Improvements to Ingot Pre-heating– a Modelling Approach

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Preparing a Direct Chill (DC) cast ingot for hot rolling is both time and energy consuming. It requires about 1.2MJ of energy per kilogram of final product just to perform the homogenisation and pre-heat operations. This compare with about 0.2 MJ/kg for the hot rolling process itself. Pit furnaces for pre-heating are still in wide use by rollers of aluminium flat products. Although they are not the most efficient method of pre-heating, they do provide a flexible store of ingots to maximise availability of metal to the hot line. A key role of the pre-heat facility is to ensure that the hot mills, where the greatest capital is tied up, are kept occupied with production. Fig 1 shows a schematic of a gas-fired pre-heat pit furnace showing also the major sources of energy loss from the furnace.

The pre-heat furnace usually performs the dual functions of homogenising the metal and of holding it at a temperature suitable for rolling. In order to achieve satisfactory final properties, the temperature distribution in the ingot during the pre-heat must be uniform. For this reason, pre-heat cycles are sometimes excessive in length to ensure that uniformity has been achieved. It would be an advantage to know the temperature distribution in the ingot throughout the pre-heat so that cycles can be no longer than necessary. Shortening cycles is one of the best ways of saving energy per kg rolled, as heat is lost from the furnace even when the ingot is simply being held at temperature.

Furnace modelling

Innoval Technology have developed a model to allow the monitoring of the ingot temperature at all places in the ingot during the pre-heat cycle. Fig 2 shows how the ingot is discretised for modelling purposes. Only a quarter of the ingot is modelled with symmetry assumed at the mid-width and mid-thickness positions. It is not possible to assume symmetry at the semi-height position as there is a significant air temperature drop down the ingot during the heating process especially at the start. The model performs [3D] transient calculations of temperature at the centre of all the elements in the ingot throughout the heating cycle. The boundary conditions for the model are the air temperature and the heat transfer coefficients on the ingot surfaces. These can be determined from first principles and then the model calibrated against experimental data from furnace trials. The model can handle loads of ingots with different sizes. If it is known that ingots in some parts of the furnace are heated differently from others then this can also be handled by running the model for each individual ingot.

Fig 3 shows how this air temperature drop down the ingot is typically reflected in the temperature in the ingot itself. This shows the temperature distribution inside the ingot in the vertical plane at the mid-width position for a typical pre-heat process after 5 hours in the furnace. There is about 110℃ difference at this s tage between the top and bottom of the ingot.

Shortening heat-up times

The important temperatures from the point of judging how to improve the cycle are the hottest (leading) and coldest (lagging) anywhere in the ingot through the cycle. Consider a pre-heat schedule in which 14 ingots each of 11.2 tonnes are heated to a target temperature of 600C over a period of 25 hours. Fig 4 shows the leading and lagging temperatures through the heat-up time for a typical pit furnace. All parts of the ingot must have a temperature between these two curves. In order to achieve the required properties, the temperature throughout the ingot must reach the required value and this can easily be assessed with a calibrated model. It may be noted from Fig 4 that in this case the ingot temperature does not become uniform until quite close to the end of the heat-up period.

It is often possible to accelerate the early part of the cycle by using higher set air temperatures. Fig 4 shows significantly higher than target air temperatures used at the beginning of the heat-up. The model indicates that for the time they are used there is no danger of over-heating any part of the ingot. Because the model effectively can give warning of excess temperature anywhere on the ingot it allows a more aggressive heating regime which can enable a reduction in overall heating time without danger of damaging the ingot. This technique pre-supposes that there is sufficient power in the burners to maintain the air temperature at or near its set value. It is important to include the power limits in the modelling and thus model the actual air temperature, not just the set value. The problem of power limitation is most acute at the start of the cycle when the ingots can absorb heat at a high rate because the are relatively cold.

