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Chapter 7 Climate and environmental control

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Introduction

The quality of the environment in agricultural buildings includes such factors as temperature, light, moisture, air quality and movement, dust, odours, and disease agents. Environment affects animal comfort and health and ultimately production. It also influences the quality and longevity of stored products. From an engineering standpoint, environment can be closely controlled. However, economic factors often limit the extent to which control can be justified.

The particular region of the nation and the resulting climatic zone will influence the manner in which environmental requirements are met. A humid area may require homes with open construction to provide continual ventilation for comfort, whereas an arid region may need buildings of great thermal capacity to protect against daytime heat, and night chill.

As a general rule Tropical Climates are found within the tropics. However, the influence of the climate on structures makes the techniques used applicable to many regions outside the tropics, e.g. the middle east.

The following brief discussion of Africa's climatic zones is general and can be found worldwide in the tropics. It illustrates the wide variety of situations with which engineers are faced in designing environmentally suitable buildings for people, animals and products.

Climatic zones

There are several climatic zones on the African Continent with widely varying characteristics.

1 Low-latitude, wet equatorial: High rainfall, humid and close to 27C mean temperature throughout the year. Congo Basin.

2 Monsoon and Trade-wind bittoral: Climate dominated by trade-winds. Maximum rain in high sun season; minimum following low sun season. Intense showers in eastern coastal zone. Warm throughout the year. Central and Western Africa and East Coast.

3 Wet-dry tropical: Typified by very wet high sun season and very dry low sun season. West and Southern Africa.

4 Dry tropical: Characterized by extreme heat at high sun season and cool at low sun periods. Gradually changes from arid to semi-arid and into wet-dry tropical zone:

Sahara, South Africa.

5 Dry subtropical: A north-south extension of the dry tropical zone. Greater annual temperature range: North and South Africa.

6 Altitude modified wet-dry tropical: Increases in altitude generally result in an increase in precipitation and a reduction in mean temperatures. Precipitation is seasonal and varies from 500 to 1500mm depending on local conditions. Inland East and South-east Africa.

Climate can also vary greatly over relatively small areas, in particular where the country is hilly.

For design purposes, local climatic data from a nearby meteorological station should be obtained if possible.

A thorough knowledge of heat transfer, air-moisture temperature relationships and ventilation, combined with a knowledge of climatic conditions and the environmental requirements of animals and farm products, enables the engineer to design the best possible systems within economic constraints. For example, the maximum control reasonable for a cattle herd might be some artificial shade, whereas a high value fruit crop might justify the expense of a refrigerated storage.

Heat terminology

Heat is a form of energy. The molecules of a body are in constant motion and possess kinetic energy referred to as heat.

Temperature is intensity of heat i.e., the velocity of the molecules. In the Sl-system it is measured in degrees Celsius (centigrade) or Kelvin (absolute).

Ambient temperature is the temperature of the medium surrounding a body, e.g., air temperature within a building.

Quantity of heat is measured in Joules. One calorie of heat will raise one gram of water 1 Kelvin. This equals 4.1 87 Joules.

Sensible heat is the heat that causes a temperature change when there is a heat transfer, e.g., heat moving through the walls of a home causing a temperature rise.

Latent heat is the heat that causes a change in state but no change in temperature, e.g., heat that is absorbed when ice changes to water or when boiling water changes to vapor. However, water will evaporate to vapour over a wide range of temperatures. When air moves across the surface of water, some of the air's sensible heat is converted to latent heat causing the air temperature to drop. The latent heat of vaporization changes with temperature:

C ....kJ/ kg

0 2500

30 2430

100 2256

Thermal capacity is the ability of a material to absorb and hold heat. It is measured in J/(kg.K). The thermal capacity of water is 4.187 kJ/(kg.K) or 4.187J/(g.K).

Specific heat is the dimensionless ratio between the thermal capacity of a material to that of water. However the actual thermal capacity measured in J/(kg. K) is often listed as specific heat.

Total heat content. Bodies with great mass can store large quantities of heat, even at low temperatures, e.g., thick masonry walls are slow to warm up in the heat of the day and slow to cool down during a cool night. A match has a high temperature and little heat content. A large tank of water may have a low temperature but still have a large heat content.

Heat transfer

Basic to any discussion of insulation and ventilation is an understanding of the way heat is transfered. Heat moves from place to place by conduction, convection, radiation or some combination of these modes whenever a temperature difference exists.

Conduction

In Conduction, heat energy is passed from molecule to molecule in a material. For heat to be conducted it is essential that there be physical contact between particles and some temperature difference. Thermal conductivity is a measure of how easily heat is passed from panicle to particle. The rate of heat flow depends on the amount of temperature difference and the thermal conductivity of the material.

Convection

Heat is transferred by convection when a heated liquid or gas, often air, actually moves from one place to another, carrying its heat with it. The rate of heat flow depends on the temperature of the moving fluid and the rate of flow. Convection transfer can occur in any liquid or gas.

Radiation

Heat energy can be transferred in the form of electro-. magnetic waves. These waves emanate from a hot body and can travel freely only through completely transparent media. Heat cannot move by radiation through opaque materials, but instead is partially absorbed by and reflected from their surfaces. The atmosphere, glass and translucent materials pass a substantial amount of radiant energy, while absorbing some and reflecting some. Although all surfaces radiate energy, there will be always be a net transfer from the warmer to the cooler of two surfaces facing each other.

Thermal resistance of building components

The calculation of temperatures within buildings or of heating and cooling loads requires a knowledge of the thermal conductivity, specific heat capacity, and density of the materials of construction. The thermal resistance of air films adjacent to surfaces and, of air spaces are also required and as the latter are dependent on the emittances of surfaces, data on these parameters are also needed.

Table 7.1 contains a list of materials with their thermal properties. The thermal resistance, which is the quotient of thickness and thermal conductivity, has been given and where appropriate, for material thicknesses most commonly used. As there is a linear relationship between thickness and thermal resistance in most cases, other values are readily calculated.

This may not be the case for granular materials when the grain size becomes comparable with the thickness and therefore caution should be shown when assigning resistance values to such materials.

Insulating Materials

The choice of an insulating material will depend on the application, availability and cost. Loose granular materials work best when installed above a ceiling or poured into existing wall cavities. Batting or blanket materials are easiest to install as walls are constructed. Rigid insulating boards may be placed under concrete floors or cemented to masonry walls.

Reflective surfaces such as aluminium foil or paint are most effective when exposed and not in contact with other materials. They are also more effective in preventing the downward flow of heat and in relatively high temperature applications.

Local natural materials such as straw, shavings, coffee hulls, etc., although not as high in resistance to heat flow as commercial insulations, may be the material of choice because of availability and low cost. A greater thickness will be required when using the natural materials and they may not be as fire and vermin resistant.

Surface Resistances

The values of surface resistances are influenced by several factors, the most important of which is the rate of air movement over the surface. Values for 3m/ s and 0.5m/ s of air movement and for still air are shown in Table 7.1.

Thermal Resistance of Pitched-Roof Spaces

The calculation of U values for a roof-ceiling combination requires a knowledge of the resistance of the airspace between the ceiling and the roofing material. Resistance values are given in Table 7.2 for four design combinations.

Overall Heat Transfer Coefficients

Table 7. 1 ***Thermal Properties of Building and Insulating Materials***

Material **(Thickness used)**	**Density** **kg/m**	**Conductivity, C**		**Resistance**		**Sp. Heat** **J/(kg K)**
		per m	**As Used**	**Per m**	**As used**	
		W/(m.K)	**W/(m.K)**	**(m.K)/W**	**(m.K)/W**	
Air Surface - Still	1.2		9.09		0.11	1012
0.5 m/s	1.2		12.50		0.08	1012
3.0 m/s	1.2		25.00		0.04	1012
Air Space, Wall,						
Dull Surface	1.2		6.25		0.16	1012
One shiny surface (See Table 7.2 for Ceiling spaces)	1.2		1.64		0.61	1012
Asbestos-Cement Board, 6mm	945	0.19	33,33	5.26	0.03	840
Bark Fiber	48	0.045		22.22		1700
Bitumin Floor	960	0.16		6.25		1470
Brick, Adobe, 300mm			4.17		0.24	300

Common, 110mm	1760	0.65	5.88	1.53	0.17	920
Concrete, solid, dense	2400	1.45		0.69		880
solid coarse	2000	0.91		1.10		800
hollow block 100mm	1450		7.69		0.13	880
200mm	1375		5.00		0.20	880
Sand and sawdust	1600	0.65		1.54		300
Coconut Husk Fibre	48	0.53		1.89		
Gypsum Plaster, 15mm	1220	0.37	2.44	2.70	0.041	1090
Gypsum Board, 15mm	1220		12.50		0.08	1090
Mortar, cement, 15mm	2000	1.12	76.92	0.89	0.013	795
Plywood, 5mm	530		12.50		0.08	
Polystyrene, 38C	16	0.039	0.78	26.64	1.28	340
-18C	16	0.030	0.60	33.33	1.67	340
Polyurethane, 50mm	24	0.025	0.50	40.00	2.00	450

Rockwool or Glaswool, 50mm	32-48	0.033	0.66	33.30	1.52	900
Soil, 14% moisture	1200	0.37		2.70		1170
Straw, 50mm	75-200	0.042	0.81	23.81	1.24	1050
Shavings	190	0.06		16.67		
;Tile, Clay roof, 19mm	1920	0.84	43.48	1.90	0.023	920
Timber, Pine radiate, 25mm	506	0.10	4.00	10.00	0.25	2090
Water	1000	0.60		1.67		4190

The overall heat transfer coefficient or thermal conductance, U. is the rate of heat transfer through a unit area of a building element (wall, ceiling, window, etc.). When the building element is made of two or more different materials, the U value is calculated as the reciprocal of the sum of the resistances of the individual components of the elements as expressed in the equation:

$R = t / c$

$R_T = R_{si} + R_1 + R_2 + \ldots + R_{so}$ **where:**

$U= 1 / R_T$

R =Thermal resistance of each homogenous material making up the building element.

R_T = Resistance to heat flow through a composite element.

R_{si}, R_{so} = Thermal resistance of inside and outside air surfaces of the building element.

U = Overall coefficient of heat transmission (air to air)

Using values from Tables 7.1 and 7.2 overall heat transfer coefficients (U) have been calculated for a number of composite wall and roof constructions. Although estimates were necessary for some materials, the U values are realistic. Table 7.3 shows several of the construction units.

The effect on U values and overall heat transfer of timber and metal frames in walls is in the order of 5% and may usually be ignored. However, local effects may be observed. The more rapid heat loss through the framing of a heavily insulated wall may result in a low enough wall temperature adjacent to the framing locations to cause condensation.

Table 7.2 ***Therrmal Resistance of Pitched-Roof Spaces***

	Resistance (m K/ W)		
	Direction of heat	**High**	**Low**

	flow	**emittance surfaces***	**emittance surfaces****
Ventilated	Up	nil	0.34
roof space	Down	0.46	1.36
Non-ventilated	Up	0.18	0.56
roof space	Down	0.28	1.09

*** dull, dark surfaces ** shiney, light surfaces**

Table 7.3 Overall Heat Transfer Coefficients, U

Table 7.3 Overall Heat Transfer Coefficients, U

Rate of overall heat loss or gain from a building

Once the U values have been calculated for each element of the building (walls, ceiling, windows, doors, etc.), the area of each element is determined, and design temperatures for inside and outside are chosen. It follows then that for each building element:

$Q=A \times U \times \Delta T$ where:

Q = Total heat transfer rate through an element (W)

A = Area of building element (m)

U = Coefficient of heat transfer for the element W/ (m. K)

∆ T = Temperature differential across element (K)

For the building as a whole the total heat exchange rate will equal the sum of the Q values. Total heat transfer in Joules for a given period may be found by multiplying kilowatts by 3.6 Megajoules times the number of hours. Figure 7.1 provides some rough approximations of maximum and minimum temperatures for design purposes. Temperature data for the immediate area in which the building will be constructed will provide the most accurate results.

Solar Load

In the countries of East and South-east Africa the effect of solar radiation can be appreciable during some seasons and at certain times of the day. The orientation, design, and materials used will all influence the amount of solar heat gain to which a building is subjected.

A method of determining the degree and extent of solar gain has been developed which is called sol-air. This concept provides a solar increment in the southern hemisphere to be added to the design air temperature used for horizontal roofs and northerly facing walls. These

increments range from 10 to 30C.

However, they apply for only a few hours per day and become of less significance if the building is designed to offset the effects of solar radiation. Two examples illustrate how this can be accomplished.

In an area of high diurnal-nocturnal temperature difference, the roof and walls of a building should be constructed of materials with a great deal of mass (adobe bricks or rammed earth). The resulting high thermal capacity will limit both daytime temperature rise and the nighttime temperature drop and thus the high solar-radiation effect is reduced to a minimum.

In the case of a refrigerated store, it would be desirable to use a roof design that allows attic ventilation and that is covered with a light-coloured reflective surface which when combined, will minimize the effect of solar radiation on the store to a minimum.

Figure 7.1 a Highest mean monthly maximum temperature (C).

Figure 7.1b Lowest mean monthly minimum temperature (C).

Example of Heat Loss from Buildings

Given: Two homes in Lesotho. One is constructed with adobe block walls and a thatch roof, while the other is made of hollow core concrete blocks with a sheet metal roof. Each house is 5 metres square, 2 metres high at the eaves, 3 metres at the ridge, has 1m of window and 1.5m

of timber door. Find the heat lost from each house when the temperature is 0C outside and is 15C inside.

From Table 7.3, the U value for a sheet metal roof is 3.03 W/(m.K); for a thatch roof, 0.26W/(m.K); for an adobe wall, 2.5W/(m.K); concrete block wall, 2.9W/(m.K), and single glass, 6W/(m.K).

The calculated U value for a 25mm timber door is 2.4W/ (m. K).

Q = A x U x Δ T

Thatched roof

Roof (5.4 x 5 = 27.0m)	27.0 x 15 x 0.26 = 105W
Walls 5 x 2 x 4 = 40.0m	
Gable ends + 5.0m	
Door and Window - 2.5m	
Total Wall	42.5m
Wall	42.5 x 15 x 2.5 = 1595W

Door	1 5 x 15 x 2.4 = 54W
Window	1.0 x 15 x 6.0 = 90W
Total Heat Loss	1844W
Metal Roof	
Roof	27 x 15 x 3.03 = 1227W
Wall	42.5 x 15 x 2.9 = 1849W
Door	1 5 x 15 x 2.4 = 54W
Window	1.0 x 15 x 6.0 = 90W
Total Heat Loss	3220W

It is obvious that much more heat must be supplied to the metal roof house. A Ceiling with 50mm of Rockwool or Glasswool would provide a substantial saving.

	R
Air layer	0.04
Metal	0.11
Air space (non Vent., dull)	0.18

Rockwool	1.52
Hardboard	0.08
Air layer	0. 11
R_T	2.04
W= 1 / R_t = 1 / 204 =0.49 W/(m.K)	
Heat losses	
Roof27 x 15 x 0.49	=198W
Wall	= 1849W
Door	= 54W
Window	= 90W
Total Heat Loss	2191W

Saving 3220 - 2191 = 1029W

While the "modern" house is almost as heat efficient as the traditional style house and should be more hygienic and durable, the traditional house can be constructed entirely from locally available materials and by local craftsmen and will thus require a minimum of cash expenditure.

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Psychrometry

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The earth's atmosphere is a mixture of gases and water vapour. An understanding of physical and thermodynamic properties of air-water vapour mixtures (psychrometrics) is fundamental to the design of environmental control systems for plants, crops, animals or humans.

Properties of Moist Air

Pressure, volume, density and thermal properties are related by the use of the laws for a 'perfect gas'. For a mixture of dry air and water vapour this law can be used with only negligible error at the range of temperatures and pressures used for environmental control.

$P = MRT/V$ where:

P = absolute pressure, Pa
M = mass, kg

R = gas constant, J/(kg.C)
T = temperature, K
V = volume, m

Dalton's Law each component in a mixture of gases exerts its own partial pressure, for a mixture of air (a) and water vapour (w).

$$P = P_a + P_a = (M_a \times R_a \times T_a) / V_a + (M_w \times R_w \times T_w) / V_w$$

Assuming a uniform mixture:

$$P = T / V (M_a R_a + M_w R_w)$$

When the volume and temperature of the mixture are equal the following is true:

$$P_W / P_a = M_w R_w / M_a R_a$$

Thus, if the total pressure and water vapour weight is known the partial pressures may be calculated.

Specific humidity (H) is the weight of water vapour in kg/ kg of dry air. It is sometimes called absolute humidity or humidity ratio. The base of one kilogram of dry air is constant for any change of condition, making calculations easier.

$$H = M_W / M_a = P_W V / R_W T = P_a V / R_a T = P_W Ra / P_a Rw = P_W Ra / (P-P_W)R_W$$

Relative humidity (RH) is the ratio of the actual water vapour pressure (Pw) to the vapour pressure of saturated air at the same temperature (Pwsat).

$$RH\% = 100\ P_W/P_{Wsat}$$

The vapour pressure at saturation (P_{Wsat}) is given in steam tables for different dry-bulb temperatures.

Specific volume is the volume of dry air per mass of dry air

Humid volume is the volume of an air-moisture mixture per mass of dry air. In ventilation calculations, the volume is in cubic metres of mixture (air + water vapour) per kg of dry air. The base of one kg of dry air is used because the kg of dry air entering and leaving the system in a given time will be constant once a steady-state flow is established. Humid volume increases as the temperature or water vapour content increases. The humid volume of air-water vapour mixtures is given in standard thermodynamic tables or may be read from a pschrometric chart.

Temperatures - air-water vapour mixtures can be described by the dry-bulb and either the wet bulb or dewpoint temperatures:

- **dry-bulb temperature is measured with a common thermometer, thermocouple or**

thermisters ;
- wet bulb temperature is the temperature at which water, by evaporating into moist air, can bring the air to saturation adiabatically in a steady - state condition;
- dew point temperature is the temperature at which moisture starts to condense from air cooled at constant pressure and specific humidity.

Enthalpy (h) is the heat energy content of an air-water vapour mixture. The energy is a combination of both sensible heat (indicated by dry-bulb temperature) and latent heat of vaporization (energy content of the water vapour). Enthalpy scales appear on pschrometric charts expressed as kJ/ kg of dry air.

Enthalpy can be calculated from the equation:

$h = S \times t_{db} + H \times h_w$ where:

S = Specific heat of dry air, 1004 kJ/(kg.K)

t_{db} = dry bulb temperature

H = Specific humidity

h_w = enthalpy of water vapour, kJ/ kg water vapour

Thus:

$h = 1.004 \times t_{db} + H(2454 + 1858 \times t_{db})$ kJ/ kg where:

2454 = latent heat of vaporization, kJ/ kg

1858 = Specific heat of water vapour, kJ/(kg.K)

Psychrometric Chart

A psychrometric chart (Figure 7.2 and appendix V:4-6) is a graphical representation of the thermodynamic properties of moist air. It is useful for solving engineering design problems. Charts for agricultural applications are usually corrected to standard atmospheric pressure of 101.325 kPa. However charts for other elevations are available. The following properties are shown on a psychrometric chart:

- **dry-bulb**
- **wet-bulb**
- **dew-point temperatures**
- **moisture content or specific humidity**
- **enthalpy**
- **relative humidity**
- **specific volume**

- **humid volume**

The intersection of any two property lines establishes a given state, and all other properties can be read from that point. The changes that take place between any two points are of particular use. The vertical lines show dry-bulb temperatures; the curved lines, relative humidity; the slant lines, wet bulb temperatures and enthalpy; the horizontal lines, dew point temperatures and specific humidity, and the steep slant lines, specific and humid volume.

The wet- and dry-bulb temperature for a building area may be read from a psychrometer and then used to establish a point of intersection on the chart. Psychrometers consist of two thermometers mounted close together, one of which has a wick on the bulb that is wet with a few drops of distilled water. Air movement is necessary. A sling psychrometer, which is actually swung in the air, is the simplest and least expensive. However, for locations with restricted space a motorized psychrometer must be used. The air movement in a ventilation duct is adequate to provide accurate readings from stationary temperature sensors.

Air-water Vapour Mixture Processes

Conditioning of air-water vapour mixtures involves heating, cooling, humidifying dehumidifying or some combination of these factors.

Sensible heat is the heat added to air without changing its specific humidity. Applications of sensible heating include heated-air grain drying and winter heating of room air in cool-climate

homes.

Sensible cooling is the removal of heat at a constant specific humidity. An example is the air passing over a cooling coil having a surface temperature above the dew point of the air. The final temperature cannot be below the initial dew-point temperature or water vapour condenses and the process removes latent heat.

Sensible Heating

Sensible Cooling

Lines a and b are starting and ending dry-bulb air temperature lines in both processes. Lines c and d show starting and ending enthalpy values. The fact that line 1-2 is horizontal indicates that there was no change in specific humidity in either process. Lines e and f show that the relative humidity dropped in the heating process and rose in the cooling process.

Evaporative cooling is an adiabatic saturation process (no sensible heat gained or lost) and follows upward along a constant wet-bulb temperature line on the chart. Air to be cooled is brought into contact with water at a temperature equal to the wet-bulb temperature of the air. The sensible heat of the initial air evaporates the water, lowering the air's dry-bulb temperature. Sensible heat is converted to latent heat in the added vapour, so the process is adiabatic. Evaporative cooling is effective in hot dry climates where wet-bulb depression (the difference between dry-bulb and wet-bulb temperatures) is large and where the disadvantage

of increased humidity is more than offset by a relatively large temperature drop.

Evaporative Cooling Process

Figure 7.2 Psychrometric Chart (By Courtesy of Carrier Corporation).

Evaporating moisture from a to b cools the air from c to d. As 1 and 2 are on the same enthalpy line, the process is adiabatic (no change in heat) the relative humidity rises from 1 to 2.

Heating and Humidifying Process

Point 2 has a higher temperature and specific humidity than 1. The heat added from a to b shows as sensible heat that caused a temperature rise from c to d end latent heat in the moisture that evaporated from e to f The relative humidity may or may not change.

Hearing and humidifying of ventilation air occurs as it moves through livestock buildings. Animals and poultry produce heat, vapour and water; both sensible heat and water vapour are added to ventilating air.

Cooling and dehumidifying is the lowering of both the dry-bulb temperature and the specific humidity. The process path depends on the type of equipment used. In summer air conditioning, air passes over a cold, finned type evaporator coil of a refrigeration unit. The air is cooled below the dew-point temperature and moisture condenses. Unless reheated or

initially saturated, the final relative humidity of the moist air is always higher than at the start. Both sensible heat and latent heat are removed from the air in this process.

As airpasses the cooling coils of an evaporator, moisture will condense from a to b giving up latent heat. The air is also cooled from c to d giving up sensible heat. Relative humidity 2 will be at 100% (saturation) as the air leaves the evaporator.

Moisture transmission

As stated in Dalton's law, water vapour in the air exerts a separate pressure that is proportional to the amount of moisture present. This partial pressure is independent of the partial pressures exerted by other components of the air.

In as much as warm air can hold more moisture than cool air, it is typical for the vapour pressure to be higher on the warm side of a wall. Where ever a pressure difference exists, there is a tendency for moisture to permeate through the wall until the pressure equalizes. If in permeating through a wall a dew-point temperature is encountered, condensation will occur and free moisture will be left to reduce the effectiveness of insulation or cause deterioration in wood or metal. In cold climates, building walls should be designed with vapour barriers on the warm side of the wall in order to reduce moisture permeation. In all climates, but especially in warm, humid areas, it is essential to install a good vapour barrier on the warm side of a refrigerated storage wall.

To understand air-moisture movement and to make the calculations in a vapour-transmission problem, it is necessary to understand the following terms:

Vapour pressure is the partial pressure in the atmosphere due to the presence of vapourized moisture. It is measured in mmHg or Pa.

Permeability is the property of a material that allows the migration of water vapour. It is measured for 1 meter of thickness and the units are g/(24hr.m.Pa).

Permeance is the term chosen for the transfer of water vapour for a material in the thickness as used. The unit used is g/(24hr.m.Pa).

The permeability of a material may be determined by subjecting it to 100% relative humidity on one side and 50% on the other (wet-cup method) or to 0% relative humidity on one side and 50% on the other (dry-cup method). Of the two, the wet cup value is usually a little higher, but either value may be used for moisture-transfer calculations.

Moisture transmission may be calculated as follows:

W = M x A xT x Ap where:

W = total moisture (grams)
M = permeance (g/24 hr.m.Pa)
A = area unit (m)

T = time unit (24 hr)
AP = pressure difference (Pa)

As with heat transfer, only resistance may be added. Therefore if a wall has more than one vapour-resisting layer, the following equation is used:

$1 / M_T = 1 / M_1 + 1 / M + 1 / M_n$ Where:

M_T = the overall permeance of the wall.
M_1 = permeance of a layer, etc.

Table 7.4 lists the permeability of several materials used in building construction.

Table 7.4 ***Moisture Permeability of Materials***

Material	**Premeability/m thickness g/(24hr.m.Pa) x 10^{-3}**	**Permeance Thickness as used g/(24hr.m.Pa) x 10^{-3}**
Air	15.3	
Exterior plywood 6mm		3.45

Pine timber	0.053 - 0.68	
Concrete	0.38	
Asphalt roofing		0.23
Aluminium paint		1.5 - 2.48
Latex paint		27.23
Polystyrene		
Extruded	0. 15	
Bead	0.26 - 0.75	
Polyurethane	0.53 - 0.23	
Polyethene 0.1 mm		0.4
Polyethene 0.2mm		0.2

Vapor barriers

Any enclosed wall that has an appreciable temperature difference or humidity difference between the two sides for a substantial part of the time should have a vapour barrier installed on or near the warm or humid side. In cold climates this applies to the wall in any enclosed building that is heated or where the humidity is high. In warm climates it applies to air-

conditioned or refrigerated buildings primarily.

Probably the most effective vapour barrier that is also reasonable in cost is polyethene sheet. The vapour barrier should be as continuous as possible. This can be achieved by using large sheets with well overlapped and sealed joints and as few nail holes as possible.

Condensation on Surfaces and Within Walls

If the insulation in the wall of a refrigerated storage is inadequate or if it has defective spots, the outside of the wall may be cool enough to be below the dew-point temperature. The result will be condensation on the outer wall surface. Remedies for this condition are:

- **better insulation**
- **reduction of outside humidity, or**
- **increased air movement across the wall.**

Materials such as stone, concrete and brick are not affected by condensation.

