REPRINT: SEED SCI. & TECH. 1:663. 1973

STORAGE OF SEED IN SUB-TROPICAL AND TROPICAL REGIONS

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Delouche, J. C., Matthes, R. K., Dougherty, G. M. and Boyd, A. H. (1973). *Seed Sci. & Technol.*, 1, 00-00

Storage of seed in sub-tropical and tropical regions

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Summary

Adequate provisions and facilities for storage of seed are important components of seed production-marketing operations in all climatic regions. However, they are essential in sub-tropical and tropical regions because of the general adversity of the climate for storage of seed.

The storability of seed in a specific environment is largely determined by its inheritance and prestorage history. Inherent differences in longevity among species and cultivars are biological facts over which seed specialists have no control. These differences, however, must be recognised and taken into account in planning for storage. The prestorage history of seed, however, is controllable. Timely harvesting and threshing, prompt and adequate drying, and careful handling minimise quality losses from field exposure, high moisture contents, and mechanical damage, and contribute to a seed history favourable for storage.

Relative humidity and temperature of the storage environment are the most important factors affecting maintenance of seed quality during the storage period. Of these two factors, relative humidity is most important because of its direct relation to seed moisture content. Ambient temperature and relative humidity in the subtropics and tropics are usually sufficiently adverse for storage of seed that some conditioning of the environment is necessary for successful storage. The degree of environmental conditioning needed is determined by ambient conditions, the kind of seed to be stored, its quality at the beginning of storage, and the length of the storage period. In most seed operations, conditions satisfactory for three storage periods are needed: (a) short term storage – 1 to 9 months; (b) intermediate term storage – 18 to 24 months; and (c) long term storage – 3 to 10 years.

The storage environment is conditioned by drying the seed to a low moisture content and packaging in moisture vapour proof containers or by air cooling and/or dehumidification. Conditions favourable for short to intermediate term storage can be achieved in well constructed storerooms with room-type airconditioners of suitable heat removal capacity alone, or in combination with condensation or desiccant dehumidifiers.

The high degree of conditioning needed for intermediate to long term storage requires special construction, moisture vapour proofing, and insulation of the storeroom, and rather sophisticated air cooling and dehumidification systems, specifically designed for efficient operation under the prevailing ambient conditions.

Experience and specialised knowledge of both environmental engineering and seed storage are needed for the proper and economical design of rooms and systems for all levels of conditioning. If this experience and knowledge is not available within the organisation concerned with seed storage, it should be obtained from a reliable source.

Résumé

Conservation des semences dans les régions tropicales et sub-tropicales

Dans toutes les régions climatiques, des dispositions appropriées et l'existence d'installations pour la

conservation des semences sont des éléments importants du système de production et de commercialisation des semences. Mais, dans les régions tropicales et sub-tropicales, elles sont indispensables en raison des caractéristiques générales défavorables du climat pour la conservation des semences.

La capacité de conservation d'une semence dans un milieu donné dépend, pour une large part, de ses caractéristiques génétiques et de son passé avant le stockage. Les différences intrinsèques de longévité entre espèces et cultivars sont des faits biologiques dont les spécialistes en semences ne sont pas maîtres. Toutefois, ces différences doivent être connues et prises en considération pour l'établissement des programmes de conservation. Le passé des semences avant leur stockage, par contre, peut être contrôlé. Une récolte et un battage au bon moment, un séchage rapide et suffisant et des manipulations faites avec soin réduisent au minimum les pertes de qualité résultant d'une exposition dans le champ, de teneurs en eau élevées et de détériorations mécaniques, et contribuent à une évolution des semences favorable à leur conservation.

L'humidité relative et la température du milieu de stockage sont les facteurs les plus importants en relation avec le maintien de la qualité des semences pendant la période de conservation. De ces deux facteurs, l'humidité relative est le plus important du fait de son influence directe sur la teneur en eau des semences. La température ambiante et l'humidité relative des régions tropicales et sub-tropicales sont, en général, suffisamment défavorables à la conservation des semences pour qu'un conditionnement du milieu soit nécessaire à la réussite du stockage. Le degré nécessaire de conditionnement du milieu est déterminé par les conditions ambiantes, le type de semence à conserver, la qualité des semences au départ et la durée de la conservation. Dans la plupart des cas, il est nécessaire de disposer de conditions satisfaisantes pour trois durées de conservation: (a) conservation de courte durée: 1 à 9 mois, (b) conservation de moyenne durée: 18 à 24 mois; et (c) conservation de longue durée: 3 à 10 ans.

Le milieu de stockage est conditionné en séchant les semences à une faible teneur en eau et en les plaçant dans des emballages étanches à la vapeur d'eau ou par refroidissement de l'air et/ou par des humidification. Les conditions favorables pour une conservation de courte à moyenne durée peuvent être réalisées dans des entrepôts bien construits à l'aide uniquement d'appareils de conditionnement de l'air de type domestique, ayant une capacité frigorifique convenable, ou en combinaison avec des deshumidificateurs agissant par condensation ou par dessiccation.

Le degré élevé de conditionnement nécessaire pour une conservation de moyenne à longue durée exige une construction spéciale, la réalisation d'une étanchéité vis-à-vis de la vapeur d'eau, et l'isolation de l'entrepôt ainsi que des systèmes assez compliqués de refroidissement de l'air et de deshumidification, conçus de manière spécifique pour une action efficace dans les conditions ambiantes prédominantes.

L'expérience et une connaissance spécialisée à la fois des techniques de conditionnement du milieu et de la conservation des semences sont nécessaires pour une conception appropriée et économique des pièces et des systèmes pour tous les niveaux de conditionnement. Si cette expérience et cette connaissance n'existent pas à l'intérieur de l'organisation concernée par la conservation des semences, elles doivent être obtenues à partir d'une source digne de confiance.

Zusammenfassung

Saatgutlagerung in subtropischen und tropischen Gebieten

Ausreichende Vorbereitungen und Möglichkeiten für die Saatgutlagerung sind wichtige Bestandteile der Saatguterzeugungs- und Vermarktungsmassnahmen in allen Klimagebieten. Unerlässlich jedoch sind sie in subtropischen und tropischen Regionen wegen deren allgemeinen Klimaungunst gegenüber der Lagerung von Saatgut.

Die Lagerungsfähigkeit von Saatgut in einer spezifischen Umgebung wird weitgehend durch seine angeborenen Eigenschaften und die Vorgänge vor der Lagerung bestimmt. Angeborene Unterschiede in der Langlebigkeit der Arten und Sorten sind biologische Fakten, über welche Saatgutspezialisten keine Kontrolle besitzen. Jedoch müssen diese Unterschiede anerkannt und bei der Planung der

Lagerung in Betracht gezogen werden. Kontrollierbar sind aber die Vorgänge vor der Lagerung. Eine zeitgerechte Ernte und Drusch, baldige und richtige Trocknung sowie sorgfältige Behandlung reduzieren Qualitätsverluste, welche durch Verbleiben auf dem Feld, durch hohe Feuchtigkeitsgehalte und mechanische Beschädigungen verursacht werden, auf ein Minimum, entsprechend einer für die Lagerung günstigen Vorgeschichte des Saatguts.

Die relative Feuchtigkeit und die Temperatur der Lagerungsumgebung sind die wichtigsten Faktoren, welche auf die Erhaltung der Saatgutqualität während der Lagerungszeit einwirken. Von diesen beiden Faktoren besitzt die relative Feuchtigkeit wegen ihrer direkten Beziehung zum Feuchtigkeitsgehalt des Saatguts die grössere Bedeutung. Die Umgebungstemperatur und relative Feuchtigkeit sind in den Subtropen und Tropen ziemlich ungünstig für die Lagerung von Saatgut, so dass die Klimatisierung der Umgebung für eine erfolgreiche Lagerung notwendig ist. Das Ausmass der erforderlichen Umgebungsklimatisierung wird bestimmt durch die Umgebungsbedingungen, die Art der zu lagernden Saat, seine Qualität zu Beginn der Lagerung und die Länge der Lagerungsperiode. Bei den meisten Saatgutvorhaben werden Bedingungen benötigt, welche 3 Lagerperioden genügen: a) Kurzzeitlagerung – 1–9 Monate; b) mittelfristige Lagerung – 18–24 Monate; Langzeitlagerung – 3–10 Jahre.

Die Lagerungsumgebung wird beeinflusst durch Trocknen der Saat bis zu einem niedrigen Feuchtigkeitsgehalt und Verpackung in wasserdampfdichte Behälter oder durch Luftkühlung und/oder Entfeuchtung. Die Bedingungen für eine kurz- bis mittelfristige Lagerung können in gut gebauten Lagerräumen entweder allein durch Klimatisierungsgeräte im Zimmertyp mit einer geeigneten Wärmeabführung oder in Verbindung mit Feuchtigkeitsfällung oder mit Entfeuchtungsmitteln erreicht werden.

