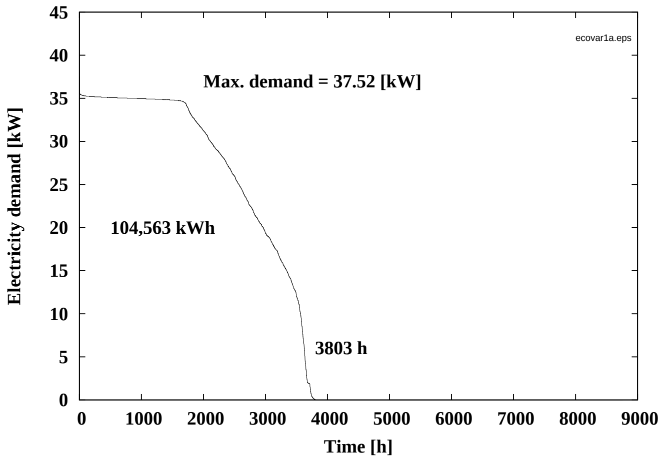

Figure 9: Electricity consumption in three UV-ovens for one full year.

kWh for June which add up to 2.5 MWh each year. The three UV-ovens used 104.6 MWh and about 2/3 of the use here, is coupled to the sealing process or 69.7 MWh, see Figure 9.

There are also one motor running a fan in each UV-oven. It is assumed that this motor of about 1 kW, likewise, operates 3,803 hours each year resulting in 7.6 MWh for one full year and two motors. The sealing process therefore needs 79.8 MWh each year.

The air velocity inside the pipes was monitored to about 5.8 m/s, which leads to 1,100 m^3/h, respectively. It should be noted here that when the lamps start to operate, the hazardous gas ozone is emitted. The contaminated air, with a temperature of about 50 °C, must therefore be led to the outside. The UV-ovens use a considerable amount of electricity but it is not easy to find an alternative. The warm air stream, 8.2 Mm^3 each year, has a considerable monetary value but the problem is to find a way to utilize it.

Infrared dryer number 2

An infrared dryer, type Finnrose 8.0 IRM 3.25/1.5, is after this implemented in the line. The electricity demand in this dryer is about 21 kW, see Figure 10.

Also this IR-dryer were used very little, during our monitoring period only 280 hours during one year, see Figure 11.

Ventilation pipes are coupled to the machine. One of the pipes leads cold air from the outside to the machine while the other transports warm air from the machine to outdoors. The ventilation monitoring showed that about 8,100 m^3/h was led into the machine while only 3,200 m^3/h was transported in the other direction. Contaminated air is therefore probably led into the factory which might be hazardous to the health. The electricity use has been monitored to 4.2 MWh for one full year.

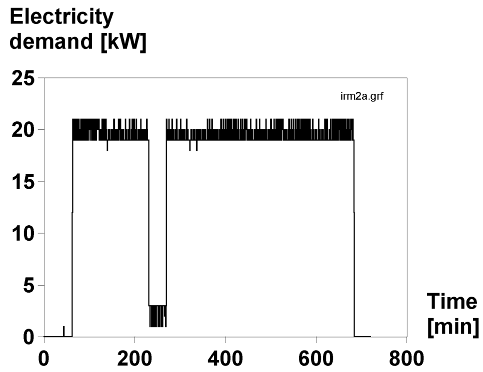

Figure 10: Electricity consumption in the infra-red dryer no 2, June 30, 1998.

Base coat UV-laquer machines

The panels are now to be coated by a first layer of UV-lacquer. For this purpose a roller coater machine is used, type Bürkle DAL 1300. As mentioned above such a machine needs about 0.9 kW but there is also a ventilation fan, coupled to a hub, driven by a small motor of about 0.2 kW. This fan, however, was not in use. When the coating has been applied, polymerization must take place. The process starts with gelling, i. e. the lacquer is not fully set, and the oven consists of only one UV lamp, type Superfici 166, included in Figure 8. It is now possible to apply a new layer of lacquer which strongly bonds to the earlier gelled layer. The coating is after this fully polymerized by use of three ovens in sequence equipped with so called "cold cure" lamps, where the UV-light is reflected in a mirror while the infrared light passes through the same device. The panels are therefore not supposed to be heated to the same degree as if ordinary UV-ovens were used. Each UV-oven is ventilated by a motor of about 1 kW and the ventilated air stream, with a temperature of 50 °C, was monitored to about 1,000 m^3/h respectively. The electricity use in these three lamps is shown in Figure 12, note that one-minute values are used.

