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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 about 100 m long. Sanding machines, roller coaters, dryers etc. are installed, and all machinery uses electricity for their operation. There are, however, other equipments coupled to the line. One example is the wood dust transportation system, and 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 is used in the surfacing line and also to propose measures to reduce this amount.

1. Introduction

The carpentry industry in Sweden is seldom a subject of academic interest. Partly, 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 in 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 stair cases, and the main result was that about 25% of the electricity cost could be avoided if the machinery were operated in an

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artful way [1]. The latest studies [2,3] deal with a small furniture factory, where different equipments are examined in order to find suitable load management measures.

2. 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 in 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, sorted due to its magnitude, is presented in Fig. 1.

3. 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". Sometimes, 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. Due to 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.

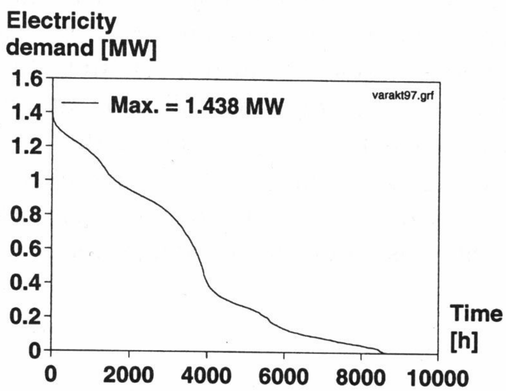

Fig. 1. Purchased electricity by Totebo Ltd. in the form of a duration graph, 1997.

3.1. 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 Fig. 2. The transportation system uses an air stream as a working fluid. This air stream is provided by two fans driven by motors M1 and M2 in Fig. 2. When the motors operate, they use a current, I, of about 33 A, each. Using $P = V \times I \times \cos\varphi \times 3^{0.5}$ (see [4], page 252), where $V = 400$ V and $\cos\varphi = 0.9$, this leads 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 is 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 manufacturer's representative says that the sanding machine should use about 15,000 m^3/h, whereas 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 get their current via the electricity meter, Mon. no. 1 in the figure. 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 is measured to be about 1600 m^3/h, which is slightly less than the flow recommended by the manufacturer, 2000 m^3/h.

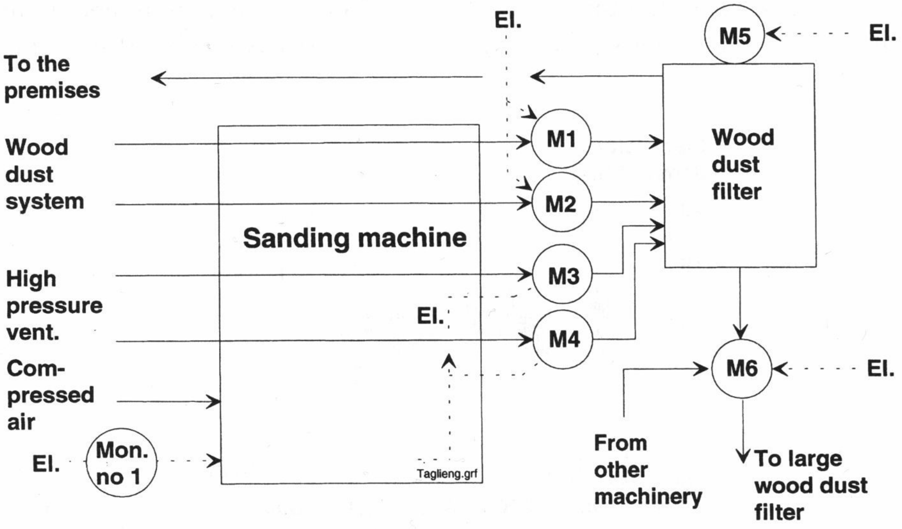

Fig. 2. Principal view of a sanding machine.

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 1700 m^3/h, uses outdoor air. We have also monitored cos φ for the sanding machine as a total and found it to be 0.49. The motors inside the machine, therefore, seem to be too big compared to the actual need. The electricity used for the sanding machine has been monitored by a modern electricity meter which sends pulses to a computer where they are stored each minute. In Fig. 3, the electricity use is shown for 8 h, starting 00.00, June 29, 1998. The maximum demand for the machine was monitored to be 16.2 kW.