Der hohe Grad der Klimatisierung, welcher für mittlere bis langfristige Lagerung notwendig ist, erfordert besondere Baumassnahmen, Prüfung des Wasserdampfdrucks und Isolierung des Lagerraums und ziemlich hoch entwickelte Luftkühlungs- und Entfeuchtungssysteme, für eine wirksame Massnahme unter den vorherrschenden Umgebungsbedingungen besonders entworfen.

Erfahrung und Spezialwissen der Ingenieurwissenschaft für Umgebungsverhältnisse und der Saatgutlagerung sind für brauchbare und wirtschaftliche Pläne der Räume und Systeme auf allen Gebieten der Klimatisierung erforderlich. Wenn diese Erfahrung und dieses Wissen innerhalb der Lagerorganisation nicht zur Verfügung steht, sollte dazu eine zuverlässige Quelle in Anspruch genommen werden

Introduction

Adequate provisions for storage of seed are a common feature of successful seed production-marketing programmes regardless of their geographical location. Seed in storage represents not only a programme or company's potential return on substantial investments in research and development, production, facilities, operations, and promotion, but also an input vital for continued agricultural production.

A successful seed storage programme does not just happen. It is the product of careful planning just as is successful seed production or an effective seed promotion campaign. To be effective planning for seed storage must be thorough and based on a clear concept of the purpose of storage, an understanding of the determinants of seed quality (Delouche, 1971; Moore, 1963) and the processes of deterioration (Delouche, 1963, 1964, 1965, 1969; Delouche and Baskin, 1970, 1971; Helmer, Delouche and Lienhard, 1962), knowledge of pertinent principles of environmental engineering (Matthes, Welch, Delouche and Dougherty, 1969; Munford, 1965; Sijbring, 1963; Welch and Delouche, 1967), data on local climatic conditions, and a careful analysis of specific seed storage needs.

Reasons for seed storage

Seed is stored for two reasons. First, since there is usually an interval of time – 1 to 10 months depending on kind of seed and cropping system – between seed harvest and planting of the succeeding crop, seed has to be kept in some place. Unfortunately, the concern of many seed workers never extends beyond this spatial requirement. The more fundamental reason for storage of seed is, of course, to preserve or maintain its physiological quality by minimising the rate of seed deterioration (Delouche, 1968a, 1968b; Owen, 1956).

The best of seed storage conditions can only *maintain* the viability and vigour of seed; quality is not improved by storage. Accepting these facts, the complete storage plan or programme encompasses more than just a physical facility and attention during the period that packaged seed is stored in the facility. Other periods of storage often overlooked in planning, and the prestorage factors that affect the quality of seed and condition its responses in storage must also be considered.

Prestorage factors influencing the storability of seed

The inherent longevity of seeds, the conditions to which they are exposed prior to storage, and traumas sustained during the prestorage operations determine their responses in a specific storage environment (Delouche, 1968b, 1971; Moore, 1963).

In our experience, one of the most important and over-looked considerations in seed storage is the quality of the seed entering storage. Vigorous, high quality seed of most species stores surprisingly well even under relatively adverse conditions, while badly deteriorated seed stores poorly even though conditions are quite favourable. The most modern conditioned storage facility cannot really compensate for delayed or incautious harvesting, inadequate or improper drying, rough handling, and poor bulk storage (Delouche and Potts, 1971; Kreyger, 1963a, 1963b).

Species

Some kinds of seed are inherently short-lived; others are long-lived (Barton, 1961; Crocker and Barton, 1953). Differences in storability extend even down to the cultivar level (Chang, 1970; Haber, 1950; Lindstrom, 1942; Yarchuk, 1966). These biological facts must be taken into account in planning for storage because there are substantial differences in storage requirements and responses among seed kinds, rice (*Oryza sativa* L.) and ground nut (*Arachis hypogaea* L.) seed, for example (Davis, 1961; Helmer and Delouche, 1964; Sittisroung, 1970). Among the vegetables, onion (*Allium cepa* L.) seeds are notorously short-lived, while those of the vine crops (*Cucurbitaceae*) are relatively long-lived (Harrington, 1959).

Seeds of the major field crops grown in subtropical and tropical countries can be roughly, and somewhat arbitrarily, classified as good, intermediate, and poor storers under ambient conditions in warm-humid areas as follows (Bacchi, 1958; Barton, 1961; Byrd and Delouche, 1971; Delouche and Potts, 1971; Gill, 1969; Helmer, Caldwell and Bunch, 1963; Sijbring, 1963)

Good Storers	Intermediate Storers	Poor Storers
Oryza sativa	*Gossypium* spp.	*Arachis hypogaea*
	Pennisetum glacum (L.) R.	*Glycine max* (L). Merrill
	Phaseolus spp.	
	Sorghum bicolor (L.) Moench.	
	Triticum spp.	
	Zea mays L.	

Differences in longevity among seed kinds under identicial storage conditions are evident from the data in Table 1. These data were taken from an extensive storage study (Delouche and Baskin, 1971) involving five storage conditions and 10–35 seed lots of each kind. The data given are the germinative responses of the best storing seed lot of each kind under favourable, moderate, and adverse storage conditions.

Field Deterioration

The physiological quality of seeds is highest at the time they attain function maturity. Since most kinds of seed attain maturity at moisture contents too high for efficient mechanical or even hand harvest, they are-in effect-stored in the field from maturation to harvest (Delouche, 1968a, 1968b). The field environment during this period is seldom favourable for storage.

The frequent and prolonged precipitation, high humidity and temperature, and strong winds characteristic of the humid subtropics and tropics can result in rapid and severe deterioration of seeds before they are ever harvested, especially when harvest is delayed (Delouche and Potts, 1971; Giles and Ashman, 1971). Although this discussion is concerned principally with seed storage in tropical regions, it should be mentioned that adverse climatic conditions of the sort characteised above are not unknown in temperate zones. Indeed, they occur with sufficient regularity in all regions except aridirrigated areas, as to constitute one of the major impediments to production of high quality seed.

In the developed countries, the problem of field deterioration of seed has been substantially moderated by mechanisation of harvest and threshing, artifiicial drying, and shifts in seed production to dry-irrigated regions. Few of the underdeveloped countries, however can presently take full advantage of these practices or alternatives because of limited foreign exchange for purchase of equipment, lack of maintenance facilities, small farm units, poor transportation and communication systems, harvesting and artificial drying, at least, must become established practices in seed operations in tropical countries. There is simply no other way to consistently and efficiently produce and successfully store the quantities of improved seed needed for accelerated agricultural development (Delouche and Potts, 1971).

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7

Table 1. Germination percentages of high quality seed lots of twelve species at intervals during storage under three conditions.

Species	Storage Condition	Storage Period (months)					
		0	6	12	18	24	30
Allium cepa	7°C–45% r.h.	96	–	96	–	94	94
	Ambient	96	90	42	–	–	–
	30°C–75% r.h.	96	0	–	–	–	–
Citrullus vulgaris	7°C–45% r.h.	98	–	98	–	–	98
	Ambient	98	98	96	95	88	86
	30°C–75% r.h.	98	93	31	–	–	–
Festuca arundinacea	7°C–45% r.h.	95	–	98	–	96	94
	Ambient	95	90	85	78	37	–
	30°C–75% r.h.	95	86	0	–	–	–
Glycine max	7°C–45% r.h.	94	–	94	–	96	94
	Ambient	94	94	85	60	42	–
	30°C–75% r.h.	94	0	–	–	–	–
Lactuca sativa	7°C–45% r.h.	96	–	95	–	90	86
	Ambient	96	90	82	68	–	–
	30°C–75% r.h.	96	61	0	–	–	–
Phaseolus vulgaris	7°C–45% r.h.	98	–	100	–	96	98
	Ambient	98	96	96	90	92	90
	30°C–75% r.h.	98	88	21	0	–	–
Phleum pratense	7°C–45% r.h.	96	–	95	–	98	90
	Ambient	96	86	76	37	–	–
	30°C–75% r.h.	96	40	0	–	–	–
Raphanus sativus	7°C–45% r.h.	98	–	97	–	99	96
	Ambient	98	98	98	98	95	95
	30°C–75% r.h.	98	80	13	–	–	–
Sorghum bicolor	7°C–45% r.h.	96	–	97	–	92	90
	Ambient	96	96	93	86	80	74
	30°C–75% r.h.	96	62	10	–	–	–
Trifolium pratense	7°C–45% r.h.	94	–	96	–	94	92
	Ambient	94	94	88	73	60	58
	30°C–75% r.h.	94	30	0	–	–	–
Triticum aestivum	7°C–45% r.h.	98	–	100	–	96	96
	Ambient	98	97	97	96	92	90
	30°C–75% r.h.	98	88	0	–	–	–
Zea mays	7°C–45% r.h.	98	–	98	–	98	98
	Ambient	98	98	96	96	85	65
	30°C–75% r.h.	98	94	30	–	–	–

* Ambient Condition: Storage at State College, Miss., U.S.A., in uninsulated metal warehouse. Jan. mean temperature, 7°C; July mean temperature, 27°C; 226 frost free days: 52 in (1321 mm) evenly distributed annual precipitation.

