3. IN-STORE COOLING OF GRAIN

3.1. MANAGING WITH DRY GRAIN

Question 3.1. *How to manage with dry grain? I harvested dry grain and put it in my grain store. I thought that I do not have to take care of it over the next few months. After several weeks, when I put my hand into the grain I realized it was hot and not dry.*

Preservation of grain stabilizes its good properties from the day of harvest to the day of utilizing it in various feeding purposes. Grain – even though it is dry – needs careful treatment. It has to be protected from many dangers, pointed out in the previous part of the handbook. Dry grain, above all, has to be cooled down, preferably to a temperature about 10 °C.

Particularly important is post-harvest preservation of freshly harvested grain. Why? **Because in every grain kernel, during several days after a harvest, the final phase of physiological maturation takes place.** The respiration process of the grain kernels and the associated microorganisms is still very intense. Respiration is a process that produces heat, moisture and carbon dioxide. In the deep bed of grain a rise in temperature and air humidity can be observed. Grain cannot be left without conservation in such a state. An easy, effective and most natural way of conservation of dry grain is its ventilation (Figure 3.1).

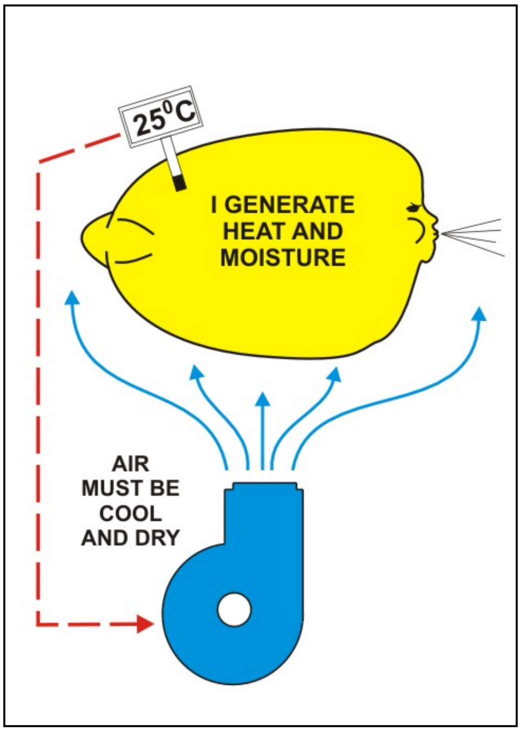

Figure 3.1. Ventilation of the grain ecosystem. During the first days after harvest, respiration takes place and grain together with fungi generate heat and moisture, so each kernel in a bulk of grain should have contact with a flow of air that can cool it down and take out this heat and moisture.

Post-harvest cooling – This is the mechanical forcing of air through the deep bed of dry grain aiming mainly at cooling down the stored grain **in the post-harvest period** and – less importantly at this stage – lowering the grain moisture content by 1 – 2% w.b.

Farmers frequently have doubts whether to cool down recently harvested grain. After all, the air during the harvests is warm. It has to be remembered that the ambient air temperature usually falls during night hours. When the temperature of the grain is higher than that of the air by several degrees Celsius, the risk of moistening of grain becomes minimal. Why? Because grain warms up the air that flows through inter-granular spaces and decreases its relative humidity. A second factor in favor of cooling is the fact that in the newly harvested grain, respiration takes place and so the grain ‘perspires’. All this favors temperature reduction of the grain due to the effect of evaporative cooling. Cooling is a result of vaporizing of moisture from the surface of each grain kernel. It is similar to cooling of a perspiring man standing in front of a ventilating fan. Typical changes of basic parameters of air that flows through a deep bed of dry grain are shown in Figure 3.2.