The project started in the spring of 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 number 1 in the sanding machine is shown in Fig. 4.

It must be noted here that our monitoring system was out of order for two periods, about 10 days in September 1998 and nine 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 h, out of 8760, 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 be 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 equipments as well. During the monitored year, the sanding machine was used 3686 h according to the electricity meter. The motors, therefore, use about 206.4 MWh for one year, and the total sanding process in the Tagliabue machine used 230.7 MWh. The fact that the air stream, which originates from inside the premises, is led 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 firing wood chips

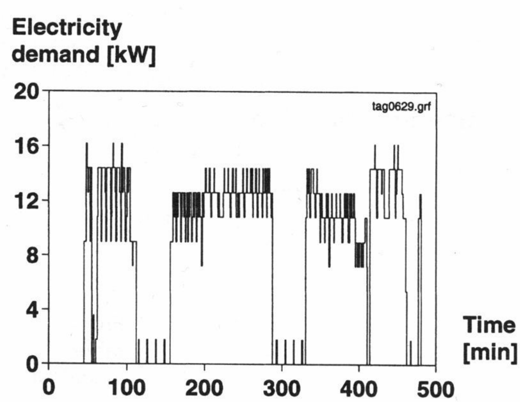

Fig. 3. Electricity demand by the Tagliabue sanding machine based on minutes.

to a cost of approximately 0.05 SEK/kWh. (US$ 1 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.

3.2. 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. Due to 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 10 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.

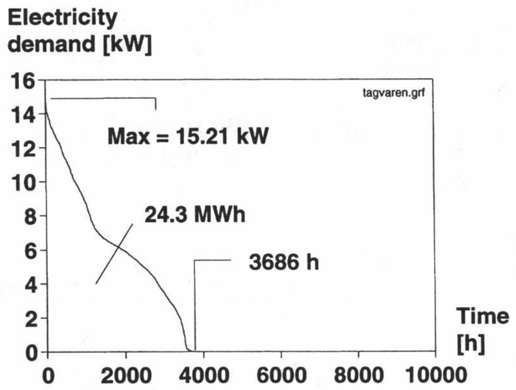

Fig. 4. Electricity consumption in the sanding machine for one full year based on hours.

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 jet nozzles. Some 7000 m^3/h, according to the manufacturer's representative, circulates and about 1000 m^3/h of the air should be vented to the outside of the factory, see Fig. 5. 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 1350 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 transported 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 [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 Fig. 5, therefore, seems to operate properly.

The hot water is led to a basin in the basement of the factory, wherefrom 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/min or 57 l/h, June 17, 1998. Steam with a temperature of 146°C has an enthalpy of 2.12×10^6 J/kg, [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 Fig. 5, with a marked demand of 10 and 1 kW, respectively. The electricity consumption has been monitored by meter number 4. The dryer is only in use when stained products pass. The conveyers, however, must operate whenever any type of panel is treated. In Fig. 6, values from the electricity meter are shown.

From Fig. 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, 5979 kWh was used, see Fig. 7.

The precise annual use of steam is not known, but for the period the electricity meter

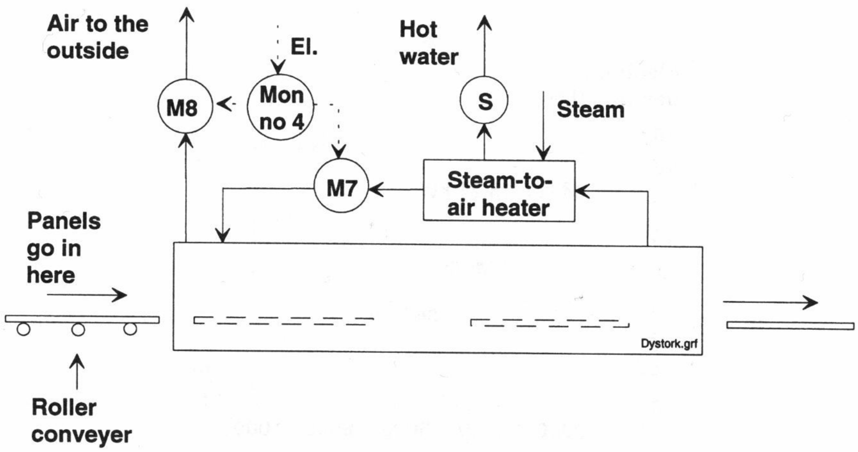

Fig. 5. Jet air drying tunnel.