A duration graph for the same lamps are shown in Figure 13 but now the values are based on averages for one hour and hence a somewhat lower peak emerges.

It is now possible to add the values for the base coat process. The two roller coaters used about 6.9 MWh, the first lamp 34.8 MWh, the three cold cure lamps 62.8 MWh and the four motors to the fans 15.2 MWh which adds up to 119.7 MWh each year. The maximum demand for the process was about 43 kW.

Sanding machine number 2

The panels are now base coated and must be sanded once again before the top coat layer is applied. This is achieved in a sanding machine, type Heesemann

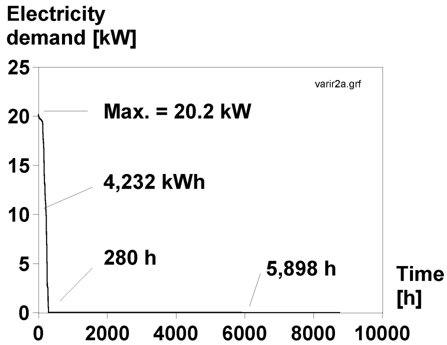

Figure 11: Duration graph for the second infra-red dryer.

LSM4. No high pressure ventilation is used here but the machine is coupled to a ventilation system which transports lacquer dust to a special filter, see Figure 14.

The air stream through the machine has been monitored to 6,800 m^3/h just before the fan coupled to motor M9 in the figure but before the pipe from the other machinery. The motor has been monitored and had a demand of 27 kW with a $cos\varphi$ of 0.79. Lacquer dust is transported to the filter and a screw run by motor M11 of about 0.7 kW transfers the dust to the pipe leading to the large filter on the factory roof via the fan coupled to M6, see also Figure 2. Other machinery is coupled via this screw while still other only need the air stream provided by the M6 motor. The air, transporting lacquer dust, is not led into the factory but instead vented to outdoors. The electricity use for the sanding machine is shown in Figure 15.

Unfortunately, there was an error in the metering device for this machine and only one week were correctly registered for June. In Figure 16, however, values have been added from later weeks it is shown that approximately 34.8 MWh electricity was used for one year.

The motor M9 is used for another sanding machine as well. This machine is located in a different finishing line but the total electricity use, about 102.9 MWh for a year, is nonetheless assumed to reflect the actual need here. There are motors and equipment following the M6 motor that are not dealt with here which probably compensates for this error. About 2.6 MWh must also be added because of the M11 motor. The total power demand is about 41 kW.

After the sanding machine the panels pass a special brushing and cleaning machine, type Paul Ernst AB1, which electricity demand is shown in Figure 17.

The maximum demand was 6.3 kW during the studied period and the motor M10 in Figure 14 is included in that value. The annual use was 17.3 MWh, see Figure 18.

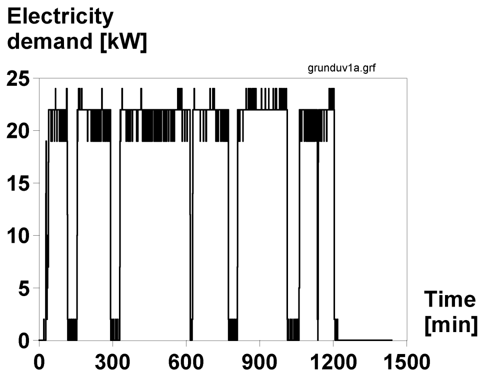

Figure 12: Electricity demand for three "Cold Cure" UV lamps.

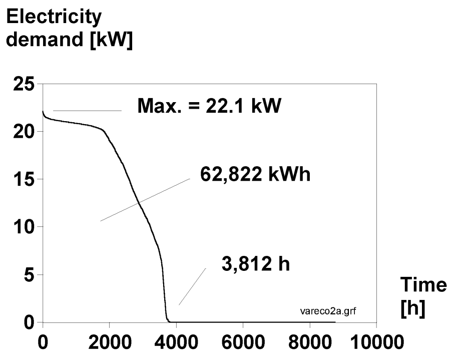

Figure 13: Electricity consumption in three UV-oven lamps for one full year.

