2. RISK OF WETTING GRAIN IN BULK

2.1. THE RISK OF CONDENSATION OF WATER VAPOR IN A GRAIN STORE

Question 2.1. *How can the phenomenon of condensation of vapor in grain stores be explained?*

CONDENSATION OF VAPOR is a very frequent phenomenon in our domestic environment. From physics we know that it is the transition of water, present in the air, from a vapor state into a liquid state. Condensation occurs whenever air is cooled below a critical level called the dew point temperature or the saturation temperature.

If the air is in a state close to the saturation of water vapor, it only needs to be chilled by a few degrees for the condensation to take place. This is probably the simplest familiar example: condensation of water vapor in air we exhale on to a smooth surface, for example mirror, glasses, etc. In the respiratory ducts, air warms up to the temperature of the body and moistens almost to the point of saturation of water vapor. After chilling of the exhaled air, condensation is easily reached and is easily visible on smooth surfaces. The amount of vapor being condensed is directly proportional to the degree of chilling and the initial level of air humidity. The phenomenon of water vapor condensation is explained in psychrometry with the use of special charts, e.g. Mollier chart. Here we will make use of some conceptual models to help explain the main phenomena.

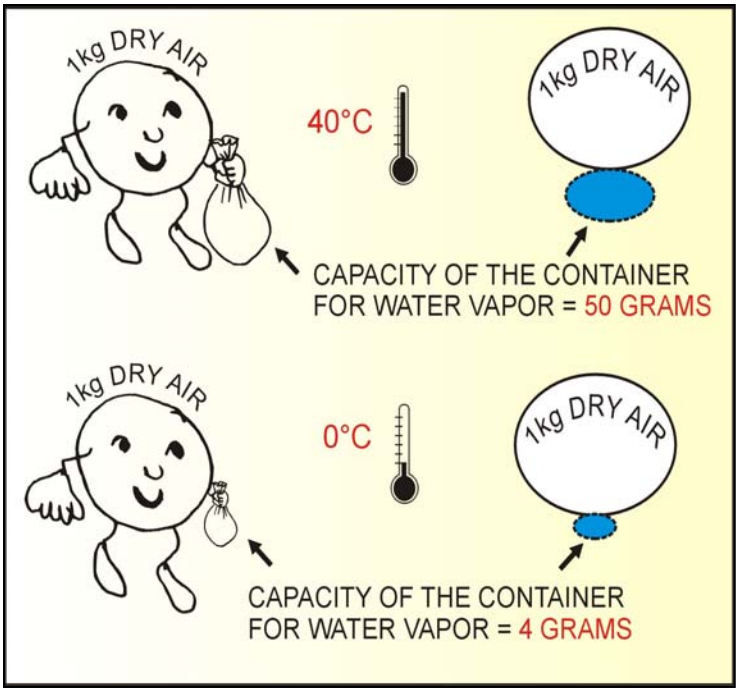

Figure 2.1. Conceptual models of moist air; dry air is carrying a container (e.g. a bag) with water vapor (not shown in proportion); capacity of container strongly depends on temperature.

The preservation medium used in drying and cooling crops is moist air. **Moist air is a binary mixture of dry air and water vapor. We say that dry air is a carrier for water vapor.** In Figure 2.1 moist air is shown as if dry air was carrying a container (e.g. a bag) of water vapor (the proportions shown are not accurate). The container (bag) for water vapor has a property that it grows together with the growth of temperature and it shrinks when the temperature falls. One kilogram of dry air with a temperature of 40 °C can 'carry' 50 grams of water vapor but the same kilogram with a temperature of 0 °C can carry only 4 grams. (It can be added that every kilogram of moist air saturated with water vapor at a temperature of 40 °C has a volume of 1.0 m^3, and at 0 °C only 0.8 m^3).

When air carries a maximum amount of water vapor that is possible to carry at a given temperature (in the conceptual model, the container is full up) we say that air is in a state of saturation or that the relative humidity equals 100%.