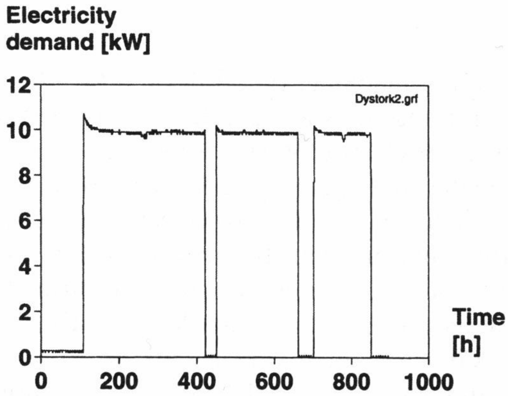

Fig. 6. Electricity consumption in the jet air dryer during 15 h, June 29, 1998.

registered higher loads than 1 kW for 630 h. It is assumed that the steam system was used for that number of hours also. As it was shown above, 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. Due to the low cost for heat, only about 1000 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.

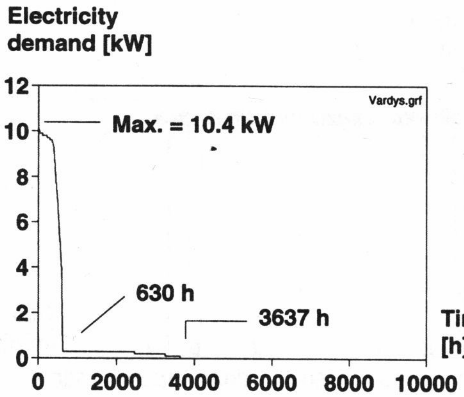

Fig. 7. Electricity consumption in the air jet dryer for one full year.

3.3. 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 Fig. 8.

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 Fig. 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 kWh for June, which adds 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 Fig. 9.

There is also one motor running a fan in each UV-oven. It is assumed that this motor, of about 1 kW, likewise operates 3803 h 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 be about 5.8 m/s, which leads to 1100 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.

3.4. Infrared dryer number 2

An infrared dryer, type Finnrose 8.0 IRM 3.25/1.5, is implemented in the line after this. The electricity demand in this dryer is about 21 kW, see Fig. 10. Also, this IR-dryer was used very little during our monitoring period, only 280 h during one year, see Fig. 11. Ventilation pipes are coupled to the machine. One of the pipes leads cold air from the outside to the machine,

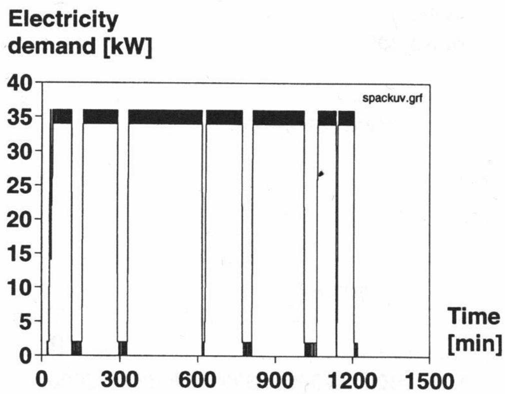

Fig. 8. Electricity consumption in three UV-ovens, June 29, 1998.

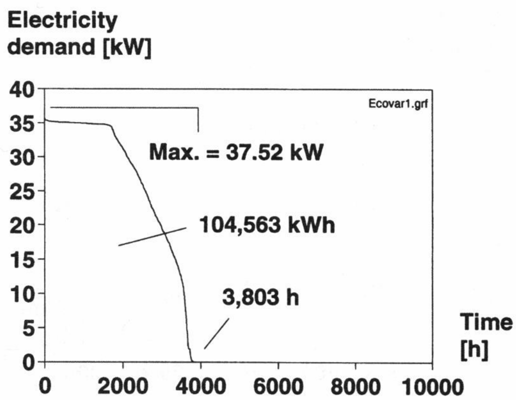

Fig. 9. Electricity consumption in three UV-ovens for one full year.

while the other transports warm air from the machine to the outdoors. The ventilation monitoring showed that about 8100 m^3/h was led into the machine, while only 3200 m^3/h was transported in the other direction. Contaminated air is, therefore, probably led into the factory which might be hazardous to health. The electricity use has been monitored to be 4.2 MWh for one full year.