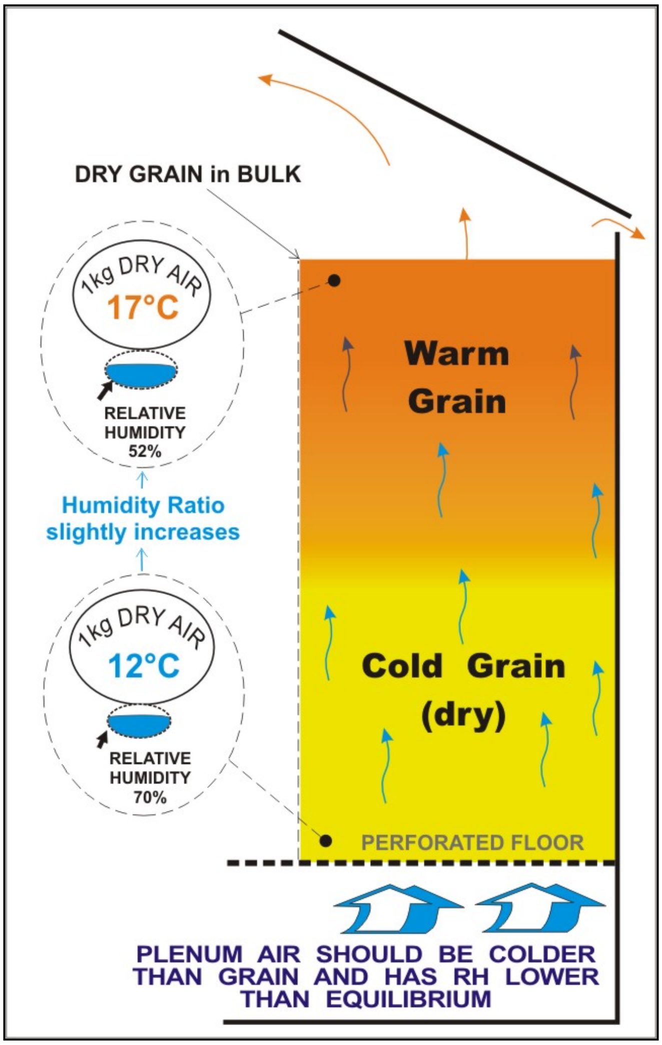

Figure 3.2. Changes of air temperature and relative humidity during cooling. Air flows through a deep bed of barley of moisture content 14% w.b. The zone of cold grain moves slowly in the same direction as the flow of the air. The presented values, although they are typical, are only examples. Humidity Ratio in this example increased only 0.1 (g water vapor / 1 kg dry air).

<u>Aeration</u> – This is the forcing of a slow movement of air through the deep bed of preserved dry grain aiming mainly at eliminating the temperature difference between parts of the bulk of grain that we often observe in **<u>long-duration storage.</u>** Such a difference in temperature is unfavorable, because of local moistening and risk of deterioration of grain. The temperature and humidity differences in the bulk of grain are dangerous because they initiate a very slow air movement in inter-granular spaces. The moving air carries moisture and deposits it onto the grain in the coldest places of the deep bed. The stored moisture, over several weeks, starts the life-processes of grain and associated microorganisms, leading to the spoilage of grain as was explained in Chapter 1 of the handbook.

3.2. DEVICES FOR GRAIN VENTILATION

<u>Question 3.2.</u> With what devices should a store be equipped to provide a safe way to ventilate grain?

To make ventilation safe and effective, sufficient air, both dry and cold, should be provided so that in every part of the deep bed of grain the flow of air is achieved. In any area where the air does not flow, grain may deteriorate. Here are the most important devices with which every store of grain (silo or flat) should be equipped:

1. Fan, also called a blower.
2. Devices that lead compressed air from the fan to the bulk of grain, most often perforated floor or perforated ducts.
3. A Measuring-Control Device (MCD).