Reducing energy losses

Fig 4 also shows the energy losses during the cycle. As seen from Fig 1, energy is lost by conduction through the furnace walls, up the exhaust stack (when gas-fired) and by leakage of air into and out of the furnace. It is typical for about twice as much energy to be supplied to the furnace as is required to raise the temperature of the metal. In the heat-up part of the cycle shown in Fig 4, the energy added to the ingots is 94GJ whereas that supplied during the 25 hours is 160GJ. A small but not insignificant proportion of this is the electrical energy expended to circulate air in the furnace. Electrical energy is usually more costly than gas energy, so that it is best to reduce fan speeds during the later “hold” parts of the cycle where rapid air circulation is not required. Although this does not reduce the total energy required, it does transfer some of it from electrical to gas energy and thereby saves cost. It also reduces the carbon footprint of the process, since electrical energy ultimately generates more carbon dioxide emissions than gas energy. In the cycle depicted in Fig 4, the fan speed is reduced after 17 hours. The total energy curve continues upwards un-interrupted but the gas energy curve becomes steeper. This is because energy previously being supplied by the electric fan must now be supplied by the gas burners.

Recuperation

In a direct fired gas furnace, a mass of air corresponding to the combustion gas and air must be extracted from the furnace and exhausted up the stack. This represents a significant energy loss. However, it can be considerably reduced by the use of a recuperator which recovers heat from the exhaust stream and transfers it to the incoming combustion air. A recuperator is a heat exchanger consisting of a tube stack enclosed in a shell or box. The hot exhausting air passes through the recuperator tubes and the incoming combustion air is drawn over the external surfaces of the tube stack. The air is thus heated on its route to the burners. Fig 5 shows the level of benefit which may be obtained by using a recuperator. This indicates a 19% reduction in the total energy supplied, or 30GJ which amounts to a saving of about 0.2MJ per kg of pre-heat load. This level of saving usually means that a recuperator will pay for itself in about 12 months at present energy costs. As energy becomes more expensive and as the drive to reduce carbon emissions increases, recuperators will become more and more attractive. Sometimes the recuperators are fitted to the burners themselves. These are known as recuperative burners. They are generally smaller and cheaper but less efficient than stand-alone recuperators.

Air leakage

Another contribution to the energy lost from furnaces is that due to air leakage out of or into a furnace. If no recuperator is fitted, it is possible to tolerate quite large leakages of air out of the furnace without affecting the energy efficiency. This rather surprising fact is because the combustion air must be extracted up the stack and air leaking out of the furnace simply reduces the flow up the stack by the same amount. Clearly, however, if the air leakage exceeds the combustion air requirement then there will be significant energy loss. This can more easily occur towards the end of the cycle when the gas firing level is low. Furthermore, if a recuperator is fitted, even low levels of air leakage out of the furnace are important as the recuperator can only recover heat from air which passes through it.

Usually there are parts of the furnace which operate below the ambient static air pressure. This is often near the base of the furnace close to the re-circulating fan intake. If the furnace is not well sealed in this region, cold air can be pulled into the furnace from outside. This has a more serious affect than air leaking out, as the in-coming cold air must be heated right up to the operating temperature of the furnace. Fig 6 shows the effect of a leakage of 0.2 m^3/s of air. This level of air leakage has been measured on a pit furnace in use. The energy loss over the 25 hour period is about 16GJ or an increase in energy of 10%. This is a significant increase in the energy supplied. Leakages of air into the furnace are not so obvious to the operators as there are no visible effects as occurs with air leaking out. It is well worth while checking the furnace sealing to minimise this source of energy loss. It is also another good reason for running the fans at low speed during the hold part of the cycle as this reduces the negative pressure in the furnace and will therefore reduce air intake.

In summary, this modelling approach can yield practical pointers to shortening ingot pre-heat times by enabling more aggressive heat-up schemes to be used without danger of over-heating the ingot. It also indicates ways of significantly reducing the energy losses of the process. Models are being used more and more as part of the process control and it is possible to envisage that in the near future these furnace models will be running on-line, calculating the best future settings for the furnace and providing warnings of furnace malfunction much earlier than would otherwise be recognised.

Captions to figures

1. Schematic of a typical direct gas-fired pit furnace with recuperator.
2. Division of an ingot into elements for modelling. A quarter of he ingot is modelled with symmetry assumed at mid-width and mid-thickness positions.
3. Modelled temperature distribution inside an ingot after five hours of heating. The temperatures are shown in the plane through the thickness at the mid-width position.
4. Leading and lagging temperatures in an ingot during the heat-up part of a pre-heat cycle. Also shown are the gas and electric energies supplied and the energy absorbed by the ingots.
5. Effect of using a recuperator on the energies supplied.
6. Effect on energies supplied of allowing 0.2 m^3/s of cold air to leak into the furnace.