3.5. 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, shown in Fig. 8. It is now possible to apply a new layer of lacquer which strongly bonds to the earlier gelled layer. The

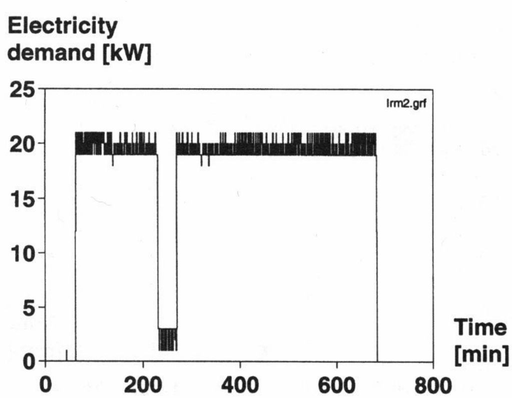

Fig. 10. Electricity consumption in the infra-red dryer number 2, June 30, 1998.

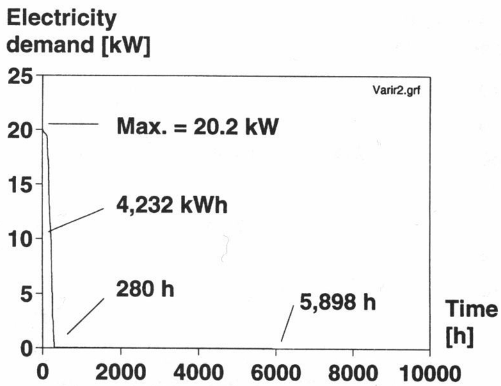

Fig. 11. Duration graph for the second infra-red dryer.

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 be about 1000 m^3/h, respectively. The electricity use in these three lamps is shown in Fig. 12, where 1 min values are used.

A duration graph for the same lamps is shown in Fig. 13, but now the values are based on averages for 1 h 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.

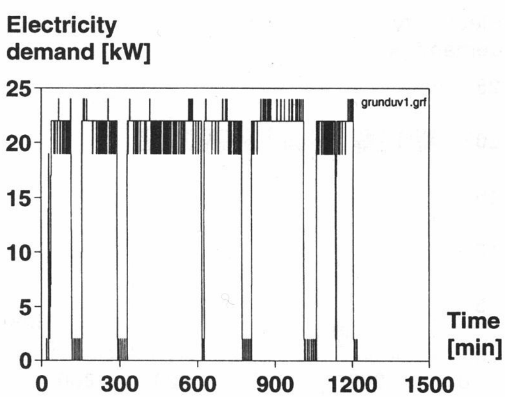

Fig. 12. Electricity demand for three "cold cure" UV lamps.

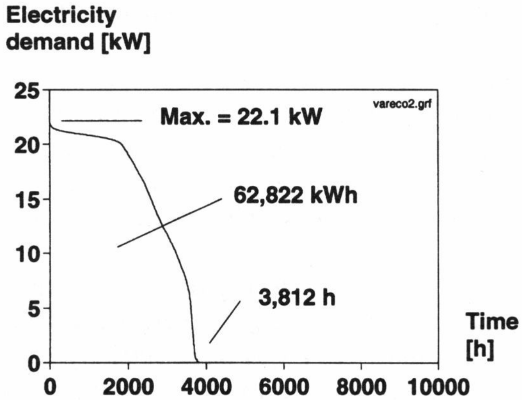

Fig. 13. Electricity consumption in three UV-oven lamps for one full year.