AIR RELATIVE HUMIDITY (RH)

From the Gibbs-Dalton law we know that atmospheric pressure ($P_{atm.}$), about 100 kilopascals (kPa), is the sum of 2 partial pressures: a) the pressure of dry air (P_a) and b) the vapor pressure exerted by the water vapor molecules in moist air (P_v) . By definition known in physics, the relative humidity is the ratio of the pressure of the water vapor contained in the moist air (P_v) to the vapor pressure in saturated air (P_{vs}) at the same temperature and atmospheric pressure ($RH = P_v/P_{vs}$), (Brooker et al. 1974) . The relative humidity of air can also be defined as the ratio of a mass of water vapor that is carried by a dry air sample to the maximum mass of water vapor that can be carried by the same sample of dry air in the state of saturation at the same temperature and atmospheric pressure (Figure 2.2). In connection to Figure 2.2 it can be added that the adjective "relative" means in relation to the total filling up of the container by water vapor.

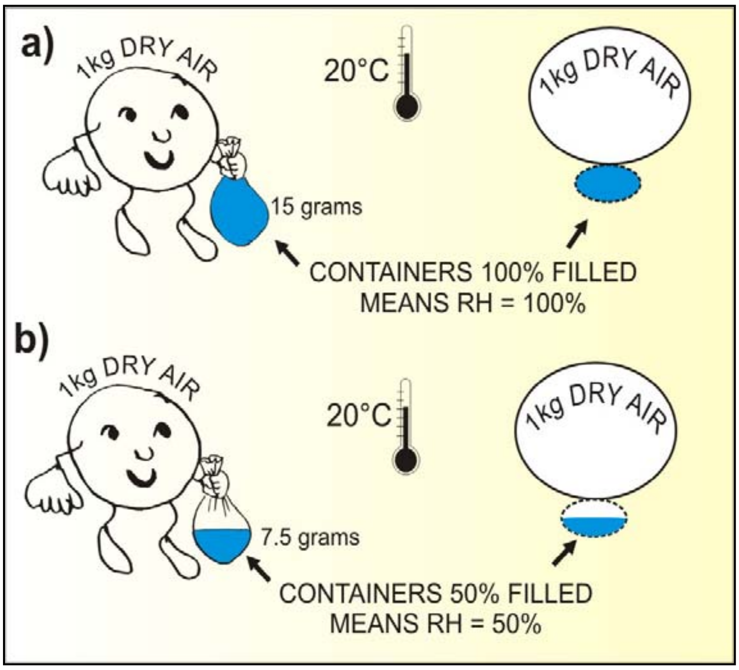

Figure 2.2. Relative humidity (RH) shown using conceptual models: the RH of air is represented by the volume of water vapor that fills the container in proportion to the total volume of the container expressed as a percent.

Question 2.2. How can the condensation of water vapor in the upper layer of grain and on the walls and ceiling of a silo be explained? What can be done to prevent it?

Condensation of water vapor in a grain store is most often visible during an intense, badly managed process of drying grain in a silo. It happens when the temperature of the air ventilating the deep, static bed of grain is too high, and in consequence the air leaving the static bulk of grain has too high a relative humidity in comparison to the ambient temperature. An example of an intense drying process is presented on Figure 2.3. It is assumed that the air blown into the thick bed of grain is heated to the temperature of 45 °C and its relative humidity is equal to 28%. Figure 2.3 presents a notional model of moist air, in which every particle of dry air carries a bag filled with water vapor (not shown in proportion). The bag shrinks as the temperature decreases.

Air that flows through the layer of grain meets with the wet grain kernels and transfers their heat onto them. The grain kernels use the heat to vaporize water from their surface which, in the form of water vapor, flows into the air. In this way air decreases its temperature and increases the amount of water vapor in it. As a result, where air leaves the deep bed of grain, the temperature is much lower (e.g. 30 °C) and the relative humidity much higher (e.g. 80%) in comparison with the temperature and humidity of air at the intake (Figure 2.3).