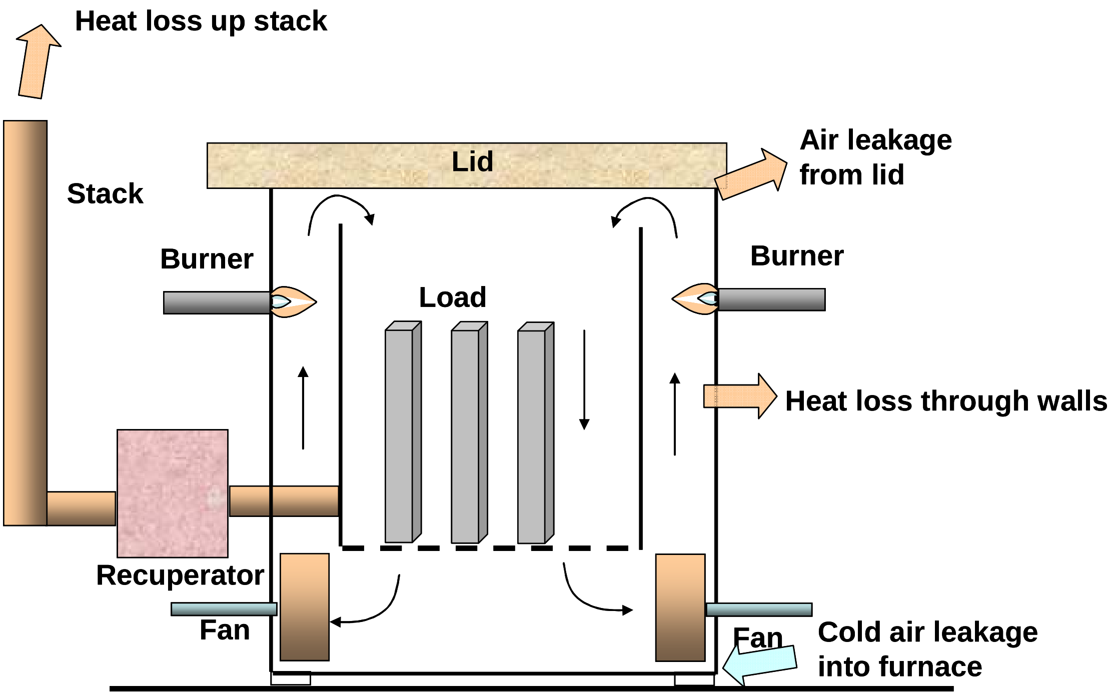

Figure 1 Schematic of a typical direct gas-fired pit furnace with recuperator.