3.6. 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 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 Fig. 14. The air stream through the machine has been monitored to be 6800 m^3/h just before the fan coupled to motor M9 in the figure but before

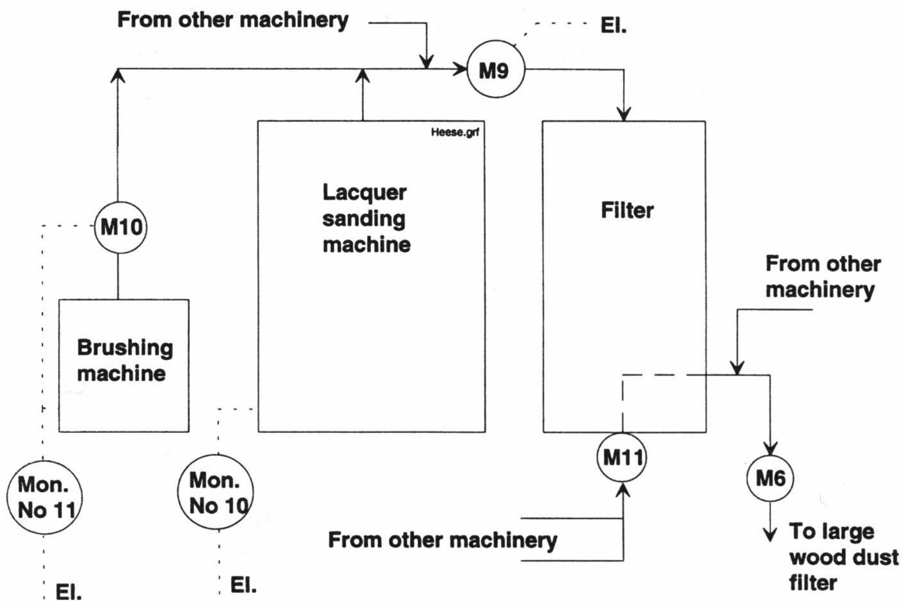

Fig. 14. Brushing and lacquer sanding machines.

the pipe from the other machinery. The motor has been monitored and had a demand of 27 kW with a cos φ 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 Fig. 2. Other machinery is coupled via this screw, while still others only need the air stream provided by the M6 motor. The air, transporting lacquer dust, is not led into the factory but instead is vented to outdoors. The electricity use for the sanding machine is shown in Fig. 15.

Unfortunately, there was an error in the metering device for this machine and only one week was correctly registered for June. In Fig. 16, however, values have been added from later weeks, and 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, having the electricity demand shown in Fig. 17. The maximum demand was 6.3 kW during the studied period and the motor M10 in Fig. 14 is included in that value. The annual use was 17.3 MWh, see Fig. 18.

3.7. 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 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

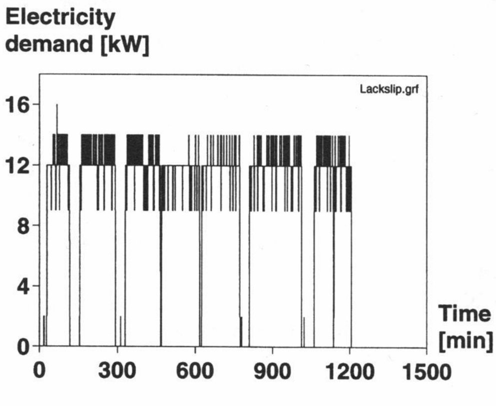

Fig. 15. Electricity use in a sanding machine, type Heesemann LSM4.

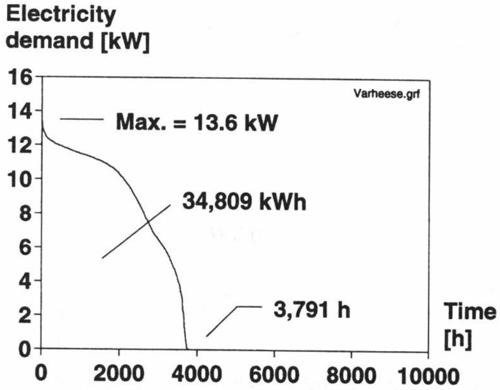

Fig. 16. Electricity consumption for one year in a Heesemann LSM4 sanding machine.