Condensation within the wall is more serious and results from either the absence of a vapour barrier or a defective barrier. In that situation moisture moves into the wall from the warm side until it reaches an inner wall layer that is below the dew-point temperature. The resulting condensation soon reduces the effectiveness of the insulation and causes permanent damage. Remedies for this situation are:

- **a better vapour seal on the warm side**
- **a more permeable layer on the cold side, or**
- **a reduction in humidity on the warm side through ventilation or other means.**

Ventilation

Ventilation is one of several methods used to control the environment in farm buildings where it fulfills two main functions: the control of temperature and the control of moisture within a building. Ventilation may also be necessary to maintain adequate levels of oxygen and to remove generated gases, dust and odours.

There is a considerable range of ventilation requirements that depend on the local climatic conditions and the specific enterprise being served. The following examples will illustrate:

- **1 A cattle shelter in a tropical climate requires little more than shade from a roof with the structure sited to obtain maximum breeze.**
- **2 A cattle shelter in a cold climate (frost occurs in season) may be open on the sunny side and provided with ventilation openings at the ridge and along the rear eaves. The temperature will be cold but condensation will be controlled.**
- **3 A poultry house (cage-equipped) in a cold climate, if heavily insulated, can be kept comfortably warm while mechanical ventilation removes excess moisture and odours.**
- **4 Potatoes that are stored in either a mild or a cold climate may be cooled by ventilation**

alone. Continual air movement is requisite to maintaining a uniform environment. The amount of insulation used will be dictated by the lowest temperature expected.

A great deal of research has been done to determine the ideal environmental conditions for various classes of livestock and types of plant and animal products. Within economic constraints, the nearer these ideal conditions can be maintained, the more successful the enterprise will be. That is, meat animals will gain faster and more efficiently, dairy cattle will produce more milk, and crop storages will maintain better quality and reduce losses.

Natural Ventilation

Thermal Convection or Stack Effect

Natural ventilation is provided from two sources - thermal convection and wind. Air which is heated with respect to the surrounding air is less dense and experiences - an upthrust due to thermal bouyancy.

Whenever a building contains livestock, the production of sensible metabolic energy is always available to warm the air entering from the outside. Similarly air may be heated in a greenhouse by incoming radiation. Provided there are two apertures with a height differential, convection currents will force the heated, less dense air out of the upper aperture to be replaced by an equal volume of cooler, denser air from outside. This is referred to as "Stack effect"

Hence natural ventilation by stack effect can provide the minimum ventilation requirement under winter conditions. While this system may be less expensive than a mechanical system, it will also be less positive in action and more difficult to control.

A building that is open on one side may be ventilated naturally by leaving the ridge open for an outlet and a slot along the rear for an inlet. An enclosed building may be more positively ventilated with stack outlets and correctly sized inlets.

To determine the inlet and outlet areas required to provide a given ventilation rate by thermal convection, the following equation based on stack effect theory can be used:

where:

A_j = inlet (m)
A_o = outlet area (m)

g = acceleration due to gravity (9.76 m/s^2)
h = height difference, inlet to outlet (m)
H_p = heat supplied to building (W)
T_p = absolute temperature in building (K = 273 C)

ρ = density of air in building (kg/m), 1. 175 at 25C
S = specific heat of air (1005 J/ kgC)
V = ventilation rate (m/s)
W = heat loss through building shell (W/C)

The values in Figure 7.3a and b were developed using this equation. The values in (a) are for a solar-flue drier, while those in (b) more closely fit the conditions in a building.

Natural ventilating systems may be non-adjustable, manually adjustable, or automatically controlled. In as much as natural systems are likely to be chosen for economy reasons where conditions are not severe, manual adjustment should be the method of choice in most cases.

Ventilation Due to Wind

As the wind flows around a building, gusts and lulls create regions in which the static pressure is above or below the atmospheric pressure in the free air stream. In general, these pressures are positive on the windward side, resulting in an inflow of air, and negative on the leeward side, resulting in an outflow of air. Pressures are generally negative over low-pitched roofs.

Mechanical Ventilation

Compared to natural ventilation, mechanical ventilation with the use of fans is more positive in its action, less affected by wind, and more easily controlled. Initial installation will usually

cost more and there is the added cost of operation. However, in many cases the advantages of mechanical ventilation outweigh the added expense.

Exhaust vs Pressure Systems

There are two main types of mechanical ventilating systems, namely, pressure and exhaust. In a pressure system the fan blows air through inlet openings into the building creating a positive indoor pressure that pushes air out of the building through the outlet openings. In exhaust ventilation the fan expels air from the building creating a lower than atmospheric pressure inside the building. The pressure difference between outside and inside causes ventilation air to flow in through the inlets. For good air flow control is important that the building is tight.

The exhaust ventilation system is popular because it is easier to control the distribution of the incoming air and is generally less expensive and complex than a pressure systems. However, there are situations when the pressure system (one that forces air into the building) performs better. These includes:

- **1 very dusty conditions that tend to load up the fans,**
- **2 buildings with excessively loose construction (many cracks), and**
- **3 when continuous recirculation is required.**

Under some circumstances pressure systems may cause humid air to be forced into building walls and ceilings. This can result in condensation and damage to wood and other materials.

A mechanical ventilation system is made up of three main components: fans, air-distribution system and controls to regulate fans.

Fans and Blowers

Axial-flow fans are normally divided into propeller and tubeaxial types. They move air parallel to the shaft and are the types most widely used. Centrifugal (radial flow) fans (blowers) discharge air at right angles to the shaft and often operate at substantial pressures.

Propeller fans are the least expensive and the easiest to install. A propeller fan may have 2 to 6 or more blades. Generally the more blades, the greater the pressure the fan will develop. The best propeller fans have a close-fitting curved inlet shroud or inlet ring which improves the efficiency of the fan. Propeller fans are most suited to moving large volumes of air at pressures in the range of 30 to 50Pa (3 to 5mm of water) and they are the most commonly used in conventional farm building ventilation. Figure 7.5.

The tubeaxialfan is a more reafined version of the propeller fan (Figure 7.6). It has aerofoil-shaped fan blades on an impeller with a large hub all mounted in a close-fitting tube. Tubeaxial fans are capable of operating against higher static pressures than ordinary propeller fans and are made for ducted installations with high resistance to air flow. If it is necessary for a tubeaxial fan to operate under very considerable pressure, it may be designed with two impellers in tandem, described as a multi-stage model.

Centrifugal (radial-flow)fans are used for ducted installations or where air must be moved through a product such as grain or potatoes. The blades on the blower may be radial, e.g., straight from the shaft, curved forward in the direction of rotation, or curved backward opposite to the direction of rotation. The latter can achieve the highest efficiencies under high-pressure performance and are most suitable for agricultural applications. The most important attribute of the backward-curve blower is its nonoverloading characteristic. Both the radial and forwardcurved types require their greatest power input when air flow is cut off. An air blockage therefore, is likely to overload the motor and cause damage. Figure 7.7.

All but the smallest-sized fan should be powered by a capacitor-start motor that is enclosed for dust and moisture protection. It should be equipped with an overload protector and bearings with long lubrication life.

The fan should be enclosed with a wire safety guard. Shutters and hoods are necessary in cold climates but should not be needed in mild climates.

The type of fan selected is largely related to operating pressure. It is important to choose a fan with a high performance efficiency in the range of operating pressures in order to avoid unnecessarily high energy consumption.

Figure 7.3a Natural ventilation stack design (drier).

Figure 7.3b Natural ventilation stack design (barn).

Figure 7.4 A solar food dehydrator.

Figure 7.5 Propeller fan.

Figure 7.6 Tubeaxial-flow fan.

Figure 7.7 Centrifugal blower.

Figure 7.8 Simple Instruments to measure pressure and air velocity.

Static Pressure

When an exhaust fan is installed in the wall of a closed building, a lowered air pressure will develop inside, or if the fan blows air into the building, a slight pressure increase will occur. Manometers or draught gauges are two simple but dependable devices which can be used to measure the small pressure differences that exist. Figure 7.8. They are usually calibrated to read in millimeters of water. That is, if the two columns of water in a glass "U" tube are equal, and then a plastic tube is connected from one side of the U tube to a building with an operating fan, the columns will become unbalanced. The difference is the millimeters of static pressure.

Fan Ratings and Selection

A fan performance is usually related in terms of volume of air moved expressed in cubic metres per second (m/s) against a pressure or resistance to air flow expressed in Pa or mm of water static pressure (mmWG). Free-air delivery is nearly meaningless since that situation seldom exists. Performance curves, available from the manufacturer, outline the performance of fans at different operating pressures. These curves also illustrate the maximum or cut-off pressure, efficiency and sound levels at different rotation velocities (rpm) and blade angle settings, as well as the power requirements for various operating conditions. Most countries that manufacture fans have an organization that tests fans and certifies the performance curves.

Fan Laws

When fan blades are mounted directly on the motor shaft, it is assumed that the manufacturer has correctly matched the combination. However, some fans are belt-driven, allowing for the substitution in service of a motor of a different speed or pulleys of different sizes. A knowledge of the following basic fan laws can avoid trouble:

- l The delivery volume of a fan varies directly with its speed.
- 2 The cut-off pressure of a fan varies directly as the square of its speed.
- 3 The power requirement of a fan varies directly as the cube of its speed.

For example, assume a fan is belt-driven by a 300W output 1725rpm motor. If that motor is replaced by a 300W/ 3400rpm motor without changing pulleys, the following would occur: The volume discharged would be doubled, the cut-off pressure would be quadrupled (22) and the horsepower requirement would be increased eightfold (23). The result would be such a badly

overloaded motor that it would burn out unless the overload protector stopped the motor before damage was done.

The mild climate of East and South-east Africa greatly simplifies the housing requirements for most animals and some plant products. However, it seems worthwhile to discuss several factors of ventilation that apply primarily to cooler climates.

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Ventilation system design cool climates

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Fan location. Assuming an enclosed building, one to three fans can be located at ceiling level midpoint on the protected side (opposite the prevailing wind) of the building. A greater number of fans may be distributed along the protected side. The high level on the wall is desirable for summer heat removal and has little effect on the efficiency of moisture removal in cold weather. Efficiency in this case means the amount of moisture removed per unit of heat used or lost. If outlet ducts are required, they should be insulated to an R of 0.5 to prevent

condensation.

Air Distribution

In addition to ventilation rate, it is necessary to consider the distribution of incoming air throughout the building. This is particularly important in both livestock production buildings and product stores.

When considering fresh-air distribution, two distinct temperature situations are involved. In areas with winter frost, outside air is cooler than that inside the buildings and fresh air must be delivered away from the stock so as to avoid cold draughts. In summer, however, the animals may be subject to heat stress and may suffer considerably unless cooling air currents are directed so as to remove excess heat from their vicinity. A good air-distribution system also ensures that the animals receive an adequate supply of oxygen and that noxious gases are removed.

Air Inlets

Ventilation is accomplished in an exhaust-type mechanical system by reducing the pressure within the building below outside pressure, causing fresh air to enter wherever openings exist. The principal factors affecting the air-flow pattern in a building are the speed and direction of the incoming fresh air. The size, location and configuration of the air inlets are, therefore, most important in designing the distribution system.

The flow of air streams through openings has been closely investigated and the results can be summarized into the following statements:

- **a The speed at which the air stream travels is directly affected by its initial speed through the inlet.**
- **b The distance the air stream travels is proportional to the initial speed at the inlet.**
- **c The higher the initial speed of air entering the building, the greater the mixing of incoming air with the existing air.**
- **d The higher the speed of cool air entering the building, the less it will sink.**

It can be deduced from these findings that in winter, openings should be small enough to provide sufficiently high velocities to avoid cold air falling directly onto the stock, to provide good air mixing, and to maintain the required air-flow pattern at the low winter ventilation rate.

Velocities of around 3.5 to 5m/s usually satisfy these requirements. However, at these velocities it is important to consider the effect of internal partitions, structural members and other obstructions to flow, and it also becomes important for the building to be relatively airtight.

When air flows through an opening of any shape, the cross-section area of the issuing jet is reduced to 60 to 80% of the total free area of the opening. 70% is a reasonable design value. This phenomenon, the venacontracta effect, increases the velocity of air emerging from the

opening. The total area of air inlet must be proportional to total fan capacity. A common rule of thumb sizes air inlets at 0.4m of area for each m/s of fan capacity.

The pressure drop across the inlet affects fan performance and therefore should be no higher than necessary. A draught gauge may be used to check the pressure difference across the inlet (between the inside and outside of the building at the inlet). A pressure difference of 10 to 20Pa indicates a velocity of 4 to 6m/ s. Inlet openings, regardless of type, must be adjustable so that the correct air velocity can be maintained throughout the year.

Compared with inlets, the fan outlets have a minor role to play in the distribution of fresh air in a livestock building. The effect of an outlet is to cause a general slow drift of air towards the outlet position. This drift is easily overcome by convection, animal movement or pattern of air movement established by the inlets. Only near the fan (within approximately 1 m) can a positive air movement be detected. This applies to outlets in both exhaust and pressurized systems of ventilation. However, it is recommended that no inlet be placed closer than 3m from a fan.

Figure 7.9 Air inlets - winter adjustment.

Table 7.5 ***Ventilation Inlet Data (Vena Contracta = 0.7)***

Static Pressure mm H_2O	**Velocity m/s**	**Inlet Area m per m/s**

5	2.9	0.493
10	4.1	0.348
1 5	5.0	0.286
20	5.8	0.246
25	6.5	0.219
32	7.3	0.196

Wind has a major effect on ventilation systems since it causes pressure gradients around buildings and directly impinges on components of the system. This pressure will cause problems of uneven air entry, with more entering on the windward side than the leeward side of the building.

Wind blowing against a fan reduces output and hoods do little to alleviate the problem. Wind blowing across a ridge chimney-type outlet may cause overventilation. Wind effects can be reduced by the following steps:

- a Orient building for minimum wind exposure
- b Provide wind breaks
- c Operate system at relatively high pressure
- d Use attic inlets or openings at the outer edge of wide soffits as shown in Figure 7.9

(top).

In situations where air must be distributed and wall or ceiling inlets are not feasible, polythene tubes punched with holes along their length work well. Usually two rows of holes are spaced at 600 to 750mm intervals along the tube. The total hole area should equal approximately 1.5 times the tube cross-section area. Ducts should be sized to provide 4 to 6m/s velocity. They may be used either to distribute air in a pressure system or as an inlet for an exhaust system. Sizing is the same in either case.

Ventilation Controls

Simple on-off thermostats have given dependable and satisfactory control of many ventilation systems. If the building is small and served by one fan, then a two-speed motor with a thermostat provided with two set temperatures will work well. When several fans are required, one or more may be operated continuously to provide the necessary minimum ventilation rate. Others may be controlled by a thermostat set at the minimum design temperature. These will cycle on and off in cold weather. The balance of the fans may be controlled with a thermostat set at the maximum design temperature. These will only operate in warm weather when excessive heat must be removed.

Filled-type or bimetallic-type thermostats placed 2 metres high near the centre of the building work well as controllers. Electronic controllers, using multiple thermistors to sense temperatures in several locations, combined with variable-speed motors and

automaticallyadjusting inlets are available. Although they undoubtedly do a more precise job of controlling the building environment, their additional cost is difficult to justify. Humidistats have not proven very satisfactory as controllers for mechanized ventilation systems.

Ventilation Design Example

Although calculating the heat and moisture balance for a building in cold (below 0C) weather is not a typical problem for Tropical Climates, a sample will show how the psychrometric chart is used and also the possible difficulties encountered in cold climates.

Assume a farm has sixty 600 kg cows housed in a 10m by 40m by 3m barn with 20m of windows and 12m of doors. R values are: window 0.17, door 1.0, ceiling 2.6 and wall 2.1. The temperature and relative humidity are -10 C and 90% outside and + 12 C and 75% inside. The total heat and latent moisture production from the animals is found in Table 10.2 and is 1130W and 0.485 kg/hr per cow. From Figure 7.2, the 1500m psychrometric chart, - 10 C and 90% equals -6kJ / kg enthalphy and 0.0016 kg/ kg specific humidity. Also +12C and 75% equals 31kJ enthalphy and 0.0078 kg/ kg specific humidity. From the chart, the humid volume at 12C and 75% equals 0.98m/ kg, the value at which the fans are exhausting air. 1 kJ = 1/3.6W.

Procedure:

Heat production 60 x 1130	= 67,800W
Respired moisture production 60 x 0.485	= 29.1 kg/hr

Heat loss from:	
Ceiling 400 x 1/2.6 x 22	= 3,385W
Wall (300-32) x 1/2.1 x 22	= 2,808W
Windows 20 x 1/0.17 x 22	= 2,588W
Doors 12 x 1/1.0 x 22	= 264W
Total heat loss	9,045W
Heat available for ventilation 67,800 - 9,045	58,766W
Minimum air flow to remove moisture 29.1/ (0.0078-0.00 16)	4694 kg / hr
Fan capacity at minimum flow 4694 x 0.980/3600	1.28m/s
Heat removed by air flow 4694 x (31.5-(-6)/3.6)	48896W

As the heat available for ventilation is greater than that actually removed by the minimum ventilation rate, the inside temperature will tend to rise or the relative humidity will fall, but a cycling of additional fan capacity will maintain the desired temperature. It should be pointed out that although the values for moisture production in Table 10.2 include normal evaporation

from feed, manure and urine, the evaporation may well run higher or lower, depending primarily on how much wet floor surface is exposed from which evaporation can take place. Greater evaporation would reduce the moisture to be removed with the manure.

If the heat removed by the ventilation is greater than that which is available for ventilation, a fall of inside temperature will result unless the insulation of the building is improved and/ or supplemental heating is installed. It should be noted that a lowered minimum ventilation rate aimed at maintaining the temperature may cause the inside air to become saturated and result in condensation on cold surfaces such as windows.

Calculations using outside summer temperatures, e.g. 21C, would show the need for additional fan capacity to remove heat and thus maintain an acceptable temperature difference between inside and outside, e.g., 4C.

Maximum ventilation rate is the product of sensible heat production divided by temperature difference (inside outside) and isobar specific heat capacity.

The sensible heat production is, according to Table 10.2, 465W per animal at 25C (inside temperature) and the maximum ventilation rate is thus:

60 x 465 (4 x 0.35) = 19.950m/hr or 5.54m/s.

Between the cold and warm weather rates, thermostats cause a cycling of fan operation that

will maintain temperatures within the desired range.

Cooling

During high temperature periods, ventilation alone may be insufficient for maintaining satisfactory temperatures in animal buildings. The following cooling system can be effectively used in totally enclosed buildings. Other cooling techniques such as spray cooling are covered in later sections.

Evaporative Cooling

The evaporative cooler operates on the simple principle of a fan drawing hot air from outside through a wet pad into the building. The hot air is cooled by evaporating water which changes sensible heat in the air to latent heat in the vaporized moisture thus causing a temperature drop.

Air temperature reduction in buildings of as much as 11C can be achieved during hot periods with low humidity. In humid weather, the cooling effect is considerably reduced, but the system may be suitable for the greater part of the hot season in many areas.

Commercial evaporative coolers are available in sizes varying in capacity from 1 to 95m/s. Since they are complete with built-in fans, it is essential that suitable units with correct ducting, diffuser and register sizes be selected to allow balanced air distribution in the building. Ample

exhaust vents should be provided around the perimeter of the building to allow the free outlet of air. A thermostat is advisable to control the units. Where humidity control is required, a humidistat can be added to the control circuit. Some designs incorporate a heat exchanger. In these, the air which has been cooled while passing the wet pads is used to cool other air which actually enters the building. While this results in less humid air being used for ventilation, the extra step causes a loss in efficiency.

An alternative to the packaged evaporative cooler can be assembled with a pad and fan system. Pads made of 50mm thick compressed "wood wool" or other suitable material are installed, usually in the long wall of the building, and exhaust fans are positioned in the opposite wall. Incoming air is cooled as it passes through the wet pads and then, after passing through the building, is exhausted by fans, Figure 7.10. For effective operation, the air velocity through the pad area should be limited to about 0.8m/s. This is accomplished with 1 to 1.5m of pad area per/m and second of air flow. The cooled air leaves the pad at a relative humidity of 85 to 90%, but is quickly moderated by the ambient air.

Water is spread evenly over the pads from a manifold supplied from a sump with a float-controlled water level. Recirculation of water through the pads should be at the rate of approximately 1 60ml/ s for each m/ s air flow. The actual water consumption, which is the evaporation ot water into the passing air, varies with the changing conditions of temperature and humidity. However, as a guide, it is approximately 20% of the water recirculation rate.

Evaporative coolers, which rely on wind pressure to force air through the wet pads, are less

effective since the air flow is likely to be either too low or too high most of the time. While naturally ventilated evaporative coolers will require larger pad areas, the fact that no fan or power to drive a fan is required recommends these designs for small scale applications in rural areas. They can usually be constructed with local materials and be operated and maintained by the farmer at low cost.

The value of evaporative cooling systems depends on the application and on the typical wet-bulb temperatures of the region. In areas of high humidity they work well for greenhouses and potato stores, but are not satisfactory for poultry and other animals that depend on respiration for body cooling at high temperatures. Evaporative cooling is much more practical in dry regions where the air can be cooled appreciably while the humidity is still low enough to have little effect on animal comfort.

Figure 7.10 Evaporative cooler.

Refrigeration

Meeting the temperature requirements for storing some products may not be possible with ventilation alone or with evaporative coolers. If the product has sufficient value to justify mechanical refrigeration, then nearly ideal conditions may be provided.

Principles of Refrigeration

Most fluids can occur as either a liquid or a vapour depending on pressure and temperature. The higher the pressure and the lower the temperature, the more likely that the liquid phase will occur. Whenever there is a change of phase there will be a concurrent latent heat exchange. That is, when a liquid changes to a vapour, heat is absorbed; when a vapour changes to a liquid, heat is given off. There are several materials that happen to change state at pressures and temperatures which make them useful in mechanical refrigeration systems.

Refrigeration Systems

A refrigeration system is comprised of four main parts:

- **a a compressor**
- **b a condenser**
- **c an expansion valve or other restriction in the refrigerant line, and**
- **d an evaporator.**

The components are connected together in a complete circuit in the order listed. In addition, there may be a receiver (small tank) between the condenser and the expansion valve. See Figure 7.11.

Figure 7. 11 Refrigeration system.

When the system is charged with a refrigerant, operating the compressor reduces the pressure

in the evaporator and causes the refrigerant to boil, evaporate and absorb heat. This causes a drop in temperature. At the same time the compressor is pumping the evaporated vapour into the condenser at high pressure. This causes the refrigerant to condense back to a liquid while giving up heat. The temperature in the condenser will rise. The receiver serves as a reservoir for liquid refrigerant. Obviously the evaporator is installed in the room to be refrigerated and the condenser is located where ambient air can readily absorb the heat produced. The expansion valve is the temperature control mechanism for the system. If it is adjusted to further restrict the refrigerant flow, both the pressure and boiling temperature in the evaporator will drop and within the limit of the system's capacity, the room temperature may be maintained at a lower level.

The pressure on the condenser side is determined largely by ambient conditions. If the air temperature is relatively low, the condenser discharges its heat easily at normal pressures.

However, in very hot weather or if the airflow through the condenser becomes restricted by dust or other debris, the temperature and pressure may rise to levels dangerous to the system, unless a high-pressure safety switch has been installed.

Refrigerants

There are a number of fluorocarbon refrigerants used for various temperature applications. The most common, refrigerant 12, is used for applications in the -15 to 10C range. Ammonia, refrigerant R717, is also used in this temperature range. R12 is odourless, non-toxic,

nonflammable and is piped with copper tubing. R717 is toxic, has a strong pungent odour, burns in certain concentrations in air, is prone to leaking and is piped with steel pipes. However, ammonia is cheaper and more efficient because it has a much higher heat of evaporation thus requiring smaller component parts throughout. Consequently ammonia systems are, because of the economies, often chosen for large stores in spite of the disadvantages, but R12 is almost universally the choice for small systems.

Evaporators

Fabricating a refrigeration system requires the specialized equipment and knowledge of a contractor. However, it is a distinct advantage for the customer to know how the evaporator size and corresponding operating temperature relate to the conditions required in the cold store.

A given storage room and product quantity will impose a particular load (watts) on the refrigeration system. That load can be met by operating a relatively small evaporator at a very low temperature (heat moves to its limited surface rapidly), or by operating a larger evaporator at a more moderate temperature (heat moves more slowly but to a much greater surface area). Air passing through an evaporator will, in nearly all cases, be cooled sufficiently to reach saturation (100% RH).

The psychrometric chart shows that the moisture holding capacity (specific humidity) of air at two slightly differing temperatures will be nearly the same, while air at widely differing

temperatures will have quite different specific humidities.

For example, assume a store temperature of 10C and an evaporator temperature of 8 C. The absolute humidity of saturated air at 8 C is 0.0066 kg/ kg. That will allow a relative humidity at 10C of 89% which is desirable for a potato store.

In contrast, onions store best at 0 C and 75%RH, so a smaller evaporator operating at -5C and 0.0025 kg/ kg at saturation would provide the desired 75%RH.

Unfortunately refrigeration contractors may not understand this relationship or they may not care and therefore present a bid for a system based on too small an evaporator which would need to be operated at too low a temperature. This would have a lower purchase cost, but fail to provide the proper conditions.

Finally it should be pointed out that in air conditioners for homes one of the objectives is to reduce humidity. Consequently small-size evaporators operated at low temperatures are quite in order.

Solar energy

The use of solar energy dates back to before recorded history and in fact has been and is being used by all farmers in the production of their crops. The purpose here is to note the nature of solar energy and relate that to some applications.

Solar Flux

The energy reaching the earth from the sun is referred to as solar flux. The energy approaching the earth's atmosphere perpendicular to the surface is 1.27kW/m. Due to the earth's atmosphere only lkW/m reaches the earth under optimum conditions and for practical purposes a value of 0.9kW/m is often used for latitudes where the altitude (angle of the sun's rays to earth) is close to 90.

Factors that affect the actual amount of energy available in a particular area are:

1 Latitude and season: As the earth is inclined 23.5 degrees, the angle that the sun makes with the earth is continually changing throughout the year. Between latitudes 23.5 north and 23.5 south, the sun will be perpendicular for two days each year and its noon altitude never drops lower than 43. However, farther north or south the sun never reaches 90 and in winter the angle may be very low. (Only 16 1/2 in winter at 50 latitude north or south).

2 Weather: The frequency of cloudy days is an important factor in the amount of radiation received over a period of time. Although the belts around the earth falling between 20 and 30 both north and south receive nearly 90% of the total solar radiation, there are great regional variations from this. Consequently, in doing design work it is imperative to have solar information for a local area, including seasonal variations.

Collectors

There are several types of solar collectors including:

- 1 parabolic focusing collectors that concentrate the sun's energy for high temperature applications,
- 2 parabolic cylinders for medium temperatures, and
- 3 flat-plate collector for relatively low temperature applications. This latter type is the simplest and least expensive and has the most applications for rural areas.