Drying

The subject of seed drying is outside the scope and objectives of the present discussion. Nevertheless, we feel that it is germane to our purposes to emphasise the crucial role of seed drying in the preparation of seed for storage. High seed moisture is the greatest single cause of losses in viability and vigour (Harrington, 1959; Kreyger, 1963b); therefore, it is of paramount importance that seed moisture content after harvest be rapidly and safely reduced to 12% or less for the cereals and 11% or less for most other kinds of seed. A few kinds of seed, e.g. citrus seed, are injured by drying to the usual moisture contents required for storage (Barton, 1961; Crocker and Barton, 1953).

Unfortunately, traditional harvesting and drying procedures in most tropical countries are not conducive to a rapid reduction in seed moisture content. Seed heads are usually cut when seed moisture drops to 14–18%, partially sun dried, then threshed, and finally sun dried to 12–13% moisture. The whole process takes a week or longer and considerable deterioration, hence loss of viability and storage potential, can occur in the interim (Delouche and Potts, 1971).

Delayed harvesting and inefficient drying contribute in a major way to the generally low quality of seed produced in the tropics. Improvements in drying procedures and facilities, therefore, must either precede or coincide with development of improved storage facilities.

Other Factors

The storability of seed is adversely affected by mechanical injury to seed, insect damage and infestations, immaturity, and plant diseases that infect seed directly or indirectly reduce their quality by causing premature ripening (Baskin and Delouche, 1971; Christensen and Kaufmann, 1969; Delouche, 1967; Giles and Ashman, 1971; Moore, 1963). Thus, plans for seed storage should include provisions and procedures for minimising the incidence and severity of these traumas.

The storage period

Provisions and plans for storage are all too often confined to the interval between the completion of processing (and packaging) and the beginning of distribution. This interval is only a segment, albeit a major segment, of the total storage period. Concentration of managerial and technical skills, funds, and facilities on this segment of storage to the neglect of others can be both inefficient and ineffective.

In the preceding parts of this discussion we have tried to emphasise the point that storage problems are magnified by any factor or condition acting to the detriment of seed quality from the time of maturation to storage. In like manner, inadequate provisions for those segments of the storage period that precede packaging increase the likelihood of serious packaged seed storage problems.

The storage period does not end with distribution. Rather, it continues in the market place after distribution and before sale, and then in the farmer's house, shed, or barn until the time the seeds are actually planted. Education of the management of local market places and the farmer on the care of planting seed should not be overlooked or neglected.

In summary, the total seed storage period comprises the following segments in sequential order: (a) bulk storage – period between drying or threshing and cleaning; (b) holding storage – period between different steps in processing and from processing to packaging; (c) packaged seed storage – period between packaging and distribution; (d) transit storage – period during transit from processing and assembly sites to local markets; (e) market place storage – period between distribution and sale; (f) farm storage – period from purchase to planting.

Environmental conditions affecting seed quality during the storage period

Previous parts of this discussion focussed on the preparation of seed for storage including the crucial step of seed drying. Assuming that preparatory operations are adequate and seed quality is reasonably good, then the major objective during storage is to maintain seed quality at this 'reasonably good level' for the desired period of time (Delouche, 1968a; Harrington, 1959; Kreyger, 1963b).

Relative humidity and temperature of the storage environment are the most important factors affecting maintenance of seed quality (Barton, 1961; Christensen and Kaufmann, 1969; Delouche, 1968b; James, 1967; Lityński, 1957; Owen, 1956). Of these two factors, relative humidity has the greater influence on longevity of seed in storage. The physiological quality of seed is affected by relative humidity in two ways: (a) seed moisture content is a function of ambient relative humidity and (b) the infestation, growth and reproduction of both storage moulds (fungi) and insects are strongly influenced by relative humidity of the microenvironment in the seed mass.

Seeds are hyjroscopic. They absorb moisture from the atmosphere or loss moisture to it until the vapour pressures of seed moisture and atmospheric moisture reach equilibrium. Since the vapour pressure of atmospheric moisture at a specific temperature and pressure is a direct function of the degree of saturation or relative humidity, the different kinds of seed attain specific or characteristic moisture contents when exposed to different levels of atmospheric relative humidity. The seed moisture content attained under these conditions is variously referred to as the equilibrium moisture content or hygroscopic equilibrium (Table 2). The hygroscopic equilibrium of seed at a given relative humidity decreases slowly with increasing temperature and increases slightly with increasing deterioration of the seed (Delouche, 1968b).

Since seed moisture content and ambient relative humidity are in equilibrium during the storage period, maintenance of a 'safe' moisture content requires an average level of relative humidity in the storage environment no higher than that in equilibrium with the desired seed moisture content (James, 1967). This favourable situation can be achieved in only two ways: (a) location of storage facility in a region where relative humidity is naturally low; or (b) reduction of relative humidity to a favourable level by conditioning of the storage environment. The maximum level of

8

Table 2. Absorbed moisture content (wet weight basis) of field crop seed in equilibrium with air at various relative humidities at 25°C (Delouche, 1968b; Harrington, 1959; James, 1967).

Species	Relative Humidity %						
	15	30	45	60	75	90	100
Arachis hypogaea	2.6	4.2	5.6	7.2	9.8	13.0	-
Glycine max	4.3	6.5	7.4	9.3	13.1	18.8	-
Gossypium hirsutum	-	-	7.5*	9.1	12.1*	19.1	-
Hordeum vulgare	6.0	8.4	10.0	12.1	14.4	19.5	26.8
Oryza sativa	-	-	9.8*	11.7	14.2*	17.1	-
Phaseolus vulgaris[a]	-	7.3	9.4	12.8	16.5	-	-
Sorghum bicolor	6.4	8.6	10.5	12.0	15.2	18.8	21.9
Triticum aestivum[b]	6.4	8.5	10.5	12.5	14.6	19.7	25.0
Zea mays	6.4	8.4	10.5	12.9	14.8	19.1	23.8

[a] Dry field beans; [b] Hard red winter wheat; * Estimated

relative humidity for successful storage of seed depends, of course, on the kind of seed, the length of the storage period, and the temperature (Delouche, 1968b).

In addition to its direct effect on seed moisture content, relative humidity of the storage environment also indirectly affects the quality of seed. Christensen's (Christensen and Kaufmann, 1969) comprehensive studies on grain storage have demonstrated that (a) storage fungi are a major cause of quality losses – including germinability – in stored grain and seed; (b) the important storage fungi cannot grow and reproduce on grain or seed in equilibrium with a relative humidity less than 65–70%; and (c) drying seed or grain to a moisture content in equilibrium with relative humidity below 65–70% and maintaining moisture content at that level during storage, eliminates the storage fungi problem regardless of other conditions of storage.

The activity and reproduction of storage insects are also dependent on relative humidity of the microenvironment in the seed mass. Activity of some of the more serious stored insect pests decreases rapidly as relative humidity drops below 50% and reproduction stops altogether at less than 35% r h (Cotton, 1963).

The tremendous influence of moisture content on longevity of seed is underscored in Harrington's convenient tule-of-thumb (Harrington, 1959): the storage life of seed is doubled for each 1% decrease in seed moisture content. This rule-of-thumb has proven to be substantially correct for many kinds of seed and for seed moisture contents in the range 6 to 16% (Delouche, 1968b; Gill, 1969; Sittisroung, 1970).

Temperature is the second most important environmental factor affecting longevity of seed in storage. Other conditions and factors being equal, the longevity on seed in storage is approximately doubled for each 5.5° reduction in storage temperatures within the range 0° to 45°C (Harrington, 1959).

Seed moisture content (or relative humidity) and temperature reinforce and compensate each other in their effect on longevity of seed. High moisture content seed (14 to 16%) of field crops can be stored for a year or more at a temperature of 10°C or lower, while low moisture seed (10% or less) can withstand temperatures in the

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range 30–34°C for the same period without appreciable loss of viability (Delouche, 1968b). The combination of high humidity and temperature characteristic of subtropical and tropical environments, however, is disastrous for storage. Most kinds of seed decrease substantially in viability and tremendously in vigour during even six months storage at 30°C and 75% r h (see Table 1).

'Safe' conditions for storage

The recommendations given in this section are primarily based on our experience. Good data on responses of seed of tropical crops under ambient and controlled storage conditions are very limited.

'Safe' storage conditions are defined by Harrington (1958) as those that maintain seed quality without loss of vigour for three years. Such conditions are indeed favourable, but they simply cannot be economically justified in regions where they do not naturally occur except for genetic seed stocks, breeders seed, some foundation seed, and the more costly or scarce kinds of vegetable, ornamental and forest seeds.

In seed programmes in the subtropical and tropical countries – as elsewhere – three levels of storage conditions are generally used: (a) conditions that will maintain seed quality from harvest to the next planting season (1–9 months); (b) conditions that will permit carry-over storage of the more elite classes of seed as a hedge against seed production failures (18–24 months); and (c) conditions suitable for long-term storage of breeders seed, genetic seed stocks, and the more costly and scarce vegetable, ornamental and forest seeds (3 to 10 years storage).