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 2000 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, 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 tunnel is used, type Eisenmann 527, see Fig. 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. On 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 number 4 in Fig. 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 actually to meter the flow through these pipes. The dampers in pipe

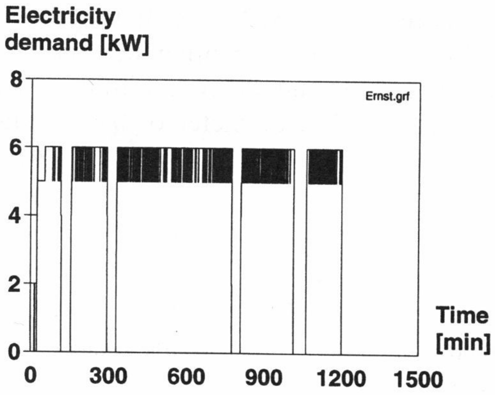

Fig. 17. Electricity consumption in a brushing machine, Paul Ernst, June 29, 1998.

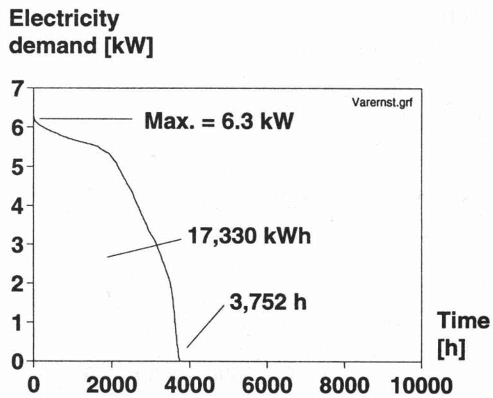

Fig. 18. Annual electricity consumption in a Paul Ernst brushing machine.

numbers 2–4 were closed, while about 6300 m^3/h were monitored in pipe number 1. Due to the large diameter, 0.5 m, our Pitot tube gave fluctuating readings, and the value must be considered as dubious. Hence, all the air seems to be taken from the premises. Each pipe has a fan and a motor coupled to that fan with electricity demands covered by our meter. The electricity use for one day is shown in Fig. 20 and for the full year, when our meter registered 16.0 MWh, in Fig. 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 Fig. 22. Pipe number 1 is located after the flash-off and pipe number 2 after the IRM-lamps. Note that the measurements started when the dryer was occasionally 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 number 1.

3.8. 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 the 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

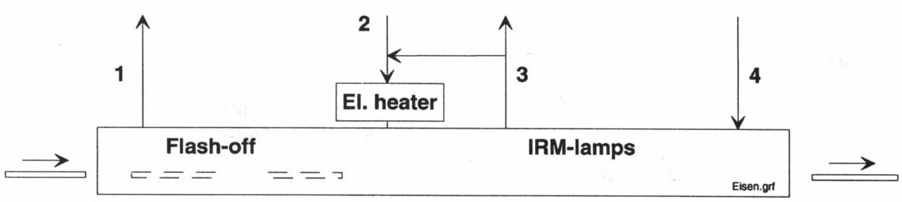

Fig. 19. Electrically heated flash-off dryer with a subsequent IRM zone.

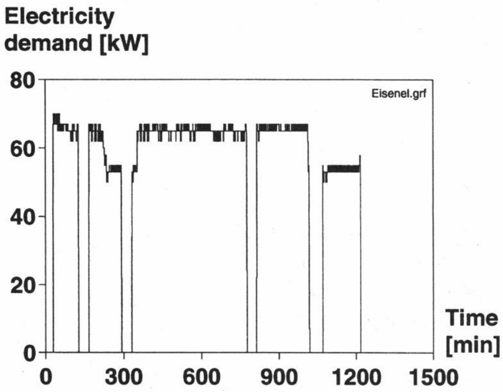

Fig. 20. Electricity consumption in the flash-off and IRM-dryer number 3, June 15, 1998.

is led outdoors via similar pipes. The air flow in each of the six pipes has been monitored and is presented in Table 1.

The pipe numbers 1, 3 and 5 provide cold outdoor air, while 2, 4 and 6 evacuate the warm air. The tunnel is designed so that number 1 is coupled to number 2, 3 to 4 and 5 to 6. About 24,000 m^3/h of cold air is, according 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 [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 pressures, sometimes only a difference of 1–2 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 Fig. 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 Fig. 21. Our meter registered 2.9 MWh for the full year.