A flat-plate collector can be as simple as a water tank painted black or it can be more complex, e.g., a collector surface painted black with one or more transparent layers that allows the sun's rays to enter while reducing the reradiation of heat, all mounted in a tight frame with insulation on the back side. Figure 7.13

Table 7.6 Mean Daily Solar Radiation on a Horizontal Surface (k Wh/m)

Place	Lat.	Elev.	Jan.	Apr.	July	Oct.	Annual
Kenya							
Kericho	0	2070	6.14	5.16	4.95	5.19	5.46
Mombasa	4	55	6.53	6.66	4.45	6.28	5.84
Nairobi	1	1890	6.34	5.31	3.72	5.47	5.24
Tanzania							

Arusha	31/2	700	7.24	5.74	4.81	6.49	6.04
Dar es Salaam	7	55	5.42	3.89	4.27	5.22	4.86
Mbeya	9	2400	4.46	4.58	6.13	5.93	5.23
Zambia							
Bulawayo*	20		9.01	7.00	5.81	8.40	9.04

*** Max. daily values**

Figure 7.12 Mean annual solar radiation on a horizontal surface k Wh/m.

In most cases the heat collected is removed with either air or water. Which one is used depends on the purpose of the collector. That is, to dry products, air would be used; to heat water, water would be used.

Collector plates may be made of metal with water tubes bonded to the plate. Copper has high conductivity and is easily soldered to the plate. Aluminium also has good conductivity but is difficult to bond to the plate. Manufactured aluminium plates have the water lines pressed into the surface.

Glass, fiberglass-reinforced plastic, and plastic films may be used to cover the collector. Glass passes over 90% of the solar energy; fiberglass about 80% if kept clean, and polythene film

90%. However, polythene loses a great deal of heat through reradiation. Glass has the longest life; fiberglass can be expected to last 10 years, and polythene only a year or two.

Figure 7.13 Exploded view of typical flat-plate collector (By courtesy of Cooperative Extension Service, Cornell University).

The efficiency of collectors varies greatly. The parabolic units mentioned earlier may reach 50 to 75%. Flat-plate units operate in the range of 25 to 50% depending on design and position of mounting. Some simple designs may be even less efficient. In many cases an inexpensive, simple design is the most practical to choose. Often an increase in size will offset low efficiency. It is important to remember that no matter what type of collector is used or how efficient it is, it can never collect more energy than the product of the local flux rate and the collector area. In fact, it may be said that size (area) of a collector is its most important characteristic.

Orientation of Flat-Plate Collectors

Collectors of any type are more effective if they are moved so that they are continually perpendicular to the sun's rays. However, controls to accomplish this are expensive and not practical for rural operations. Instead an effort is made to orient the collector to the best average position. To understand this requires the explanation of two angles, azimufh and altitude. Figure 7.14.

Figure 7.14 Azimuth and altitude (southern hemisphere).

The azimuth is the horizontal angle of the sun in relation to the true south meridian. In the morning it will be measured in an easterly direction and in the afternoon, in a westerly direction. The altitude is the vertical angle the sun makes with the horizontal plane at the earth's surface. At the equator the sun's altitude will be to the north from March to September and to the south from September to March. As one goes farther south the sun has a north altitude for a longer and longer time, until south of latitude 23.5S the altitude is always to the north.

Since the sun's altitude is so high in the small latitudes, placing a collector horizontal works quite well. However, some angling of the collector will improve the average performance. The following angles from the horizontal are suggested:

Year round operation - The latitude angle
Summer operation only - Latitude minus 10
Winter operation only - Latitude plus 10

For example, a collector to be installed in Lusaka, latitude 15 S. for year round use should be tipped 15 to the north and faced within 10 east or west of north.

Application of Solar Energy

Increased use of solar energy depends in large part on the cost of alternate sources of energy and on the improvement in designs of equipment for the use of solar energy. Although this energy is free, the equipment to use it is not. This means that applications that can be used throughout the year and those that are simple enough to be low in cost are most likely to be practical.

Some possible applications in rural areas are:

- **1 Open-sided buildings facing north to warm and dry the interior. (Most practical in latitudes south of 25 S).**
- **2 Crop drying in thin layers in the sun.**
- **3 Food drying in small solar dehydrators-figure 7.4**
- **4 Water heating - Figure 7.15.**
- **5 Forced-air drying of grain by blowing air through a long plastic duct before it enters the drying bin.**

Figure 7.1 5 Solar water heater.

Sound insulation - noise control

From room to room:

Sound transmission through a wall occurs as a result of the structural members being set into

vibration by the sound waves, which in turn cause vibrations in the air on the opposite side. Therefore the heavier the construction the less easily it is set into vibration and the better its sound-insulating value. However, the sound-insulating value of a dense barrier such as a masonary wall may be seriously diminished if the sound is transmitted along structural members which link the rooms, e.g., ceilings, floors and plumbing lines. In addition, any openings such as gaps around doors or between ceiling and walls will allow noise to bypass a sound-insulating member. Noise from a roof due to the druming of rain and cracking of metal roofing can be reduced by installing a ceiling or panelling on the underside of the rafters. The sound insulating value of a ceiling is further improved by adding a layer of insulation which tends to absorb some of the sound before it is transmitted. Heavy construction will help to attenuate the sound.

Within a room:

Rooms having many hard surfaces tend to be very noisy and speech becomes distorted. This is because the sound is reflected and rereflected several times by the surfaces, thus creating an echo effect. Sound absorbents will reduce the time taken for the sound vibrations within the room to decay. Fibre boards and other soft materials are very efficient in dampening high frequency sounds, but for low frequency sounds a thin panel covering an air space works best.

Lightning conductors

Lightning striking a building can cause substantial structural damage and a fire may be started. Buildings with thatched roofs located in prominent positions present the worst risk, while concrete and steel frame buildings offer a low risk. A lightning-protective installation has three major parts; an air termination, a down conductor and an earth termination and its function is to provide a simple and direct path for the lightning to discharge to the ground.

The air termination consists of one or several pointed copper rods fixed above the highest point on the roof. One down conductor (e.g., 25 x 3mm copper tape) can serve a building of up to 100m. The earth termination consists of a 10 to 12mm copper-plated rod driven into the ground at least 2m. If the soil tends to become very dry at any time during the year, additional ground rods driven 2.5m deep will offer greater protection.

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Sand and dust

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In many dry areas sand and dust may cause considerable discomfort, eye irritation, problems

with food preparation, increased wear of machinery and even damage to buildings due to erosion. Sand is carried by the wind and can be stopped by hedges, screen fences or similar semiopen structures that reduce wind velocity and cause the sand to come to rest. Dust is more difficult to stop, but tightly closing shutters will give a large measure of protection as will vegetation around buildings.

Building shapes which create pockets or surfaces on which sand and dust may accumulate should be avoided since the added weight may conceivably cause structural failure.

Earthquakes

In areas where earthquakes occur frequently buildings must be designed to resist the stresses caused by the tremors. While the intensity of tremors can be much greater in loosely compacted soil than in firm soil or solid bedrock, one- and two-story buildings are at greater risk on the firm ground or bedrock because of the shorter resonance periods.

Casualties are most likely to be caused by the collapse of walls causing the roof to fall, and the failure of projecting elements such as parapets, watertanks, nonmonolithic chimneys and loose roof coverings. The outbreak of fire caused by the fracture of a chimney or a break in the mains supply line presents an additional hazard.

While small buildings, having timber frame walls or a wooden ring beam supported by the posts of a mudandpole wall, can resist quite violent earthquakes, the following measures will

increase the resistance of a large building to collapse due to earth tremors:

- Use a round or rectangular shape for the building. Other shapes such as "L" "T" or "U" should be divided into separate units. To be effective, this separation must be carried down through to the foundation.
- Avoid large spans, greatly elongated walls, vault-anddome construction and wall openings in excess of one third of the total wall area.
- Construct a continuously reinforced footing that rests on uniform soil at a uniform depth - even on sloping ground.
- Securely fix the roof either to a continuously reinforced ring beam on top of the walls, or to independent supports, which will not fail even if the walls collapse.
- Avoid projecting elements, brittle materials and heavy materials on weak supports.
- Avoid combustible materials near chimneys and power lines.

Ductile structures have many joints that can move slightly without failing, e.g., bolted trusses. Such structures have a greater capacity to absorb the energy of earthquake waves. A symmetrical, uniformly distributed ductile framework and with the walls securely fixed to the frame, is suitable for large buildings.

Masonry walls are sensitive to earthquake loads and tend to crack through the joints. It is therefore important to use a good mortar and occasionally reinforcing will be required.

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Chapter 8 Functional planning

The majority of African farmers are small-holders who have limited resources and income and thus a low standard of living. The primary goal for most of these farmers is to produce food for the family together with some marketable surplus that can provide the income for such things as children's education and goods for personal consumption. However, as urban populations increase, the demand for commercial crop production is turning many farmers to the goal of financial profit in operating their farm businesses. In any case, the farmer will want to make optimum use of his resources (land, labour, capital and fixed asset), in order to achieve the desired results.

Functional planning is essential if this goal is to be realised. A good plan should provide an understanding of the situation and how it can be changed and thus assist the farmer to see his problems, to analyse them and to enable him to make soundly based decisions when choosing between alternative uses of his resources.

While farm management planning helps the farmer to choose the type and quantity of commodities to produce, the advice from crop and livestock production specialists is required to help him decide how to produce it in an efficient way. When an enterprise requires buildings or other structures, the farm building specialist will suggest alternative designs for efficient use of resources. The best plan for the whole farm operation will result from the various disciplines of farm planning being considered together.

The great number of small farms in most developing countries makes it impracticable to devise a plan for each farm. Instead, a few case studies that are representative of farms in the target population should be analysed to produce guidelines that can be promoted among the farmers in the region by the extension service.

Similarly, the farm building engineer can produce standard designs that are directly, or with small modifications, suitable for a large number of farms in an area. However, the number of case studies and designs must be sufficient to allow any farmer to be given advice that reflects his situation and which he is likely to adopt.

When plans are executed and resources invested in a farm enterprise, the resources will be

tied up and unavailable for alternative plans for some period of time. Since buildings are fixed assets that have a relatively long life span and consume a relatively large amount of resources for their construction, it is of special importance that they be planned for efficient and profitable use throughout their life. Planning done on paper is an inexpensive way and analyse alternatives and discuss the possibilities for satisfying the objectives as established by the farmer. Once a building is erected, however, it is expensive to make changes.

Rural planning

Clearly, a plan for an individual farm is influenced by a number of factors over which the farmer has no direct control e.g. as climate, soil fertility, government policies, state of knowledge about agricultural techniques, and value of inputs and outputs. However, since many african smallholders produce mainly for the farm household, they are only slightly affected by changes in policy and prices.

Nevertheless, national and regional rural development plans should be considered as they may provide the basis for plans for a community of farmers or an individual farm. Rural planning is carried out in the national interest to improve living conditions, balance agricultural production to demand and conserve natural resources. Many factors in the national or regional plans may directly influence the choice of production at a farm and thus the requirement of buildings.

The aims of the planning strategies in rural areas are based on political decisions. They can include:

- **1 Provision of supportive services such as extension education, market development, processing and credit.**
- **2 Development of infrastructure such as roads, electricity and water supplies.**
- **3 Self-help activities to develop community facilities.**
- **4 Increased non-farm employment opportunities.**

An improved road network may, for example, make new urban markets accessible, thus making it feasible for the farmers to go into vegetable or milk production. This in turn may require housing for animals, stores for produce and feed . It would therefore be wise to investigate any plans for rural development in an area during the planning stages at an individual farm or an extension campaign promoting improved building designs in that area. Government policy is often an important factor in determining the long term market trends and thus profitability of market production, and is therefore of special importance when planning for production operations involving buildings.

Economic planning of the farm operation

Most textbooks on agricultural economics describe methods of economic planning for commercial farms in developed western countries, but very few deal with methods relevant to

the African small-holders. Although the principles of economic theory may be relevant when reviewing African small-scale farms, their applications will undoubtedly differ from those used when reviewing commercial farms. Traditional applications assume, for example, that crop and livestock can be analysed separately, that the concept of farm size can be unequivocably defined, that the farmer makes all the decisions concerning farm operations, and that increasing cash income is the major objective. However, African agriculture is traditionally based on communal landownership and many include a multifamily situation in which two or more wives each have their own plots, but also participate in joint enterprises and are subordinate to the husband's general decisions. This situation would make an approach to local community groups more relevant than to emphasize individual farms. A multiple cropping system or a livestockfeedcrop system may serve to reduce risk and result in a more uniform supply of food and cash as well as family labour demand and, although the yields of the individual enterprises may be low, provide an acceptable overall result.

Money is the commonly used medium of exchange in economic calculation and often the most convenient. However, other units may occasionally be more relevant when small farms, having limited cash flow and strong nonmoney relations between production operations and household, are analysed. A subsistence farmer may, for example, value the security of having his own maize production so much that he will produce enough for the household even if an alternative enterprise using the land and labour would generate more than enough cash to buy the maize at the market. The principles of economic theory are valid whatever appropriate medium of exchange is used to specify the quantities, e.g. units of labour used to produce units of grain, meat etc. The difficulty is to find a suitable alternative unit to use where the

gains and losses are a mixture of money and non-money elements and to take into consideration the farmer's personal beliefs so that the resulting plan reflects his goals and value system.

The initiation of a building production process (see Chapter 6) is often a reason to review the economic planning for the entire farming operation. The plan will establish the resources available and the limitations and restrictions that apply to the construction of a proposed building. A comprehensive economic plan for a farm, whether an actual farm or a case study farm, may include the following steps:

1 Establishment of the objectives, priorities and constraints the farmer has for his farm operation. The objectives should preferably be quantified so that it can be determined whether they are being or can be achieved.

2 Analysis of financial resources, i.e. the farmer's assets as well as the cost and possibility of obtaining loans.

3 Listing of all available resources for the farming enterprises, quantifying them and describing their qualities, e.g. quantity and quality of land water resources, tools and machines, roster of labour including a description of training and skills, existing buildings and evaluation of their serviceability, the farmer's management skills, etc.

4 Description of all factors in the physical, economic and administrative environment which directly influence the farming enterprises but over which the farmer has no direct influence, e.g. laws and regulations, rural infrastructure, market for produce, availability of supplies, prices and market trends etc.

5 Individual analysis of each type of farm enterprise, whether crop or animal production, to determine its allowance of total capital. Note that where multiple cropping is practiced, the mix of various crops grown together is considered to be one enterprise.

6 Determining the optimum mix of enterprises that satisfies the farmer's objectives and makes the best use of resources.

The resulting plan will be an expression of the farmer's intentions for the future development of the family farm. The plan will contain several interrelated sub-plans as shown in Figure 8.1.

Figure 8.1 Schedule of a sub-plan in a farming enterprise.

Note that the sub-plans in Figure 8.1 may interplay in many more ways than have been illustrated. Many of these inter-relationships are of great importance when trying to maximize the result of the total production at the farm, whether the product is sold or not. Optimization of each individual enterprise may not necessarily mean that the total farming enterprise is

optimized.

Where one is satisfied that the farmer already operate his farm according to a sound economic plan, a less ambitious approach, involving analysis of only the enterprise requiring a new or remodeled building and an investment appraisal, may suffice. A number of investment appraisal methods have been advocated for use in agriculture to give a rough indication of the merits of an investment. However, small-holders generally heritate to risk cash for investment in fertilizer, pesticides and feed concentrate as well as improved buildings and machinery until enough food for the household is produced, a market with a cash economy is readily available and the farmer is confident in his own technical, agricultural and economic skills. Money therefore, may not always be the most relevant unit to use in the calculations.

An approach to building planning

Once the building requirements have been established in the economic planning, it will be the task of the farm building engineer to work out the functional and structural designs and deal with the farmstead plan.

The planning process always starts with a list of available resources and restrictions and other bac kground material. The major outline for the design is then sketched. The final design is developed by working from rough sketches towards more and more detailed plans of the different parts of the building. Often however, when some internal units such as a farrowing

pen has been designed and the number required established, the dimensions of the final building will be influenced by the pen size and number. The farmer will often impose restrictions on the design before the planning process begins. these should be critically evaluated and their effectiveness examined before they are accepted as part of the final design. it will be useful to discuss the extent of the proposed building and enterprise with an agricultural economist if the plan has not been based on an overall economic plan.

Standard solutions, published by demonstration structures and extension campaigns will, for some time future be the most important means of introducing improved building designs to small-scale farmers. However, the improved standard designs will be widely accepted by farmers, only if they are based on thorough understanding of the agricultural practices and human value systems prevalent in the local farming community and are developed to utilize locally available building materials and skills. New ideas, materials and construction methods should be developed and introduced to complement the strengths of the indigenous methods. Local builders, will be valuable sources of information regarding indigenous building methods and effective channels through which innovations, can be introduced. Close cooperation between builders and farmers will help the local community to deal with its own problems and to evolve solutions from indigenous methods and local resources which will have good prospects of getting accepted.

Background Information

An economic plan for the farming operation, will provide much of the bac kground information

required by the farm building engineer. As this is often missing, such information will have to be obtained by interviewing farmers and by studying similar farms in the area. Where the design is developed for a specific farm, priority should be given to gathering as much information as possible from that farm. All information should be critically evaluated prior to its acceptance as bac kground material for the design of the proposed building or for a standard drawing.

In the previous section a number of factors that should be considered in developing an economic plan are listed. The farm building engineer should obtain as much of that information as possible, in addition to data relating to the following factors:

- **1 A comprehensive master plan of the farmstead.**
- **2 For storage structures dates over expected acreage and yield of crop to be dried and stored, the length of the storage period i.e. the amount of produce to be sold or consumed at time of harvest.**
- **3 For animal housing the quantity and quality of existing animals and the possibility and time to increase and improve the herd through a breeding programme should be considered.**
- **4 Availability of building materials and constructions skills at the farm.**
- **5 Laws and regulations applicable to the proposed building.**

Calculations

The standardized economic calculations used to determine the gross margin in a farm operation are often limited in scope and therefore a more detailed examination of the enterprise housed in the building may be of use. Knowing the expected production volume, additional data is calculated using the bac kground information.

In the case of a storage building, the expected volume of crop to be stored as well as the required handling capacity is determined. In a multi-purpose store where several different commodities are held, a schedule of the volumes and storage periods will be useful to determine the maximum storage requirement.

Analysing the Activities

Activity analysis is a tool used in planning the production in large, complex plants such as factories, large-scale grain stores and animal production buildings, but it can also be a useful instrument in smaller projects, particularly for the inexperienced farm building engineer.

Figure 8.2 Diagram for the lay-out planning procedure.

Most production operations can be carried out in several ways involving various degrees of mechanization. By listing all conceivable methods in a comparable way, the most feasible method from a technical and economical point of view can be chosen. This will ensure good care of produce and animals and effective use of labour and machines. Uniformity in the handling improves efficiency, e.g. produce delivered in bags to a store should be kept in bags

within the store, particularly if it is to be delivered from the store in bags.

In animal housing projects, the handling operations for feed, animals, animal produce and manure are similarly analysed. Note that the analysis of handling operations for feed produced at the farm should include harvesting and transport from the field since these operations may determine the most appropriate storage and handling methods inside the building.

Figure 8.3 Example of a material flow diagram for a dairy unit.

When all handling operations have been analysed the result is summarized in a schedule of activities.

Labour efficiency is often an essential factor in small farm development. If a farmer has a reasonable standard of living, cultural norms and social pressures may limit his willingness to invest his labour for a relatively low return, while labour efficient methods allowing for a reasonable return on the labour invested, may increase his willingness to produce a surplus.

Room Schedule

This is a brief description of all rooms and spaces required for work, storage, communication, service of technical installations, etc. Because variation in yield and other production factors are to be expected, an allowance is added to the spaces and the volumes. It would not be uneconomical however, to allow for the most extreme variations, particularly if a commodity

to be stored is readily marketable and can be bought back at a reasonable price later.

The total space requirement is then totaled. Also, partial sums indicate how the production operations can be divided into several houses.

Communication Schedule

This describes the requirement and frequency of communication between the various rooms and spaces within the building and between the building and other structures at the farmstead. A schedule for movements between farmstead and the fields and the market is also essential. It may also include quantities to be transported. Based on this information rooms having frequent communication can be placed close together for convenience and work efficiency when the building is being designed. The communications schedule is not always accounted for separately, but instead may be included in the schedule of activities.

Following the principle of working from the major outline of the project towards the details, the next step is to place the proposed building on the farmstead. Some factors under farmstead planning will be discussed in section Farmstead Planning. Efficient communication within the farmstead is of great importance in creating a functional and harmonious operation. The schedule of functions serves as a checklist when transport is analysed. The room schedule provides information on the size of the buildings and the structural concept likely to be used.

A standard design can obviously not be shaped to fit at a specific farmstead. Nevertheless may the group of farms that the design is developed for have common features, which allow the designer to make recommendations concerning the placing of the new building. Some structures have special requirement as to where at the farmstead they be constructed. A maize drying crib must for example be exposed to wind.

Where the plan includes the addition of a new building to an existing farmstead, alternative locations for the proposed building are sketched on the master plan or, better still on transparent paper covering the master plan, and the communication routes are indicated by arrows between the buildings, the fields and the access road.

Considering all the planning factors and requirements, one location of the proposed building is likely to have more advantages and fewer disadvantages than other alternatives. The transport routes to and from the building are then further studied and noted for use when the interior of the building is planned.

The farmer will often have a firm opinion about the placing of the building from the start of the planning process. His opinion should be critically examined, but naturally it should be given considerable weight when the site is finally chosen.

Functional Design of the Building

The sketching of alternative plan views of the building is mainly a task of combining and

coordinating the requirements that have been analysed in earlier steps. Some general guidelines are as follows:

- **1 Concentrate functions and spaces that naturally belong together, but keep dirty activities separated from clean activities.**
- **2 Make communication lines as straight and simple as possible within the building and to reduce the number of openings, coordinate them with those outside as shown in the farmstead plan.**
- **3. Avoid unused spaces and long communication corridors.**
- **4 Provide for simple and efficient work. Put yourself in the situation of working in the building.**
- **5 Use as few different handling methods as possible and choose methods that are known to be reliable, flexible and simple.**
- **6 Provide for good environment for labourers and animals or produce.**
- **7 Provide for future expansion.**
- **8 Keep the plan as simple as possible within the limits of production requirements.**

Finalization of Sketching

After a number of sketches have been produced they are carefully analysed to select the one that best reflect the farmer's objectives. However, because a farmer's objectives are usually complex and difficult to elicit, it is common to use more readily evaluated criterious such as total construction cost or cash expenditure. The selected building plan is then drawn in its

correct size, sections and elevations are sketched and, where applicable, the building is positioned on the master plan. Frequently, the result of earlier steps in the planning process such as activity schedule or room schedule will have to be reviewed and adjusted as the work progresses.

Prior to being widely promoted, standard designs are often tested at a few typical farms. The construction phase and a period of use will often give rise to useful experiences that may result in improvements of the design. Only if the designer is continuously prepared to modify the design as needed to adapt it to changing agricultural practices will it have a good chance of being successful in the long run.

A 'one of its kind design' intended for a specific farm can obviously not be tested in practice prior to its construction. Therefore the sketch including a cost estimate, must be presented and carefully explained to the farmer so that he understands them and feels confident that he can run an efficient and profitable production in the building. Not withstanding this, the farmer is likely to have objections and suggestions for alterations, which must be considered and worked into the final sketches. Because an understanding of the operation and a positive attitude by all concerned are basic requirements for efficient production, farm labourers and members of the farmer's family who will be working in the building, should also be given an opportunity to review the sketches.

Final Design

When all sketches (farmstead plan, functional plan and structural concept) have been corrected, coordinated and approved by the farmer, the final building documents as described in Chapter 1 are prepared.

Farmstead planning

The farmstead forms the nucleus of the farm operation where a wide range of farming activities take place. It normally includes the dwelling, animal shelters, storage structures, equipment shed, workshop and other structures. A carefully organised farmstead plan should provide an arrangement of buildings and facilities that allows adequate space for convenient and efficient operation of all activities, while at the same time protecting the environment from such undersirable effects as odours, dust, noise, Dies and heavy traffic. A wide range of factors, described in section Communication Schedule, should be considered when planning the arrangement of buildings and services at the farmstead.

Although the immediate objective of these plans may be the inclusion of a new building in an existing farmstead, provision should be made for future expansion and replacement of buildings. In this way a poorly laid out farmstead can be improved over the long term.

Zone Planning

Zone planning can be a useful tool, but it is most effective when planning a new farmstead. The farmstead is divided into zones 10 to 30 metres wide by concentric circles as shown in

Figure. 8.4.

Figure 8.4 Zone planning in four zones.

Zone 1 at the centre of the farmstead is for family living, and should be protected from odour, dust, flies, etc. In Zone 2 clean, dry and quiet activities, such as implement sheds and small storage structures can be placed. In Zone 3 larger grain stores, feed stores and small animal units are placed, whereas large-scale animal production is in Zone 4 and beyond.

The advantage of zone planning is that it provides space for present farm operations, future expansion and a good living environment. However, in many African cultures the livestock has traditionally been placed at the centre of the farmstead. Thus the zone concept runs counter to tradition and may not be desirable.

Farmstead Planning Factors

Good drainage, both surface and sub-surface, provides a dry farm courtyard and a stable foundation for buildings. A gentle slope across the site facilitates drainage, but a pronounced slope may make it difficult to site larger structures without undertaking extensive earth-moving work. Adequate space should be provided to allow for maneuvering vehicles around the buildings and for future expansion of the farm operation.

Air movement is essential for cross ventilation, but excessive wind can damage buildings. Since

wind will carry odours and noise, livestock buildings should be placed downwind from the family living area and neighbouring homes. Undesirable winds can be diverted and reduced by hedges and trees or fences with open construction. Solar radiation may adversely affect the environment within buildings. An orientation close to an east-west axis is generally recommended in the tropics.

An adequate supply of clean water is essential on any farm. When planning buildings for an expanded livestock production, the volume of the water supply must be assessed. Where applicable, the supply pipe in a good building layout will be as short as possible. Similarly, the length of electric, gas and telephone lines should be kept to a minimum.

The safety of people and animals from fire and accident hazards should be part of the planning considerations. Children especially, must be protected from the many dangers at a farmstead. It is often desirable to arrange for some privacy in the family living area by screening off the garden, outdoor meeting-resting places, verandah and play area.

Measures should be taken for security from theft and vandalism. This includes an arrangement of buildings so that the farm court and the access driveway can be observed at all times, especially from the house. A neat and attractive farmstead is desirable and much can be achieved toward this end, at low cost, if the appearance is considered in the planning, and effective landscaping is utilized.