Short Term Storage

Good quality seed of the major subtropica and tropical crops can be stored satisfactorily from harvest to the next planting season – 1 to 9 months depending on whether or not multiple cropping is practised – under the following storage conditions:

a. 30°C–50% r h (seed moisture contents ranging from maximum of 12% for cereal seed to 8% for oil seeds).
b. 20°C–60% r h (seed moisture contents ranging from maximum of about 13% for cereal seed to 9.5% for oil seeds).
c. Other combinations of temperature and relative humidity as favourable as those above.

The conditions recommended above are *minimal* for safe storage for periods up to nine months. Some loss in vigour will occur even though germination percentage is maintained. Thus, more favourable conditions should be maintained when possible.

Intermediate Term Storage

Successful carry-over storage (18 months) of the seed of major field crops in the subtropics and tropics can be accomplished under conditions that do not exceed the following:

10

a. 30°C–40% r h (seed moisture content ranging from maximum of approximately 10% for the cereals to 7.5% for oil seeds).
b. 20°C–50% r h (maximum seed moisture contents ranging from 12% for cereals to 8% for oil crops).
c. 10°C–60% r h (maximum seed moisture contents ranging from about 12% for cereals to 9% for oil seeds).
d. Other combinations of temperature and humidity as favourable as those above.

Long Term Storage
Cold and dry conditions will maintain the quality of seed for many years in storage. For three to five years storage, conditions of 10°C and 45% r h are satisfactory for most kinds of field crop seed. Successful storage for five – fifteen years can be achieved under conditions of 0° to 5°C and 30–40% r h (James, 1967). These levels of temperature and relative humidity can only be obtained in specially constructed, insulated rooms conditioned with heavy duty refrigeration-dehumidification systems.

Storage facilities

Ambient temperature and relative humidity in tropical countries frequently exceed the levels of these two factors recommended for even short term storage. Consequently, special precautions during the segments of the storage period preceding packaging and some conditioning of the packaged seed storage environment are usually necessary for successful storage. The phrase *usually necessary* should be emphasised because the real need for conditioned storage can only be determined by actual measurement of the storage responses of seed of local kinds and varieties of crops under prevailing ambient conditions. Unfortunately, data of this type are generally not available. Thus, storage plans have to be developed most often on the basis of experience and a set of assumptions.

Unconditioned (Open) Storage
Unthreshed and Bulk Seed. Conditioning of the storage environment during the period from drying to threshing and/or packaging is neither practical nor economically feasible for most kinds of field crop seed. Increasingly, seeds are handled in bulk during these stages, thus, natural ventilation, forced air aeration, and periodic redrying are used to maintain a satisfactory seed moisture content, prevent temperature stratification, moisture migration and heating while the seeds are in bulk storage.

With limited mechanisation and in the absence of more suitable facilities, field expedient procedures can be used for temporary holding storage of unthreshed rice, sorghum and wheat heads, ear maize, unshelled peanuts, unhulled beans, etc., between partial or complete drying and threshing. The slat house illustrated in Figure 1 is satisfactory for temporary holding storage of this sort (Barre and Sammet, 1950). Construction features include slatted walls, which are louvered and may be lined on the interior with wire mesh screen, a roof with extended eaves along sides and ends to

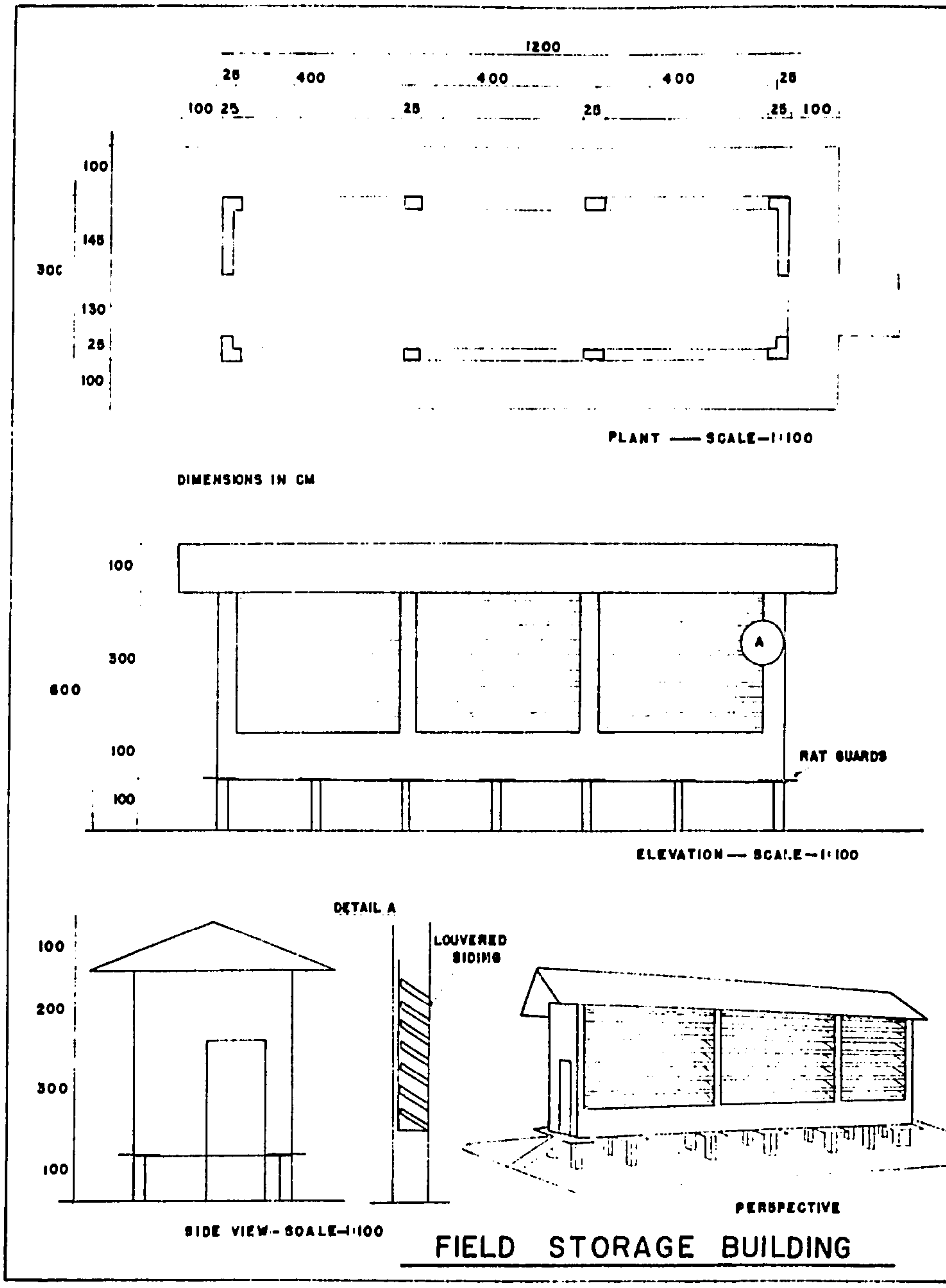

Fig. 1. Slat house for holding storage of unthreshed seed.

keep out rain, and an elevated floor (1 m) supported on columns or poles and fitted with metal shields to keep out rodents. The slat house should be constructed on well drained soil, positioned so that its sides are at right angles to the direction of the prevailing wind, and be not more than 2 m wide for good natural ventilation.

Wire mesh cribs similar in function to the slat house have been designed for holding storage of ear maize and are commercially available. The slat house and wire mesh crib can be fumigated by covering the entire structure with plastic film.

Unthreshed seeds are also commonly stored in large burlap bags under some type of roofed structure. This procedure is satisfactory for holding storage provided the bags are supported on a 10–15 cm high false floor to prevent contact with concrete slab or sod and provide for bottom ventilation, and stacked to facilitate lateral and top ventilation.

After seeds are threshed and dried to a desirable moisture content the major problems during bulk storage are reabsorption of moisture, temperature stratification and moisture migration in the seed mass which can lead to localised 'wet' spots and heating. These problems can largely be obviated by using metal or masonry silos (grain type bins) for bulk storage that are fitted with elevated, perforated metal floors and equipped for forced air aeration. Bulk storage and handling facilities of this type were designed and recommended for a rice seed programme in East Pakistan a few years ago (Delouche, 1963). The cylindrical metal bins were arranged in a circle around a central elevator efficient, mechanical loading and unloading (Figure 2). One aeration fan was used for each two bins and it was capable of aerating the seed at the rate of 0.8 m^3 per minute for each m^3 of seed. Periodic redrying can be accomplished in a modular system of the type illustrated by equipping one bin with a blower and heater sufficient for drying, leaving it empty, and rotating the seed from the other bins through it as needed.