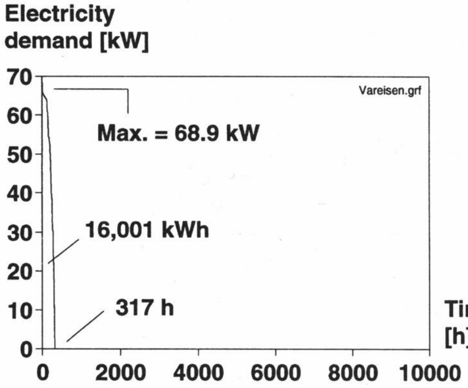

Fig. 21. Electricity consumption in an Eisenmann flash-off and IRM-dryer for one year.

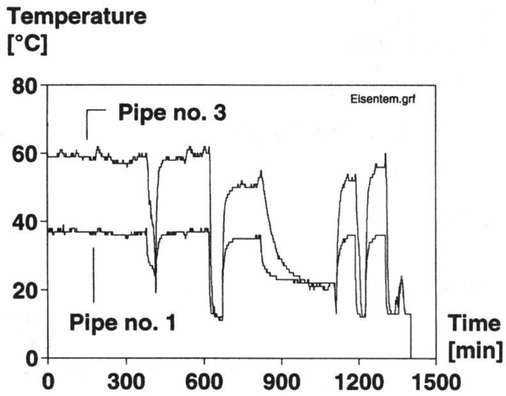

Fig. 22. Temperatures after flash-off and IRM-lamps, June 15, 1998.

3.9. 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 Fig. 24.

It shall be noted that only two of the three ovens after top coat number 2 were used. For one full year, 176.2 MWh were present in the meter, see Fig. 25.

Each lamp also has a 1 kW motor for the cooling fan. The electricity usage in these adds 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 1400–1600 m^3/h.

Table 1
Air flow through the Finnrose cooling tunnel

Pipe number	Airflow[m^3/h]	Direction
1	5900	In
2		Out
3	7100	In
4	15,300	Out
5	7100	In
6	8700	Out

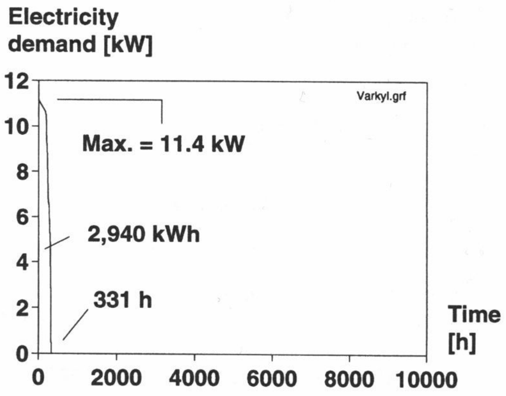

Fig. 23. Electricity consumption by a cooling device for one full year.

4. 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 equipments, 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 8249 h 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 part is where the temperature of the outflowing air is supposed to be higher than 40°C, and the other part is for lower temperatures. This is 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 at other times, outdoor air is used, see e.g. the cooling tunnel. This must be considered because the indoor air too must be heated during the winter. Warm indoor air is, therefore, a valuable asset which should not be wasted during winter conditions. Outdoor air

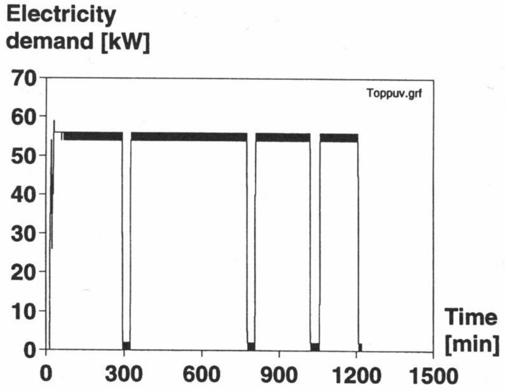

Fig. 24. Electricity usage in four top coat UV-lamps, June 29, 1998.