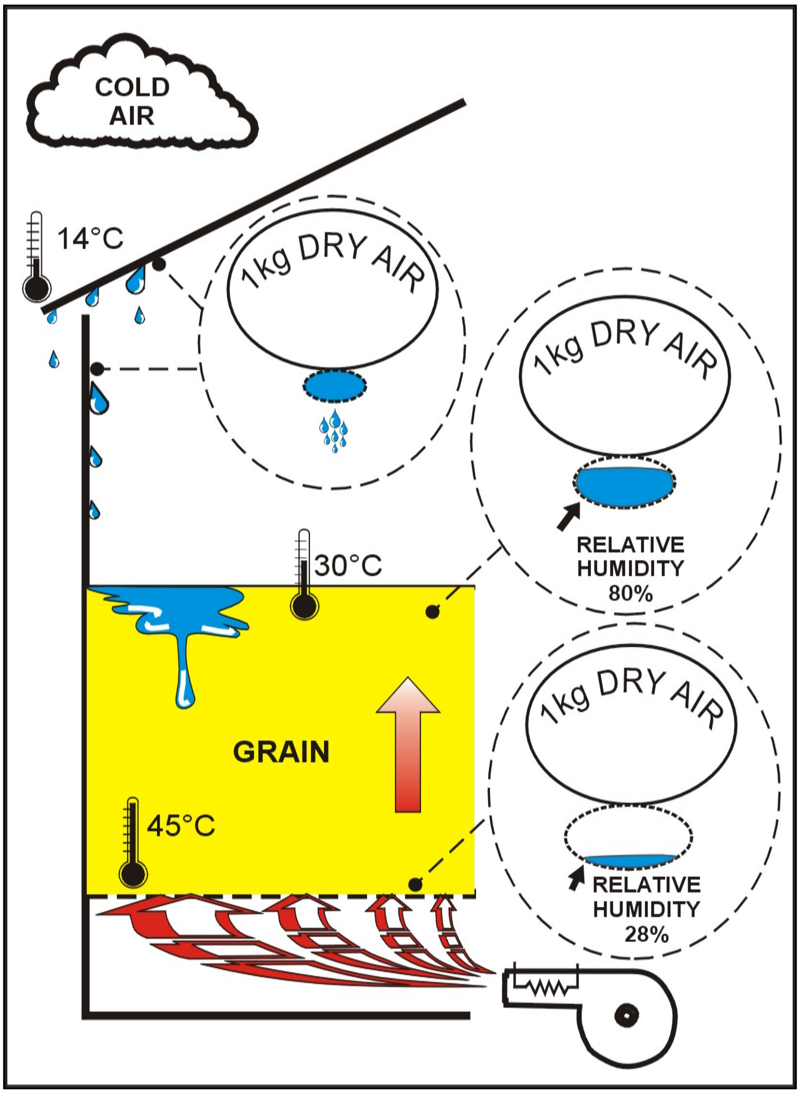

Figure 2.3. Condensation of water vapor on the inner walls of the silo is an effect of cooling down of air that is saturated with water vapor. Most frequently it occurs when drying is the result of an intense process of heating the air, and when low temperature air surrounds the silo. The presented values, are only examples. Each kilogram of air at the conditions shown, leaving the bulk of grain, has to lose 12.7 grams of condensed water.

After leaving the grain, the air on its way to the exhaust from the silo very often makes contact with colder walls and the ceiling. In the example

(Figure 2.3) it was assumed that the temperature of the walls and ceiling was 14 °C. When the temperature of the mentioned air cools down to 27 °C, it has reached dew point temperature which means its relative humidity equals to 100%. Further cooling of air has the effect of bringing about the change from water vapor to liquid water. Water vapor condenses on the ceiling and walls and can flow down or drop down to the grain. In the example the humidity ratio of the saturated air at 27 °C is equal to 22.7 (g vapor water / kg dry air) and at the temperature of 14 °C is only 10 g/kg, so each kilogram of dry air leaving the bulk of grain has to lose 12.7 grams of condensed water.

Condensation of water vapor onto grain can take place not only outside of the grain bulk, but **also inside**. This happens when the air temperature falls below the dew point temperature while it is still inside the bed of grain.

What can be done to prevent wetting of grain with condensed water vapor inside the grain store? Here is the most important advice:

1. As shown by the foregoing illustrations, problems arise in conditions that tend to overfill the 'water vapor bag' inside the store. This happens when: a) the temperature of the air blown into the deep bed of grain is too high so that the exhaust is near saturation, b) the temperature of air at the exhaust is too high in relation to the ambient temperature or, c) the air flow through the deep bed is too slow.
2. The rules concerning the construction of grain stores and matching of the fan, heater and the control device must be kept. Here, the most important recommendations are provided:

(a) **the higher the initial moisture content of the grain, the lower should be the depth of the bed of grain**;
(b) in stores where intense drying is taking place, one should install above the bed of grain (e.g. on the ceiling) some extra exhaust fans;
(c) faster drying of a static deep bed of grain, if this is required, should be a result of an increased flow of air through the bed of grain, not an increase in the drying air temperature.

2.2. THE RISK OF WETTING DURING FORCED VENTILATION

Question 2.3. *What humidity should the air have for the grain to be safely ventilated?*

The shortest answer would be: one should not allow the grain to be wetted. This means that the relative humidity of air going through the bed of grain should be lower than the so-called equilibrium air humidity. This new concept will be explained.