Another type of bulk storage bin is illustrated in Figure 3 (Seed Technology Laboratory, 1967). It was designed for a rice seed operation in Honduras and utilised an existing quonset-type building for both drying and aerated storage. The seeds are loaded over the air ducts, layer dried, and then periodically aerated or redried as necessary until they are processed and packaged. Plastic film was incorporated in the floor of the quonset dryer-bulk storage facility to prevent moisture migration from the soil. This is an important feature and should be incorporated in all seed store houses.

Forced aeration of seed stored in bulk is very effective in preventing temperature stratification and moisture migration if properly scheduled. Generally, seed should be aerated during clear days from about 1000 to 1600 hours when relative humidity is lowest. It should not be aerated during rainy weather or at night when humidity is high.

Packaged Seed. In areas where environmental conditions permit, seed can be stored after processing in porous bags in an unconditioned warehouse. Unconditioned warehouses should be constructed on a well drained site with gravel fill and plastic film between the soil and concrete slab. Walls should be high and provided with vents for good ventilation. Masonry walls, an insulated ceiling and attic ventilation will minimise heat build-up in the warehouse during the daylight hours. The entire structure

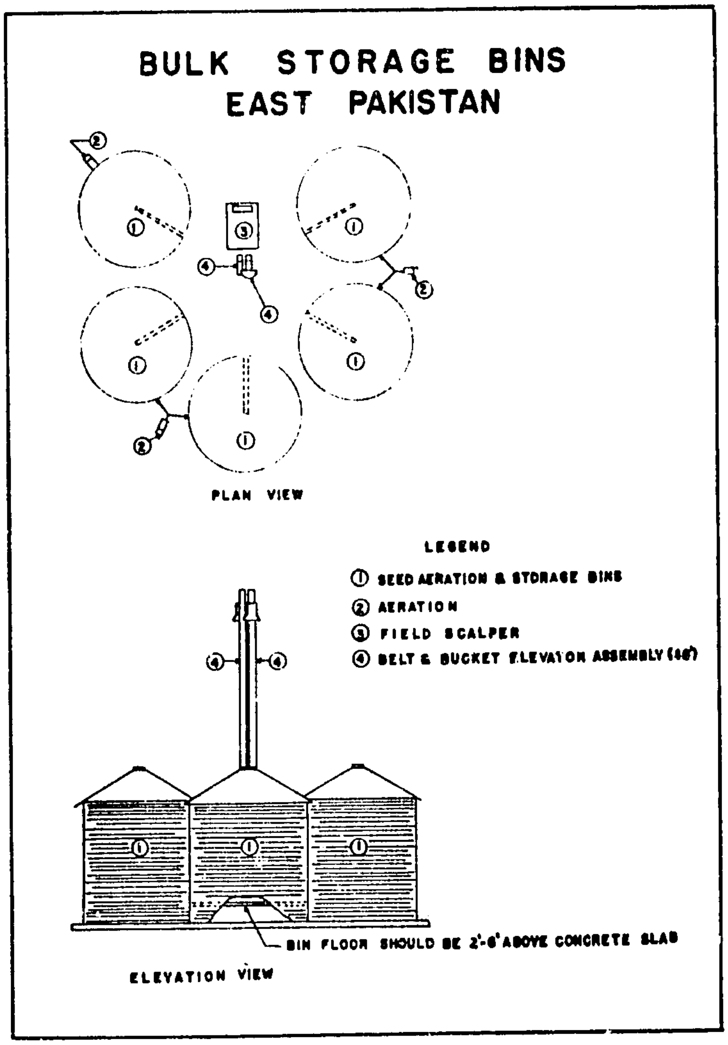

Fig. 2. Aerated bulk storage facility designed for rice seed multiplication farms in East Pakistan, (Bunch, Johnson and Matthes, 1969).

should be as rodent-proof as possible. This can be accomplished by pouring the floor on gravel fill at least 1 m from the ground, and providing rodent shields across the bottom of all entreways.

Unconditioned storage of packaged seed can also be used in regions where environmental conditions are quite adverse if the packages are moisture vapour proof (Asgrow Associated Growers, Inc, 1954; Cooper, 1959; Harrington, 1958; 1963; Helmer, Caldwell and Bunch, 1963; Helmer and Delouche, 1964; Toole, Toole and

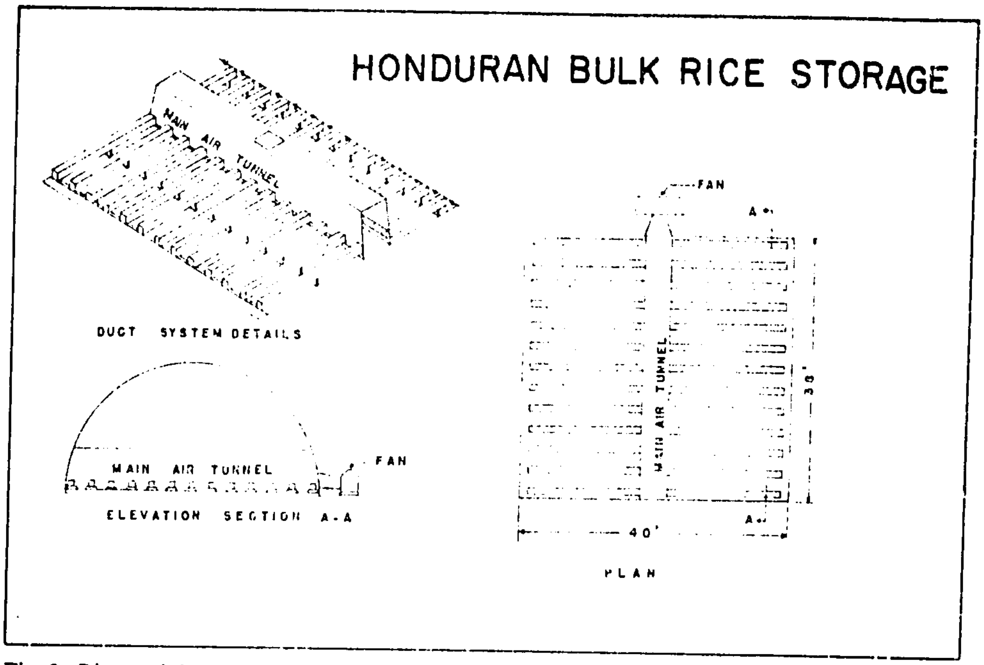

Fig. 3. Rice seed dryer-bulk storage unit designed for existing metal quonset-building in Honduras. (Seed Technology Laboratory, 1967).

Nelson, 1961). Moisture vapour proof packaging maintains seed moisture content and relative humidity of the microenvironment in the package at a favourable level. If seed moisture content is low enough in the package, the seed will store satisfactorily even under the rather warm ambient temperatures of tropical environments. Sealed storage is discussed in detail in another paper in this issue of Seed Science and Technology.

Conditioned Storage

Conditioned storage can be defined as storage in which the temperature, the relative humidity or both are controlled by mechanical and/or chemical (relative humidity) means. Since conditioning of bulk storage is usually not economically feasible, this section is focussed on storage of processed, packaged seed.

Conditioning of the storage environment requires removal of heat and moisture. These tasks can be accomplished efficiently only in a room specially constructed to retart heat and moisture vapour transfer between the exterior environment and the interior of the storage space (Cook, 1966; Munford, 1965; Sijbring, 1963). Thus, the first considerations in designing conditioned storage facilities are the type of construction and quantity of heat and moisture (heat and moisture loads) that must be removed to maintain the design conditions (Longetronics, Inc., 1965; Remington Air Conditioning, 1965).

Moisture Load. Maintenance of a relative humidity in a storage room lower than the ambient condition requires continuous removal of moisture in the storeroom at a rate equal to the rate of infiltration of excess moisture from the outside plus the moisture released inside the room by workers, seed and other sources. This moisture load must be calculated in order to determine the dehumidification capacity needed to maintain design conditions.

Maintenance of relative humidity in a storeroom substantially lower than the ambient condition is greatly enhanced by tight construction of the room and incorporation of a moisture vapour barrier in walls, floor and ceiling. Moisture vapour enters a storeroom by interchange of dry inside air with moist outside air. This interchange is basically a diffusion process caused by a difference in moisture vapour pressure on the outside (high) and inside (low) of the room (Haynes, 1969; Shortly and Williams, 1953). Since diffusion is a very prominent process, small openings or cracks in the walls or ceiling, or around the doors allow a tremendous amount of moisture transfer. The rate of moisture transfer (infiltration) from the exterior to the interior of a conditioned storage room, therefore, depends on the type and care of construction.

Calculation of moisture loads due to infiltration is complicated and involves many subjective judgements on rate of moisture transmission through the construction material, 'tightness' of joints and doors, frequency of opening doors, length of time they remain open, and so on. Because of these uncertainties, moisture loads are usually estimated on the high side and on the basis of experience (Longetronics, Inc., 1965). Infiltration rate varies from as high as three complete air changes per hour for the normal factory-type masonry construction with regular doors, a normal complement of windows, poorly sealed cracks and frequent opening of doors to less than 0.1 air change per hour in a tightly constructed storeroom, with vapour barrier in walls, ceiling, and floor, well sealed cracks, gasketed doors, no windows, and infrequent opening of doors (Longetronics, Inc., 1965; Remington Air Conditioning, 1965; Munford, 1965). Rate of infiltration into the average well constructed storeroom with insulated ceiling, gasketed doors, no windows, vapour barrier in floor, well sealed cracks, and 3–5 door openings per day is of the order of 0.20 to 0.50 air changes/hour (Longetronics, Inc., 1965; Remington Air Conditioning, 1965; Munford, 1965).