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Fire protection

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Measures to prevent the outbreak of fire and to limit its effect must be included in the design of buildings. Fire prevention measures include the separation of buildings to prevent fire from spreading and to permit fire-fighting, and a farm or community pond as a source of water for extinguishing fires.

Fire Resistance in Materials and Construction

The ability of a building to resist fire varies widely depending upon the materials of construction and the manner in which they are used. Resistance to fire is graded according to the period of time that an element of construction is able to withstand standardized test conditions of temperature and loading.

Bare metal framework and light timber framing exhibit a low order of fire resistance and both types of construction fail to qualify for a grading of one-hour fire resistance, which in many

countries is the lowest grade recognized. In contrast, most masonry walls have good fire-resistance ratings. Timber framing can be improved with the use of fire-retardant treatments or fire-resistant coverings such as gypsum plaster or plasterboard. Steel columns can be protected with plaster or concrete coatings while steel roof trusses are best protected with suspended ceilings of gypsum plaster or plasterboard.

Classification of Fire Hazards

Some types of activities and installations in farm buildings constitute special fire hazards. Wherever practical they should be isolated in a room of fireproof construction or in a separate building away from other buildings. A list of special fire hazards includes:

- **1 Flammable, highly combustible or explosive materials in excess of very small quantities, e.g. liquid and gas fuel, ammonium nitrate fertilizer, hay and bedding.**
- **2 Hot-air grain drying also dust from grain handling may, in high concentrations, be explosive.**
- **3 Furnaces and heating equipment; poultry brooder; fire places.**
- **4 Farm workshop (especially welding) and garage for vehicles.**
- **5 Electrical installations; continuously running mechanical equipment.**

In addition, lightning, children playing with fire, smoking and lanterns are origins for outbreaks of fire. Thatched roofs are highly combustible and prone to violent fires.

Fire Separation

Fire spreads mainly by wind-borne embers and by radiation. Buildings can be designed to resist these conditions by observing the following suggestions:

- **1 Adequate separation of buildings by a minimum of 6 to 8 metres, but preferably 15 to 20 metres, particularly where buildings are large or contain special fire hazards. A minimum distance may be stated in the building code.**
- **2 Construction using fire-resistant facing and roofing materials.**
- **3 Avoidance of roof openings and low roof slopes, which can be more easily ignited by embers.**
- **4 Use of fire-resistant walls which divide a large building into smaller fire compartments. To be effective, such walls must go all the way up through the building and root and any openings in the walls must be closed by a fireproof door.**

Evacuation and Fire Extinguishers

In the event of a fire outbreak, all personnel should be able to evacuate a building within a few minutes and animals within 10 to 15 minutes. Equipment, alleys and doors should be designed to facilitate evacuation. Smoke and panic will delay evacuation during a fire, that evacuation during a fire drill must be much faster.

In animal buildings exit doors leading to a clear passage, preferably a collecting yard, should

have a minimum width of 1.5 metres for cattle and 1.0m for small animals so that two animals can pass at the same time. Buildings with a floor area exceeding 200m should have at least two exit doors as widely separated as possible. The travel distance to the closest exit door should not exceed 15 metres in any part of the building.

Fire extinguishers of the correct type be available in all buildings and in particular where there are fire hazardous activities or materials. Water is commonly used for firefighting, but sand or sandy soils are effective for some types of fire. Dry powder or foam type extinguishers are best for petrol, diesel, oil and electrical fires. Regardless of type, fire extinguishers require periodic inspection to ensure their proper operation in an emergency.

Bushfire

The dry season or any period of prolonged drought brings with it a constant fire hazard. Fanned by strong winds and intensified heatwave conditions, a large bushfire is generally uncontrollable.

Firebreaks are an essential feature of rural fire protection and should be completed before the fire season starts. It is desirable to completely surround the homestead with major firebreaks at least 10 metres wide. Breaks can be prepared by ploughing, mowing, grazing, green cropping or, with great caution, by burning, and may include any water-course, road or other normal break which can be extended in width or length.

Shelter belts or even large trees are useful in deflecting wind-borne burning debris. For further protection, all flammable rubbish and long dry grass should be removed from the surroundings of the buildings and any openings such as windows, doors and ventilators covered with insect screens to prevent wind-borne embers from entering the building and starting a fire.

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Chapter 9 Crop handling, conditioning and storage

Introduction

Although in many parts of Africa some crops can be produced throughout the year, the major food crops such as cereal grains and tubers, including potatoes, are normally seasonal crops. Consequently the food produced in one harvest period, which may last for only a few weeks, must be stored for gradual consumption until the next harvest and seed must be held for the next season's crop. In addition, in a non-controlled market, the value of any surplus crop tends to rise during this period provided that it is in a marketable condition. Therefore the principal aim in any storage system must be to maintain the crop in prime condition for as long as possible.

Crops grown for food fall into two broad categories, perishable crops and non-perishable crops. This normally refers to the rate at which a crop deteriorates after harvest and thus the

length of time it can be stored. While some crops fall clearly into one or another category, others are less well defined. For example cereal grains can be stored for over a year and are considered to be non-perishable, whereas tomatoes are perishable crops and when picked fresh, will deteriorate in days. Tubers such as potatoes, however, may be successfully stored for periods extending to several months.

Although there are methods for preserving many of the perishable crops such as canning, freeze drying etc., but these are normally industrialized processes and not found on farms. It is possible, however, to apply farm-scale methods of preservation to cereals and pulses and the less perishable crops such as potatoes. To do this successfully, it is necessary to know the ways in which a crop can deteriorate and hence the methods for controlling this deterioration. Crops may need conditioning at harvest time to get them into a storable state and they may also require periodic inspection and care during the storage period. Viability of seed must be maintained and susceptibility to damage by fungal and insect pests must be reduced.

The storage and handling methods should minimize losses, but must also be appropriate to other factors such as economies of scale, labour cost and availability, building costs, and machinery cost.

Grain drying

The handling and storage of grains will be discussed in an orderly sequence. First the

requirements for safe storage, including the principles involved in both natural and artificial drying, followed by drying methods suitable for the small grower as well as for the larger scale operations of cooperatives and commercial farms.

Finally, various types of storage from family size up to commercial units will be discussed along with management suggestions for preventing damage during the storage period.

Properties of Grains

Cereal grains are edible seeds and as such would eventually be released from the plant when fully mature. Grains can be divided into three groups; cereals (maize, wheat, millet, rice etc.), pulses (beans, peas, cowpeas etc.), and oil seeds (soyabeans, sunflower, linseed, etc.).

Requirements for Safe Storage

Crops left standing unharvested start to show diminishing quantitative and qualitative returns through shatter losses, and attacks by insects, mould, birds and rodents.

It is important therefore that harvesting is completed as soon as possible. In addition, it is necessary to remove dust and contaminants which can include insects, vegetable materials such as bits of straw and chaff, and weed seeds etc. These will fill up pore spaces within the crop and inhibit air movement and add to any possible spoilage problems. The crop must therefore be clean.

One of the most critical physiological factors in successful grain storage is the moisture content of the crop. High moisture content leads to storage problems since it encourages fungal and insect problems, respiration and germination. Moisture content, however, in the growing crop is naturally high and only starts to decrease as the crop reaches maturity and the grains are drying. In a natural state, the seed would have a period of dormancy and then germinate either when re-wetted by rain, or by having a naturally high enough moisture content.

Another major factor influencing spoilage is temperature. Grains are biologically active and respire during storage. One of the products of respiration is heat and reduction of the temperature of the crop can help to reduce the rate of respiration and hence lengthen the storage life by reducing the possibility of germination. Another major temperature effect is on the activity of insect and fungal problems. With a lowering of temperature, the metabolic rate is reduced and consequently the activity causing spoilage.

A damp or warm spot in grain will increase the rate of respiration. In addition to heat, another product of respiration is moisture. The heat and moisture from such a "hot spot" can spread by convection encouraging moulds and bacteria which in turn respire and give off more heat and moisture. It thus becomes a self-generating process. Insect activity also increases with a rise in temperature.

These spoilage mechanisms can also affect the viability of grain required for seed or malting where inability to germinate would render it unmarketable.

The relationship between moisture content and temperature on the storability of crops is shown in Fig. 9.1. It can be seen that the moisture content of grain must be reduced at higher temperatures.

Figure 9.1 Effects in the store at different temperatures and moisture content.

Moisture Content

The moisture content (me) of a crop is normally given on a "wet basis" (wb) and is calculated as follows:

(Weight of moisture / Weight of wet sample) x 100

Occasionally "dry basis" (db) moisture content is given and it is important to know which has been used.

For example, if 100 kg of moist grain is dried and loses 20 kg of water, the mc is:

20 x 100 / 100 = 20% on a wet basis (wb) or

20 x 100 / 80 = 25% on a dry basis (db)

Grain will normally be harvested at a moisture content between 18% and 25% (wb) though it can be substantially higher or lower depending on many factors (such as stage of maturity,

season, weather pattern and drying facilities).

Moisture Content Measurement

Moisture can be determined in the laboratory by a number of methods, of which the oven drying method and the distillation method are the most accurate, these are normally used as references for moisture meters used under field conditions.

Laboratory methods requires a representative sample of the grain. Since the mc is unlikely to be uniform throughout a batch of grain, it is essential that:

- either several samples be taken and tested or a sample be taken from several places, thoroughly mixed, placed on a net surface and quartered, with the procedure repeated until a suitable size sample is obtained;
- the sample taken is kept in a sealed container (e.g. tightly fitting tin, bottle or plastic bag) between the time of sampling and that of determining the moisture content.

The oven-drying method is the most straight-forward and requires an accurately weighed sample of grain to be dried for a period of time and then re-weighed. The scales should preferably be electronic unless a large enough sample is used in which case good mechanical scales can be used.

The rapid oven method is one of a number of more rapid laboratory methods that have been

designed. Those methods range from simple, inexpensive pieces of equipment to highly sophisticated and expensive instruments.

A typical simple method consists of shining an infrared lamp on a balance pan containing a ground sample of approximately 5g. The sample is exposed to the intense heat of the lamp for a predetermined period and the loss in weight is shown on a scale calibrated in percentage moisture content.

The Salt-jar Method is a simple field method of determining whether maize is dry enough for storage in bags.

A teaspoon full of dry non-iodized salt is placed in a thoroughly dry jar (or bottle) with a tight cover. The salt should not stick to the sides of the jar when it is rolled. Then a cob of maize is shelled, the kernels placed in the jar and the cover put on tightly. The jar is then shaken and rolled gently for 2 to 3 minutes. If the salt does not lump or adhere to the sides of the jar, the moisture is usually below 15%.

Moisture Meters measures one or more electrical properties of the grain which are closely related to moisture content. Although acetylene and hair hygrometer measurement techniques have been used in the past. the most commonly used now are the electrical moisture meters.

Relative Humidity (RH)

Relative humidity as a measure of air moisture is defined in Chapter 7. It is a useful factor relative to grain drying. The relative humidity of ventilating air indicates how much, if any, moisture can be removed from the grain with unheated air and is a basis for deciding on ventilation rates and air temperatures.

Relative Humidity Measurement

Of the devices available for measuring RH, one of the simplest and most accurate is a psychrometer. The temperatures of the wet-bulb and dry-bulb thermometers mounted on the instrument are noted and the values used with a psychrometricchart. In fan systems the psychrometer may simply be held in the air stream to get a reading.

Drying Theory

Equilibrium Moisture Content

All produce has its own characteristic balance (or equilibrium) between the moisture it contains and the water vapour in the air with which it is in contact.

This is known as the equilibrium moisture content (EMC). When food grains containing a certain amount of moisture are exposed to air, moisture moves from the grain to the air or reverse until there is a balance between the moisture in the grain and in the air.

Each food grain has a characteristic equilibrium curve which is obtained by plotting a graph of moisture content against relative humidity and temperature of the air. Curves for some common food grains are given in Figure 9.2. These values must be considered only as a guide since different types and varieties of grain vary in their equilibrium values. The EMC will also vary slightly with the temperature. For most cereals it will drop about 0.5% for every 10C temperature rise at the same %RH of the air.

Figure 9.2 Equilibrium Moisture content for some different crops

Table 9.1 shows Moisture Content Equilibrium Values for a range of produce at 70% relative humidity and 27C, the maximum acceptable level for storage of any sample.

Since sacks are porous and allow air to circulate through the crop readily, it is generally acceptable to allow the grain to be stored at 1 % to 2% mc higher than in bins or containers with non-porous walls.

Table 9.1 ***Equilibrium Moisture Content Values EMC at 27 C and 70%RH***

	EMC
Maize	13.5
Wheat	1 3.5
Sorghum	13.5

Millet	16.0
Paddy	1 5.0
Rice	1 3.0
Cowpeas	1 5.0
Beans	1 5.0
Groundnuts (shelled)	7.0
Copra	7.0

In addition to temperature and moisture content, storage of grains can also be affected by atmosphere. If damp grains is held in a sealed container, respiration of grain and insects, will make use of the available oxygen. As this is depleted, it is replaced with carbon dioxide. This in turn inhibits the activity of the insects and fungal problems and it will decrease to the point that it virtually ceases. Storage in this manner can however cause taints in the grain which render it less acceptable for human consumption.

Storage of seed grain requires conditions which will not only maintain viability at it's peak, but at the same time will avoid all possibility of germination in store. High moisture content and low oxygen storage may decrease viability and therefore should be avoided for seed storage. At the same time, to avoid any danger of germination or fungal and insect problems in store, seed should be dried to 1% to 2% drier than for human consumption. Additionally, it is

important to maintain the temperature of the seed as low as possible.

Temperature, Psychrometrics of Drying

Grain to be stored in bins or sacks may have too high a temperature or too high a moisture content or both. If ambient temperatures are low, then air alone may cool the stored grain enough to prevent mould and insect damage while the moisture content is being slowly reduced to a safe level. If the air temperature is too warm (over 10 C), drying may be hastened by heating since by heating the air further, it increases it's capacity to pick up moisture.

Psychrometrics are discussed in Chapter 7, but as an example, Figure 9.3 shows the effect of heating the air, thereby increasing its capacity to pick up moisture.

Example: The ambient air at 25C and 70% RH is heated to 45C and 24% RH. Then upon passing through the grain, it gains enough moisture to again reach 70% RH while the temperature drops to 30.1 C. Then each kg of air will have removed (0.0230.0167) = 0.0063 kg of moisture. Whether the air returns to 70%, RH or some other level, will depend on air velocity through the grain

Figure 9.3 The effect of heating air for drying (from 1500m psychrometric chart).

Loss of Moisture As grain dries, it releases its moisture into the drying air and consequently loses weight.

The weight of grain after drying may be found with the following equation:

$W_2 = W_1 - W_1 (M_1 - M_2) / (100 - M_2)$ where:

W_1 = Weight of undried grain (kg)
W_2 = Weight of dried grain (kg)
M_1 = Moisture content of undried grain (%)
M_2 = Moisture content of dried grain (%)

For example, if 200 kg of peas at 32% moisture content are dried to 19% moisture content, what is the weight of dried peas?

$W_2 = 200(32 - 19) / (100 - 19) = 200 - 32.1 = 167.9$ kg

When the moisture content of the grain to be dried has been determined, it is possible to check the progress of the drying process by using the following procedure: Before the drying starts, place a weighed sample of the undried grain in a porous sack and bury it in the surface of the bin of grain. At any time during the drying process, the sack may be removed, weighed, and returned to the bin. Then, using the initial weight, the initial moisture content and the newly observed weight in the following equation, the current moisture content at that specific level may be calculated:

$$M_2 = 100 - W_1 (100 - M_1) / W_2$$

Drying Systems

Selection Systems for drying grains range from thin layer drying in the sun or a simple maize crib to expensive mechanized systems such as continuous flow driers. The choice is governed by a number of factors including:

Rate of harvest: the capacity of the system must be able to keep pace with the rate at which the grain arrives at the store on a daily basis. It is essential that loading and drying does not hold up the harvest.

Total volume to be dried: this may not be the total volume of the crop. If the harvest normally starts as a rainy period finishes, it may be necessary to dry the early part of the harvest, but not the later part.

Table 9.2 *Weight of Grain After Drying (% of Original Weight)*

Initial	Final mc %								
mc (%)	18	17	16	15	14	13	12	11	10
28	87.8	86.7	85.7	84.7	83.7	82.8	81.8	80.9	80.0
27	89.0	88.0	86.9	85.9	84.9	83.9	83.0	82.0	81.1

26	90.2	89.2	88.1	87.1	86.0	85.1	84.1	83.1	82.2
25	91.5	90.4	89.3	88.2	87.2	86.2	85.2	84. 3	83.3
24	92.7	91.6	90.5	89.4	88.4	87.4	86.4	85.4	84.4
23	93.9	92.8	91.7	90.6	89.5	88.5	87.5	86.5	85.6
22	95.1	94.0	92.9	91.8	90.7	89.7	88.6	87.6	86.7
21	96.3	95.2	94.0	92.9	91.9	90.8	89.8	88.8	87.8
20	97.6	96.4	95.2	94.1	93.0	92.0	90.9	89.9	88.9
19	98.8	97.6	96.4	95.3	94.2	93.1	92.0	91.0	90.0
18		98.8	97.6	96.5	95.3	94.3	93.2	92.1	91.1
17			98.8	97.6	96.5	95.4	94.3	93.3	92.2
16				98.8	97.7	96.6	95.5	94.4	93.3

Storage system: In many cases, the storage system and the drying system may be the same structure. For example a ventilated maize crib (see fig. 9.5) used for drying the crop naturally, is likely then to be used to store the crop shelled in bags. Some bin drying systems have a similar dual purpose.

Cost: both capital cost and running cost should be taken into account.

Flexibility: the likelihood of different crops requiring drying should be considered.

Drying Systems fall into two principle groups:

Natural drying **using ambient air temperature, and either direct sunlight or natural air movement through the crops.**

Artificial drying **using fan assistance to move air through the crop with the air either at ambient temperature or artificially heated.**

Additionally, drying can be considered in terms of the thickness of the bed of grain being dried, i.e. either shallow layer drying or deep bed drying. Natural drying requires the grain to be in shallow layers whereas certain fans can push air through grain several metres deep.

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Natural Drying

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The traditional methods used by farmers for drying grain rely on natural air movement to reduce moisture content to a safe level for storage. In additional they may utilize the extra drying capacity gained by exposing the produce to the sun. With good ventilation through the store the grain can be harvested just after it is ripe (about 30% MC for maize) but most methods allow some of the drying to take place naturally while the crop is still standing in the field.

Natural drying may be divided in three principle approaches:

- a Drying in the field before harvested
- b Drying in shallow layers and exposed to sun and wind on a surface which prevents moisture from the ground to reach the produce.
- c Drying in or on a structure which has open sides to permit air movement through the bulk.

Field Drying

The method of leaving the crop standing in the field for drying is popular in areas where maturity of the crop coincides with the beginning of a dry season. However, a crop left unharvested is exposed to attack by insects, birds, rodents, wild animals, strong wind and occasional rain showers which can damage and reduce the crop considerably. These factors are

particularly important with the new improved high yielding crop varieties that are often more susceptible to damages from the environment than the traditional varieties. For instance a hybrid maizecob has less leave cover than the old maize and therefore more open to attack by insects and birds.

Field drying of the crop will also delay the clearing of the field. This should be taken into account in areas where the field should be prepared for a second rainy season or where the humidity is high enough at the end of the growing season to allow for an additional crop of for instance beans.

Shallow Layer Natural Drying

The harvested crop is spread on hard surface ground, on roofs or purposely built platforms or trays. Exposed to the sun the crop will dry fairly quick depending on the humidity of the ambient air. The produce should be stirred frequently to ensure even drying. The disadvantage of the method is that the crop has to be brought in or covered every evening or before rain. The labour may be reduced considerably by placing the crop on a plastic or tarpaulin sheet for easy handling or on a platform/tray covered by for instance transparent plastic as shown in figure 9.4

Figure 9.4 Tray Drier for natural drying of crops in shallow layers. The tray has meshwire bottom and a pitched roof of transparent plastic.

Ventilated structures for natural drying

The very small producers may suspend bundles of the crop from trees or poles so they are freely exposed to the air. With larger quantities the harvested crop may be heaped on platforms or racks and topped by a layer of straw for rain protection. The method is commonly used for sheaves of paddy and cereals as well as for cob-maize and groundnut plants. Since the drying is depending on the free flow of air through the crop, the heap should be made as open as possible.

The next step is to have a more permanent ventilated structure in which the crop may be heaped for drying well protected from rain.

For maize the tradition in most part of Africa is to leave the crop in the field until the moisture content has falled to about 18% and then continue the drying of the maize on the cob with or without husk (sheath) in a granary which most commonly has the shape of a circular woven basket placed on a platform 1-3 feet above the ground. The predrying in the field in normally necessary because the basket is too tightly woven or too wide to allow for sufficient ventilation.

This "two-step" drying worked fairly well with the traditional farming systems where the farmer used maize with good sheathcover and could break new farmland regularly. The high increase in population experienced in many countries has resulted in scarcity of good land which forces the farmer to use the same land for the same crop year after year. In most cases

this will lead to an accumulation of pests (e.g. insects). This together with the higher susceptibility to insect attack by most improved high yielding crop varieties (see the Field Drying section) shows that the crop should be harvested as early as possible, just after maturity, and moved away from the field for quick drying and safe storage. For maize the circular traditional granary may still be used with some modifications. The basket has to be more loosely woven or the wall can be made slatted with at least 40% air space, and with a diameter varying up to l50cm depending on the humidity of the air. The restriction for the width makes it more economical to build the drying structure rectangular as soon as the production exceeds the yield of 5-9 bags. The rectangular structure in Figure 9.5. with slatted walls and floor is called a Ventilated Maize Crib. Although it can be used with small modifications for any crop that need to be kept ventilated, it is mostly used for drying of maize on the cob without the husk.

Figure 9.5 Ventilated maize crib for drying maize on cobs. The structure has slatted walls and should be placed with the long wall facing the prevailing wind.

The crib can be constructed in many different ways but what is important for the drying effect is the width and that the long wall is facing the prevailing winds. The width may vary from 60cm in very humid areas to 180cm in areas with semi-arid climated. Except for this extreems a width of 100-150cm as recommended in East Africa will suit many maize growing areas. The walls should not limit the airflow through the maize, this requires at least 40% openings. In areas with rodents the floor should be lifted 90cm above the ground and the legs fitted with ratguards. If the width does not exceed what is recommended for the area it is possible in a

ventilated crib to dry maize with an initial moisture content of 30% without getting problems with mould, but if it takes too long time (more than 10- 15 days) to get the moisture content below 18% mould may develop regardless of where the maize is, in the field or in a store.

The drying rate is depending on the relative humidity of the air and the air velocity. When the moisture content of the produce has reached the equilibrium with the humidity of the ambient air the drying will stop. Maize will dry down to about 13.5% m.c. if the mean relative humidity of the air is 70% (Figure 9.2).

Table 9.3 ***Capacities of Crib at different Lengths (section length 150cm)***

Crib width 150cm. No. of sections	**Volume in m**	**No. of bags wet maize on cobs**	**No. of bags of 90 kg dry shelled maize**
1	2.7	26	9.3
2	6.0	58	20.7
3	9.4	91	32.5
4	12.8	124	44.8

Artificial Drying

If the air humidity is too high to allow grain to be dried adequately by natural means and storage methods do not facilitate further drying, it is necessary to dry the produce by using forced air or heat or the two in combination. Various local methods using available materials have been developed. In some areas storage is restricted to the amount which can be dried on a heat supply similar to that available from a kitchen fire. Thus panicles of paddy and maize stored on horizontal grids are kept dry by heat from a fire which is lit occasionally underneath the grid and the heap of panicles is turned at regular intervals to prevent the development of mould. There are raised granaries beneath which fires are lit to complete drying. The produce receives a characteristic odour and flavour when exposed directly to smoke from the fire as well as to the hot dry air. This problem is overcome by using driers designed with a hot-air chamber or heat-exchange unit and smoke stack or chimney. See Figure 9.6.

Figure 9.6 An Oil Barrel Drier.

The fire is lit at the mouth of the oil-barrel tube, hot air and smoke is exhausted via the chimney. The heated barrels in turn heat the surrounding air which rises through the crop.

When heat is used to dry grain there must be some provision for aeration as well. Either very thin layers or frequent stirring is advisable as natural convection currents seldom move enough air.

The forms of artificial drying may be characterized by the depth or thickness of grain being dried. There are:

- **deep layer driers**
- **shallow layer driers**
- **in sack driers**

Large Scale System driers can be derived into the following categories:

- **a storage driers**
- **b continuous flow driers**
- **c batch driers**
- **d sack driers**

They may also be either high temperature or low temperature systems.

Air Volume Requirements

Whatever the system, artificial drying depends on forced air ventilation with, or without, added heat. Knowing the amount of moisture to be removed, together with the moisture carrying capacity of the air under the existing conditions, it is possible to estimate the weight of dry air required to complete a given drying operation. The humid volume of air is found on a psychrometric chart and from that the total volume for drying can be determined. Drying will take place as long as the RH of the drying air is below the equilibrium of the produce.

For example, the air described in Figure 9.3 contains 0.0167 kg moisture/ kg dry air at 25C and

70% RH. The holding capacity of this air is 0.0186 kg moisture/ kg dry air when fully saturated, and the specific volume is 1.04 m 1 kg dry air.

Table 9.2 shows that e.g. one tonne of grain dried from 22 to 16% m.c. will yield 71 kg of water (1.000 - 0.929) x 1000 kg = 71 kg).

Weight of air required = 0 0186 - 0.0167

Air volume is then 37368 kg x 1.04-= 39963 m kg

If the same air is heated to 45C the RH will drop to 23.6% and the holding capacity when fully saturated will increase to 0.025 kg moisture/ kg dry air.

The specific volume is now 1.11 m/ kg dry air (Figure 9.3)

Weight of air required =71 / (0 025 - 0.0167)

Air volume is then 8554 kg x 1.11 = 9495m or 1583m/tonne and % moisture reduction.

From this result the total volume of air and rate of flow is calculated in order to complete the drying operation in the necessary time.

Experience shows that the air volume needs to be increased somewhat depending on air velocity and grain depth. Air leaving a drier using high air velocity and shallow grain layer, is

seldom fully saturated with moisture. Certain minimum airflow rates are necessary to prevent the formation of mould during drying. These rates are given in Table 9.4. It should be noted that these figures are for loose grain through which air can be blown.

Table 9.4 ***Minimum Required Airflow Rates for Wheat and Shelled Maize***

	Grain Moisture percent, w.b.	**Airflow m/s/m**
Wheat	20	0.06
	18	0.04
	16	0.02
Maize	25	0.10
	20	0.06
	18	0.04
	16	0.02

Deep Layer Driers

These consist of beds, bins, silos or rectangular warehouses equipped with ducting or false

floor through which air is distributed and blown through the grain. The depth of the grain layer may be from 30cm and up to 350cm.