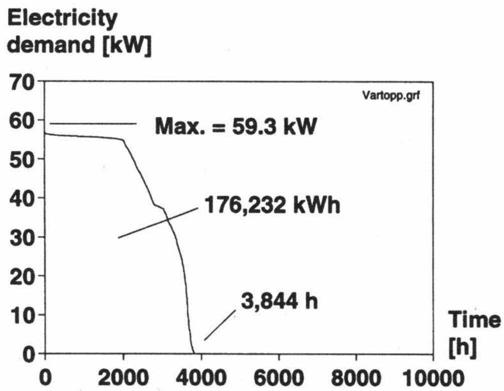

Fig. 25. Annual electricity consumption in the top coat UV-ovens.

has no 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 taken into accounts. In Table 2, the origin is shown as "I" for indoor and "O" for outdoor air.

In Fig. 1, it is shown that the maximum demand for the factory was 1438 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 the surfacing line used about 18% of that value. Note that there is also another surfacing line which has not been studied here.

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

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	1350	–	I
IRM-dryer 1	7	1	–	–	–	–
Sealing machine	28	80	–	2200	–	I
IRM-dryer 2	21	4	–	8100	–	O
Base coat UV	43	120	–	2000	–	I
Sanding 2	41	140	–	–	6800	I
Brushing machine	6	17	–	–	–	I
Curtain coater	4	1	–	–	2000	I
Flash-off and IRM-dryer 3	70	16	–	6300	–	O
Cooling tunnel	11	3	–		20100	O
Top coat UV	63	192	–	6000	–	I
Sum	379	821	20			

5. 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 do 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 equipments 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 4500 kCal/kg (see [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 1 m^3 weighs about 1.18 kg, (see [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 1 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 h, there is an annual value of about 100,000 SEK in this air.

6. 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 are only a few points where cooling is needed, e. g. in the end of the line. The cooling tunnel uses 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 cooling tunnel, see Tables 1 and 2. Pipes 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 Fig. 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 off these motors as well and let the Eisenmann motor do the work, which saves about 5000 SEK each year. Pipes 5 and 6 in the cooling tunnel can be coupled to the lacquer sanding and 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 Fig. 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, and 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 8100 m^3/h which is sufficient for the UV-ovens. These UV-apparatus fans might, therefore, be possible to be turned off, which saves an additional 5000 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 need of heat in the premises only about a distance of 50 m 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 uses 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 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, eliminates 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 not be 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 equipment in the form of motors for fans will

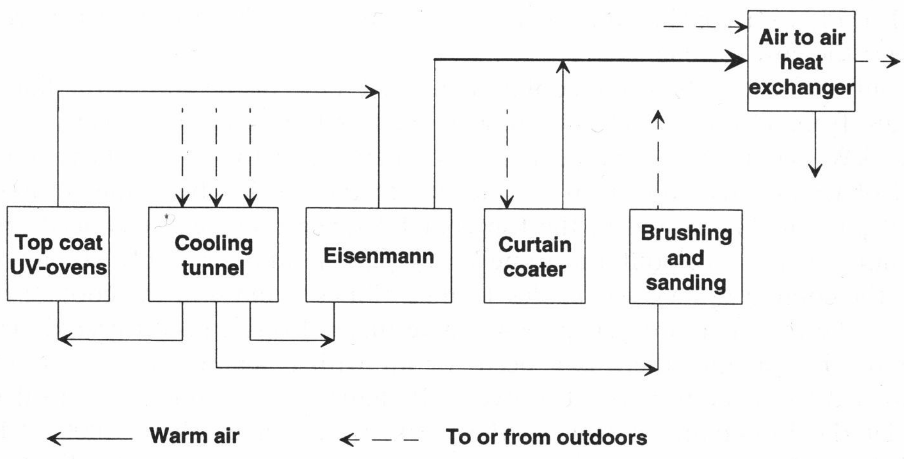

Fig. 26. Proposed principal air flow solution in the end of the surfacing line.

save about 25,000 SEK each year. If a payback period of two years is acceptable, investment in the duct and the heat exchanger may cost about 200,000 SEK.

7. 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 machine, the air jet dryer. Heat in the form of steam is cheap because the company uses 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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