The moisture load due to infiltration can be calculated by the following formula (Barre and Sammet, 1950);

$$M = \left\{\frac{Ho}{SVo} - \frac{Hi}{SVi}\right\} (V)\,(N)$$

where,

M is the rate of moisture infiltration in kg/h,
H is the absolute humidity of air in kg/water/kg dry air;
SV is the specific volume of air in m^3/kg dry air,
V is the volume of the room in m^3,
N is the number of air changes per hour,
o denotes exterior condition, and
i denotes interior condition.

16

H and SV are determined with a psychrometric chart from the ambient temperature and relative humidity and the design levels of these two factors in the store room. Or, the needed information can be easily obtained from Table 3, which gives the litres of water contained in 100 m^3 of air at various levels of temperature and relative humidity. The amount of moisture that must be removed per hour due to the infiltration component of the moisture load alone is equal to the difference in the quantity of water per 100 m^3 under ambient and design conditions multiplied by the number of 100 m^3 in the total volume of the storeroom, and the infiltration factor (air changes per hour).

Table 3. Amount of moisture contained in air: Litres of water per 100 m^3 air.

Air Temp. °C	Relative Humidity of Air in %						
	90	80	70	60	50	40	30
35	4.0	3.1	2.7	2.3	1.9	1.5	1.1
30	2.6	2.4	2.0	1.8	1.5	1.2	0.9
25	2.1	1.9	1.6	1.4	1.2	0.9	0.7
20	1.8	1.5	1.4	1.2	1.1	0.7	0.6
15	1.2	1.1	1.0	0.7	0.6	0.5	0.4
10	0.7	0.7	0.6	0.6	0.5	0.4	0.3
5	0.6	0.5	0.4	0.4	0.3	0.3	0.2
0	0.5	0.5	0.4	0.3	0.3	0.2	0.1

Other components of the moisture load in a conditioned seed storage room are the moisture vapour released by workers and seed. The moisture load due to workers is negligible because they are only active in the room during loading and unloading and at these times the doors are open so frequently and long that the conditioning equipment should be turned off. Moisture release by seeds as they come into equilibrium with the design conditions in the room, however, is an important component of the moisture load.

A dehumidified store room is a very inefficient dryer, so the seed should enter storage at a moisture content not more than 1–2% above the hygroscopic equilibrium with conditions in the room.

The rate of moisture release from seed will be influenced by the relative humidity in the room, seed moisture content, packaging material, method of stacking, etc., but a 30–60 day period for establishment of equilibrium when seed moisture content is 1–2% higher than the hydroscopic equilibrium value is a reasonable period for design purposes (Haynes, 1969).

The moisture load due to release of seed moisture can be calculated from the following formula:

$$M(a) = W\left\{\frac{MC_i - MC_e}{100 - MC_e}\right\}\left\{\frac{1}{24d}\right\}$$

where,
M(a) is the moisture load in kg/h,
W is the initial weight of seed in storage in kg,
MC is seed moisture percentage (wet weight basis),
d is the number of days required for seed to reach hygroscopic equilibrium, and
i, e denote initial and equilibrium moisture contents (%) of the seed, respectively.

The total moisture load in the storeroom is equal to the sum of the infiltration and seed moisture components. This sum will be in kilograms of water that must be removed each hour during the seed equilibrium period. Thereafter, moisture removal will drop to the infiltration load.

Heat Load. Maintenance of a storage temperature lower than the ambient condition requires sufficient refrigeration to reduce temperature of the air and materials in the room to the design condition and to maintain it at that level against heat transfer through wall, ceiling and floor, and heat release from condensations (or absorption) of moisture, motors, lights, people and seed. Heat load estimates are always important but they are doubly so in design of dehumidified storerooms because dehumidification is an exothermic process and temperature in the storeroom will rise alarmingly unless heat of condensation is compensated for by air cooling.

Heat transfer through walls, ceiling and floor can be reduced by insulation. The insulation value of a material is a measure of how well it resists the transfer of heat through it and is dependent on its thickness and the inverse of its thermal conductivity values for various materials are given in Table 4.

Total heat transfer through the walls, ceiling and floor can be calculated by the following steps (Barre and Sammet, 1950):

Table 4. Coefficients of thermal conductivity of various construction materials. (Barre and Sammet, 1950).

Material	(K) (BTU/hr-ft²-°F/in.)	(K) (Kcal/hr-m²-°C/cm.)
Stone, typical	12.50	155.0
Stucco, typical	12.50	155.0
Concrete, cement mortar	12.00	148.0
Plaster, Portland cement	8.00	100.0
Gypsum	3.30	41.0
Brick, common	5.00	62.0
Glass, window	4.80	59.5
Asbestos	1.50	18.6
Wood, oak	1.44	17.8
Plywood	0.80	10.0
Insulating board, fiber	0.34	4.2
Blanket Insulation	0.27	3.3
Styrofoam	0.20	2.5
Air (still)	0.17	2.1
Urethane	0.10	1.2

(a) Determine the insulation value or resistivity (r) of each material used in construction of the walls (brick, air space, wood, polymer foam, sheet insulation, etc.).

r = x/k, where x is the thickness of the material in cm, and k is the thermal conductivity of the material in Kcal/h/m²-°C/cm.

(b) Sum the insulation values (r) of the materials used in construction of the walls to obtain the resistance (R) and determine the combined heat transmission coefficient (U).

$R = r_1 + r_2 + r_3 + \ldots\ldots$

$U = \frac{R}{1} = \text{Kcal/h/m}^2/^\circ\text{C}$

(c) Determine the total heat transfer through the walls,

$Q = UA\,(T_o - T_i)$, where,

Q is the heat flow in Kcal/h,

U is the heat transmission coefficient in Kcal/h/m²/°C,

A is cross sectional area in m²,

T_i is the design or desired temperature in °C, and

T_o is the average prevailing outside temperature in °C,

(d) Repeat steps a, b, and c for ceiling and floor (for floor assume that T_o is 20°C).

(e) Sum the Q's for total heat transfer into the storeroom in Kcal/h.

The other major component of the heat load is heat of condensation. Condensation of water by a dehumidication system releases heat at the rate of 540 Kcal/litre water condensed.

Seeds placed into a conditioned storage room are usually at ambient temperature. Thus, the quantity of heat that must be removed from the seeds to lower their temperature to the design condition is part of the heat load on the room. The total heat that must be removed to cool seed to the design temperature is calculated as follows: multiply the total seed weight by the specific heat of seed, which is assumed to be 0.5 Kcal/°C, the product by the temperature drop (initial temperature of seed minus the design temperature) in °C, and divide by the number of hours desired to effect the temperature change (e.g. 48 hours). The result is in Kcal/h.

Other sources of heat in a storage room include lights (heat added at rate of total watts in Kcal/h and electric motors (heat added at rate equal to their rated horse power multiplied by 700 Kcal/h) (Longetronics, Inc., 1965).

The total load on the storage room is the sum of the various components and is usually expressed as Kcal/h that must be removed to maintain design conditions.

Use of moisture and heat load data in design of seed storage facilities can best be illustrated with an actual example. In 1965–66 we designed two complete seed facilities for the Direccion General de Desarrollo Rural in Honduras (Seed Technology Laboratory, 1967). One of the facilities was to be located on the Northen Coast near the very tropical city of San Pedro Sula. Included among the design requirements was a storage house suitable for 9–12 months storage of 10,000 cwt (508,000 kg) of maize, rice and bean seed. Monthly maximum temperatures averaged about 88°F (31°C) and relative humidity averaged near 75%.

Experiences in other tropical areas, as well as some storage data from the San Pedro

19

Sula area, indicated that some conditioning of the storage environment was needed to maintain the quality of maize, bean and rice seed for 9–12 months. Again, largely on the basis of our own experiences and tests, 75 °F (24 °C) and 50 % r h were selected as the design conditions.

Overall dimensions of the storehouse were 206 ft × 32 ft × 11.5 ft (62.8 m × 9.8 m × 3.5 m) (floor to ceiling). It was subdivided into five independently conditioned units of approximately 42 ft × 32 ft (12.8 m ×f9.8 m), each of 2000 cwt (101,600 kg) bagged seed capacity, for economy of operation when the facility was only partially filled and to 'spread' the risk of equipment failures. General features of construction are illustrated in Figure 4.