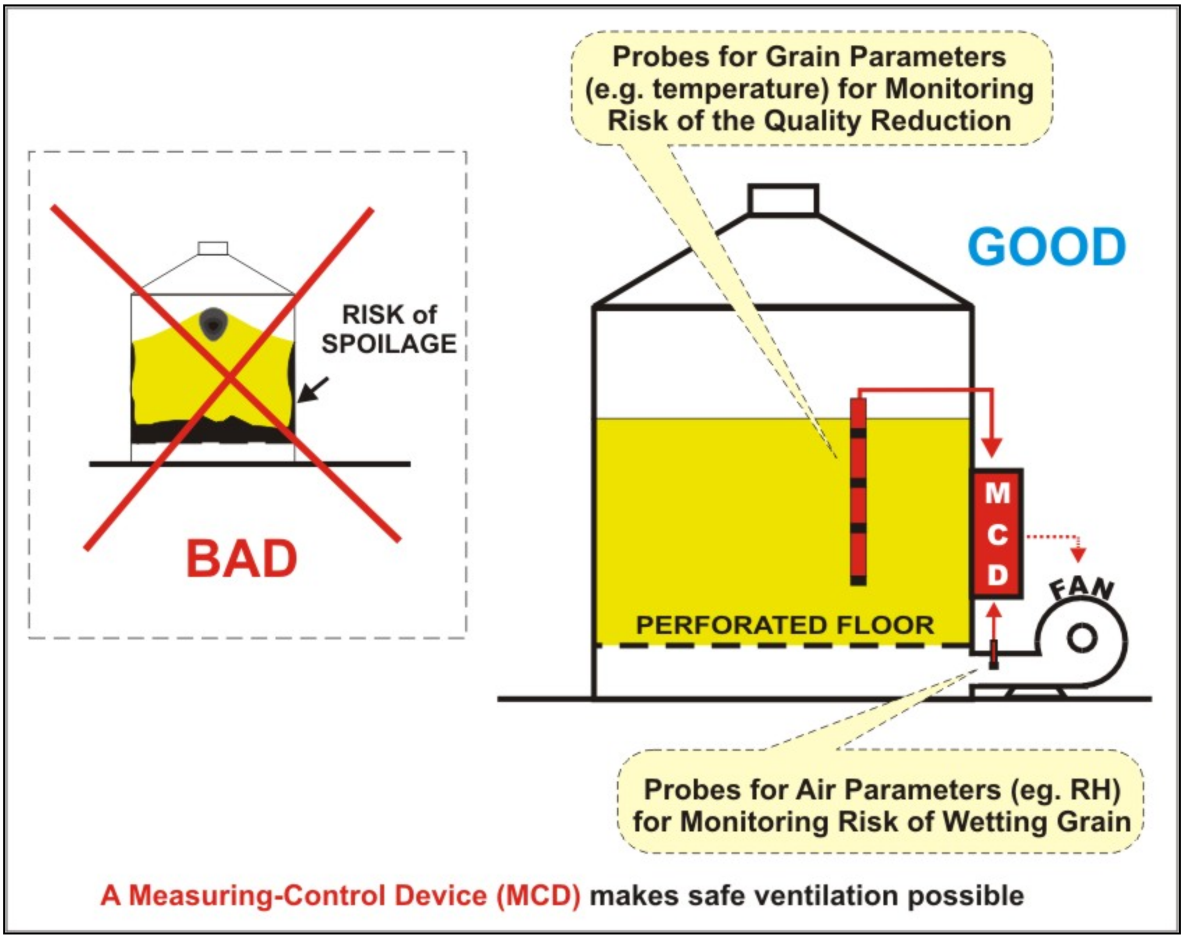

Figure 3.3. The set of devices enables the preservation of dry grain with a near-ambient method.

Presented in Figures 3.3 and 3.4 is the set of devices that enables the conservation of dry grain with the near-ambient method, using the cooling potential of atmospheric air. This kind of device has become popular in many countries around the world, for example in the European Union or North America. It is a part of the equipment of most farms in these countries. It became popular when combine harvesting was adopted because that was when problems concerning post-harvest maturation in grain stores first appeared.

<u>FAN</u> or blower has to be selected precisely, to assure an appropriate flow of air through the deep bed of grain, taking into account the surface area of the store and the thickness of the deep bed. In practice, the following airflow ventilation rate the fan should deliver is recommended.

For grain crops of moisture content below 15% w.b., a ventilation rate of **20 m^3/(h·t) [cubic meters of air blown per hour for every tonne of grain].** This is an ISO recommendation for European countries (ISO 34/4/2 N 125). Earlier in Poland a ventilation rate of 10 m^3/(h·t) was recommended. In a colder North-American climate of the prairie smaller ventilation rates of air are recommended, about 6 m^3/(h·t). The smaller the ventilation rate, the longer the cooling of the deep bed.