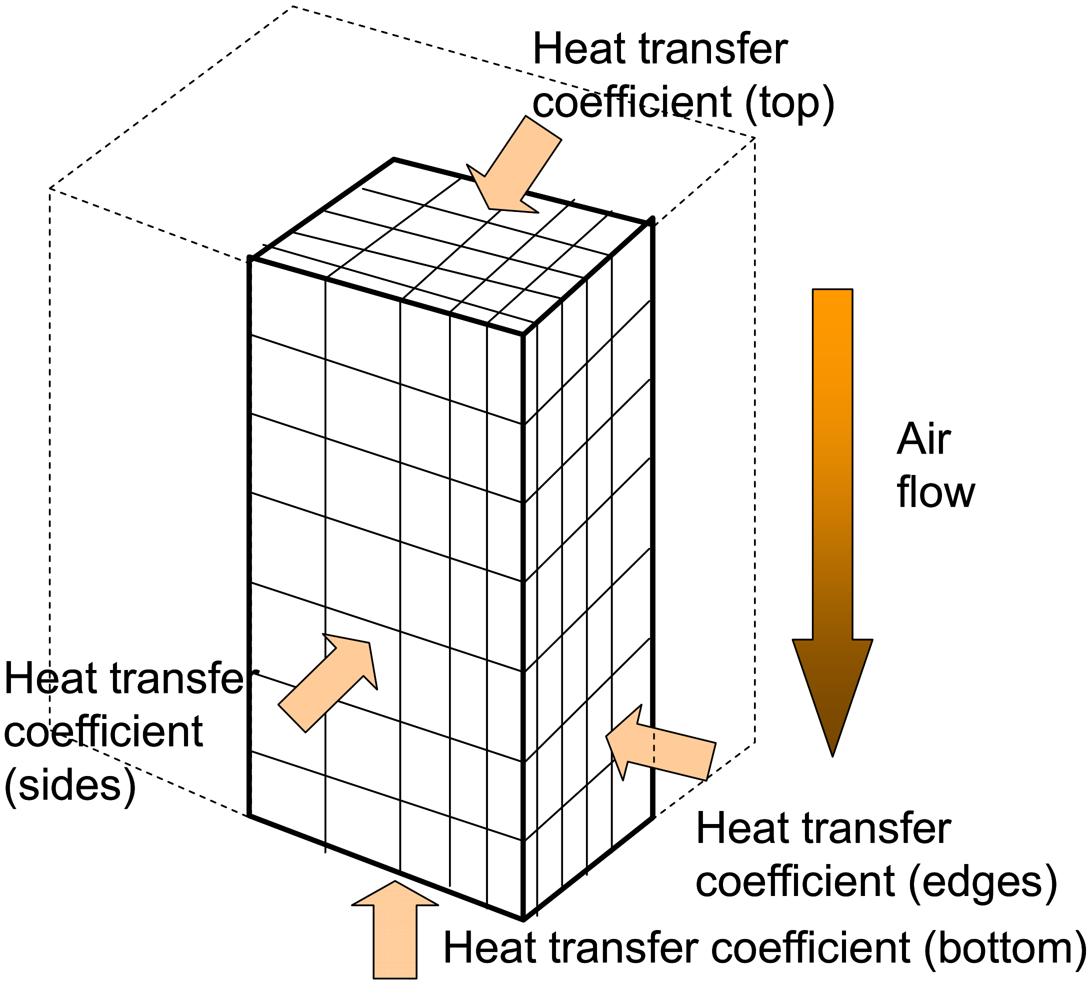

Figure 2 Division of an ingot into elements for modelling. A quarter of he ingot is modelled with symmetry assumed at mid-width and mid-thickness positions.

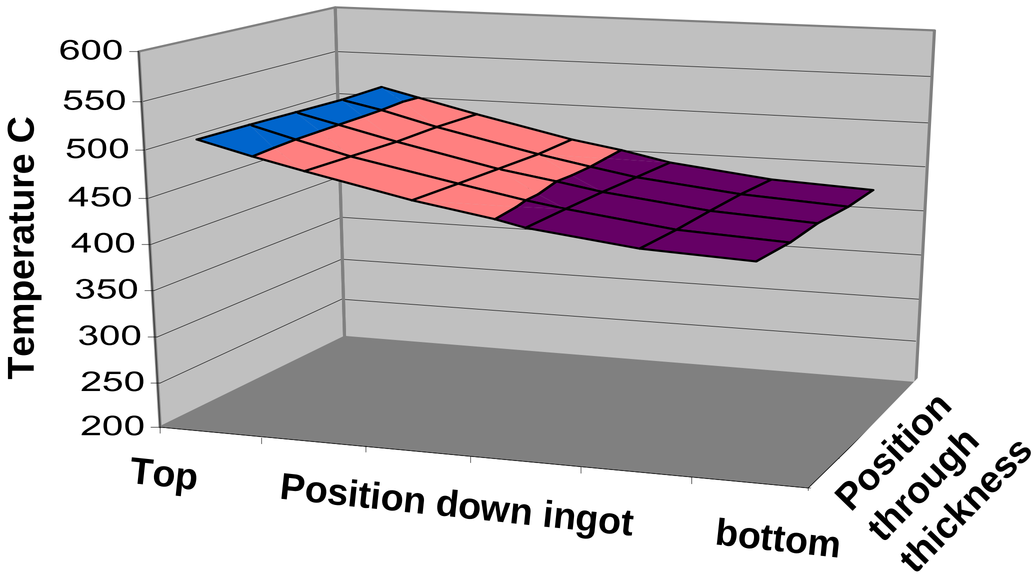

Figure 3 Modelled temperature distribution inside an ingot after five hours of heating. The temperatures are shown in the plane through the thickness at the mid-width position.