Curtain coater

Sometimes there are panels which shall be coated by opaque pigmented lacquer, i. e. they are painted. This procedure is achieved in a curtain coater, type VAW, where a thin film of paint is applied on the panel surfaces. Much thicker layers can than be used, up to 450 g/m^2 instead of 50 g/m^2 in a roller coater machine. The original surface of the panel is therefore totally covered with paint and the surface structure is no longer visible. This curtain coater machine has not been monitored separately but the electricity demand is assumed to be about 1 kW. There is, however, a hub located over the machine which is coupled to a ventilation pipe. The air flow of about 2,000 m^3/h is achieved by a motor of 2.7 kW with $cos\varphi$= 0.54. The machine was used 317 h during the year, see below, and thus about 1.2 MWh are used for the curtain coater process.

The paint from the curtain coater cannot be dried in a UV-oven because the pigments shade off the UV radiation. Instead an electrically heated drying

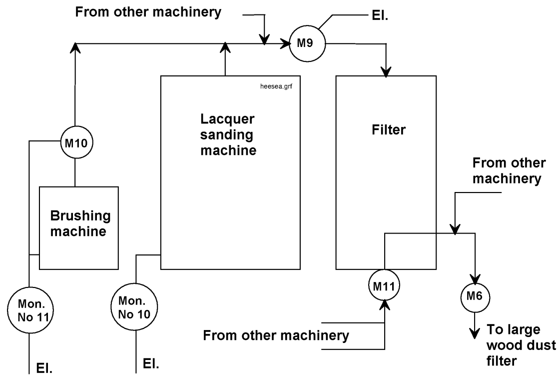

Figure 14: Brushing and lacquer sanding machines.

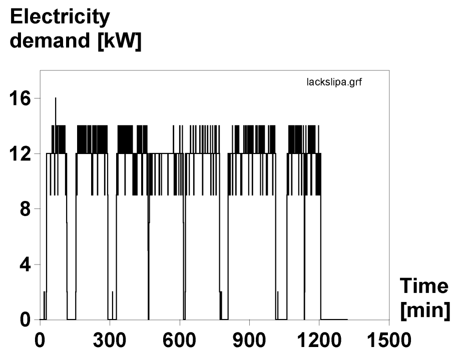

Figure 15: Electricity use in a sanding machine, type Heesemann LSM4.

tunnel is used, type Eisenmann 527, see Figure 19.

In the first part of the tunnel a relatively low temperature is used, about 30 - 40 °C. In this part the volatile part of the lacquer is removed. In the other end 27 IRM-lamps are located, each with a demand of 3.25 kW, but it is not necessary to use all of them at the same time. The lamps must be cooled by an air stream which comes from the outside through pipe no 4 in Figure 19. The warm air can be sent out through pipe number 3 but also utilized in the flash-off zone. It is also possible to use outdoor air through pipe number 2, heat it in a heater using electricity and after this evacuate the air through pipe number 1. Unfortunately, there was no possibility to actually meter the flow through these pipes. The dampers in pipes no. 2, 3 and 4 were closed while about 6,300 m^3/h were monitored in pipe no. 1. Because of the large diameter, 0.5 m, our Pitot tube gave fluctuating readings and the value must be considered as dubious. Hence, all air seems to be taken from the premises. Each pipe has a fan and a

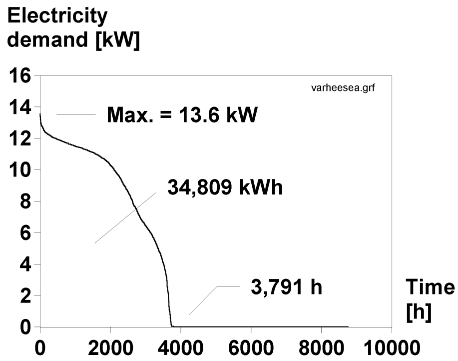

Figure 16: Electricity consumption for one year in a Heesemann LSM4 sanding machine.

motor coupled to that fan with electricity demands covered by our meter. The electricity use for one day is shown in Figure 20 and for the full year when our meter registered 16.0 MWh, Figure 21.

The maximum demand was found to be about 70 kW. The machine has not been used very often, only 317 h during the studied year.

The temperatures in two of the pipes have also been monitored and the conditions on June 15, 1998, are shown in Figure 22.

Pipe no. 1 is located after the flash-off and pipe no. 2 after the IRM-lamps. Note that the measurements started when the dryer occasionally were in operation and, hence, the high temperatures from the beginning of the graph. Air with a temperature of about 60 °C therefore seems to leak through the damper while air with a temperature of 40 °C is led out from the factory through pipe no. 1.