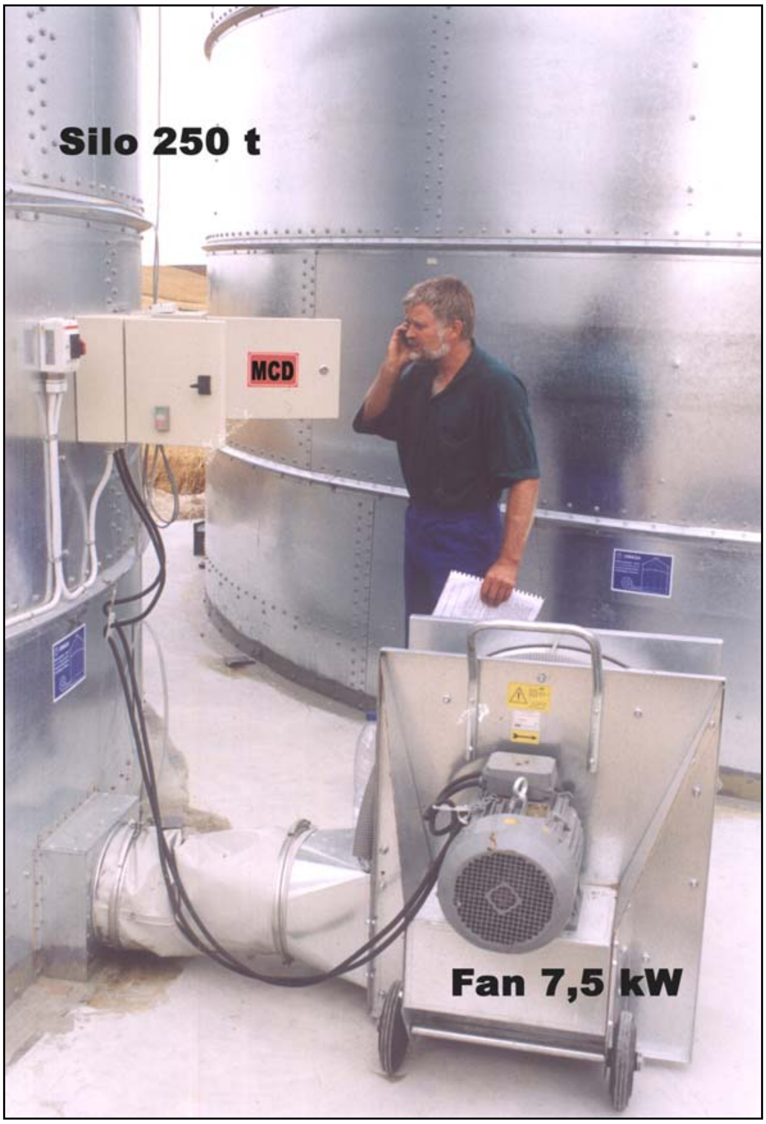

Figure 3.4. Example of devices enables the preservation of dry grain with a near-ambient method (courtesy the KBN company, Esbjerg, Denmark).

To determine a ventilation rate, also called the specific airflow rate (q) in m^3/(h·t), the formula is usually used: q = Q/m, where: 'Q' is the volume flow produced by a fan in m^3/h, and 'm' is the mass of ventilated grain in tonnes. Knowing the recommended airflow rate and the mass of grain in the store, the necessary volume flow that the fan should deliver to the store floor can be calculated (Ryniecki and Szymański 2002). For example, for a 100-tonne store a fan would have to deliver the following quantity of air to the store floor: 100 t multiplied by 20 m^3/(h·t) = 2000 m^3/h, divided by 3600 seconds that is in one hour = 0.56 m^3/s. Knowing the area of a floor, an average air speed across the store floor can be calculated. For the previous example, assuming the floor area is 23 m^2 (typical area of the 100 t silo) the air velocity should be: 0.56 m^3/s divided by 23 m^2 = 0.024 m/s. Moreover, knowing the geometrical measures of the ducts and the bed depth of grain the necessary pressure the fan should deliver can be calculated.

The air velocity across the store floor, calculated above, is used mainly for aeration of dry grain in order to eliminate the temperature differences in the bulk of grain in long-duration storage. Higher velocities of air should be used to cool down the grain in the post-harvest period. They can be as large as those used in near-ambient drying, e.g. 0.07 m/s. A good practice is to use one fan with a Y-connector equipped with throttles, connected with two silos to provide the proper airflow rate for drying grain in one of the silos or the proper airflow rate for cooling grain in both silos simultaneously – the example of connection is shown in Figure 3.5.