Moisture load calculations indicated that approximately six pints (3.4 l) of water would have to be removed every hour from each 15,000 ft^3 (425 m^3) storage unit to maintain the design relative humidity (50 %) against moisture infiltration (estimated at 10 air changes every 24 hours). An additional six pints water/h would have to be removed during the first 30 days of storage to take care of moisture loss from the seed (estimated 2 % decrease in seed moisture content). Thus, a dehumidification capacity of 12 pints (6.8 l) water/h were needed for each storage unit for the first 30 days, and six pints/h thereafter. Since the sedes were to be loaded into the storage units over a 40–50 day processing period, seven dehumidifiers each with rated capacity of six pints/h water removal were specified. One dehumidifier was permanently stationed in each storage unit, while the other two were rotated among the rooms to take care of moisture release from newly loaded seed.

Heat load calculations indicated that a cooling capacity of approximately 40,000 BTU's (42,200 kJ) was needed to maintain storage temperature at 75 °F (24 °C). Accordingly, one self-contained window-type 36,000 BTU (38,000 kJ) air conditioner (largest available with local maintenance) was specified.

In 1970, Viera (1970) reported on the performance of the storage rooms during the two year period, 1968–70. Relative humidity in the storage units ranged from a high of 55 % to a low of 47 % for an average of 52 % (compared with 82 % average ambient r h). Temperature in the storerooms ranged from 62° to 75 °F (17 °–24 °C) for an average of 68 °F (20 °C). Maize, bean and rice seed stored in the conditioned units maintained quality for somewhat longer than the design period (9 to 12 months).

Construction Features. Seed storehouses are most commonly constructed of reinforced concrete and/or masonry with steel framing. Both materials are usually available locally and produce sturdy, tightly constructed, durable structures. All joints between walls and floor and ceiling (or roof) must be tightly sealed with mortar or concrete.

For light to moderate conditioning (short to intermediate term storage) the walls should be finished with plaster and painted with two coats of good quality moisture vapour retardant paint (Figure 4). A reinforced concrete ceiling (roof) should be painted on the interior side and coated with tar or asphalt and gravel on top. Other types of ceiling should be moisture vapour proofed and insulated with 5–10 cm polymer type insulation such as styrofoam or urethane. These materials will both

20

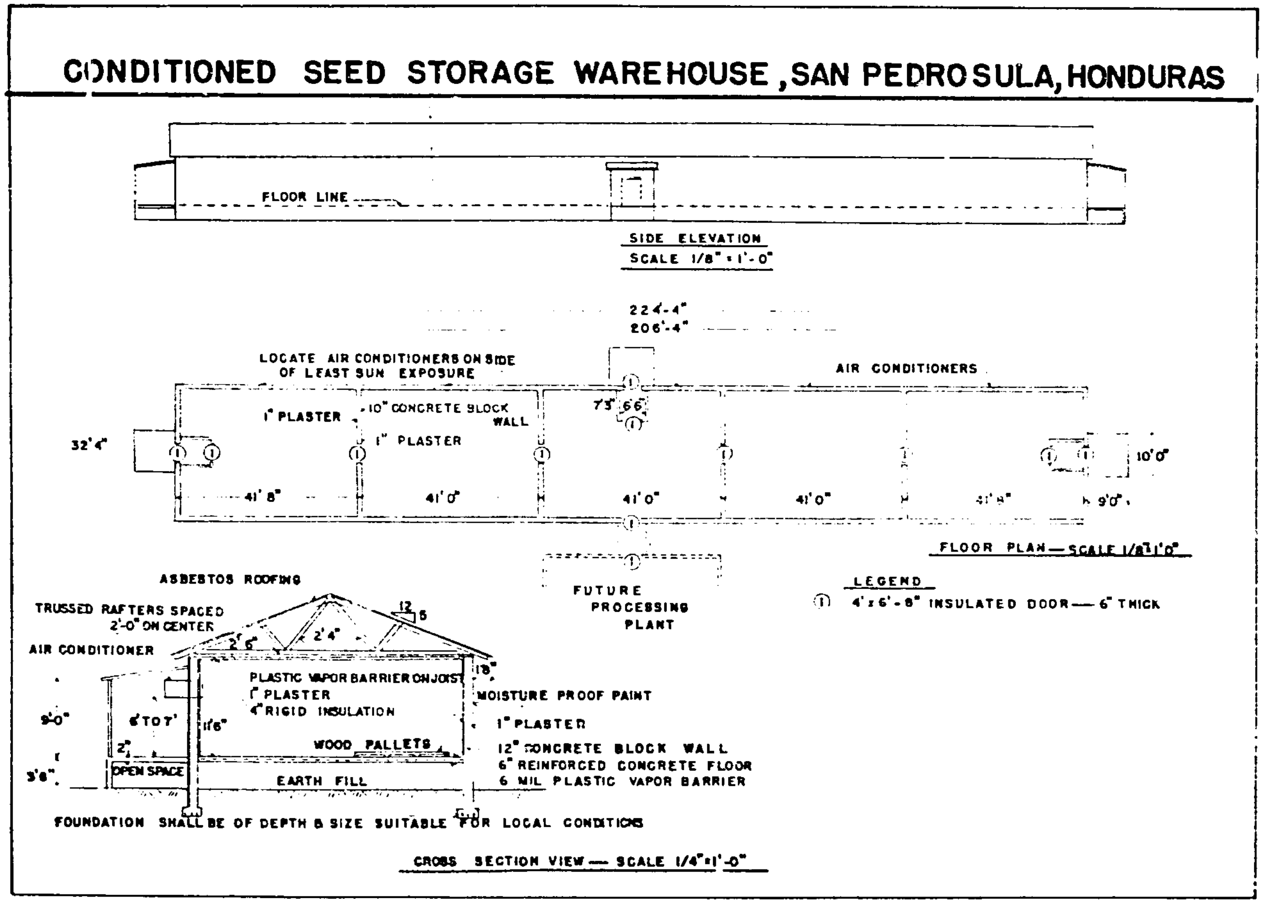

Fig. 4. Construction details of a conditioned facility designed for short-term storage of seed in Honduras. (Seed Technology Laboratory. 1967).

insulate and moisture vapour proof the ceiling provided the joints are well sealed with mastic. The floor should be a concrete slab poured over a vapour barrier (plastic film) about 1 m from the ground to facilitate control of rodents. The storehouse should not have any windows and all doors should be moisture vapour proofed and gasketed. Air locks in the main entrances are also desirable.

Storage structures that are to be moderately to highly conditioned (intermediate to long term storage) must be more tightly constructed, heavily insulated, and moisture vapour proofed for efficient and economical operation (Figures 5 and 6). The walls and ceiling should be well insulated and provided with a vapour barrier of plastic film or metal foil on the warm (outside) side of the insulation. Vapour barrier in ceiling should overlap barrier in walls. The concrete slab floor should be elevated 1m, poured over a moisture-vapour barrier and insulated by use of an appropriate additive to the concrete or incorporation of rigid polymer insulation in the slab. The insulation should be sealed to the structural slab and covered by a 5–8 cm 'wearing' surface of poured concrete. Air locks should be provided in all entreways and fitted with cold room-type doors with positive lock closures and heavy rubber gaskets.

Short cuts and shoddy workmanship in construction should not be tolerated. They will surely lead to difficulties during operation and correction will be very costly if feasible at all.

Although the problem of storage insects is not considered in this discussion, it should be pointed out that insect control by fumigation is facilitated by tight construction of storerooms.

Conditioning Systems. Conditioning of the environment in a room to a level satisfactory for seed storage when ambient conditions are not favourable requires air cooling, dehumidification or both. The type and amount of air cooling and/or dehumidification is determined by the kind of seed, length of storage period, and ambient conditions.

Moisture is removed from the air in a storage room by the process of dehumidification. Two basic methods are used: (a) condensation of moisture vapour on cold refrigerated coils; and (b) absorption of moisture vapour on a drying agent or desiccant (Longetronics, Inc., 1965; Remington Air Conditioning, 1965; Munford, 1965; Sijbring, 1963). Refrigeration or condensation dehumidification systems remove moisture by drawing air across refrigerated coils cooled to a temperature below the dew point of the air. Moisture is condensed on the coils, collected in a drip pan and drained from the room through a plastic or metal pipe. In highly conditioned rooms, the dew point is usually below freezing, thus, moisture is condensed on the coils as ice or frost. This ice will accumulate insulating the coils and reducing cooling efficiency unless periodically removed by defrosting. In well designed systems, the cooling coils are defrosted at automatically timed intervals by activation of electric heating strips near the coils or by reversal of the flow of hot discharge gas so that it passes through the coils.