Cooling tunnel

The panels get warm when passing the IRM-lamps. If they have a temperature higher than about 30 °C they cannot be piled on top of each other because hot lacquer will act like a glue. They must therefore pass a cooling tunnel, type Finnrose. Air to this tunnel is provided from the outside through three pipes with a diameter of 0.6 m and the somewhat warmer air is led outdoors via similar pipes. The air flow in each of the six pipes have been monitored and is presented in Table 1.

Pipes no. 1, 3 and 5 provides cold outdoor air, while no. 2, 4 and 6 evacuate the warm air. The tunnel is designed so that no. 1 is coupled to no. 2, 3 to 4 and 5 to 6. About 24,000 m^3/h of warm air is, due to Table 1, led from the tunnel while about 20,100 m^3/h is transported outdoors. Some air must therefore be taken from the premises. It should be noted here that the air flows were monitored with a Pitot tube, see Reference [7] page 94, and a U-shaped glass pipe to a part filled with alcohol. The large diameter of the air pipes in Table 1 resulted in small differences between the static and the dynamic

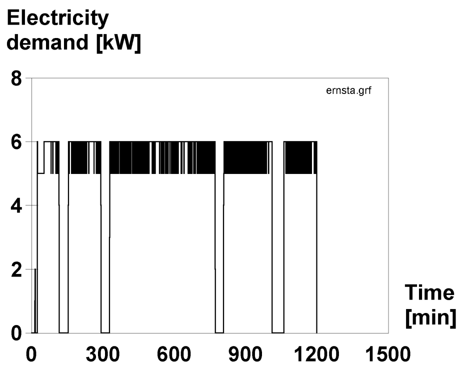

Figure 17: Electricity consumption in a brushing machine, Paul Ernst, June 29, 1998.

Pipe no.	Air flow m^3/h	Direction
1	5,900	In
2	-	(Out)
3	7,100	In
4	15,300	Out
5	7,100	In
6	8,700	Out

Table 1: Air flow through the Finnrose cooling tunnel.

pressures, sometimes only a difference of one to two mm were present in the U-shaped tube, and hence a low velocity of the air was registered. Large errors in the flows must therefore be expected. The air flow in the pipes is achieved by six motors and the total demand added up to about 11 kW according to the electricity meter, see Figure 23.

Note that the cooling tunnel was only used at times when the curtain coater operated, i. e. 331 h during the studied year, compare with Figure 21. Our meter registered 2.9 MWh for the full year.

Top coat lacquer machines

The finishing line ends by two roller coater machines for applying top coat lacquer. The roller coater machines have a relatively low electricity consumption, about 0.5 kW and for June only 151 kWh were registered in the meter. The value is valid for one of the two roller coaters and hence 3.3 MWh is assumed for one year. Also here there are UV-ovens. After the first coater two lamps are present while there are three after the second machine. The electricity usage in these five ovens is shown in Figure 24.

It shall be noted that only two of the three ovens after top coat number two were used. For one full year 176.2 MWh were present in the meter, see Figure

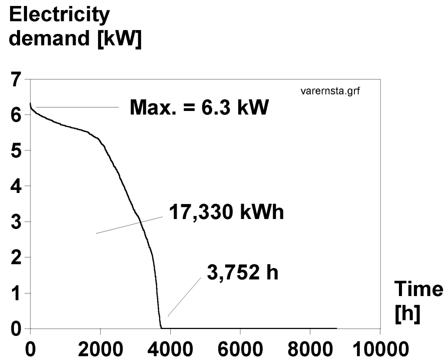

Figure 18: Annual electricity consumption in a Paul Ernst brushing machine.

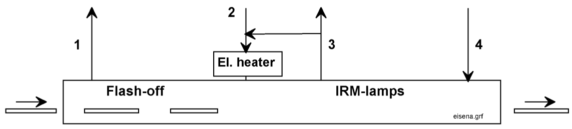

Figure 19: Electrically heated flash-off dryer with a subsequent IRM zone.

25.

Each lamp also has a 1 kW motor for the cooling fan. The electricity usage in these add up to 15.4 MWh. The top coating process is therefore assumed to use 191.6 MWh each year while the power demand is about 63 kW. The air flow in the ventilation pipes coupled to the ovens is for each about 1,400 to 1,600 m^3/h.