In deep layer driers unheated or slightly heated air (less than 6 C) is forced through the grain by a mechanical fan. The grain dries first at the point where the air enters, a drying front passes through the mass in the direction of air movement, and the grain at the air discharge location dries last. Most of the drying occurs just below the drying front in a layer called the drying zone which develops and then moves through the bulk (Figure 9.7). The depth and rate of progress of the drying zone depends largely on the dampness of the grain and the air speed. A low ventilation rate results in a shallow slow moving zone whilst a higher rate produces a deeper zone which progresses more quickly.

Figure 9.7 Deep Layer Drying.

The grain furthest from the air source will remain wet, and may even become wetter (due to condensation), until the drying zone begins to move out of the crop.

For successful results, the drying zone must reach the surface before the grain in this area deteriorates. It is therefore normal practice to limit the depth of grain so that the drying front reaches the top in time.

Although increasing airflow increases the drying rate, it will be noted in Table 9.5 that the static pressure due to the resistance of the grain to the flow of air, rises at a very rapid rate. In

general therefore, it is common practice to limit the airspeed through the crop to 0.10 - 0.15 m/s to avoid the necessity of excessive fan capacity.

Table 9.5 ***Typical Resistante to Airflow (Pa) per meter of Crop Depth***

Crop	**Air speed through crop m/s**				
	0.05	0.10	0.15	0.20	0.25
Wheat	140	330	570	850	1070
Maize	70	180	320	500	720
Peas	50	110	190	290	410

Note: Values for the other small grain cereals, such as rice, are similar to wheat and values for very fine seeds such as herbage seeds may exceed 2500Pa for 0.10 m/s airspeed.

A floor drying system in a godown or warehouse type of building is shown in Figure 9.8.

Figure 9.8 Floor drying system.

The crop is piled over the lateral ducts which are fed with air from a main duct. The main duct is often large enough for a man to walk inside in order to close off laterals where the grain is already dry.

The lateral ducts can be installed above or below floor level. The above-ground laterals are cheaper but will have to be removed during unloading the store. Below-ground laterals are left in place and can be driven over.

Fan capacities

When planning for deep layer driers it is important to have the fan performance in mind. Figure 9.9 shows typical fan performance curves for modern high pressure propeller fans.

Figure 9.9 Fan performance curves for some modern, high pressure, propeller fans.

Example

A village cooperative is planning a deep layer drier. Find a suitable size of the drier and choose a suitable fan. The following data is given:

Quantity of grain: 10 tonnes of maize/batch
Time available for drying 60 hours (6 days)
Initial moisture content (MC) in maize 21%
MC reduction for sack storage 6%
Incoming air at 25C and 50% RH
Assumed exhaust air at 85% RH and 19.5C
Air volume required to remove 1 kg Water:

From the 1500m Psychrometric chart it is found that the given air can remove, 0.0143 - 0.0118 = 0.0025 kg H 20/ kg dry air.
The volume of incoming air is 1.03m/ kg dry air.
Required air volume to remove 1 kg of water.
1.03 / 0.0025 = 412m/ kg H_2O

Moisture to be removed from maize

$W_1 - W_2 = W_1(M_1 - M_2) / (100 - M_2) = 706$ kg H_20

Total air volume required 412 x 706 = 290824m
Total air flow/hour 290824 / 60 = 4847 m/ h
Minimum Air Velocity required 0.07 m/ s (from Table 9.4)

Try different heights of the layer considering the airflow resistance.

	Height of layer (m)		
	1	1.5	2
Floor area required (density of maize 720 kg / m)	13.9	9.3	6.9m

Airflow	4 x 7/13.9= 349	521	702m /hm
Air velocity	0.10	0.14	0.20m s
Airflow resistance	180	480	1000Pa

From Figure 9.9 it can be seen that the 2.2kW fan can easily manage a 1.5m layer, that is; 4850m/h at 480Pa. Under the same conditions with wheat instead of maize the airflow resistance would be 330, 860 respectively 1700Pa and the layer should therefore be reduced to 1m or a centrifugal fan with higher performance to pressure would be more suitable.

The calculations assumes ideal conditions and the real moisture reduction may be decreased because of other climatic conditions or moisture content in the grain. The fan performance should therefore be a bit higher than calculated.

In the example the grain depth was given as 150cm. However, this sort of drying and storage unit may have a capacity of 300-400cm. To avoid the problem of spoilage in upper layers, it is normal practice to dry in batches of 150cm before adding more grain. The additional grain will then start drying from the point.

Commercially available bins for drying and storage are normally made of corrugated steel. Round bins have no theoretical limit to the diameter. However, for practical purposes, a diameter of 7 to 8m is likely to be the maximum. The minimum diameter is dictated by the ability to roll the sheet to a tight radius and is likely to be approximately 2-3m.

Rectangular bin sizes are limited by the ability of a straight length of wall to resist thrust. The practical limit is about 3m and these bins may well be built "nested" together (Figure 9.10). It is possible to omit the cross wall and replace it with tie-rods.

Figure 9.10 Nested bins with rods replacing cross-walls.

Another type of in-bin drier is a radially ventilated bin, in which there is a vertical perforated duct up the centre of a circular bin. The bin wall is of perforated steel or of timber staves alternating with perforated steel strips. The distance between the duct and the bin wall is 1 m to 2m, depending on bin size. The air path through the grain is thus limited to the radius of the bin. The air velocity will also decrease gradually towards the outer wall. They are normally used as a batch drier with the grain then transferred to a store for either bulk or bag storage. When drying wet grain the height in the bin should be decreased in order to increase the air velocity and eliminate too high pressure on grain in the bottom of the bin.

Shallow layer driers

Batch Driers

These are shallow layer dryers, often in the form of a tray with a perforated base. The dimensions may be 1 to 2m wide and 2 to 4m long with the grain bed being 150 to 300mm deep. The drier can also be built vertical with channels for both inlet and outlet air going through the grain, see Figure 9. 11. Warmed air is blown into the plenum chamber beneath

and then up through the grain. This type of dryer is suited to a smaller operation than continuous-flow driers. They may be either mechanically or manually loaded and unloaded.

Figure 9.1 1 Section showing the principle of a vertical shallow layer batch drier.

Continuous-flow Driers

The grain passes through these driers in a continuous flow at a controlled rate. The grain is kept in a thin sheet, approximately 100 to 150mm deep and hot air is blown through the crop. In this system, the air temperature can be substantially higher than in bulk driers. The rate of throughput can be controlled and hence the length of time exposed to the hot air. This is adjusted according to the amount of moisture to be removed. The latter part of the path through the drier is an ambient air section to cool the grain. Continuous-flow driers are high in cost and are applicable only in highly mechanized situations.

Grain Cooling

Failure to cool grain that has been dried with heat may cause an increase in mc great enough to seriously shorten its storage life.

It can been seen on a psychrometric chart that for a given air mc (absolute humidity), a drop in air temperature causes an increase in RH. It follows that if hot grain is allowed to cool naturally the RH of the air in the bin will rise and, if the saturation temperature is reached or

passed, condensation can cause the grain mc to rise again. To prevent this possibility, after drying, the grain should be cooled until ambient temperature is reached.

Figure 9.12 The principles of a Continuous-flow drier.

The methods adopted to cool grain are dependent on the drying system.

Sun-dried grain can reach high temperatures if in the direct sunlight. If it is to be stored in any container through which air cannot freely pass, it should at least be left shaded for an hour or more before storing.

Air can circulate around sack stacks to some extent and therefore can cool naturally. Even so, it is preferable to ventilate to cool the stacks.

Fan ventilated batch driers of all types, including sack driers, should have the fan left running with no added heat until the crop is at ambient temperature before discharging the crop from the drier. This is most easily determined by comparing the temperatures of the incoming and exhaust air and waiting until there is essentially no difference.

Cooling Buffer Storage

Low volume ventilation (LVV) or aeration may be employed to cool grain that has been put in storage. Although it can be used in conjunction with other driers as a cooling system, the main objective of LVV is to cool the grain positively at harvest time and thus prevent infestations of

insects and mites and the development of mould. The deterioration of viability is slowed and the migration of moisture from warm spots to cooler ones in the grain mass is avoided.

It must be stressed the LVV is not a drying system. Consequently if grain is too wet at the start (over 18%) it will be unlikely to store well, and for human consumption it would be preferable to start with a mc lower than 18%.

Principles

Ambient air passed through the grain at the rate of 6 m/ h to 8 m/h for each tonne in the storage has proved adequate in practice. Depending on the static pressures involved, this range of ventilation rates would require from 190 to 560W per tonne.

Drop in temperature occurs in three ways: a Removal of respirational heat by airstream b Contact cooling of the grain by colder air c Evaporative cooling when the RH of the cooling air is below the EMC level of the grain.

Air flow may be upwards or downwards and investigations have shown little real difference in overall effect.

Once the grain is cooled and the ventilation stopped, it is advisable to turn the fan on every 2 to 3 weeks to check for storage problems. A musty odor will indicate a moisture and temperature problem.

Equipment

Fans to be used for grain cooling can either be centrifugal or single-stage axial fans. Motors ranging from 370 to 746W cover the vast majority of fan sized used. They are usually small enough to be picked up by hand and runs on 13 amp switched outlets. The volume of air delivered varies with the climate but should at least be 10m/h and tonne.

Ducts similar to those in on-floor storage are satisfactory.

Management

With the aim of cooling the grain, only air that is cooler than the grain under treatment should be used.

The preferred method of cooling grain is to blow when ambient air is 3C cooler than the warmest grain. This entails knowing the temperature of the grain in the bin or heap. A spear thermometer or a thermistor will be needed, the quicker reaction of the latter greatly speeds up the chore of taking grain temperatures at several points. In a bin the hottest spot will be in the centre some 1.2 to 1.8m below the surface with upwards ventilation or about 1.2m above the duct with downwards airflow. In a natural heap the hottest places are the apex, the shoulders or at the foot of the side wall (Figure 9.13).

Sack Drying

Grain in sacks can be dried in a stack or the sacks may be laid one or two layers on a platform drier as shown in Figure 9.14.

A platform drier consists of a plenum chamber with an open top of wire nesh, bamboo or other means of supporting 2 to 3 layers of sacks. Using an airflow rate of 0.1 m/ s per m of platform area, air heated to about 14C above ambient should reduce the cm about 0.5%/hr, though a temperature increase of 6C to 10C may be more usual.

In the stack system, a perforated plenum tunnel is used to form the base of the stack and to distribute the air uniformly. See Figure 9.15. The initial moisture content determines how large the stack can be: 8 sacks high for an initial mc of 25% and 12 to 13 high for an initial mc of 18%. A fan is used to blow air through the stack. This is normally diesel powered.

Figure 9.13 Warmest areas in grain.

Figure 9.14 Platform drier with concrete panels on brick piers.

With both platform driers and sack-stack drying, there are some points which need to be borne in mind. Firstly, any gaps between sacks should be filled with empty bags or straw to minimize air leakage. Secondly, as pointed out earlier grain should be cooled before being left for storage.

Drying Problems

Overdrying grain with excessive temperature can set up stresses in the individual kernels leading to cracking and loss of viability. Another effect of overdrying is that all moisture lost below the safe storage mc is a loss in the value of the crop if not considered when the grain is sold. For example, 10tonnes of grain at 15% mc weights 340 kg less at 12% mc.

Air Short-circuiting means that the air will always take the path of least resistance which, with grain, is usually the shortest route possible through a batch. Figure 9.16 illustrates this principle and emphasizes the need to level the grain and provide a uniform depth in any forced air system.

Figure 9.15 Sack drying with a diesel powered fan.

Figure 9.16 Air taking shortest path.

Dirty Crops such as grain with a large proportion of chaff, fine seeds and dirt becomes more difficult to dry as the resistance to airflow increases due to spaces between grains being blocked. Table 9.5 while dealing with clean grain, shows the great effect that small particle size has on the resistance to air flow. It is important therefore to have grain as clean and uncontaminated as possible.

Cleaning techniques range from the traditional winnowing of crops by throwing them into the air, to sophisticated modern high throughput equipment. The two techniques used on small farms are winnowing and sieving.

Sieving is usually a two stage operation. The first sieve is just coarse enough to let the grain through while rejecing all larger particles. The second sieve is just fine enough to hold the grain being cleaned, but it passes weed seeds and particles that are smaller than the grain.

Grain may sometimes have a preliminary cleaning before storage to remove the majority of contaminants, and then a second more thorough cleaning before sale. This would apply in particular to seed grain.

Instruments

The measuring of temperature, relative humidity, static pressure and air flow are discussed in Chapter 7. However, the special situations found in making these measurements relative to grain drying and storage will be discussed in more detail.

Thermometers

Although mercury-in-glass thermometers are fragile and rather slow acting, they are probably the most dependable means of measuring temperature. They may be protected by mounting in a groove in a wooden or metal probe so that temperatures deep in piles or bins may be checked. Care should be taken to allow several minutes for the temperature to stabilize.

Thermistors and thermocouples are convenient for remote measurements but they are more costly and subject to misadjustment.

Air Flow Meters

Airflow meters similar to the one shown in Figure 9.17 are available to measure the vertical air speed through grain being dried in bulk. The conical clear plastic tube contains an aluminium disc which can slide on a wire mounted along the axis of the tube. A metal cone at the base of the plastic tube supports the instrument on the grain and collects the emerging air. The plastic tube is graduated in m/ s and the air speed is read at the point where the disc is 'floating' on the air passing up the tube. In order to obtain consistent and accurate readings the disc should move freely on the wire.

For very simple and rough airflow assessment in a fan ventilated bin, a square of light material such as a handkerchief, about 300mm square, laid on the surface of the grain should be lifted if enough air is passing through the crop.

Figure 9.17 Grain airflow meter.

Manometers

The quantity of air delivered by a fan is related to the static pressure against which the air is being delivered. By measuring static pressure and referring to the relevant fan performance data, an approximate guide to the quantity of air being delivered can be obtained. Figure 7.8 shows a simple manometer.

For all types, it is important that the sensing head (static tube) be mounted in a position in the main air duct where the mean static pressure can be monitored. In practice, a position near the top of the main air duct and a distance of at least twice the fan diameter from the fan is normally satisfactory. The lower the airflow at the sensing location, the truer the static pressure reading will be.

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Grain storage

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Parameters

The major objectives of crop conditioning and storage . were discussed earlier. To be able to achieve these objectives, the store must satisfy the following parameters in so far as possible: a the grain must be kept dry; b the grain should be kept at a uniform temperature; c the grain should be protected from insect attack; d rodents and birds should be excluded.

It is evident from previous sections that drying and storage are in many cases provided for in mne structure. Combining these functions is economical and allows further conditioning at later stages if required. For example, if a hot spot develops in a storage bin, it can be easily ventilated again. It may also be possible to provide some low-volume ventilation in an otherwise pure storage system.

There are however, situations when the storage is considered quite separately from drying, ranging from the storage of naturally dried crops, to the storage of grain from a continuous-flow or batch dryer.

The size and type of storage facilities is likely to be dictated by: a Total volume of crop to be stored. b The storage requirements for the crop to be stored. c The unit cost of various types of storage. d The form in which the crop is stored, i.e. cob maize vs shelled maize or bagged wheat vs bulk wheat.

The volume of the store required can be estimated from the expected yield and the land area.

A comparison between different forms of storage is normally done through calculation of costs/tonne of capacity.

The form of storage depends not only on how the crop is harvested, the volume and the way it is delivered to the market, but also the overall costs.

Where drying is a problem bag storage has the advantage that it allows higher moisture content than bulk storage. For maize, the requirement for safe storage is maximum 15 and 12% moisture content respectively. in general terms the advantages and disadvantages of bag and bulk storage respectively, are:

Bags	**Bulk**
Flexibility of storage	Inflexible storage
Partly mechanizable	Mechanizable
Slow handling	Rapid handling
Considerable spillage	Little spillage
Low capital costs	High capital costs
High operating costs	Low operating costs
Easy inspection	Inspection more difficult

Soild-wall bins and silos for bulk storage Soild wall bins may be anything from a small plastered basket to large steel or concrete silos holding several thousand tons. The traditional bins used by the African farmers are small with capacity of up to 2-3 tonnes and include gourds, clay pots, mud plastered baskets raised off the ground and mud walled silos ("rumbus'). Many of these have limitations, particularly in durability, protection against

rodents and insects as well as moisture from ambient air. Solid wall bins or silos should only be used in areas where the produce can be dried sufficiently before storage. Several attempts have been made to improve on the traditional stores to make them more suitable for long term storage.

Figure 9.18 Clay silo for storing grain in 4 compartments. [he stone c hips forms the moisture barrier.

Improved traditional bins

Many traditional stores perform excellenctly in their appropriate climatic conditions and others can be made to do so with minor changes. Efforts should be made to prevent cracks in the surface of the walls and to seal the entrance to the bin. This can be done for instance by adding lime or cement to the mud (i.e. a stabilized soil technique) or by incorporating an airtight lining (e.g. plastic) in the wall.

Figure 9.19 Improved traditional hint

Figure 9.19 shows a woven basket made of sticks or split bamboo plastered with mud mixed with cement. The walls slope towards a covered manhole in the top An outlet is near the bottom. The bin, which is placed on a raised platform, is covered by a thatch roof or hat.

The major improvements are:

Floor raised from the ground to avoid moisture

Supporting legs of hardwood made 90cm long and equipped with baffles to keep rats away.

Instead of mud the walls may be plastered with cement or mud mixed with cement/lime.

Inlets and outlets should be made with airtight and lockable covers.

Thatched roof to protect the bin from rain and strong sun.

The area around the store is kept clean.

Underground Pits

In a few countries, e.g. India, parts of Africa and Latin America, underground pits are claimed to keep grain without damage for many years.

The pits keep grain cool, and some of them are relatively airtight. Grain on top and around the sides can however often be mouldy.

There are several types of pits, most of them flask shaped covered with sticks, cowdung and mud, or a large stone embedded in soft mud. The area should be free from termites and relatively dry.

Improvements of the pit may include:

- **Better lining of straw and mats,**
- **Plastic sheets and concrete or ferrocement**
- **Use of plastic bags in the pit**
- **Improved covering**
- **Surface drainage**

Figure 9.20 Underground pit.

Brick-walled silo

Brick walled silo or bins are suitable for small and medium size stores. The strengthening requirements makes them uneconomical when the height exceeds about 7-8 m. The wall may be made of bricks or blocks of mud, stabilized soil, burnt clay, stones or cement. To withstand the pressure from the grain the wall will need reinforcement depending on the size and strength of the building materials. Reinforcement can be reduced and even omitted by building the walls thick and heavy (gravity walls). Figure 9.21 shows a silo with gravity-walls where the bricks are placed radially. No reinforcement is needed for this size but more building material is required.

Walls made of bricks, mud or cement will absorb moisture from the ambient air. In areas with high relative humidity it is therefore necessary to protect the grain by adding a moisture

barrier to the silo walls. It will help considerably to bagwash or plaster the walls on the outside with a mortar of cement-lime-sand (1 :1:5) for burnt bricks or cement, and cement-sand-mud (1:2:6) for mud walls. Then the walls can be painted with plastic paint or coaltar if better protection is needed.

An alternative to plastering and painting the silo is to incorporate a lining of plastic sheeting in the middle of the wall, floor and roof in such a way as to make the container airtight. The Pusa Bin is such a structure and has been developed by the Agricultural Research Institute in New Delhi. Originally the bin was rectangular with walls of two layers of brick; the floor and the roof made of two layers of mud. The system can be used for silos of any shape and will, if properly done, give a good protection against air and moisture.

Figure 9.21 Silo built of bricks laid radially (gravity wall).

Reinforced Concrete Silos

Concrete can take very little tension and needs to be reinforced when used for silos. Small silos suitable for farm level may be reinforced with chicken-wire

The ferrocement store or ferrumbu is a typical example, figure 9.22. One or two layers of 12mm chickenwire are tied to vertical sticks or rods placed in a circle. The chickenwire is then plastered from both out and inside. The verticals are removed after the outside isfinished. Taller silos 3-4m or more may be framed by welded mesh wire and with 12mm chicken-wire

tied to the outside. With bags or plastic tied to the outside it is possible to plaster the silo from the inside first and then from the outside a few days later after having removed the bags. These techniques make it possible to construct walls with thickness of 3 to 6 cm.

Figure 9.22 Cross-section of a ferro-cement store (ferrumbu).

Larger concrete silos are built by using a sliding mould which is moved upwards continuously or step by step. Reinforcement and concrete are supplied from the top Concrete silos can be made airtight if openings are properly sealed.

Steel bins

Steel bins ranging from properly cleaned-out steel oildrums to commercial stores with capacity of several thousand tonnes figure 9.23. In most cases steel silos are more expensive than concrete silos but have the advantage of being easy to erect, and for the small sizes, also possible to move. The welded steel silo is normally airtight if the openings are properly sealed, but even a silo assembled of corrugated iron sheets can be made air tight if all joints are sealed with rubber gaskets or bitumen.

Figure 9.23 Commercial storage silos.

Bag Storage

The most common method for grain storage in many countries is bag storage in a variety of

buildings, e.g. stone, local brick, corrugated iron, and mud and wattle, with or without plastered walls and with an earth, stone, or cement floor and corrugated iron or thatched roof.

As mentioned before, the form in which the produce should be stored will depend on the quantity, harvest method, handling method, moisture content and costs.

The advantage of bag storage is listed earlier. The disadvantage is that jutebags do not give any protection against insects which means that an insecticide has to be used. In some countries with a dry climate it is common practice to stack the bags on plinths and cover them with a tarpaulin for temporary storage. Examples are the hard stands used in Zambia and the groundnut pyramids near Kano in Northern Nigeria. However, if the grain is going to be kept for some time it is recommended to store the bags in a building. A simple store would be to use the ventilated maize crib that was used for drying, with the only difference being that the walls should be covered as protection against rain see figure 9.24.

If the bags are stored in a multi-purpose farm shed or even in the farmers dwelling they should be kept out range from rats and mice. A raised free-standing platform equipped with ratguards will serve the purpose.

For larger quantities a special building is recommended Figure 9.25 shows a small block-built bag store (20m) with the capacity of about 15 tonnes of cereals.

Figure 9.24 Ventilated maize crib used for storage of shelled maize in bags.

Figure 9.25 Small block-built bag store.

Whatever the size, the floor should be of good quality concrete, the door should fit tightly to prevent entry of rodents, and ventilation openings should be screened to keep out birds. The gaps between the wall and the roofing sheets must be closed for instance with cement.

If fine mesh is used to prevent insects from coming in through the ventilation openings it must be maintained regularly; dust should be brushed away and holes repaired immediately. Figure 9.26 shows a multi-purpose store with 90m (extendable) storage space suitable for cooperatives and villages.

Figure 9.26 Multipurpose store (196m).

Storage Management

Storage management is important for all types of storage. For bag-storage the four important points are:

1 Prevent damp from the floor and walls to reach the produce by stacking the bags on pallets off the ground and away from the walls.

- Damp from the roof is avoided through proper ventilation and using damp absorbing

materials.

2 Stack the bags properly to allow:

- **Optimal use of space**
- **Ease of sweeping the floors**
- **Ease of insepction of produce for rodents and insect**
- **Ease of counting the bags.**

3 Control insects and rodents

- **Make sure the building is rodent proof**
- **Treat the building and produce against pests**
- **Keep the warehouse clean**
- **Close all holes at doors, roof etc., where pests can enter**
- **Repair cracks in walls where pests can hide**
- **Remove and destroy any infested residues that can contaminate newly introduced produce.**
- **Bag stacks should be carefully constructed to maximize use of space, maintain hygienic conditions and to facilitate good management. If one lays the bags exactly on top of each other in successive layers the stack will be extremely unstable. To overcome this one must ensure that there is an overlap in each successive layer see figure 9.28.**

Figure 9.27 Proper stacking for easy management. The bags are placed on dunnage.

Insect Control

Losses caused by insects: a Weight loss. Insects as they develop will feed on the produce. Losses vary with the commodity, for grain and legumes

- **a loss in the range of 10-30% might be expected over the storage season.**
- **b Loss in quality and market value. Damaged grains will have reduced market value.**
- **c Promotion of mould development. "Respiration" water from insects will lead to mould-formation in poorly ventilated stores.**
- **d Reduced germination in seed material. Many insects prefer to eat the embryo because it is the most nutritious part of the grain.**
- **e Reduced nutritional value. Removal of the embryo of grain will reduce the overall protein content of the grain.**

Figure 9.28 Bags stacked in five respective eight bags layers.

Sources of infestation

- **a The insects can survive from one season to the next in: Infested residues in the field. The structure of the store Natural habitats like natural vegetation**
- **b Fresh produce can be infested by: Active migration to the crop in the field and store**

Infested produce put into the store

Control measures

A great variety of techniques are used for control of insect pests in stored produce, from sunning and smoking at the traditional farm level to irradiation in the largest scale bulk-handling. This paragraph is concerned with proven techniques, variously suitable for use in small to medium scale storage under tropical conditions. Specific recommendations are difficult to make, a technique must be tested for a particular situation depending on the value of the crop, occurrence and resistance of the pest, which farming system is used, and the availability of insecticides. When selecting a technique it is important to consider its effectiveness against the target pests; hazards to the farmer and the consumer, and will the result pay the cost of carrying it out?

Insect control techniques:

- **a Sanitation: Do not mix new grain with old. Old infested material should be removed or thoroughly fumigated. Clean the storage structures, machinery and disinfect bags and baskets by sunning or chemical treatment. Large structures will require chemical treatment while smoke may be adequate in small stores.**
- **b Natural Resistance. Crop varieties differe in their susceptibility to storage pests. Traditional varieties are usually more resistant to storage pests than new varieties. For instance maize with good husk cover can reduce field infestation.**

- **c Hermetic Storage. In airtight conditions, reduced oxygen and increased carbon dioxide will arrest insect and mould development.**
- **d Chemical Control. The traditional method for preserving the crop in storage is to treat the grain with smoke and special plants or, when stored in closed containers, to mix the grain with ash or sand. The method is much used for small volumes like seed, but for larger quantities the method becomes cumbersome.**

Chemical control involves, in most cases, the use of an insecticide which can be used on the produce as

- **dust**
- **spray**
- **fumigants**

Besides killing the insects, all insecticides are, more or less, toxic to mammals. The toxicity is usually expressed as a "LD_{50}". Technically, this is the dose required, in mg active ingredient per kg of body weight of consumer, under specific conditions, method of application and time span, to kill 50% of the test population, usually rats.

Most insecticides do not kill all insects and mites; choose a chemical that is either "broad spectrum" or one that specifies toxicity to moths and beetles; mites may require special treatment.