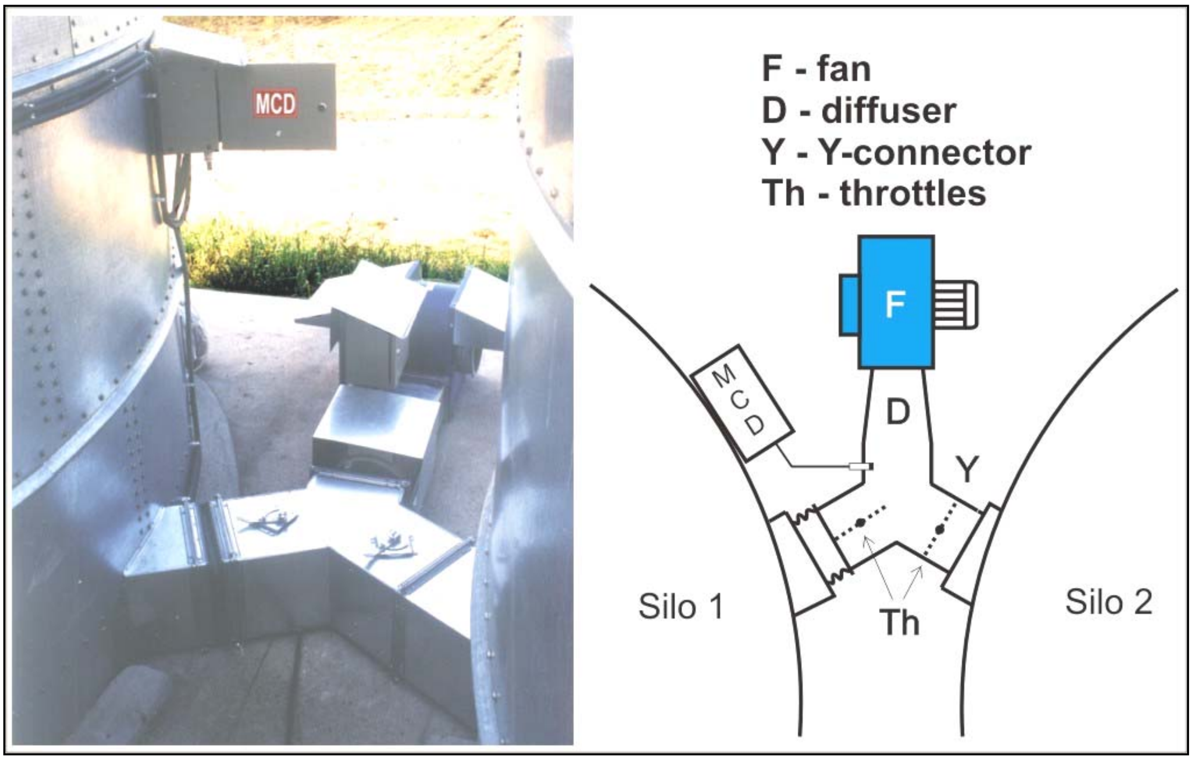

Figure 3.5. Example of connection of one fan with two silos using a Y-connector and throttles. This can provide the proper airflow rate for drying grain in one of the silos or the proper airflow rate for cooling grain in both silos simultaneously; "MCD" means Measuring-Control Device.

PERFORATED FLOOR or perforated ducts (sometimes only perforated drainage pipes) should enable a even delivery of air to the bulk of grain. The most even distribution of air is given by a floor, perforated over its whole surface. Partly perforated floors or ducts have some practical advantages but air movement through the grain may be less uniform. Air delivered by the fan to the floor below the deep bed of grain flows up through the inter-granular spaces. The objective is to ensure the air flows equally through the whole area, so that it can reach every part of the bulk, and remove heat and humidity from the store. An even distribution of flow of air through the whole surface of the deep bed has to be enabled, hence several things inside a silo have to be taken care of:

• density of the crop (grain and some foreign material) has to be equal in the whole bulk of grain,
• the top layer of the deep bed has to be leveled (Figure 3.6).