Forced or active ventilation of grain using air with temperature close to that of the ambient temperature is the core of near-ambient methods of preservation: drying, cooling and aeration. The most popular set of devices is: blower, measuring-control device and possibly a heater.

Near-ambient methods of preservation of grain are potentially cheap because they use the natural drying and cooling proprieties of atmospheric air. These, very profitable properties of atmospheric air appear in the European climate, although conditions are also sometimes unfavorable. The idea of near-ambient preservation was known long ago. However it could not be applied properly in the European climate due to a lack of measuring-control devices that could eliminate a risk of wetting and moulding of grain. The risk of moistening the grain is high and the negative effects so important that they need to be known. The key to understanding is the notion of:

EQUILIBRIUM RELATIVE HUMIDITY OF AIR (ERH)

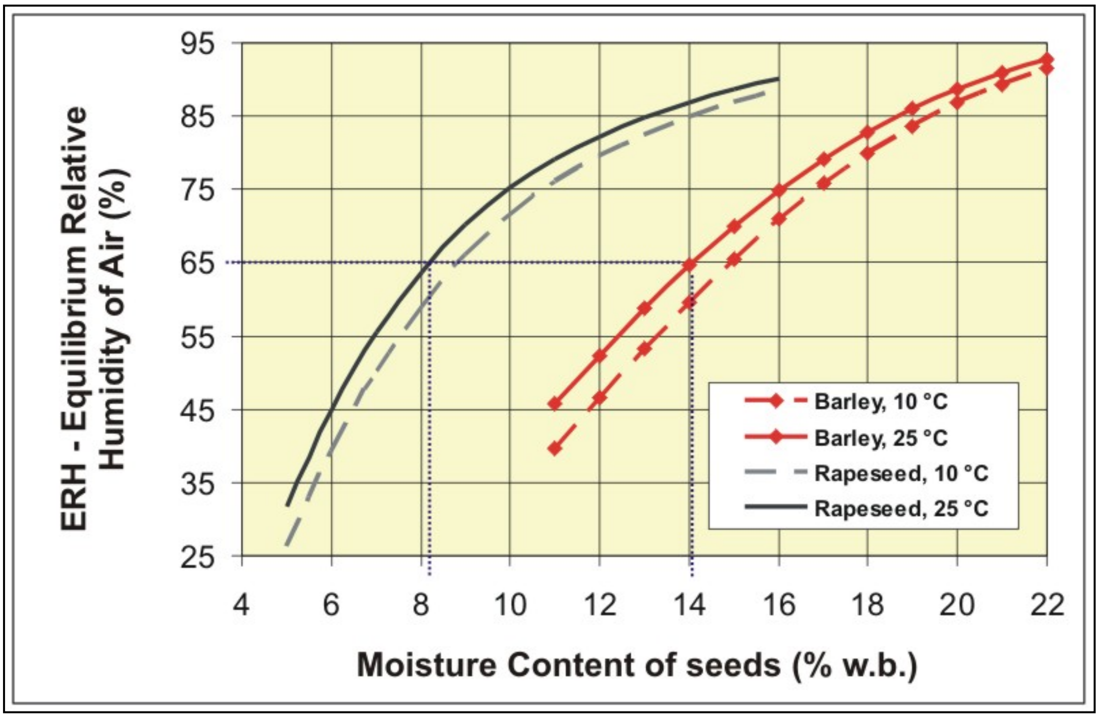

Figure 2.4. Equilibrium relative humidity of air (ERH) shown for oilseed rape and for barley, which is similar to the ERH values for other cereal grains; ERH was calculated from Modified-Halsey equation (rapeseed) and Chung-Pfost equation (barley) using the ASAE Standards 2000. The value of the ERH of 65% that is shown in Figures 1.4 ÷ 1.7, which corresponds with moisture content of 14.1% w.b. for barley in temperature of 25 °C (dotted lines), corresponds for rapeseed with moisture content of 8.2% w.b. only, and it is a consequence of its high oil content.

Let us try to imagine what is happening inside the ventilated thick layer of grain. In the space between every single grain kernel and air a **constant flow of water vapor takes place**. Moisture flows from the kernel to the air, when the air in the inter-granular spaces has an appropriately low relative humidity. If the relative humidity is high and higher than the critical level, the flow of moisture from the air to the grain kernels takes place. This critical level is the equilibrium grain-air humidity, or simply equilibrium air humidity.