With regard to persistence; insecticides will tend to lose their effectiveness with high humidity, high temperatures and sunlight.

It is important that the insecticide is applied, in the correct dosage. Excessive and/or inappropriate use of chemicals will lead to the insects becoming resistant and can be a hazard to human health.

Application:

- **1 Dusts are usually admixed with the grain in diluted form at 10-15 parts per million active ingredient (ppm A.I.) at the time of loading/bagging. Suitable chemicals: Organophosphorus insecticides, pirimephos-methyl (Actellic) or pyrethroids.**
- **2 Sprays may be added to bagged produce by spraying each layer of bags as the stack is built. This will give protection for several months but in the case of reinfestation, the surface of the stack can be resprayed. For bulk storage the sprayer may be mounted on a belt conveyer used for loading the bin. Liquid insecticides is very suitable also for both space and surface treatment. For application a small domestic applicator (shelltox type) is sufficient for the small scale farmer, but a knapsack sprayer will reduce labour demand. The liquid form of the insecticides mentioned under (1) may be used.**
- **3 Fumigation can be used for killing all pests where airtight conditions can be provided for at least 3 days for Phostoxin, or one day for Ethylene dibromide, after adding the chemical The treatment is used for closed container as well as bagged produce if covered under tarpaulin or plastic sheets. A fumigation has only an instant effect so the grain must**

be subsequently protected from reinfestation. Common chemicals: Phosphine gas, e.g. Phostoxin is supplied in tablets of aluminium phosphide, which release phosphine in contact with moisture in the air; ethylene dibromide, metyl bromide, carbon tetrachloride, various combinations and formulations are available e.g. as "Trogocide" all volatile liquid fumigants; capsules and sachets are available for small scale applications and pressure-cylinders for large-scale.

Commercial insecticides usually consist of a small quantity of the toxic compound the "Active Ingredient" (A.I.) with other substances called the "filler". It is important to be able to convert from one basis to another; example: "Actellic should be applied at 15 ppm A.I." This means we should apply 15 grammes of active ingredient to every million grammes of produce i.e., to one tonne.

Example

If we start with 5% dust, this means that 100 grammes of crude product (C.P.) contains only 5 gr of A.I. The dose of chemical to be applied will be

$q = (15 \text{ ppm} \times 100) / 5\% = 300\text{gr/tonne of produce}$

Rodent and Bird Control in Stores

Besides consuming large quantities of stored grain and food, rodents contaminate stored

produce through droppings, urine and hairs, and may spread human diseases. Control of rodents requires an integrated approach since no single method is completely effective. It should be focussed on creating an unfavourable environment and excluding rodents from stored grain. Methods used to minimize the damage caused by rodents include good housekeeping, proofing, repelling, trapping and poisoning. Keeping a cat around a grain store is another effective method of control. The requirement for good housekeeping is the same for rodent as for insect control; the store should be kept clean inside and outside and easy to inspect. In the following paragraph emphasis will be on how construction can be improved to keep rodents out.

Birds are likely to be a nuisance in ware houses if no precautions are taken.

Construction Details

- **a Local granaries, cribs and other small stores can be made rodent-proof if the floor is raised to a minimum of 90cm from the ground and if the legs are equipped with conical ratguards made of metal sheets; see figure 9.5.**
- **b All openings between the floor and the walls should be closed. This is especially important in warehouses with walls of corrugated iron sheets. The floor should be of strong concrete to avoid rodents from coming up.**
- **c The door should fit closely to the frame and covered with sheet metal for added protection. Boards dropped vertically into slots on either side of the door, about 50cm high, will form a barrier while the door has to be kept open.**

- **d Ventilators and windows should be covered with wire mesh with openings not exceeding 12mm. This will also form a barrier against birds.**
- **e To keep birds out, other openings like the gaps between the walls and the roof should be closed or covered with wire mesh with 12mm openings and the door kept shut as much as possible.**
- **f Ideally the proofing of large central storage depots should be considered during the planning stage; then it can be incorporated at every low cost in the construction of each building.**
- **g Existing stores can in many cases be protected by means of a rodent proof fence at least 90mm high. This should be constructed of small-gauge wire netting topped by a horizontal metal sheet and should completely encircle the store. The bottom of the fence should be buried to a depth of at least 30cm**

With the protective measures described above it is possible to reduce and even eliminate the rodent problem if the measures are properly maintained.

Storage Management, Hygiene and Safety

Condensation and Moisture movement

If bins and in particular silos are exposed to direct sunlight or if the grain inside the silo is warmer than the external air, convection currents can be started. This results in the moist air being carried through the grain and where it meets a cooler surface i.e. the silo wall, the

moisture will condense out and dampen the grain in the immediate vicinity. Clearly this can be a major problem with grain stored in steel silos in hot climates, particularly in areas where the sky is clear during both day and night. A clear sky results in high daytime temperatures and cool nights.

For small silos the problem can be reduced by covering the silo with a roof or hat that prevents the sun from heating up the surface. For larger silos other solutions have to be found, either by ventilating the grain in the store or moving the grain from one silo/cell to another. This will mix the grain enough to even out the moisture content. If the moisture content is too high it will be necessary to run the grain through a drier.

Hygiene

Reference is made to what has been said about insect and rodent control for bag storage. However, it is essential that all types and sizes of grain stores the cleaning will have to be done when it is empty. If the insect population is building up, the whole store may have to be fumigated or sprayed.

Safety

Dust is stirred up when grain is handled. Inhalation can cause respiratory problems, especially if exposed to slightly mouldy grain. Breathing filters should be used. Since grain dust is explosive it is important to enforce the "No Smoking" rule and ensure that all light bulbs and

electric equipment are shielded. Good ventilation is recommended.

Falls: all catwalks where a person could fall more than 150cm should have guard rails 100cm high and a toes board of 15cm

Crusts: can be formed indamp grain beneath which the grain has run out. Walking on bridged grain can cause failure of the crust, resulting in being burried and suffocated.

Machinery: all moving parts should have guards fitted and all wiring should be maintained regularly.

Grain flowing out of a container tends to form a funnel at the centre. This highly unstable surface can stuck a man in, within seconds.

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Grain handling equipment

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There us a wide variety of such equipment available on the market, and table 9.6 is an attempt to categorise their ability to move grain.

Table 9.6 ***Grain Handling Equipment***

Type of Equipment	**Fixed or Portable**	**Horizontal or H Vertical V**	**Capacity range**	**Power Requirement**	**Cost**	**Advantages**	**Disadvantages**
Belt and Bucket elevator	F	V	medium	low	medium	1. efficient	1. can be
			to		to	2. Minimum	difficult
			high		high	maintenance	to erect
						3. high capacity	2. expensive
						4. cleanable	
Auger (Screw conveyor)	F P	H + V	medium	medium	medium	1. wide range	1. can damage
						available	some material
							2. medium to
							heavy wear

Belts	F	H	high	low	high	1. long distances	1. expensive
		If belt is				2. low power	2. angle very
		ribbed max				3. self cleaning	limited
		30 angle					
General purpose elevator with belt or chain with slats	F P	H	medium	low to	medium	1. multipurpose	1. noisy with chain
		and inclined with ribs		medium		2. inexpensive	
Tractor shovels	P	H	medium	on tractor	low	1. (flexible	requires space
			to	- high		2. high output in	to operate in
			high			short time - for loading lorries	
Sweep	FP	H		medium	medium	medium	1. unloading
						round bins	

Augers	P	H		depends on	-	-	1. high labour
Sack			distance.				requirement.
	P	H + V	low	high	high	1. flexible	1. noisy
barrows			to				2. much dust
Pneumatic			medium				3. reduced cap for wet grain

Belt-and-Bucket Elevator

A flat belt is carried between a crowned pulley at the top and bottom of casing. Small buckets or scoops are fixed to the belts at regular intervals and these carry the grain from the elevator bottom to the top. The capacity depends upon width of buckets, spacing and belt speed. Elevators of up to 20m height and capacities of 50tonnes/h are available.

Auger (Screw Conveyors)

Auger elevators are reasonable in cost, comparatively light in weight, and dependable in their operation. They are available in a wide range of lengths and capacities and are usually powered by an electric motor. Long augers may be mounted on wheels for easy transport. The angle of operation is adjustable, however, the capacity goes down as the auger is raised, see

table 9.7. High moisture content also reduces the capacity.

Table 9.7 *Example of Auger capacity and power requirements per 3m length of auger (0150mm)*

Moisture content %	Angle of Elevation									
	0 t/hr kW		22.5 t/hr kW		45 t/hr kW		67.5 t/hr kW		90 t/hr kW	
14	27	0.42	25	0.61	21	0.64	17	0.62	13	0 52
25	17	1.32	15	1.40	13	1.33	10	1.08	7	0.52

Note: Auger speed 400 rpm

Power requirement is directly proportional to the auger length.

Flat Belt Conveyor

These are used in practice horizontally although up to 15 inclination is possible. With ribs the angle can be increased to 30. The capacity is high and loading and unloading can be done any place along the belt. It does not cause any damage to the crop and raises little dust.

Chain and Slats Conveyor

These consist of a chain carrying traverse slats which drag the grain along a metal or wooden trough. Slat width up to 300mm spaced 150 to 300mm apart and chain speeds of 10 - 77 cm/s are used to give outputs up to 30 tonnes/in. Small sized models have no support frame and can be carried by two men.

Sack elevator

These may be a continuous belt with ribs or a chain conveyor with slats.

Dumping Pits

To achieve high capacity with tractors and trailers when taking grain to the store, an effective system of receiving grain must be used. Ideally, it should be possible to dump a trailer load and pull away within minutes. Such a reception facility will normally be associated with an elevator to raise grain for conditioning or storage.

Reception Pit with an Elevator

A concrete wood or steel-lined pit with an inverted pyramid or V-shaped bottom is built in the ground, see figure 9.29.

Figure 9.29 Dump Pit with an auger moving the grain to the elevator.

The crop is dumped from a trailer into the reception pit from which it flows by gravity or by the help of an auger into a second pit containing the bottom end of an elevator. Much time is saved, if reversing to the tipping pit by the farm transport is avoided, by having a "run-over" pit. This requires a safety grid, which must be strong enough to carry a loaded trailer.

Shallow Surface Pits

These are usually in conjunction with an auger. Two simple pits of this kind are shown in Figure 9.30.

Figure 9.30 Small Simple Reception Pits.

Overhead Grain-loading Bins

Hopper-base gravity discharge bins, when erected at a suitable height, facilitate the loading of transport vehicles at high rates. This will cut the waiting cost and should therefore be considered where the capacity of the loading equipment is low compared to the load capacity of the vehicle.

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Semi-perishable crops

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In contrast to grain, crops such as potatoes, yams, carrots and onions are more perishable and require carefully managed storage conditions to maintain top quality. While market value is seldom great enough to justify the expense of ideal levels of temperature and humidity control, the desired conditions will be discussed and then various methods of achieving levels as close as economically feasible will be described.

Properties

The properties of the many horticultural crops are far more varied than grains and pulses. This in turn results in highly varied storage characteristics. For example, yams and potatoes can be stored adequately for several months, while cassava can be kept for only a few days without deterioration if not processed.

The initial moisture content following harvest is much higher in these mature crops than in grain. With grain, a loss of moisture is desirable for storage and does not affect the use of the crop. This is not the case with fruits and vegetables. Loss of moisture may cause the crop to become unmarketable. Yet with a high moisture content, storage of these crops is more difficult since there is a greater likelihood of insect and fungal problems. Whereas lowering the moisture content of grain will inhibit sprouting, though not affect viability, the high moisture

vegetable crops, which cannot be allowed to dry out, are more prone to sprouting. However, there is generally a period of dormancy following harvest which can be used to good advantage.

The perishable and semi-perishable crops are living organisms and as such, continue to respire. Consequently any storage will need ventilation to remove the heat and moisture of respiration and to prevent condensation on cool surfaces.

Fruits and vegetables are nearly always susceptible to physical damage such as bruising, cutting and cracking. Much of this results from dropping the fruits or tubers on to hard surfaces or on to other fruits and tubers as they are loaded into containers or bins. In many cases, 200 to 300mm is a maximum safe drop.

Further losses can occur if the heat of respiration is allowed to cause a temperature rise. "Black heart" in potatoes, for example, is a serious problem resulting from high temperatures under storage conditions.

In contrast, low temperatures approaching freezing produce a characteristic sweetening in potatoes.

Losses can also be caused by disease. This tends to be worse if the crop has been damaged, thus allowing the disease organisms to enter through cuts and cracks in the surfaces. Removal of earth from the crop and careful loading before storage can help to reduce this problem.

Storage Requirements for Potatoes and Other Horticultural Crops

Potatoes are the most commonly stored root crop and the greatest amount of research has been conducted relative to ideal storage requirements. In general, however, very similar facilities and operating conditions are suitable for several other crops of varying perishability. The following sections will deal primarily with potatoes, but much of the information, including the storage facilities described, will be suitable for other semi-perishable crops.

As mentioned, some bruising and cutting of the tubers is likely to occur during harvest. These fresh wounds are an ideal entry place for disease and rot organisms. The infection can be minimized by storing the potatoes for the first one to two weeks at a temperature of 13 to 20C and a relative humidity of 90 to 95%. During this curing period the skin toughens, making the tubers much less subject to further injury or disease problems.

Potatoes are naturally dormant for about two months. However, it is often necessary to store them for longer periods of time by extending the dormancy period and by keeping shrinkage to a minimum. Temperature and humidity are important factors in this respect. Suitable temperatures for long term storage are related to the eventual use of the potatoes.

For seed stock, temperatures of 3 to 5C will delay sprouting for up to 8 months. For ware potatoes, 4 to 8C will allow several months (4 - 8) of storage without serious sprouting, while lower temperatures increase the risk of sweetening, that is, the conversion of starch to sugar. Finally, for processing potatoes, a minimum temperature of 7 to 10 C is required in order to

prevent discolouration and to keep sweetening to an absolute minimum. In stores with higher temperatures it is possible to control sprouting in ware and processing potatoes for up to 6-8 months by using a sprout supressant chemical.

The relative humidity (RH) of the air in the store is of great importance. Low RH will lead to shrinkage and weight loss while too high RH will cause condensation on the surfaces. This is objectionable since free water on the potatoes greatly increases the possibility of rot and the spread of diseases. A potato tuber is about 80% water and strictly speaking, air is in equilibrium with the tuber at a relative humidity of 98%. However, in practice, to avoid condensation the relative humidity is kept between 90 and 96%.

Potatoes exposed to direct or indirect sunlight will turn green and develop a bitter taste which is poisonous and make the tubers unsuitable for human consumption. Stores should therefore be without windows and ventilation openings should have light-traps.

Potatoes that have been held at low temperatures tend to be brittle and subject to considerable damage if handled. If the store has been maintained at low temperatures throughout the storage period, it is best to warm the store to about 10C for a few days before the potatoes are removed.

Storage Without Buildings

Delayed Harvest

The simplest form of storage for some crops is to leave them in the ground and harvest them only as required. There is risk of pest and rodent damage, but the deterioration which may take place after harvest may exceed the field losses; hence delayed harvest is a reasonable choice. This is particularly useful for cassava where field deterioration is normally substantially less than post harvest losses due to even short term storage. On the other hand, some crops deteriorate substantially in quality if left in the ground beyond a certain stage. Carrots, for example, tend to become tough and woody.

Clamp

In areas that have low mean soil temperatures, a simple ground clamp (Figure 9.31) may be suitable, especially for potatoes. They are piled on the ground in a long row and covered with 150 to 200mm of straw or coarse grass. Chicken wire is put all around the base to resist rodents and then soil is dug out around the pile and placed on the straw. This store is not likely to be satisfactory for more than a month or two unless the soil temperature is near 10 C and night air temperatures are 10 C or less. To control soil pests the ground can be treated with an insecticide before the clamp is made.

Figure 9.31 Simple roof crop clamp.

Covered Clamp

Another simple store for short time storage is the covered clamp (Figure 9.32) consisting of a

raised platform on which the potatoes are heaped and then covered with 10cm of grass or straw. Air is free to circulate through both produce and straw. A thatch roof above provides shade to help reduce daytime temperatures. Protection from rodents will be needed.

Figure 9.32 Covered clamp raised from the ground.

Storage in Multi-purpose Buildings

Slatted Boxes or Bins

Square boxes of slatted construction, each holding about 1 m of potatoes offers a good possibility for small as well as large scale stores. The boxes can be larger but not deeper than 1m. If located in a well isolated building, the fluctuation of daytime temperatures will be reduced. The boxes should be raised about 250 to 300mm above the floor so that air can circulate freely. With little insulation and only natural ventilation this method is best suited to cooler areas and then for relatively short storage periods of 3 to 4 months.

Smaller boxes can be handled manually, while the larger boxes of 1m and more can not be moved manually when filled. See Figure 9.33.

Figure 9.33 Box store for root crops.

Clamp on Floor

Using a building similar to that shown in Figure 9.33 a clamp offers an alternative to boxes. To allow adequate ventilation with cool night air, a duct under the crop is included as shown in Figure 9.34.

Figure 9.34 Duct under produce heap.

Naturally ventilated stores

Figure 9.35 shows an example on how to build a potato store suitable for small scale production. The store, which holds about 1500 kg., is naturally ventilated and measures 150 x 160cm square. The walls are 1 50cm high and a slatted floor is placed 90cm off the ground to keep rodents away. The store shown in the figure is made of offcuts but other materials may be just as good. For insulation the walls have a 20cm thick layer of straw which will be compressed to about 10cm when the store is loaded. The floor should be covered with about 5cm of straw before loading and on the top 20cm of straw should be spread evenly to protect the potatoes from sunlight and drying.

Figure 9.35 A Naturally Ventilated Store.

The method of operating the store is depending on the average temperature on the place. If the average temperature is above 20C it is necessary to extend the walls on three sides down to the ground like an apron. The forth side will have a flap that is kept open only at night in order to take advantage of the cooler air for the ventilation.

For higher altitudes with mean temperatures below 20 C it is possible to operate this potato store with continuous ventilation and the apron and the flap can be left out. In this case the store legs should be fitted with rat guards.

The ventilation should be just enough to remove heat caused by respiration without causing any excessive loss of moisture.

Larger Stores

Buildings to store large quantities of potatoes or other root crops in bulk must be of substantial construction to resist the force of the crop against the walls. Further, the walls and ceiling must be well insulated whether outside air or refrigeration is used for cooling.

The wall sills must be securely anchored and the studs firmly fastened to the sill in order to withstand the high lateral force of the potatoes. It is desirable that the concrete floor be tied to the foundation with reinforcing bars.

Tie beams should connect the top of the side walls on opposite sides of the building to resist the load and braces at frequent intervals are needed to withstand uneven loading.

Insulation and Vapour Barriers

Regardless of the climatic area in which they are built, large air cooled or refrigerated stores should be well insulated. In uplands e.g. in Southern Africa some insulation will prevent

freezing of the potatoes in midwinter. In contrast, in hot regions where mechanical refrigeration may be necessary, substantial insulation will help to reduce the cost of operation. An R value of 4 to 5 in the ceiling and 3 to 3.75 in the walls should be adequate to prevent condensation in a cold climate and to allow economical operation in warm areas. These large storage are expensive buildings and it is important to install high quality commercial insulation.

As discussed in Chapter 7, vapour barriers are essential to prevent the accumulation of moisture in the insulation. It was pointed out that moisture travels from the warm side to the cold side of a wall or ceiling. Thus the vapour barrier is installed on the warm side. A refrigerated store in a warm area poses no problem in choosing the outside of the wall and ceiling as the warmest and therefore the proper place to install a polythene vapour barrier. However, air cooled stores are much more difficult to design as the outside temperature may be warmer at the start of the storage season and the inside warmer later on. A very careful assessment must be made to choose whether vapour barrier should be used or not, and if so which side to install the vapour barrier. Alternatively a nonpermeable rigid type insulation can be installed to resist moisture penetration from either side.

Ventilation System

There are many different types of air distribution systems incorporated into large stores, not only for potatoes but for several fruits and vegetables as well. They range from simple natural ventilation to manually controlled fans and inlets and finally to sophisticated automatically

controlled dampers and variable speed fans. The choice of system will be determined not only by environmental needs but also by economic factors.

A ventilation system of medium complexity is shown in Figure 9.36 and can be installed in a store similar to that shown in Figure 9.37. The ventilation system allows complete exchange of air, complete recirculation or various mixtures in between. Although automatic controls will provide more accurate regulation of the system, manual control is possible because conditions change slowly in a large store. To control the relative humidity in the store, a humidifier can be installed in the ventilation system. This also reduces the temperature of the incoming air.

Air Distribution

Air from the proportioning system is forced into a main distribution duct and from there into lateral ducts cast into the concrete floor. The laterals may be covered with removable 50 by 100mm wood slats, thus allowing an elevator to be set up in the duct for unloading the bin.

The spacing of the lateral ducts are limited to 80% of the height of the heap i.e. 0.8H between centres and designed in size to limit air velocity to no more than 5m/s. They should be tapered or stepped in order to maintain a fairly uniform velocity as air is fed off to one bin after another. Because the potatoes cover about 75% of the open area, the wood slats should be spaced to give 4 times the area needed for the correct velocity.

Evaporator Size

As described in Chapter 7, evaporator size influences the temperature at which it can operate, and the difference in evaporator temperature and store temperature greatly affects the relative humidity of the store.

It is satisfactory to choose an evaporator size that will require about 6C temperature difference during the loading period. Then when field heat is gone and the heat load is much smaller, the difference can be dropped to less than 2C and an adequate humidity will be maintained. Unit blower evaporators are most commonly chosen for produce storage.

Any cool store should have an adjacent room for grading, packing and shipping the produce. It should be well lighted and adequate in size to store empty containers and packed produce to be shipped immediately.

As mentioned earlier, potatoes need to be warmed to at least 10C prior to handling after a period of cold storage. If they have been stored in bulk in the store, they must be warmed in place. If they have been stored in pallet boxes, they may be warmed in the packing room which can be maintained at a temperature comfortable to the workers.

Figure 9.36. Ventilation system.

Figure 9.37 Large bulk store.

If the cool store is used for other produce it may be desirable to have some refrigeration in the

packing room so that grading and packaging of perishable produce can be completed under cool conditions.

Later in this chapter the storage requirements for a number of fruits and vegetables is discussed. In many cases the temperature and humidity requirements are similar to those for potatoes and what has been covered in relation to potatoes holds equally true for the other produce with few reservations. If produce is held in storage for a short time, the air distribution system is probably not necessary and unit-blower evaporators will be adequate. Further, the non-compatibility of several fruits and vegetables to simultaneous storage, even when they require similar conditions, should be noted.

Grading and Handling Facilities

Grading crops for sale is more likely to be required where large volumes are handled. The principle requirements of a structure for this purpose are to protect the crop while being handled and to allow grading to be carried out without being affected by the weather.

Both the stored produce and the workers require protection from sun, rain, wind and dust. In some cases a pole building without walls will be adequate. In other situations, an enclosed room with lighting, ventilation and perhaps either heating or cooling will be required.

Seed Potatoes Stores

Seed potatoes must be kept from one season to the next. It is clearly important to maintain the tubers in good disease free condition and to keep the viability as high as possible. Seed potatoes may be satisfactorily held in a refrigerated store at 4 to 5C for up to 8 months, but that is not always possible. Alternatively, and at lower cost, potatoes can be held in naturally ventilated stores at ambient temperatures where sprouting is allowed under the influence of diffuse sunlight. This technique is well proven and seed held for long term has been nearly as viable as that held in refrigerated stores for a similar length of time. This method of using the ambient temperature together with diffuse sunlight which allows chits (short sturdy sprouts) to form, can be used for seed potatoes as soon as the dormancy period has come to an end. Once the chits have developed, however, it is important to control aphids by routine application of a systemic insecticide, otherwise, virus diseases are likely to be introduced.

Potato Chitting Trays

Regardless of how seed potatoes are stored, it is desirable for the tubers to chit (sprout) before planting and this is done by deliberately exposing them to either artificial or diffused natural light. The light must reach all of the potatoes and consequently shallow trays with slatted bottoms are required both for good light distribution and adequate air circulation. A good design is shown in Figure 9.38. To give good light penetration, the alleyways between stacks of trays should be at least a meter wide and lines of trays should be placed in the store to give the best lighting from the sides and top (if lighting panels are fitted in the roof). Space under the bottom trays is essential for air circulation.

Figure 9.38 Potato chitting tray (approx. 350 x 500mm).

Small Seed Potato Chitting Stores

For the small landholder who requires a limited quantity of chitted potatoes, a rack similar to that shown in Figure 9.39 built under the eaves of the family home is a simple and inexpensive solution.

Figure 9.39 Small-scale chitting racks.

Buildings for chitting stores can be very simple. They may be built of poles, blocks, bamboo, reinforcing wire and netting and are constructed so that the sides let in light and ventilation. The interior is always at ambient temperature and lit by indirect daylight. As a result, once potato dormancy finishes, the tuber sprouts grow but only slowly, remaining short, green and strong.

Figure 9.40 Medium-sized chitting store with shelves.

Direct sunlight must be avoided and if roof-lights are installed, a shading device should be fitted below the roof to diffuse the light. Whitewashed strip-bamboo curtains suspended about a metre below the roof-lights serves this purpose well.

These naturally ventilated ambient temperature stores are best suited for areas or altitudes with maximum temperatures in the 18 to 24C range. Results have shown losses somewhat

higher than in expensive refrigerated stores, but satisfactory seed quality remains after 5 to 6 months providing the insecticide application has been continued on a regular basis.

Larger stores having similar characteristics can be built to suit the amount of seed to be stored see Figure 9.41. It is also quite possible to use the maize crib shown in Figure 9.5 for chitting seed potatoes if it is not needed for maize storage at the time.

Figure 9.41 Larger-scale potato chitting store.

Perishable crops

Fruit and Vegetables

The majority of fruits and vegetables are highly perishable commodities with a short storage life. The exceptions, including apples and potatoes can, if well stored, last for several months. Table 9.8 describes the primary differences between the non-perishable and perishable crops.

Table 9.8 ***Comparison of Cereals vs Horticultural Crops***

Cereals and Oil Seeds	**Horticultural Crops**
* Low moisture content, typically 10% to 20%	* High moisture content, typically 70% to 95%

* Small unit size, typically less than 1 gram	* Large unit size, typically 5g to 5 kg
* Very low respiration rate with very small generation of heat.	* High to very high respiration rate.
* Heat production is typically 0.05 megajoules/tonne/day for dry grain.	* Heat production is typically from 0.5 to 10 megajoule / tonne/day at 0C to 5 to 70 megajoules/tonne/day at 20C.
* Hard texture	* Soft texture, easily bruised
* Stable - natural shelf life is from one to several years	* Perishable - natural shelf life is a few days to serveral months
* Losses usually caused by molds, insects and rodents.	* Losses usually caused by rotting (bacteria, fungi), senescence, sprouting. and bruising.