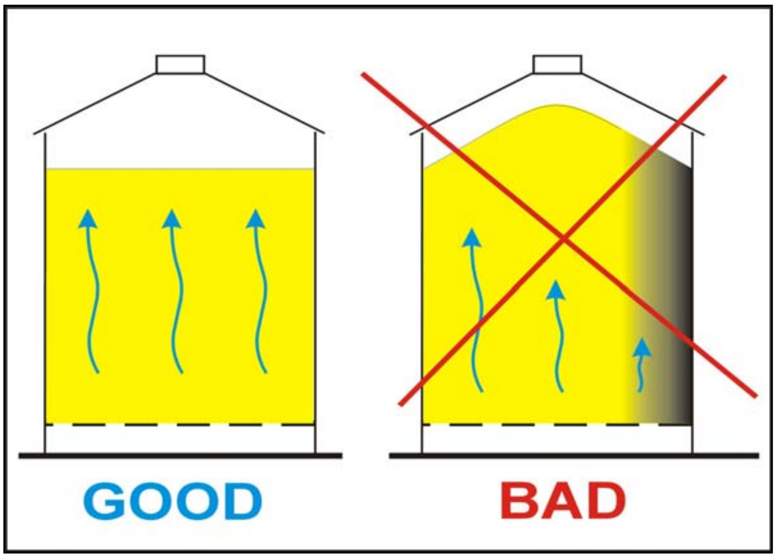

Figure 3.6. An even distribution of flow of air on the whole area of the bulk has to be enabled: 1) crop has to have even density in whole space of a silo (crop should be evenly spread throughout the bin) and 2) the grain depth has to be leveled in a silo.

Before loading the grain inside the store the grain has to be cleaned, with the use of a grain cleaner. During loading to a silo or a flat store, care is necessary so that areas of higher density should not be formed because these are harder for the air to penetrate. This is particularly likely to happen when foreign materials are present. In such circumstances small particles of foreign materials and smaller kernels have a tendency to gather in one place, forming a zone of higher density that the air does not ventilate. In consequence, that zone provides ideal conditions for mould growth and grain quality deterioration. Grain cleaners should remove cobs, stalks, husks, fines, chaff, weed seed, and dirt. Removal of these materials increases permeability to air so clean grain is less likely to spoil in storage.

To improve ventilation, devices for stirring the grain may be used. They look like drills and are slowly turning round using relatively small electric motors. The whole device is installed in the upper part of the silo or flat store. More about stirrers can be found in the next chapter.

3.3. MEASURING-CONTROL DEVICE (MCD)

Ventilation of grain should be controlled in order to avoid wetting of grain. As is already known from the previous part, wetting and risk of the grain quality deterioration takes place when the air relative humidity flowing through the bulk of grain is higher than the equilibrium humidity.

Controlling the process of ventilating grain to avoid wetting has been based some years ago on the so-called Theimer's table proposed in 1940's in Germany - presented here as Table

3.1. By using this table, one can be sure it is safe to turn on the fan. To make use of the table the following data needs to be collected, with the use of a measuring device(s):
• the plenum air temperature and relative humidity while the fan is running,
• the grain temperature and moisture content.
The sensors that collect the data need to be placed in specific areas, exactly as shown in Figure 3.3.

Table 3.1. Theimer's table for safe ventilation of cereal grain and rapeseed.

The temperature difference* between air and grain, [°C]	The highest allowable air relative humidity for ventilation seeds, [%]										
	Cereal grain moisture content, % w.b.										
	11%	12%	13%	14%	15%	16%	17%	18%	19%	20%	21%
	Rapeseed moisture content**, % w.b.										
		6.5%		8%		10%		12%		15%	
-8	78	90									
-7	73	84	96								
-6	68	79	90	100							
-5	63	74	84	93							
-4	59	69	78	87	95						
-3	55	64	73	82	89	96					
-2	52	60	68	76	83	90	95	100			
-1	48	56	64	71	78	84	89	94	97	100	
0	45	53	60	67	73	79	83	88	91	93	95
+1	42	49	56	63	68	74	78	82	85	87	89
+2	40	46	53	59	64	69	73	77	80	82	83
+3	37	43	49	55	60	65	69	72	75	77	78
+4	35	41	46	52	56	61	64	68	70	72	73
+5	33	38	44	48	53	57	60	63	66	67	69
+6	31	36	41	45	50	53	57	60	62	63	65
+7	29	34	38	43	47	50	53	56	58	59	61