When the air humidity in the spaces between the grain kernels is equal to the equilibrium humidity we deal with a drying equilibrium. At that time the grain moisture content does not change.

On what does the equilibrium air humidity depend? It depends mostly on the current moisture content, temperature and internal structure of the grain kernel. Kernels have porous structures. Differences in structure between different types of grain kernels can be observed. Special tables or mathematical formulas give the value of equilibrium air humidity for different types of grains and other plant materials. In Figure 2.4 curves of equilibrium humidity of air for cereal grains and rapeseed are shown.

Let us compare the equilibrium humidity with the relative humidity of air in the climate that is the mixture of maritime and continental climates in the post-harvest period. In Figure 2.5, changes in relative humidity of air in comparison with the equilibrium humidity, calculated for seeds of the maximum moisture content for safe storage (e.g. 14.5% w.b. for cereal grains, 7.5% w.b. for rapeseed) and a temperature equal to that of the ambient, are shown.

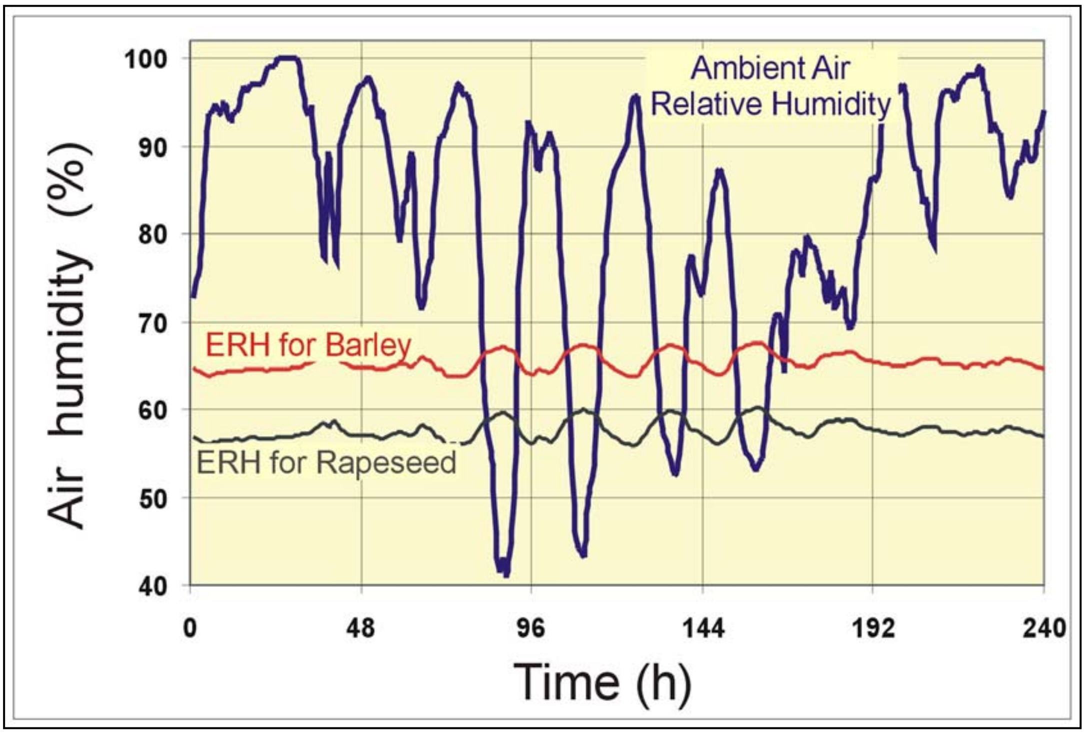

Figure 2.5. Risk of wetting cereal grains and oil seeds during forced ventilation in the so-called 'wet' year; Weather data from meteorological station in the climate that is the mixture of maritime and continental climates in Poznań, Poland; Equilibrium Relative Humidity (ERH) shown for oilseed rape and barley, which is similar to ERH for other cereals; ERH was calculated from Modified-Halsey equation (rapeseed) and Chung-Pfost equation (barley) using ASAE Standards 2000.

The graph shows that the relative humidity of the ambient air is almost always higher than equilibrium humidity (ERH). Then a risk of wetting the grain is present. The equilibrium air humidity was marked on the basis of data from a meteorological station Poznań, Poland from a post-harvest period of 1977. It was a typical year of wet harvests.