ANNUAL ENERGY USAGE

In the examined finishing line a number of processes and machines are used. All these machines operate by use of electricity. There are also other equipment, such as the wood dust transportation system, which must operate at the same time but these systems are not really a part of the machine. In Table 2 the energy needed for one year is shown.

These values are calculated based on the 8,249 hours actually monitored. Air is used as a cooling and transportation fluid and the air flow is also presented. The flow has been split in two parts. One where the temperature of the outflowing air is supposed to be higher than 40 °C and one for lower tem-

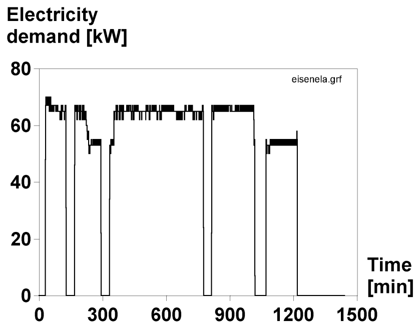

Figure 20: Electricity consumption in the flash-off and IRM-dryer no. 3, June 15, 1998.

Machine	Power kW	Electricity MWh	Steam MWh	Air >40 °C m^3/h	Air <40 °C m^3/h	Origin
Sanding 1	71	231	-	-	-	-
Staining roller coater 1	1	1	-	-	-	-
Staining roller coater 2	1	2	-	-	-	-
Roller conveyors	2	7	-	-	-	-
Jet dryer	10	6	21	1,350	-	I
IRM-dryer 1	7	1	-	-	-	-
Sealing machine	28	80	-	2,200	-	I
IRM-dryer 2	21	4	-	8,100	-	O
Base coat UV	43	120	-	2,000	-	I
Sanding 2	41	140	-	-	6,800	I
Brushing machine	6	17	-	-	-	I
Curtain coater	4	1	-	-	2,000	I
Flash-off and IRM-dryer 3	70	16	-	6,300	-	O
Cooling tunnel	11	3	-		20,100	O
Top coat UV	63	192	-	6,000	-	I
Sum	379	821	20			

Table 2: Annual energy usage for equipment in the finishing line at Totebo AB.

peratures. This because it must be more profitable to use high temperature air when energy conservation measures are considered. Only one of the machines used steam, i. e. the jet dryer. The air comes sometimes from the indoor environment e. g. in the sanding machines while other times outdoor air is used, see e. g. the cooling tunnel. This must be considered because the indoor air must be heated during the winter. Warm indoor air is therefore a valuable asset which should not be wasted during winter conditions. Outdoor air has not a monetary value from the beginning but after passing the machines such a value is obtained, i. e. if some of the heat could be recovered and utilized. When the profitability of different energy conservation measures is considered the origin of the air therefore must be dealt with. In Table 2 the origin is shown as "I" for indoor and "O" for outdoor air.

In Figure 1 it is shown that the maximum demand for the factory was 1,438 kW. The surfacing line therefore might be responsible for about 20 % of the demand in kW. The electricity consumption was about 4.5 GWh and

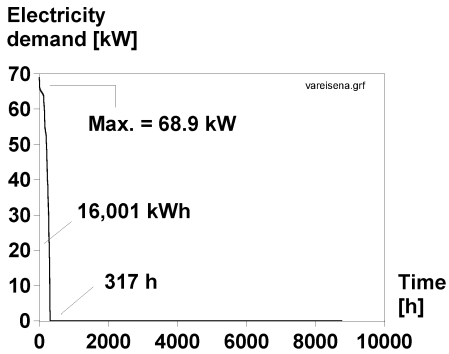

Figure 21: Electricity consumption in an Eisenmann flash-off and IRM-dryer for one year.

the surfacing line used about 18 % of that value. Note that there is another surfacing line which have not been studied here.

ENERGY COST

The factory buys electricity from two companies, one which only distributes the power and one that delivers the actual kWh. The cost for electric energy is very low, about 0.2 SEK/kWh because industries does not have to pay any energy taxes or VAT. There is also a demand fee of about 460 SEK/kW. Applying those values on the surfacing line shows that the energy cost is about 164,000 SEK while the demand fee is about of the same magnitude. Note that all equipment in Table 2 are not used at the same time.