Storage Requirements

The major requirements for the storage of perishables are the need to lower temperature substantially and to retain moisture in the produce. Table 9.9 illustrates the storage conditions and storage life for a number of fruits and vegetables.

Mixing Commodities

Some crops produce odours in storage while others emit volatile gases such as ethylene. Ethylene stimulates the ripening of many fruits and vegetables. This is negligible at low temperatures but may be a nuisance at higher temperatures.

Consequently, even when two or three crops require the same storage conditions, it is not advisable to store them together.

Products that emit ethylene include bananas, avocados, melons, tomatoes, apples, pears and all fleshy fruits. Lettuce, carrots and greens are damaged with stored with fruits or vegetables which produce ethylene. Even very small amounts can be harmful. It is recommended that onions, nuts, citrus fruits and potatoes each be stored separately.

Onions

The following technique for the harvesting, drying and storage of onions has been developed:

- 1 Onions are harvested when at least one third of the tops have fallen over
- 2 If weather is dry, the onions are left in the field to dry. The neck must become tight and

the outer scales should rustle when dry. This is most important and successful storage depends on full drying or curing.

If weather is unsuitable for outside curing, the onions may be placed on slatted shelves in a well ventilated open shed. Layers should not be more than 10 to 15cm deep. (The seed potato store can be used for this purpose).

Onions will keep at higher temperatures than shown in Table 9.9 and this seems practical, particularly in dry areas. This involves placing cured onions in a slatted-floor store which is freely ventilated except during damp conditions.

Storage Structures for Perishables

A Low-cost Cool Store

A simple low-cost structure in which vegetables can be stored for the few hours between harvesting and transporting to market should be useful to growers of all sizes. The basic construction is similar to that shown in Figure 9.32. A simple frame is constructed with poles or other low cost materials. Covered with grass or other thatching material, protection is provided for the produce from excess temperature and moisture loss until it can be transported to market.

Table 9.9 ***Ideal Storage Temperatures, Relative Humidities and Expectecl Storage Life of Fruits***

and Vegetables

Commodity	**Storage Temperature C**	**R.H.%**	**Expected Storage Life**
Asparagus	0 - 2.0	95	2 - 3 weeks
Beans (green)	5.0 - 7.0	90 - 95	7 - 10 days
Carrots	0	90 - 95	2- 5 months
Cauliflowers	0	90 - 95	2 - 4 weeks
Cucumbers	7.0 - 10.0	90 - 95	10 - 14 days
Cabbage	0	90 -95	3 - 6 weeks
Chillies, Capsicums	7.0 - 10.0	90 -95	2 - 3 weeks
Courgettes, Zucchini	0- 10.0	90	5 - 14 days
Eggplants, Brinjals	7.0-10.0	90	1 week
Melons	0 - 4.4	85 -90	5 - 14 days
Okra, Lady Fingers	7.0 - 10.0	90 - 95	7 - 10 days
Onions (dry)	0	65 - 70	1 -8 months

Potatoes (white)	5.0 -10.0	93	2 -5 months
Potatoes (sweet)	12.0 - 16.0	85 - 90	4 -6 months
Tomatoes (ripe)	7.0 - 10.0	85 -90	4 -7 days
Tomatoes (green)	12.0 - 20.0	85 - 90	1 -3 weeks
Watermelons	4.4 - 10.0	80 - 85	2 -3 weeks
Apples	1.0 - 4.4	90	3 -8 months
Avocados	4.4 - 12.5	85 -90	2 -4 weeks
Mangos	12	85 - 90	2 -3 weeks
Pineapples	7.0 - 12.5	85 -90	2 -4 weeks
Papayas	7.0	85 -90	1 -3 weeks
Carnations	0 - 2.0	90 - 95	3 -4 weeks

The wall should be extended to ground level on three sides but left open on the fourth (prevailing wind) side for ventilation. This allows for free air movement most of the time, but canvas flaps should be provided for closing the ventilation openings if desirable.

The grass roof and walls can be kept wet with a sprinkler pipe-line, or if that is not available, the thatching can be hand sprinkled as required. The interior will be kept cool and moist with temperatures as much as 5 to 8C lower than outside. More important, produce harvested late

in the afternoon can be cooled during the night with resulting temperatures the following noon as much as 10C below ambient.

Commercial Cool Store

As shown in Table 9.9, only a few crops, including potatoes, onions, carrots and apples can be stored for periods longer than a few days or weeks. However, the wholesale merchant will require short term refrigerated storage for his produce and as indicated, separate rooms will be needed for crops that are not compatible with each other in storage. As with refrigerated potato stores, attention must be given to adequate insulation, good vapour sealing and large size evaporators which help to maintain high humidity.

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Chapter 10 Animal housing

The main purpose for man to keep livestock is to convert energy in feed into products which can be utilised by human beings, such as milk, eggs, meat, wool, hair, hides and skins, draught power and manure (fertilizer). Traditional, extensive livestock production involving indigenous breeds and low cost feeding will usually have low performance and can therefore only justify minimal, if any, expenditure for housing. However, where improved breeds, management and feeding is available it will usually be economically beneficial to increase the production intensity and to construct buildings and other livestock structures to provide for some environmental control, reduced waste of purchased feed stuffs and better control of diseases and parasites, but this rule is not invariable. It is, for example, difficult to identify an economic benefit in sheep production arising from any but the use of the least expensive buildings. At the other end, a relatively expensive farrowing house, providing a high level of environmental control, may improve the survival rate in piglets sufficiently to both justify the cost and add to the profitability of the production unit.

The planning and design of any structure for a livestock production system involves many alternatives for each of numerous variables and can therefore be turned into a complex and theoretical subject, but is usually far simpler in reality. However, every facet of the design, be it the production system, equipment, building materials, layout or location, will play a part in determining the profitability of the production and any variation in one of them may significantly affect the profitability on the whole. One special difficulty when designing livestock structures for tropical climates is that most research and development has, up to now, been concerned with the conditions in temperate or cold climates. Any recommendations derived from such experiments and applied uncritically in warm climates may result in an adverse environment for the animals and in very high building and operation costs.

Animal behaviour

Introduction

Understanding of domestic animal behaviour and man's relationship with farm animals may greatly contribute to increased economic benefit in animal husbandry and easier handling of the animals. The importance of animal behaviour aspects in the design of animal housing facilities generally increase with the intensity of production and the degree of confinement. Many modern farming systems greatly reduce the freedom for animals to choose an environment in which they feel comfortable. Instead they are forced to resort to an

environment created by man.Animals that as far as possible can exercise their natural species-specific movements and behaviour patterns are less likely to be stressed or injured and will therefore produce better. In practical design of an animal production system and any buildings involved, many other factors such as feeding, management, thermal environment, construction and economics can be equally or more important, however.The animals can to some extent adapt their behaviour to suit a bad design and on a long term basis they can be changed by breeding and selection, but generally it will be much easier to fit the husbandry and building design to the animals. The life span of a building is usually 5 to I 5 years and that makes it clear that even a small increase in production or decrease in frequency of injury and disease, in waste of feed or in labour requirements for handling of the animals will repay all the thought and care that has been put into the design, lay-out and construction of the building. Furthermore it may cost as much to construct a building that is poorly designed and equipped for the animals as one that works well.

Behaviour Patterns

Farm animals are born with certain fixed behaviour patterns such as pecking in chickens and nursing in mammals, but most behaviour patterns develop through play and social contact with other animals of their kind and under the influence of environmental stimulation and genetic factors. Behaviour variation within a species is mainly caused by differences in the environment and between the sexes but breed, strain and individual variance also have an influence. Domestic animals show great ability to modify their behaviour patterns in relation to environments and to learn by experience.Animals often form a daily cycle of habits caused

by the uniformity of husbandry, for example, the, regular variation in light during night and day relate to internal physiological rhythms. This is why cows Bather around the barn just before milking time. Some behaviour patterns change from season to season, partly as a response to the changing weather. Cows tend to be more active during the night in the hot season and spend less time lying down if outside in the wet season. Many domestic animals show a slight seasonal breeding pattern.Domestic animals under conditions of close captivity, frequently show abnormal behaviour such as stereotyped movements or inappropriate sexual behaviour, particularly if they are unable to escape from or adapt to the situation. However, many disturbed behaviours have more complex causes. For example, tail and ear biting in pigs may be associated with boredom, breakdown of social order, too high stocking rate, too low fibre content in the feed, malnutrition, poor ventilation leading to high humidity and temperature, no bedding, inadequate trough space and watering points, skin disease, parasites, teething problems etc.

Social Rank Order

Domestic animals are highly sociable and naturally form groups. Males and females form separate groups, except during the breeding season, and the young tend to form small groups in the proximity of the female group.When strange adult animals meet for the first time they are likely to fight to establish dominance-subordinance relationships. The resulting pecking order or social rank order in which one or two animals are invariably dominant is usually formed quickly. Physical age and weight are the main factors determining social rank, but sex, height and breed can also be of influence. The group can live in relative harmony as long as

each animal knows its place and gives way to animals of higher rank. However, the order is seldom strictly hierarchic or static. Some animals of low rank may dominate others whose positions are normally higher and fast growing and maturing animals may move up the ladder.Introduction of new animals in a group or mixing of groups will normally lead to fighting until a new social order is formed and this may cause a growth check as wellas injury.The normal response to aggressive behaviour in a group with established social order is for the subordinate animal to move away. The building layout must allow space for this and narrow passages and corners where one animal can be trapped by another should be avoided in pens and yards. The order is usually stable provided the group is small so that all animals in it can remember each others position, i.e. fewer than 60 to 80 cows, 12 to 15 pigs or about 100 chickens.

Design of animal housing, its furnishing and equipment, usually employ either of the following methods:

- **a A choice of environment is provided for the animals and their preference for the different facilities is recorded.**
- **b The behaviour of animals in an experimental environment is studied and the result is compared to the behaviour of animals in a reference system, on a free range, or that of their wild relatives. Often the study is confined to activities like resting, eating, standing/walking, but sometimes the frequency of other behaviour patterns, such as investigative, agnostic, sexual, care-giving, caresoliciting, eliminative, etc. is included.**

In addition productivity and frequency of injury and disease is recorded.

Animal Behaviour and Building Design

Below are some examples of how animal behaviour can influence the design of structures. More examples will be given when housing facilities for the various species are described later in this chapter.

Cattle normally live in herds, but when giving birth, the cow attempts to find a quiet, sheltered place away from the disturbance of other cows and humans. The cow needs to be alone with her calf for some time after birth for the cow-calf bond to be established. A cow, confined in a loose housing system, who is approaching calving, should therefore be removed from the herd and put in an individual pen.

Hens spend considerable time in the selection of a nest, which is on the ground. Nesting is characterized by secrecy and careful concealment. Hens in deep litter systems therefore, sometimes lay eggs on the floor instead of in the nestboxes, especially if the litter is quite deep or there are dark corners in the pen.

To avoid this, plenty of fresh litter is provided in the nests, and they are kept in semi-darkness and designed with a rail in front so that birds can inspect the nests prior to entry. An additional measure is to start with the nestboxes on the floor and slowly raise them to the desired level over a period of days.

Sows are nest builders and should be transferred to clean farrowing pens one to two weeks before giving birth, and given some bedding so that they can build a nest. Oestrus, especially in gilts, is increased by the smell, sight and physical presence of a boar. Gilts and sows awaiting mating should therefore be kept in pens adjoining the boar pen.

Cattle prefer to be able to see while drinking, therefore more animals can drink at once from a long, narrow trough than from a low round one. With cattle (and hens) feeding is typically a group activity, therefore space at the feed trough must be provided for all the animals at one time. At pasture, uncle sized feed or water troughs can result in inadequate feeding and watering of the animals which are lowest in rank, because these animals will likely be excluded from the trough, but they will still tend to leave with the rest of the herd after feeding or watering.

To prevent waste of feed a trough should be designed to suit the particular behaviour pattern each species exhibits while feeding i.e. pecking in hens, rooting with a forward and upward thrust in pigs, wrapping their tongue around the feed (grass) and jerking their head forward in cattle.

Artificially reared calves bunt the bucket instead of the cows udder, and this requires a sturdy holder for the bucket. The habit of suckling each other is a problem in dairy calves. The problem can be reduced by making the calves suckle harder and longer for their feed by using a rubber teat rather than a bucket and by giving them access to dry feed. Assuming intersuckling is not a problem, a group pen for calves is more natural than individual pens and

helps ensure normal activity and resting.

Sheep are vigilant and tight flocking, and respond to disturbance by fleeing. When designing handling facilities these characteristics should be taken into account. A race should be straight, level, fairly wide, without blind ends, and preferably have close-boarded sides. Sheep which are following should be able to see moving sheep ahead, but advancing sheep should not see the sheep behind as they will tend to stop and turn around. Sheep move best from dark into light areas and dislike reflections abrupt changes in light contrast and light shining through slats, grates or holes. Handling facilities should be examined from the height of the sheep's eye level rather than the human to detect flaws in the design.

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Animal environmental requirements

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The capacity of an animal to produce differs between species, breeds and strains as a result of genetic factors. However, a complex of inter-related factors in the animal husbandry will

influence the animal's ability to utilize that capacity for growth, development and production.

Progress in breeding and feeding for further increase in production and efficiency can be limited by environmental factors. Research into these factors has therefore been increasing in recent years, especially in countries having intensive animal production.

Animal housing design is mainly concerned with the physical environment, in particular climatic and mechanical factors, but all other factors should also be considered in order to create a good layout, where healthy, high yielding animals can be provided with correct feeding, can be easily handled and can produce without stress or suffering physical harm.

Heat Regulation

All domestic livestock are homeotherms; that is, they maintain relatively constant internal body temperatures, usually within a 1 to 2 C range. Normal body temperatures of some domestic animals and humans are given in Table 10.1.

Table 10.1 ***Normal Body Temperatures of Domestic Animals and Humans***

Animals	**Temperature C**	
	Average	**Range**
Dairy Cow	38.6	38.0 - 39.3

Beef Cow	38.3	36.7 - 39.1
Pig	39.2	38.7- 39.8
Sheep	39.1	38.3 - 39.9
Goat		38.7 - 40.7
Horse	37.9	37.2- 38.2
Chicken	41.7	40.6 - 43.0
Human	37.0	

The body temperature of most domestic animals is considerably higher than the environmental temperature to which they are exposed most of the time. They maintain their body temperatures by balancing internal heat production and heat loss to the environment. The hypothalmus gland acts as a body thermostat by stimulating mechanisms to counteract either high or low ambient temperatures. For example, increased conversion of feed to-heat energy is used to counteract low ambient temperatures, while for example increased respiration (rate and volume) and blood circulation in the skin counteracts high ambient temperatures. Varying temperature also results in changed behaviour. Most animals reduce their level of activity in a hot environment and, for example, pigs lie clustered in a heap at low temperatures, while they lie spread out with extended limbs at high temperatures. This would suggest increased space requirement for pigs held in a warm, tropical climate. The body can tolerate short periods of heat stress, but if the ambient temperature exceeds the body temperature for an extended period, it may prove fatal.

Figure 10. 1 Classification of factors influencing livestock production.

When feed is converted by the animal's metabolism for the production of milk, eggs, meat, off-spring etc., heat is produced as a by-product. An increased production level and thus feed requirement will therefore result in increased internal heat production. High yielding animals are consequently more likely to suffer from heat stress in a hot climate than are low yielding ones.

Feeding fibre-rich, low digestible feed stuffs like hay will result in high heat-production because of increased muscular activity in the alimentary tract and, in ruminants, increased micro-organism activity in the rumen. An increased share of concentrates in the feed may therefore reduce heat stress in an animal under hot climatic conditions.

Animal Moisture and Heat Production

Heat is produced centrally in the deep body. The surplus is conducted to the skin surface where it is given off to the atmosphere as sensible heat by means of convection, conduction and radiation and as latent heat by means of evaporation of moisture from the lungs and skin. Increasing ambient temperature, resulting in less temperature difference between the body surface and the air, will decrease the amount of heat that can be emitted as sensible heat. Instead a larger proportion is given off as latent heat, that is, heat employed to vapourize moisture.

Table 10.2 lists values for animal heat and moisture production at various temperatures. The heat and moisture produced by the animals confined in a structure must be removed by ventilation. In the tropics, sufficient ventilation flow is usually provided for by the use of opensided structures.

However, if an enclosed building is used, a range of ventilation flow rates must be provided for in the building design. The minimum ventilation rate should remove the moisture produced, but retain as much sensible heat as possible during cold periods. The maximum ventilation rate should remove enough of the sensible heat produced so that a small temperature difference, usually 2 to 4C, can be maintained between inside and outside. It should be noted that ventilation alone can only maintain the building temperature at slightly above ambient. Ventilation is discussed in more detail in Chapter 7.

Climatic Factors

Temperature

The over-riding environmental factor affecting the physiological functions of domestic animals is temperature. For most farm animals a mean daily temperature in the range 10 to 20C is referred to as the "comfort zone". In this range the animal's heat exchange can be regulated solely by physical means such as constriction and dilation of blood vessels in the skin, ruffling up the fur or feathers and regulation of the evaporation from lungs and skin. At the upper and lower critical temperatures the physical regulation will not be sufficient to maintain a constant

body temperature and the animal must, in addition, decrease or increase its metabolic heat production.

A further decrease or increase in temperature will eventually bring the temperature to a point beyond which not even a change in heat production will be sufficient to maintain homeothermy.

A very young animal, lacking fully developed temperature-regulating mechanisms, particularly the ability to increase heat production by increased metabolism, is much more sensitive to its thermal environment and requires higher temperatures.

Humidity

Poultry do not have sweat glands, so all evaporative heat loss must originate from the respiratory tract. Other livestock species have varying abilities to sweat and in descending order they are as follows: Horse, donkey, cattle, buffalo, goat, sheep and pig.

In a hot-dry climate evaporation is rapid, but in a hot humid climate the ability of the air to absorb additional moisture is limited and the inadequate cooling may result in heatstress.

Too low humidity in the air will cause irritation of the mucous membranes, while too high humidity may promote growth of fungus infections. High humidity may also contribute to decay in structures. If possible keep the relative humidity in the range of 40 to 80%.

Radiation

The heat load on a grazing animal can be considerably increased by direct solar radiation and radiation reflected from clouds or the ground. A white hair coat will absorb less radiant energy than a dark, but the heat penetrates deeper in a white, loose coat. Air movements will dispel the heat and reduce the differences. Furthermore, solar radiation may adversely affect the animal's skin in particular breeds having unpigmented skin.

Heat gain by radiation can be effectively reduced by the provision of a shaded area. It must, however, be sufficiently large to allow space between the animals so that the heat loss by other means is not reduced. Grass covered ground in the surroundings of the shade will reflect less radiation than bare soil.

Air Movements

Air movements will assist in heat loss by evaporation and by conduction/ convection as long as the air temperature is lower than the skin temperature. When the air temperature approaches the skin temperature rapid air movements are experienced as comfortable, but at low temperatures it will lead to excessive cooling of unprotected skin areas (cold draught). In addition air movements are required to remove noxious and toxic gases and to supply the animal with fresh air for breathing. A wind velocity of 0.2m/s is generally regarded as a minimum requirement, but it can be increased to 1.0m/s, when the temperature is nearing the upper critical, or more when it goes beyond that.

Precipitation

Heavy rain my penetrate the fur of an animal and decrease its insulation value. A strong wind can in such circumstances lead to excessive cooling. However, a naturally greasy hair coat will resist water penetration and with the provision of a shelter for the animals the problem may be avoided altogether.

Effect of Climatic Factors on Livestock Performance

In tropical and subtropical countries an animal may often be under heat stress. When the environmental temperature exceeds the upper critical level (18 to 24C, depending on the species) there is usually a drop in production or a reduced rate of gain. Furthermore, when the temperature falls outside the comfort zone, other climatic factors assume greater significance. Humidity becomes increasingly important as do solar radiation and wind velocity.

Dairy Cattle show a reduced feed-intake under heat stress resulting in lowered milk production and reduced growth. Reproduction is also adversely affected. There are, however, important differences between breeds. European cattle (Bos Taurus) produce well at temperatures ranging from 4 to 24 C even at high humidity. Much lower temperatures (-10C) have little effect as long as fluctuations are not too rapid or frequent. On the other hand, a drop in milk production results with temperatures exceeding 25C. The drop may be as much as 50% at temperatures of 32C or higher. In contrast, Zebu cattle (Bos Indicus), which are native to warm climates, have a comfort zone of 1 5 to 27 C and milk production begins to drop only

when temperatures rise above 35C.

Table 10.2 ***Animal Heat and Moisture Production***

Livestock	**Weight**	**Ambient temperature***	**Moisture g/h, animal**		**Sensible heat /animal**		**Total heat[1] /animal**	
	kg	C	*C	+25 C	* C	+25 C	* C	+25
Dairy Cow	400	+12	410	835	685	395	960	960
	500	+12	445	910	745	430	1045	1045
	600	+12	485	985	805	465	1130	1130
	700	+12	515	1045	855	495	1200	1200
Dairy Calf	50	+12	70	105	70	75	115	145
	75	+12	185	365	220	120	345	365
	150	+12	205	365	280	170	420	420
	200	+12	160	330	270	155	380	380
	300	+12	220	450	370	215	520	520
	400	+12	275	565	460	265	645	645
Swine	5	+27	30		20	-	40	

	10	+24	35	40	35	35	60	60
	20	+20	60	70	55	50	95	95
	30	+ 16	65	90	80	65	125	125
	50	+16	75	120	125	85	175	165
	70	+16	100	150	145	105	215	205
	90	+16	115	170	165	120	245	235
Dry sow	180	+12	85	165	210	135	270	245
Sow one week prior to birth	180	+12	120	220	285	185	365	335
Sow with piglets	180	+16	175	300	340	245	460	450
Laying hen	1.5	+20	5.2	6.5	6.6	5.7	10.1	10.1
	2.0	+20	6.0	7.6	7.6	6.6	11.7	11.7
Broilers	0.1	+32	3.1	-	0.9	---	3.0	
	1.0	+20	5.0	6.5	6.6	5.6	10.0	10.0
	1.5	+20	6.2	8.0	8.1	6.9	12.3	12.3

***Referring to temperature stated in the column "ambient temperature".**

[1] Total heat equals sensible heat plus latent heat (latent heat equals moisture in g/h x 0.675 Wh/g).

It is important to note some of the physical differences between these two types of cattle that suits each to its climate of origin. The Zebu is characterized by a hump, large ears and loose, thin skin including a prominent dewlap. These characteristics promote heat loss by convection and evaporation and thus efficient body temperature regulation under hot climatic conditions. In addition, the Zebu has less subcutaneous fat, a lower body volume for the surface area, and short smooth hair all of which contribute to the animal's comfort under hot conditions. The European breeds on the other hand have thick skin held tightly to the body, long hair and a large amount of fat which serve as insulators, traits desirable for cold or temperate climates. Although there is a considerable range in size within each bread, the Zebu is a relatively small animal, a fully grown bull rarely exceeds 700 kg, while the European cattle are large, reaching 1,000 kg liveweight. Figure 10.2 illustrates the configurations of the two types of cattle. Calves seem most sensitive to cold draughts and poor ventilation, but are quite tolerant of a wide range of temperatures.

Figure 10.2 Characteristic appearance of Zebu and [European type cattle.

Beef Cattle make their best gains at temperatures below 25 C. They can easily tolerate temperatures below 0 C if they have a good supply of feed.

Pigs require a change in ambient temperature as they age and grow, and like cattle, they show a decreased feed intake when under heat stress. Piglets survive and develop best at 30 to 32C initially followed by a gradual reduction to 20C over the first three weeks. Feeder pigs (30 to 65 kg) make good gains in the temperature range of 10 to 25C with 24 C reported optimum. The optimal ambient temperature for pigs weighing 75 to 120 kg is 15 C. Brood sows do well at 15C but suffer badly at 25C and above since they do not perspire when hot. Reproduction rates fall under heat stress and sows are more apt to trample their baby pigs in the discomfort of hot weather.

Sheep can tolerate a wide range of temperatures but should be protected from wind and rain. However, a long period of high ambient temperatures inhibits reproduction. Heat stress also reduces lambing percentage, decreases the incidence of twinning, and decreases the birth weight of lambs. When temperatures are below 7C at breeding time, ewes show improved reproductive efficiency.

Goats are affected by temperature, humidity and rain. In hot climates, goats need shelter from intense heat during the day. In humid areas they need protection from prolonged heavy rain. Excessive wetting from rain can cause pneumonia and an increase in parasitic infestation.

Poultry. The environmental requirements for poultry vary with age. Chicks should be started at 35 C. After one week the temperature is reduced gradually to 24C by the fifth week. Broilers and young turkeys reared at ambient temperatures below 18C are heavier than similar stock reared within the 18 to 35C range, but their feed conversion efficiency will be less. Laying birds

produce the greatest number of eggs and the largest sized eggs at 13 to 24 C. The best feed conversion efficiency is achieved between 21 to 24 C. With increasing environmental temperature there is a decrease in feedintake and alterations in behaviour. Within the temperature range of 5 to 30C there is a reduction of about 1.6% in feed intake for every 10C increase in ambient temperature. Above 24C there is a reduction in egg production and egg size. A continued rise in temperature to 38C or more may prove lethal. High humidities at high temperatures create conditions that are more likely to be lethal because of a breakdown in body cooling through respiration.

Rabbits are affected most by sun and heat, wind, rain and draughts. Sunlight is of benefit to breading stock and the growing young, but it will also fade the coat of coloured rabbits and discolour a white one. While rabbits enjoy the sun, they must have the chance to get out of the direct rays. Because of their thick fur coats they tolerate cold better than extreme heat, but they are susceptible to chilling from draughts. Rabbits also need protection from rain and dampness.

Horses. Horses do not require warm surroundings, but they do not easily tolerate draughts, dampness and high humidity. When exposed to high temperatures and vigorous exercise, horses sweat and the evaporation of this perspiration cools the skin and helps to maintain normal body temperature.

Humans. In as much as the subject of rural housing is covered elsewhere in the book, human comfort zones will be discussed briefly. Man has the ability to become acclimatized to a

constant temperature. Thus people living in cold climates easily tolerate low temperatures just as people living in tropical climates do not mind the heat. In temperate climates, most sedentary people dressed in light clothing find optimum comfort at approximately 26C. However, a relative humidity of over 70% may produce discomfort. At 22C people may feel cool regardless of humidity. Above 26C they are likely to feel warm and as the relative humidity rises above 45%, discomfort increases. People who are dressed warmly and doing active work can be comfortable to temperatures of 0C and below.