* Minus means that air temperature is lower than grain temperature
** Rapeseed moisture content estimated based on the ERH shown in Fig. 2.4

The way to turn on/off the fan according to the table is as follows:

a) read the appropriate data from the measuring device(s);
b) calculate the difference in temperature between grain and air;
c) read from the Theimer's table the highest relative air humidity that is acceptable for ventilating and compare it with the air relative humidity read from the measuring device;
d) make a decision whether to turn the fan on or off: if the relative air humidity is lower than the acceptable level, it can be turned on – ventilating will be safe. Example: wheat grain has a moisture content of 14% w.b., air is colder than the grain by 4 °C, what shall we do? The fan can be turned on only when the air relative humidity is lower than 87%;

e) during the ventilation the difference between the temperature of grain and air will change, so the decision about turning the fan on or off should be repeated by following steps from a) to d) as often as necessary.

As can be seen, the need to repeatedly use Theimer's table is inconvenient and carries a risk of making a mistake. We suggest using a Measuring-Control Device (MCD), which automatically turns the fan on or off. Manual control is often not appropriate, especially when one would like to avoid mistakes, and when the grain needs to be ventilated by night. The Measuring-Control Device, popular in some European countries, the 'BIT' monitoring and control system, is presented on Figure 3.7.

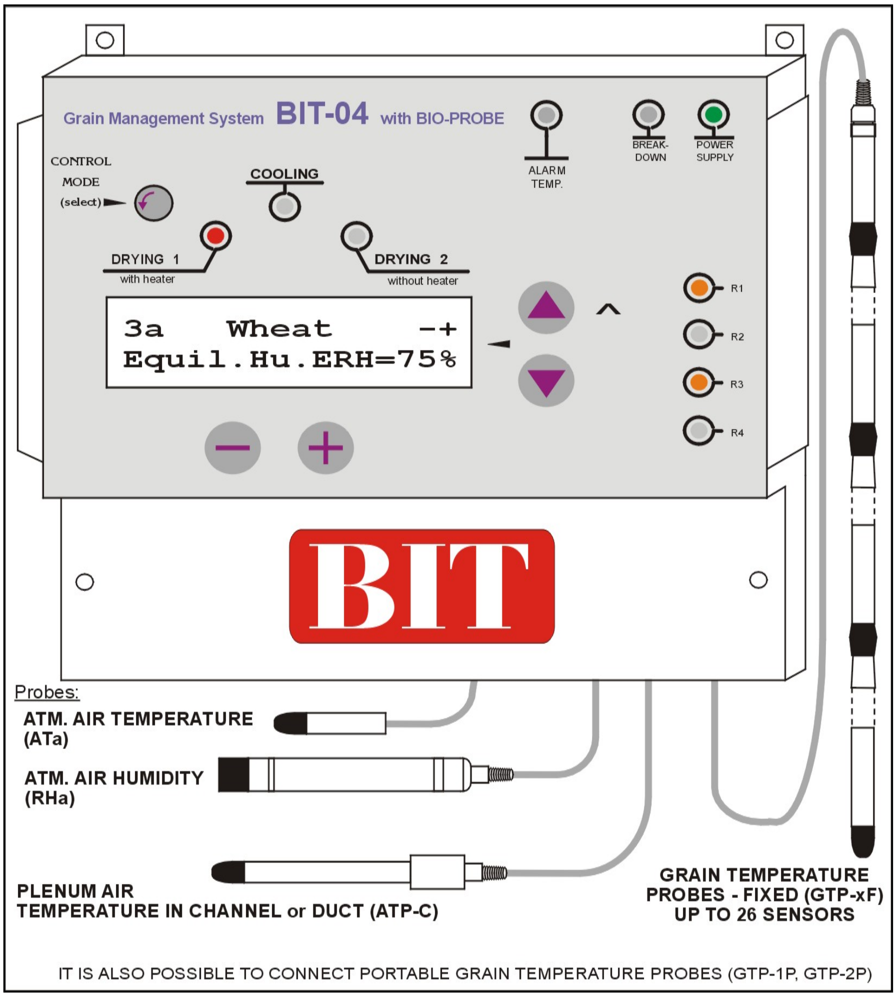

Figure 3.7. Example of the MCD - Measuring-Control Device, the 'BIT-04' – popular in some European countries.