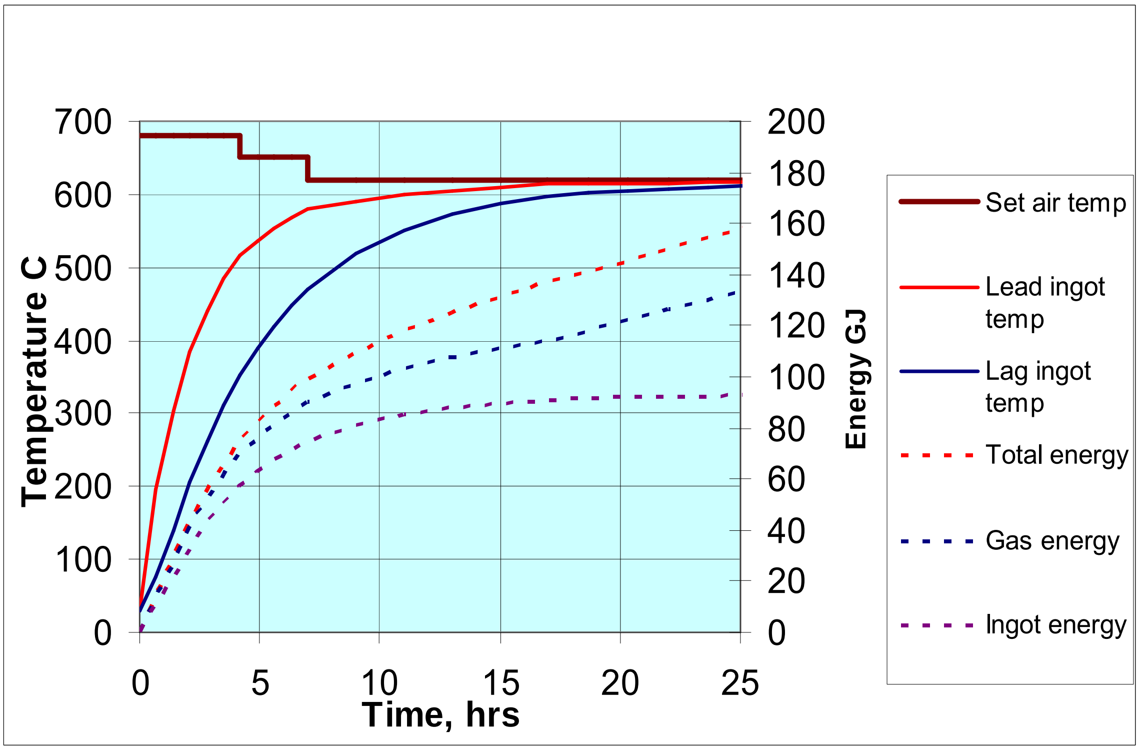

Figure 4 Leading and lagging temperatures in an ingot during the heat-up part of a pre-heat cycle. Also shown are the gas and electric energies supplied and the energy absorbed by the ingots.