The cost for heat from the wood chips boiler must be based on some considerations. It is, however, possible to sell wood chips as a biofuel. The price is about 300 SEK for each 1000 kg or ton. Absolutely dry wood contains about 4,500 kCal/kg, see Reference [8] page 150, which equals 18.8 MJ or 5.2 kWh. The applicable price will therefore be about 0.06 SEK/kWh or somewhat lower because the wood chips are not absolutely dry, say 0.05 SEK/kWh. The efficiency of the boiler might make this value somewhat higher but it is assumed that 0.05 SEK/kWh is applicable here. All surplus heat from the machinary is in the form of warm air. One kg contains about 1.005 kJ/°C while one m^3 weighs about 1.18 kg, see Reference [9], page 646. Each m^3 therefore, contains 0.33 Wh/°C. In our case we have air of about 50 °C and it is assumed that the outdoor air is about 0 °C during the heating season which in turn implies that the heat in one m^3 has a value of, say 0.00082 SEK. In Table 2 it is shown that about 55,000 m^3 of warm air is led to the outside of the factory with an approximate value of 45 SEK/m^3. If it is assumed that the heating season corresponds with the working hours for about 2500 hours there is an annual value of about 100,000 SEK in this air.

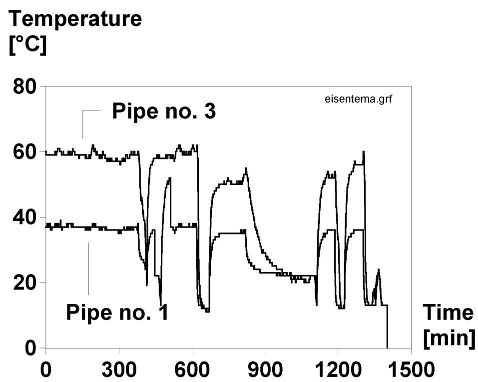

Figure 22: Temperatures after flash-off and IRM-lamps, June 15, 1998.

CONSERVATION MEASURES

There is, however, one obstacle, there is no need for more heat in the premises where the surfacing line is located. The warm air must therefore be transported to another part of the factory which leads to a considerable cost. It is therefore necessary to find more measures in order to reduce the cost for energy.

There is only a few points where cooling are needed, e. g. in the end of the line. The cooling tunnel use air from outdoors. The air flow is achieved by use of 6 electric motors with a demand of 11 kW, see Table 2. The demand and energy cost for this is about 6,000 SEK each year. Instead of leading the somewhat warmer air to the outside from the cooling tunnel it is proposed that part of this is used in the top coat UV-ovens. These ovens need about 6000 m^3 of air each hour which is about the same as in pipe 1, and probably should be in pipe 2 connected to the the cooling tunnel, see Tables 1 and 2. Pipe 3 and 4 in the cooling tunnel should be connectet to the Eisenmann dryer, pipe 4, where there also is a need for cold air, see Figure 19. In pipe 2 in the Eisenmann there is a need for air with a temperature of about 40 °C. This could be provided from the top coat UV-ovens. Perhaps it is possible to turn of these motors as well and let the Eisenmann motor do the work, which saves about 5,000 SEK each year. Pipe 5 and 6 in the cooling tunnel can be coupled to the laquer sanding and the brushing machines which therefore use cold outdoor air instead of air from the premises. This saves about 10,000 SEK each year in the form of warm air with a temperature of 25 °C. See Figure 26 for a principal view.

From the Eisenmann dryer pipe 1 the air must be led through a duct where all warm air from the line is gathered. Note that both the Eisenmann and the cooling tunnel are passive during long periods, the air just passes through. To this duct the ventilation flow from the curtain coater should be coupled. There are also warm air flows from the base coat UV-ovens. The temperature of the air is about 40 °C which is used in the IRM-dryer for cooling. The outflow from this dryer is then connected to the duct. The IRM-dryer input air fan provides a flow of 8,100 m^3/h which is sufficient for the UV-ovens. These UV-apparatus

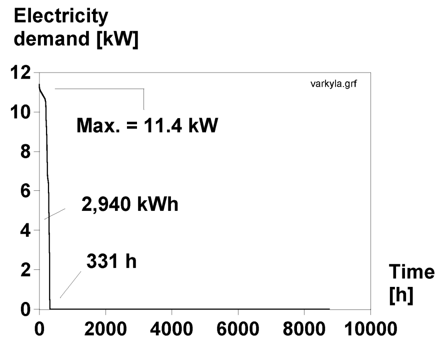

Figure 23: Electricity consumption by a cooling device for one full year.