The 'BIT' system measures both the grain temperature in the most important locations as well as the relative humidity (RH) of the air blown through the grain bed and takes into account the risk of rewetting the grain. Therefore, **the fan is switched on only when** the following 3 conditions are fulfilled simultaneously**:**

a) the temperature of the air blown in grain is lower than the temperature of the grain by the value of the factor that can be adjusted, **usually 2 – 5 °C**;

b) the relative humidity of the air blown in grain is lower than the equilibrium relative humidity (ERH). The ERH is calculated in the 2 seconds time intervals using the following information: a) temperature of the raw material measured on-line in chosen location, e.g. in the bottom part o the bed, b) the seeds maximum moisture content for safe storage (e.g. 14.5% w.b. for cereal grains, 7.5% w.b. for rapeseed), and c) set type of the stored raw material, which includes:

Wheat	Corn/Maize	Soybeans
Barley	Buckwheat	Durum wheat
Rye & Triticale	Flaxseed/Linseed	Hard red wheat
Oats	Beans	Sunflower
Rapeseed & Canola	Peas	Rice;

on top of it, the control system takes into consideration the change of air relative humidity after it enters the grain layer – in accordance with the relationships given by Theimer (that are based on the psychrometric terms);

c) cooling continues while the product **temperature is above 10 °C.**

Condition (b) was introduced in order to prevent dangerous rewetting of the grain during cooling. The biological activity of grain as well as microorganisms, insects and mites feeding on them is minimal at the temperature of 10 °C (Brooker et al. 1974) and that is why condition (c) was introduced. Further cooling would be unnecessary and could increase the risk of condensation in the springtime, e.g. when ambient air has high RH and temperature higher than grain temperature (it was explained in the Chapter 'Risk of wetting grain in bulk').

Apart from turning the fan on or off automatically during ventilation, the MCD can also provide important information during the whole period of grain storage, namely, it can inform about any temperature rise in the deep bed and about a risk of wetting of the grain, as presented in Figure 3.3.

Some MCD's, e.g. the "BIT-04" system, are provided with a bio-probe that informs the user about the allowable preservation and storage time of the grain (as shown in the Chapter 1) or so-called the quality maintenance indicator. The calculation uses a safe storage criterion based on growth of moulds in their latent form – before they become dangerous for the stored grain kernels. "BIT", in a semi-optimal way, enables the use of cooling properties of atmospheric air in the maritime climate, the continental climate and the climate that is the mixture of maritime and continental climates (most European countries).

3.4. SOME OTHER QUESTIONS

Question 3.3. What benefit does a transfer of grain between silos give?

Transferring grain between bins is used mainly in two cases. The first case occurs in long-duration conservation of dry and mature grain in stores where there is no possibility of ventilating the grain using a fan. The second case occurs when hot grain, transferred from a high temperature dryer, is cooled down in a bin. In both cases the aim of transferring grain between bins is to remove the gradients of temperature and moisture content in a bulk. Transferring grain between silos may be useful even after ventilating the grain using near-ambient conditions. It is useful in a situation where in a part of the deep bed some unwanted material is accumulated or when the operator is not sure that the flow of air is reaching all the areas of the deep bed. In areas where the air does not reach, zones of self-heating of grain may begin. In such a situation, transferring the grain to a different silo can help. Another method to even out the temperature and moisture content differences and to improve the conditions of grain ventilation is stirring of the deep bed, explained in the next chapter.

<u>Question 3.4.</u> I know that there is a possibility to chill grain with the use of refrigeration devices – is it necessary?

Refrigeration devices provide not only cold air but also dry air, so they are most advantageous in helping to achieve good storage conditions in a deep bed of grain. They are necessary where cold atmospheric air cannot be blown into the bulk of grain, e.g. in countries with a warm and humid climate. In the North and Central European climate, atmospheric air has enough cooling potential. It is not difficult to find periods of sufficiently low temperature to cool down grain with the use of the devices previously mentioned. Before making a decision about using refrigeration devices, investments costs should be taken into account.