Microbiological Environment

Disease remains a major profit-limiting factor in animal production in many tropical countries. Sanitary control measures should be incorporated in any building design, so that a good hygienic standard can be easily maintained. An animal which is well fed and watered and in good condition will have a high resistance to disease. Good management can do much to remove or reduce the effects of adverse environmental factors, such as climatic stress, which otherwise would weaken the body's natural defences.

New born stock should always receive colostrum (first milk), which contains antibodies. It takes time for an effective immune system to develop in an animal and therefore good hygiene is of special importance in facilities for young animals. Pens, in particular those for calving, farrowing, etc., should be constructed in easily cleaned and disinfected materials and be without corners and recesses where manure and dirt can accumulate.

The whole building should be cleaned and disinfected periodically and any pen that is emptied should be thoroughly cleaned before other animals are transferred to it. Rearing and fattening of young animals should be organised so that the building can be emptied, cleaned and disinfected between batches. This 'all-in, all-out' policy is particularly beneficial for disease control, where the animals are bought from outside the farm and in finishing units for pigs as well as broiler and layer houses.

Disease is transmitted in many ways including direct contact between animals, air-borne micro-organisms, biting insects and ticks, manure, soil, contaminated feed and water, birds and rodents and the stockman's boots. Direct contact between animals can be reduced by decreasing the number of animals in each group and by constructing solid partitions between pens. Solid walls may however obstruct air movements and thus contribute to heat-stress. Ideally, the waste handling system should prevent animals of different groups coming into contact with each other's manure. Especially young animals must be prevented from contact with manure from adult animals.

Good stockmanship includes regular observation of the animals to detect any change in behaviour, which could indicate disease. Sick animals should immediately be separated from the herd to prevent further spread of infectious disease and to allow the animal to rest. The sick animal should be isolated in a pen kept especially for this purpose and ideally in a separate building.

Newly acquired animals and animals returning from a market or other place where they may have been exposed to the risk of infection must be quarantined for an adequate length of time to detect any disease they may be carrying before they are allowed into the herd.

Other Environmental Factors

Acoustical factors will only, as far as known, have marginal effect on the animal's development and production. Nervous animals may, however, react adversely to intermittent sudden noises. Pig squeals prior to feeding can become a hazard to the stockman's hearing. Soft radio music in a milking parlour may have a smoothing effect on the cows.

Day length or photoperiod varies with latitude and season and has a direct influence on animal performance, especially on the breeding season for sheep and egg production of poultry. Under natural conditions, there is a correlation between length of day and rate of laying. Artificial light is used in the temperate zone to equalize egg production throughout the year. Additional hours of light before dawn and after dusk are recommended in hot climates to encourage the hens to eat during the cooler hours.

Dust can carry micro-organisms, which may cause an outbreak of disease.

Toxic and noxious gases are produced by manure which accumulates in buildings or storages. Especially in connection with agitation of manure slurry stored in a pit in a building, harmful amounts of gases can be released. However, problems with gases are not likely to arise in the open-sided buildings used in the tropics.

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Cattle housing

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Cows play an extremely important role in most African cultures. The ownership of cattle will often be the deciding factor in a man's social position in the community because the herd may be the only practical way of accumulating wealth. However, of greater importance is the fact that cattle represent a source of high protein food, both milk and meat.

This chapter focuses on housing requirements for cattle kept primarily for milk production. Little or no housing is required for herds maintained only for beef production and special handling and support facilities are discussed separately.

Much of the dairying in East and Southeast Africa occurs at elevations of 1500 metres or more. European breeds have been successfully established under these circumstances. However, European bulls crossed with Zebu cows have produced animals that are more tolerant of high temperatures than the European breeds and significantly better producers than the Zebus.

Whether purebreds or crosses, they will not provide a profit to the farmer if they are left to find their own feed and water and are milked irregularly. Experience has shown that cattle respond favorably to good management, feeding and hygiene all of which is possible in a system with suitable housing.

Herd Profiles

The composition and management of cattle herds vary considerably. At one extreme, nomadic herdsmen graze their entire herd as one unit. The small holder with only a few head may keep his heifer calves for replacements or sell them. The commercial dairy producer typically has about four-fifths of his cows milking and one-fifth waiting to calve, while heifers 10 months to calving age plus calves of various ages will approximately equal the number of milkers. Mature dairy cows are bred annually and are milked for 300 to 330 days after calving.

At a closer examination it will be found that several factors influence the number of animals of various categories found in the dairy herd. In a herd of say, 24 cows, having calving evenly distributed throughout the year and a 12-month calving interval there will be, on an average, two calves born per month. The calves are normally kept in individual pens for two to three months, there is thus a requirement for four to six pens in a herd of 24 cows. However, the need for calf-pens is halved in herds where the bull calves are sold or otherwise removed from the herd at one to three weeks of age. A longer calving interval and high mortality among the calves will decrease the required number of calf-pens, while a concentration of the calving season in the herd will increase the pen requirements. If all calving is concentrated in six

months of the year, the requirement of calf-pens will be doubled.

A number of cows in a dairy herd will be culled each year for reasons of low milk yield, infertility, disease, old age, etc. These cows are best replaced with young stock from their own herd, since any animals acquired from outside the farm may bring disease to the herd. Cows are commonly culled after three to five lactations, corresponding to a replacement rate of 20 to 30% per year.

In herds with very intensive production there is a tendency for higher replacement rate, but it can not exceed 40%, if the heifers are obtained exclusively from the herd itself, since only about half of the calves born are female and of these some will die or be culled before first calving due to disease, infertility, etc.

The number of maturing heifers will increase with increasing age of the heifers at first calving, increased replacement percentage and a shorter calving interval. Concentrated calving may slightly increase the number of animals during some periods of the year, and will greatly affect the distribution of animals to the different age groups. The age at first calving of heifers of European breeds is typically 24 to 27 months, while heifers of the slower maturing Zebu cattle often are 36 months or more.

Maturing heifers require little or no housing facilities in the tropics. Knowledge of their exact number and distribution in various age groups during different months is therefore not as important to a building designer as to the manager of the herd.

Heifers should be introduced in the dairy herd at least a couple of months prior to their first calving to learn and become adjusted to the handling routines and feed. In loose housing systems with free stalls (cubicles) or in tiebarns this may slightly increase the need for stalls, but normally the heifer will simply take over the stall used by the culled cow, which it replaces.

In herds where cows are taken to a special calving pen during calving, one such pen per 30 cows is sufficient, since the cow and her calf will spend only a few days there. However, in herds where the calving is concentrated in a short period the requirement can increase to one calving pen per 20 cows. The pen should be at least 3.3m by 3.3m.

General Housing Requirements

As has been pointed out, cattle will be more efficient in the production of milk and in reproduction if they are protected from extreme heat, i.e. temperatures of 25 to 30C, and particularly from direct sunshine. Thus in tropical and subtropical climates shade becomes an important factor. If cattle are kept in a confined area, it should be free of mud and manure in order to reduce hoof infection to a minimum. Concrete floors or pavements are ideal where the area per cow is limited. However, where ample space is available, an earth yard, properly sloped for good drainage is adequate.

Sun Shade

With these needs in mind a shade structure allowing 2.5 to 3m: per animal will give the

minimum desirable protection for cattle, whether it be for one animal belonging to a small holder or many animals in a commercial herd. A 3x7m roof will provide adequate shade for up to X cows. The roof should be a minimum of 3m high to allow air movement. If financially feasible, all the area that will be shaded some time during the day should be paved with good quality concrete. The size of this paved area depends on the orientation of the shade structure. If the longitudinal axis is east and west, pan of the floor under the roof will be in shade all day. Extending the floor approximately one third its length on the east and on the west as shown in Figure 10. 3, a paved surface will provide for the shaded area at all times.

If the longitudinal axis is north and south, the paved area must be 3 times the roof area i.e. 1/3 to the east, 1/3 to the west and l/3 underneath. Obviously this means an increase in the cost of paving. In deciding which orientation to build, the following factors need be considered:

- **1 With the east-west orientation the feed and water troughs can be under the shade which will allow the cows to eat and drink in shade at any time of the day. The shaded area, however, should be increased to 3 to 4m per cow. By locating the feed and water in the shade, feed consumption will be encouraged, but also more manure will be dropped in the shaded area which in turn will lead to dirty cows.**
- **2 With the north-south orientation, the sun will strike every part of the floor area under and on either side of the roof at some time during the day. This will help to keep the floored area dry. A shaded area of 2.5 to 3m per cow is adequate if feed and water troughs are placed away from the shaded area.**

- 3 If it is felt that paving is too costly, the north-south orientation is the best choice in order to keep the area as dry as possible.
- 4 In regions where temperatures average 30C or more for up to five hours per day during some period of the year, the east-west orientation is most beneficial.

Figure 10.3 shows shade patterns at various times and orientations. A gable roof shade is shown in Figure 10.4. The gable roof is more wind resistant than a single pitch roof and allows for a center vent. A woven mat of local materials can be installed between the rafters and the corrugated iron roof to reduce radiation from the steel and lower temperatures just under the roof by 10C or more.

Figure 10.3 Shadows cast at various times and dates at latitude 10 south.

Figure 10.4 Sunshade with insulated corrugated steel roof:

Yards

If space is severely limited and only 4 to 5m per cow is available, then concrete paving is highly desirable. If up to 40 to 60m per cow is available, then unpaved yards should be quite satisfactory as long as the feed and shade areas are paved and the yard is graded for good drainage.

If the small holder is unable to afford an improved structure such as a shade or a paved area for feeding, then conditions can be prevented from becoming intolerable by building mounds of earth in the yard with drainage ditches between them as shown in Figure 10.5. From 20 to 30m per cow will keep the animals out of the worst of the mud. The soil in the mounds can be stabilized by working chopped straw or straw and manure into the surface. A number of trees in the yard will provide sufficient shade.

Figure 10. 5a Yard with fenceline feed trough, paved feed area and earth mound.

Figure 10.5b Dimensions for an earth mound.

Deep-Bedded Sheds

In a deep-bedded system, straw, sawdust, shavings or other bedding material is periodically placed in the resting area so that a mixture of bedding and manure builds up in a thick layer. Although this increases the bulk of manure, it may be easier to handle than wet manure alone. This system is most practical when bedding is plentiful and cheap. Table 10.3 gives the space requirements for various ages of animals when there is access to a yard. By designing the building to be partially enclosed on the east and west, the shading characteristics can be improved. In as much as a well drained earth floor is quite adequate, such a building will compare favourably in cost with a shaded area which is paved.

Loose Housing with Free Stalls (Cubicles)

Although simple yard and a shade or yard and bedded shed systems are entirely satisfactory in warm climates, particularly in semi-arid areas, some farmers may prefer a system with somewhat more protection. A loose housing yard and shed with free stalls will satisfy this need. Less bedding will be required and less manure will have to be removed. Free stalls must be of the right size in order to keep the animals clean and to reduce injuries to a minimum. When stalls are too small, injuries to teats will increase and the cows may also tend to lie in other areas that are less clean than the stalls. If the stalls are too large, cows will get dirty from manure dropped in the stall and more labour will be expended in cleaning the shed area. A bar placed across the top of the free stalls will prevent the cow from moving too far forward in the stall for comfortable lying down movements, and it will encourage her to take a step backwards when standing so that manure is dropped outside the stall.

The bar must, however, not interfere with her normal lying and rising movements. Table 10.3 lists recommended dimensions for stalls. The floor of the stall must be of a non-slippery material, such as soil. A good foothold is essential during rising and tying down movements to avoid injury. A 100mm ledge at the back edge of the free stall will prevent any bedding from being pulled out to the alley. The number of stalls should ordinarily correspond with the number of animals housed, except that in large herds (80 or more), only about 90% of the animals need to be accommodated at one time. Figure 10.6 shows two free stall designs.

Young stock may be held in yards with shade or in sheds with either free stalls or deep bedding.

The alley behind the free stalls (cubicles) must be wide enough to allow the cows smooth passage and the following minimum widths apply:

Tie-Stall Sheds

Only in the case of purebred herds where considerable individual attention is given to cows can a tie-stall system be justified in tropical areas. If such a system is chosen, stalls and equipment may be purchased, in which case floor plans and elevations may be available from the equipment supplier. However, if equipment is to be manufactured locally, Table 10.5 provides some typical dimensions.

Table 10.4 ***Alley Widths in Conjunction with Free Stalls (Cubicles)***

Alley between a row of free stalls and a through (increase to 4.0m if there are more than 60 cows in the group)	2.7 - 3.5m
Alley between a row of free stalls and a wall	2.0 - 2.4m
Alley between two rows of free stalls	2.4 - 3.0m
Alley between a feed trough and a wall	2.7 - 3.5m

Table 10.3 ***Area for Bedded Sheds and Dimensions of Free Stalls (Cubicles)***

Animal	Age Months	Weight kg	Bedded ShedArea per Animal (m)		Free Stalls Dimensions (m)	
			A	B	Length	Width
Young stock	1.5 - 3	70 - 100	1.5	1.4	1.2	0.6
Young stock	3 - 6	100- 175	2.0	1.8	1.5	0.7
Young stock	6 - 12	175 - 250	2.5	2.1	1.8	0.8
Young stock	12 - 18	250 - 350	3.0	2.3	1.9	0.9
Bred heifers and small milking cows		400 - 500	3.5	2.5	2.1	1. 1
Milking cows		500 - 600	4.0	3.0	2.2	1.2
Large milking cows		> 600	5.0	3.5	2.3	1.2

A - Enclosed and fully covered bedded shed
B - Bedded shed in conjunction with exercise yard

Figure 10.6 Free-stall cubicle designs.

Table 10.5 ***Tie-Stall System Dimensions (metres)***

	Cow live weight		
Stall Section	450 kg	550 kg	650 kg
Platform width	1.1	1.2	1.3
length1	1.6	1.7	1.8
Manger width	0.5	0.6	0.65
Platform slope	2 - 4%		
	Nose Out System		Nose In System
Flat manger feed alley	1.7 - 2.0		1.6 - 2.0
Feed Alley (excluding step manger)	1.2 -1.4		1.2 -1.4
Service alley width		1.4 - 2.0	
Manure gutter width		0.4 - 0.7	
depth		0.25 - 0.35	

[1] **If cows are allowed to lie with their heads over the through, otherwise add 0.4 - 0.5m to the**

length.

The tie and feed barrier construction must allow the cow free head movements while lying down as well as standing up, but should prevent her from stepping forward into the feed trough. Most types of yokes restrict the cow's movements too much. A single neck nail, set about 1 m high and 0.2m in over the merger may bruise the cow's neck when she pushes forward to reach the feed. The feed barriers that best meet the requirements are shoulder supports and the comfort stall, shown in Figure 10.7. Note the fixing rods for the cross tie which allows vertical movements of the chain. Stall partitions should be used at least between every second cow to prevent cows from trampling each other's teats and to keep the cow standing straight so that the manure falls in the gutter.(figure 10.7c)

Figure 10.7a Shoulder support system.

Figure 10.7b Comfort stall.

Figure 10.7c Stall Partitions.

Bull Pens

A bull pen should have a shaded resting area of 12 to 15m and a large exercise area of 20 to 30m. The walls of the pen must be strong. Eight horizontal rails of minimum 100mm round timber or 50mm galvanised steel tubes to a total height of 1.5m and fixed to 200mm timber

posts not more than 2m apart will be sufficient. The gate must be designed so that the bull cannot lift it off its hinges and there should be at least two exits where the herdsman can escape.

A service stall where the cow can be tethered prior to and during service is usually provided close to the bull pen. The stall can have ramps at the sides to support the bull's front feet.

Calf Pens

Calf mortality is often high in tropical countries, but proper management and suitable housing that protects the calf from climatic stress, infections and parasites can reduce this.

Individual pens for calves from birth to 2 to 3 months of age are often built with an elevated slatted floor. This floor, which is best constructed from 37 to 50mm by 75 to 100mm sawn timber boards leaving a 25 to 30mm slat between each board, will ensure that the calf is always dry and clean. The required minimum internal dimensions for an individual calf pen are 1200 by 800mm for a pen where the calf is kept to two weeks of age, 1200 by l000mm where the calf is kept to 6 to 8 weeks of age and 1500 by 1 200mm where the calf is kept from 6 to 14 weeks of age. Three sides of the pens should be tight to prevent contact with other calves and* to prevent draughts. Draughts through the slatted floor may be prevented by covering the floor with litter until the calf is at least one month of age. The front of the pen should be made so that the calf can be fed milk, concentrates and water easily from buckets or a trough fixed to the outside of the pen and so that the calf can be moved out of the pen without

lifting. The milk or milk substitute fed to the calf will not provide it with enough liquid and therefore it should be given fresh, clean water daily or preferably have continuous access to water in a drinking nipple. All calves, but especially those which are weaned early, should have access to good quality forage as soon as possible to stimulate rumen development. Forage can be supplied in a rack placed above the side wall of the pen. Figure 10.8 shows a thatched shed with six slatted floor calf pens. This construction with a feed alley will be rather expensive but can be cheaper if calves are fed from outside. Calf pens are recommended where the cows are kept in a semi-zero grazing or zero grazing system.

Another system that works well is the use of individual hutches as shown in Figure 10.9. The hutch must be thoroughly cleanedset up in a new location each time a new calf is housed in it. Plenty of litter is placed directly on the ground inside the hutch. Protection from wind, rain and sun is all the calf requires, but always moving the hutch to clean ground is the key to success.

Housing for the Small Herd

For the small holder who wants to make the very best use of his crop land and to provide his cattle with good housing that will encourage high production, a zero grazing system is recommended.

Figure 10.10 shows perspective, elevation and plan views of a zero grazing unit for 3 cows, 2 heifers and a young calf. Additional stalls can be added up to a total of about 10. After that

consideration should be given to two milking places and a larger feed store.

Gum poles may be used instead of the cedar posts and sawn rafters, but any wood in contact with or within 5Ocm of the ground should be well treated with wood preservative. It is desirable to pave the alley, but if that is not possible, the distance between the free stalls (cubicles) and the feed trough should be doubled or tripled.

A concrete pit or sloping slab in which to accumulate manure is essential. If the alley is paved, the pit can also collect urine. In fact, paving the alley not only saves space, but the value of the urine will help to pay for the paving.

The circular manure tank shown in Figure 10.10 has a volume of 10m. This will be adequate to store the manure produced during one month plus any rainfall collected in the alley. If more stalls are added the capacity of the tank will need to be increased or the interval between the emptyings shortened.

A water tank to collect water from the roof can be very useful unless there is an abundant supply of water nearby.

Housing for the Medium to Large Scale Herds

For the farmer with up to about 30 cows a yard with paved shade and feed area would be suitable. The yard and feeding area may alternatively be combined with an open sided barn

designed for deep bedding or equipped with freestalls and where the herd consists of high yielding cows the milking shed may be equipped with a bucket milking machine. Some farmers with up to 30 cows may even consider using an open sided tie-stall shed.

In general a medium or large scale dairy unit may include the following facilities:

1 Resting area for cows: a Paved shade, or b Deep bedding in an open sided barn, or c Free-stalls in an open sided barn
2 Exercise yard (paved or unpaved)
3 Paved feed area:

- **a Fence line feed trough (shaded or unshaded), or**
- **b Self feeding from a silage clamp**

4 Milking Centre:

- **a Milking shed or parlour, and**
- **b Collecting yard (part of the exercise yard), and**
- **c Dairy including milk store, and**
- **d Motor room**

5 Bull pen with a service stall
6 Calving pen(s)

7 Calf accommodation
8 Young stock accommodation (yard with paved shade and feed area)
9 Bulk feed store (hay and silage)
10 Concentrate feed store
11 Veterinary facilities:

- **a Diversion pen with Artificial Insemination stalls, and**
- **b Isolation pen**

12 Waste store:

- **a Slurry storage, or**
- **b Separate storage of solids and effluents**

13 Office and staff facilities

Figure 10.8 Calf shed.

Each of the parts of the dairy unit may be planned in many different ways to suit the production management system, and the chosen method of feeding. Some require ments and work routines to consider when the layout is planned are as follows:

- **1 Movement of cattle for feeding, milking and perhaps to pasture.**

Figure 10.9 Calf hutch.

Figure 10.10 Zero grazing system for the small holder.

- **2 Movement of bulk feed from store to feeding area and concentrates from store to milking shed or parlour.**
- **3 Transfer of milk from milking shed or parlour to dairy and then off the farm. Clean and dirty activities, such as milk handling and waste disposal, should be separated as far as possible.**
- **4 The diversion pen with Artificial Insemination stalls and any bull pen should be close to the milking centre as any symptoms of heat or illness are commonly discovered during milking and cows are easily separated from the rest of the herd while leaving the milking.**
- **5 Easy and periodical cleaning of accommodation, yards, milking facilities and dairy, and transfer of the waste to storage and then to the fields.**
- **6 The movements of the herdsman. Minimum travel to move cows in or out of milking area.**
- **7 Provision for future expansion of the various parts of the unit.**

Milking and Milk Handling

Hand Milking vs. Machine Milking

In developed countries, where labour is scarce and expensive, machine milking has become

very widespread and it is also practiced on many large commercial dairy farms in the tropics. Milking machines not only reduces labour requirement and eliminates the drudgery of hand milking, but in most cases performs a better quality milking operation than would be done by hand. However, most of the many small dairy farms in developing countries have a surplus of cheap labour and the number of cows milked at each of them is not sufficient to economically justify the installation of a machine. Furthermore, machines require power and are more expensive to purchase then the few pieces of equipment needed for hand milking. In many developing countries there is an irregular supply of spare parts and a lack of skilled mechanics.

Machine Milking gives a good quality and operates with a uniform vacuum of 275 - 350mm of mercury, provides a massaging effect on the teats, and is easily cleaned. The milking machine simulates nursing by the calf. Two vacuum lines lead to the teat cups. A pulsator supplies an intermittent vacuum to one line at the rate of 45 to 60 pulses per minute. The line, connected to the shell of the teat cup, causes the teat inflation (rubber liner) to alternately expand and collapse. This massaging action promotes normal blood circulation in the teat. The second line maintains a continuous vacuum on the teat and carries the milk either to a stainless steel bucket or through a pipeline directly to the milk cooler.

Figure 10.11 Basic sketch of a layout for a medium to large scale dairy unit, showing the relative location of the various parts and a suggestion for extension. (Not drawn to scale).

Bucket Milking Machine as shown figure 10.12 is the simplest and least expensive to install, but the milk must be hand carried to the cooler. This type of system is often chosen for the

small and medium size herd and where the cows are milked on a level floor of a stable or milking shed. The labor of carrying the milk to the cooler can be avoided by installing a transfer system. This consists of a 30 litres receiving tank, including a built in filter, mounted on wheels so that it can be moved around the stable. It is connected to the cooler with a plastic hose and the milk is drawn to the cooler by vacuum from the milker pump. The hose is reeled in or out as necessary as the cart is moved around the stable.

Pipeline Milking Plants transports the milk through a pipe direct from the cow's udder to the milk cooler. Figure 10.13 illustrates such a system. Pipeline milking systems are usually installed in milking parlouts where the operator stands below the level of the cows. Although they are expensive, they save backbreaking labour and are usually designed to be cleaned in place, a feature that not only saves labour but helps to ensure good sanitation. They may also be installed in stanchion or tie-stall bates but the extra pipeline needed makes the system even more expensive.

Milk Room and Cooler

Sanitation is the primary consideration in the handling of milk whether it is from one or two cows belonging to a small holder or from a commercial herd supplying milk for the city. In either case an adequate supply of potable water is essential for cleaning the milking equipment immediately after use. Hot water (85C) mixed with a chemical detergent is required for effective cleaning and cold water is used for rinsing.

Milk should be handled in a separate area that can be easily cleaned and that is free of insects, birds, rodents and dust. The small holder producing milk only for his own household, may be able to process, curdle, or consume his milk within a short time so that cooling is not necessary.

Selling milk to the public requires higher standards of sanitation and more elaborate facilities. Whether the cows are hand or machine milked, a separate milk room adjacent to the milking stalls or milking parlour is needed. This room should be well ventilated and designed with a concrete floor sloped 20mm/m to a drain and with masonry walls having a smooth, water resistant surface that can be easily and thoroughly cleaned.

Figure 10.12 Bucket milking machine.

Figure 10.13 Pipeline milking system.

Table10.6 *Minimum Water Requirements for Parlour and Milkroom Washing*

	Hot Water, 85C	Warm Water, 40C	Cold Water 4 - 10C
	litre	litre	litre
Hand milking equipment	10/wash		20/wash
Bucket milking equipment	20/wash		40/wash

Pipeline milking equipment	30/ wash		60/ wash
Cooling of milk in			2 - 3 times the
plate type milk cooler			amount of milk
Parlour floor wash		1/ m, day	3 - 6/ m, day
Milkroom floor wash		l / m, day	1 - 3/ m, day
Car wash	3/car		6/car
Bulk tank wash	25 - 40/wash	20 - 30/wash	25 - 35/wash
Miscellaneous	20- 50/day		30 -100/day

Milk is strained and cooled in this room in preparation for sale. As soon as the cow has been milked the bacteria in the milk starts to multiply, but cooling of the milk to about 4 C within 2 hours will drastically reduce bacterial growth. However, proper cooling is a very difficult problem for the small scale producer. The only practical solution may be for the individual farmers in an area to bring their milk to a central collection depot for cooling immediately after milking. Figure 10.14.

On dairy farms of sufficient size and where power is available, the milk can be cooled by cold water circulated between an evaporative water cooler and a milk cooler (plate heat exchanger), through which the milk is passed until it is adequately cooled. Where milk is stored and transported in cans, cooling can be accomplished by immersing the full cans in a

water-filled refrigerated cooler or by passing cold water through a coil, which is immersed in the can. The large scale dairy farm, having a pipeline milking system, and the milk collection by a road tank van, will require a refrigerated cooler and holding tank.

Figure 10.14 Milk collection centre. The dimensions (A) should vary with the capacity of the cooling and holding tank.

Milking Parlour for the Medium Scale Herd

For the farmer with 10 to 30 cows and a yard with a paved shade and feed area, the milking parlour shown in Figure 10.15 is of suitable design. Two stands will be sufficient where the herd number is 8 to 14, but more stands should be added as indicated when the herd number increases. Hand milking would probably be used for an operation of this size. If machine milking is installed the vacuum pump and the engine, which powers it, can be put in the engine room, which is indicated in outline in the plan view. This is arranged by closing off a portion of the store room with a simple partition.

A milk cooler will be necessary to cool and hold the milk for pick up. This and facilities for washing and storing the milking equipment will be accommodated in the milk room, while concentrates are kept in the store room.

A milk room should face the prevailing wind to ensure good ventilation and to keep it as cool as possible, but any openings should be screened with insect mesh.

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