Can you dangerously wet grain also in dry years? In 'dry' years periods also occur, most often during the night hours, where the relative humidity of air exceeds this critical level, the equilibrium humidity. Moreover, grain can be easily wetted by blowing air that is warmer than the grain with a relative humidity close to the level of equilibrium humidity. The relative humidity of such air will rise after being chilled in the thick layer of grain and can quickly pass the equilibrium humidity level. After a significant refrigeration of air, condensation of water vapor in a store can take place, as explained above. And it is much easier to wet the grain than to dry it out. Wetting of grain provides ideal conditions for the development of any living organisms, e.g. toxin-producing moulds. **It is necessary to use control devices for safe preservation of grain.**

2.3. THE RISK OF WETTING DURING STORAGE OVER LONG PERIODS

Question 2.4. Why was a considerable part of the grain wet and mouldy when observed during unloading of the store in spring? The post-harvest conservation of grain was done well.

Even after correct drying and cooling of grain, it cannot be forgotten for long periods. Some people are of the opinion that in the deep bed of grain no changes will occur. They are not right. Theoretically it could be so if the storing conditions did not change. Unfortunately the conditions do change, as a result of changes in temperature outside the store. In long-duration storage the fall of ambient temperature during winter and its rise in spring in comparison to the grain temperature is important. Differences in temperature caused by heating of the southern wall of the store by the sun are also very dangerous.

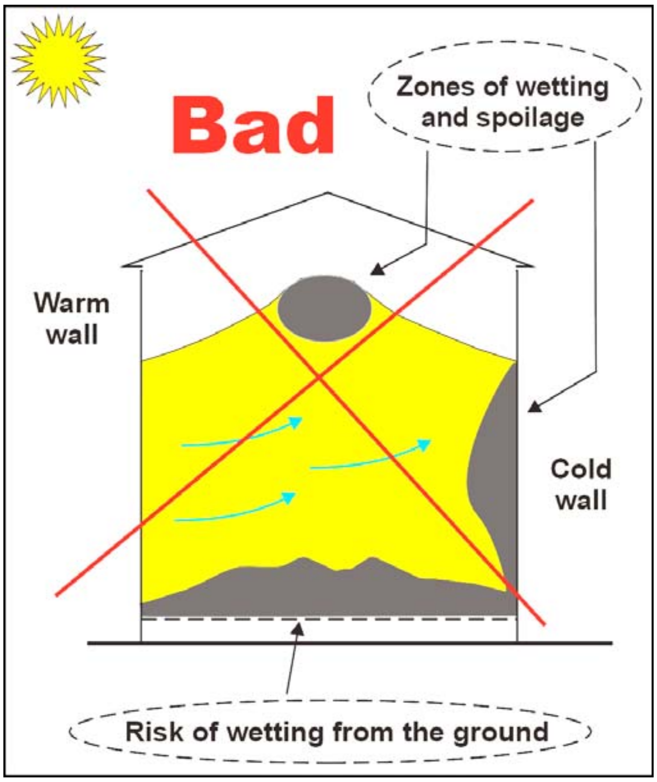

Figure 2.6. Risk of wetting grain during long-term storage.

In a situation where a temperature difference inside the stored layer of grain is higher than 5 °C a slow movement of air in the spaces between grain kernels can be measured. Part of the air movement is from the warmer parts of the deep bed to the colder ones. This air carries a small amount of moisture which it returns to the grain in the colder parts (due to cooling). A typical situation is presented in Figure 2.6, where a slow movement of air in the spaces between grains is marked using arrows. As a result the warmer parts are slightly dried whereas the colder ones are slightly moistened. In the moistened parts of the deep bed, biological activity is speeded up by the moisture in, among other things, toxin moulds. If this phenomenon is not prevented, in time it will lead to deterioration or lowering the quality of the wetted layers of grain.

A second reason for wetting and moulding the lower parts of the deep bed can be moistening of the space under the perforated floor on which the deep bed of grain lies. This moistening can be an effect of water flow under the floor or of bad isolation of the foundation (Figure 2.6).

A question arises of how to proceed with the deep bed to prevent wetting during long-duration storage. Most important is periodical aeration of grain in a safe way. Safe ventilation in this case has to be: a) very gradual, especially when we blow in air that is warmer than the grain itself and b) controlled in a way to prevent wetting of grain.