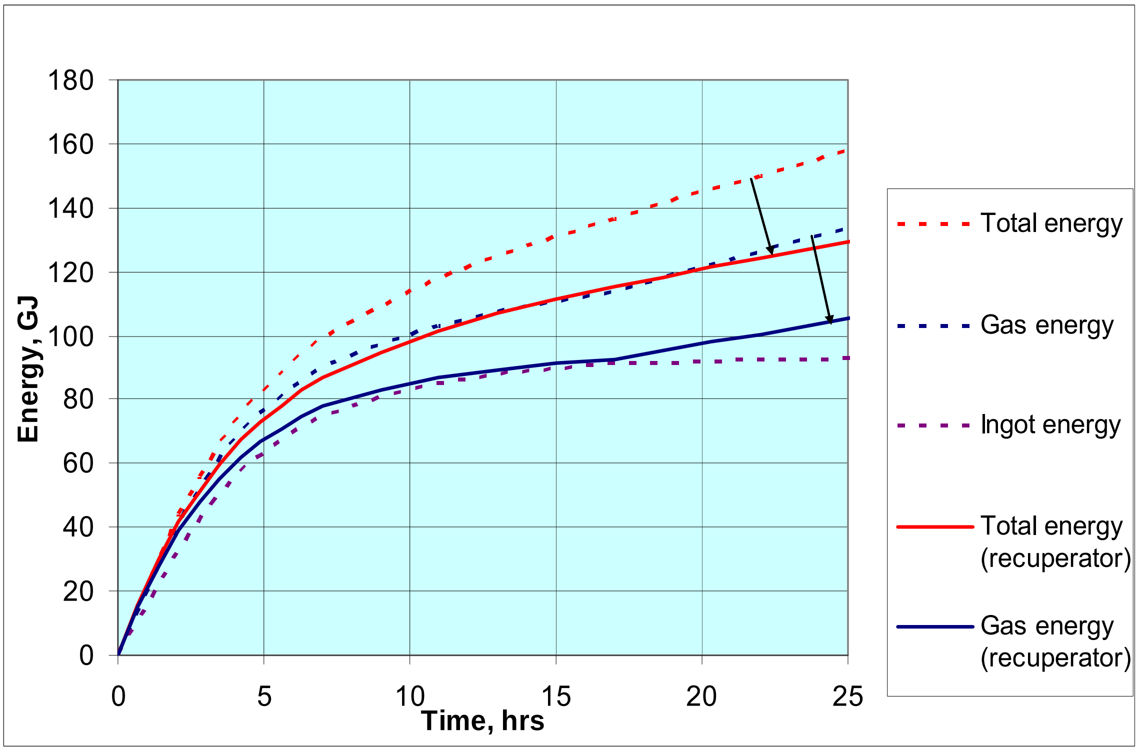

Figure 5 Effect of using a recuperator on the energies supplied.

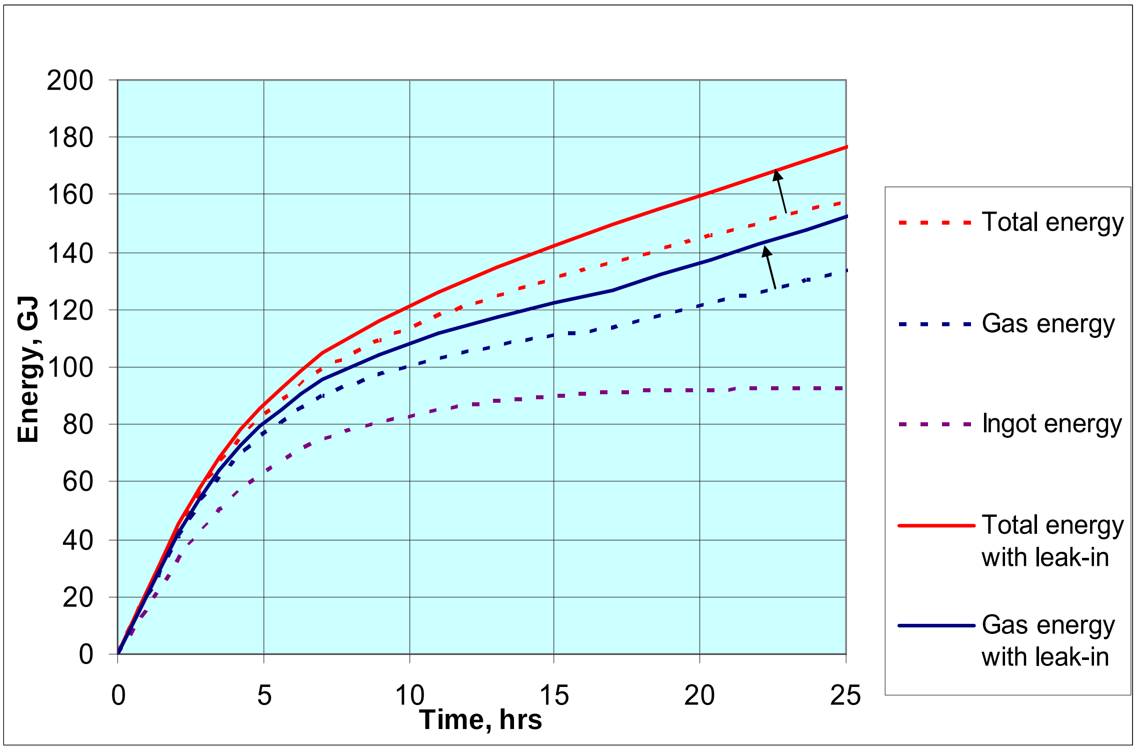

Figure 6 Effect on energies supplied of allowing 0.2 m^3/s of cold air to leak into the furnace