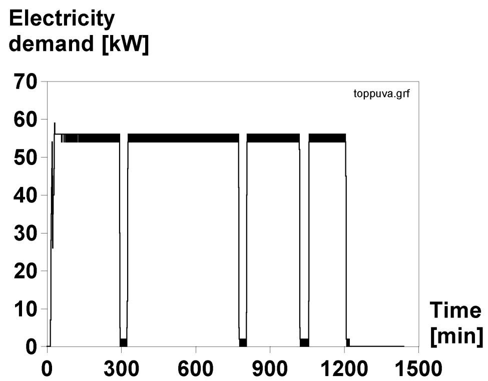

Figure 24: Electricity usage in four top coat UV-lamps, June 29, 1998.

fans might therefore be possible to turn off which saves an additional 5,000 SEK each year. There is also a warm air flow from the steam heated jet dryer which should be coupled to the large duct.

All this warm air must now be coupled to a large new air-to-air heat exchanger in another part of the factory. Fortunately, there is a need of heat in premises only about a distance of 50 metres away from the Tagliabue sanding machine. The length of the line makes it necessary to build a duct of about 150 m. The wood dust transportation system use a lot of air which is not led into the facory in a contolled way. Instead the air leaks into the factory through unsealed windows and doors. The wood dust system therefore provides a ”vacuum” inside the factory. This is utilized for transporting cold air from the outside which passes the heat exchanger and in turn is warmed up by the outflowing warm, but hazardous, air from the surfacing line. If the temperature in the premises gets too high the workers will open windows and doors which in turn elimi-

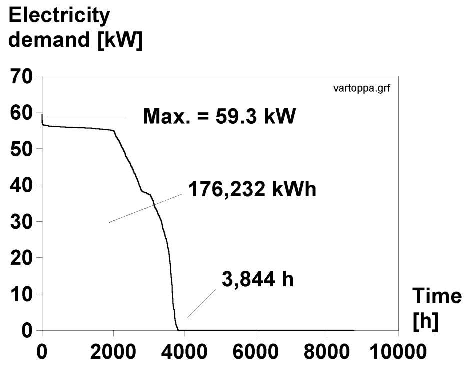

Figure 25: Annual electricity consumption in the top coat UV-ovens.

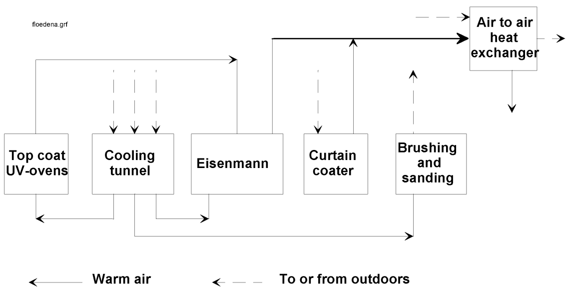

Figure 26: Proposed principal air flow solution in the end of the surfacing line.

nates the vacuum. The system will therefore regulate itself without any fans for the incoming air. On the outgoing warm air a fan is proposed because it is important that dangerous substances is not led out into the factory. This might, however, lead to the possibility that other fans in the surfacing line can be turned off. The efficiency of the heat exchanger is probably of the magnitude 0.75 which leads to possible savings of about 75,000 SEK each year. Turning off unnecessary equipent in the form of motors for fans will save about 25,000 SEK each year. If a pay-back period of two years is acceptable, investment in the duct and the heat exchanger may cost about 200,000 SEK.

CONCLUSIONS

One of the two finishing lines for panel furniture parts at Totebo AB uses about 816 MWh of electricity each year which is about 20 % of the need for the total factory. The cost for this is about 330,000 SEK each year. About 20 MWh in the form of steam is used in one of machines, the air jet dryer. Heat in the form of steam is cheap because the company use the residuals from the wood cutting processes as a fuel. A substantial amount of indoor air, with a temperature higher than the prevailing 24 °C, is also utilized, which together with air from the lacquer process represents a cost for the company of about 100,000 SEK each year. Savings from using the same cooling air for many machines and utilizing warm air for heating of the premises saves about 75,000 SEK each year. A number of fans operating by electricity may then be turned off saving an additional 25,000 SEK each year. New equipment could therefore be purchased for about 200,000 SEK if a pay-back period of two years is acceptable.

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