In desiccant dehumidification, air is drawn through a bed of desiccant where moisture vapour is adsorbed. The dry air is then passed back into the room. Since desic-

72

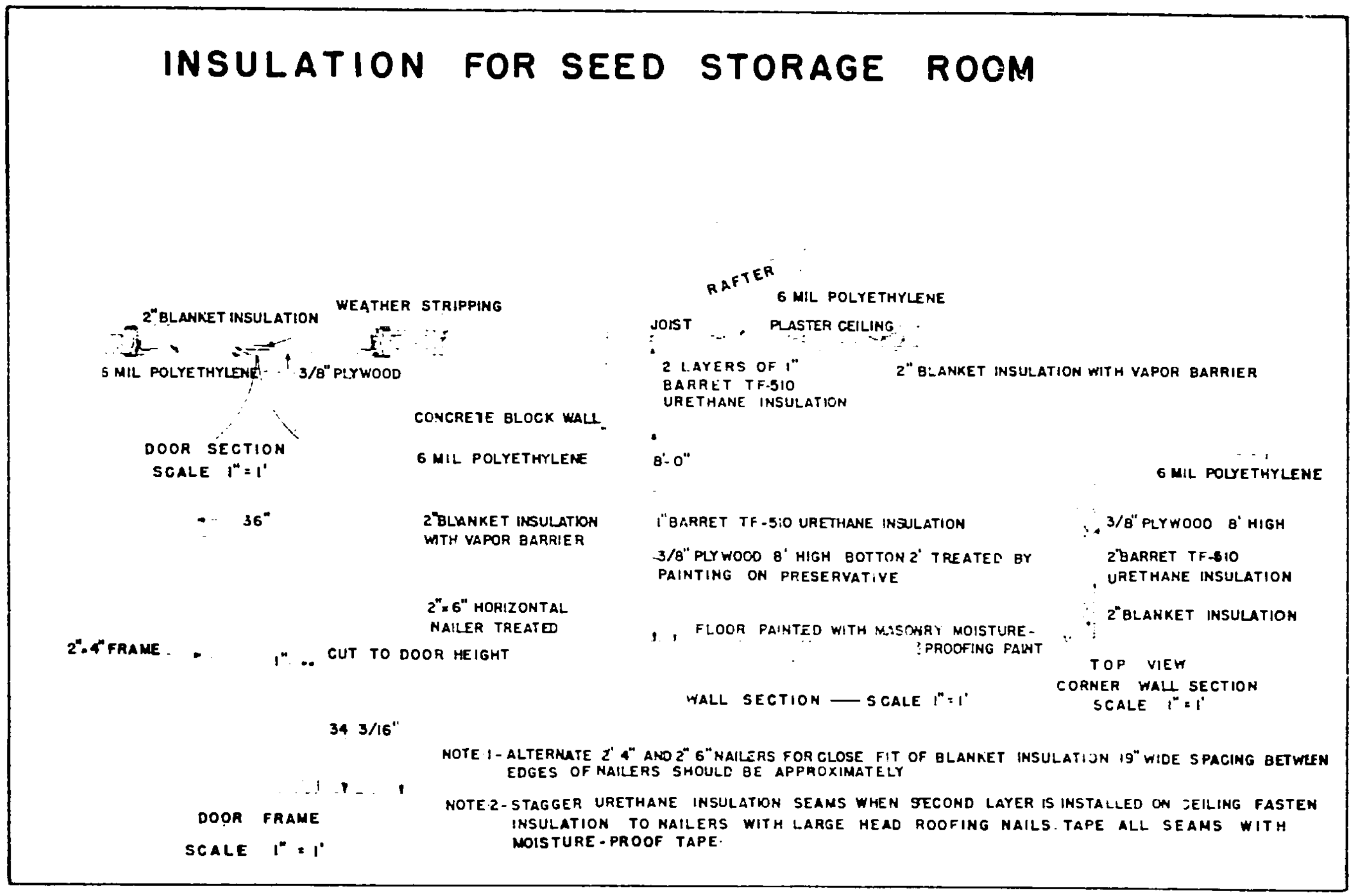

Fig. 5. Construction features and insulation for an intermediate-term seed storage facility.

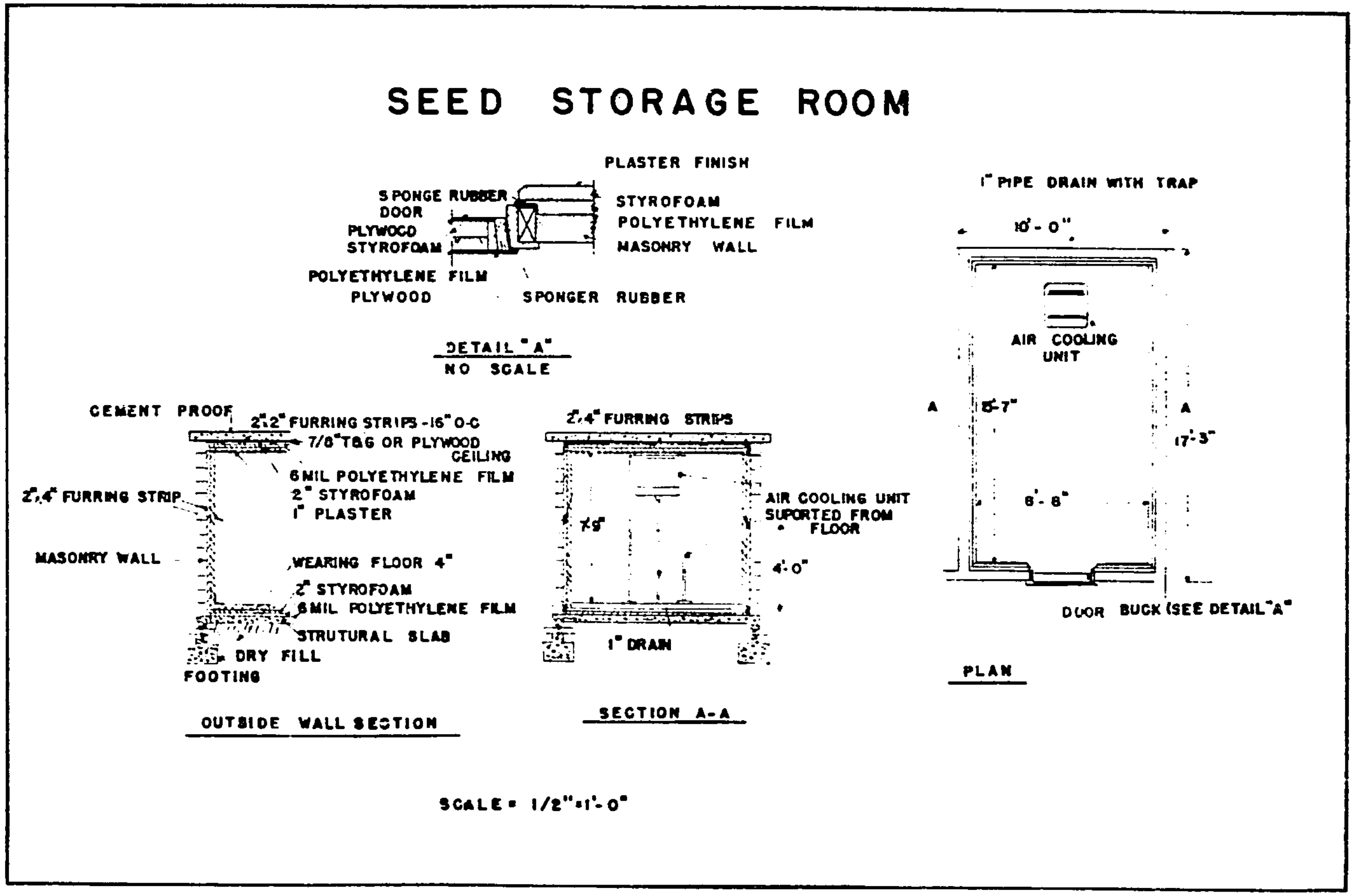

Fig. 6. Construction details of a long-term storage unit designed for a seed programme in El Salvador, (Seed Technology Laboratory, 1968).

cants adsorb only a certain quantity of moisture, they must be periodically dehydrated (reactivated) by heating. Dehydration of the desiccant in most commercially available dehumidifiers is automatically accomplished by activation of heaters in the desiccant bed. Many desiccant dehumidifiers have two drying beds so that while one is dehydrating, the other is dehumidifying. Desiccant dehumidifiers are more efficient than refrigeration dehumidifiers at low temperatures and can maintain a relative humidity as low as 10%.

Heat is a product of dehumidification regardless of the type of system used. Condensation or absorption of moisture releases heat at the rate of 540 Kcal/litre. Consequently, if any substantial amount of moisture is being removed in a closed room, temperature will rise above the ambient condition unless air cooling is provided. The temperature rise from dehumidification without air cooling will depend on the quantity of water removed and how well the room is insulated. In the common types of storerooms constructed in tropical countries, the temperature rise from dehumidification is usually sufficient to require at least enough air cooling to compensate for the sensible heat gain from dehumidification. Most often ambient temperature is so high (30°C plus) that cooling capacity has to be also sufficient to reduce temperature in the room by 5° to 10°C for short to intermediate term storage.

Dehumidification and air cooling systems are available in many models and capacities ranging from the small, low capacity 'basement' type refrigeration dehumidifier, that only dehumidifies, to large capacity refrigeration systems put together from several components and capable of conditioning both temperature and humidity to low levels. Selection of a conditioning system for a storeroom in a specific location is based on ambient and design conditions, construction features of the room, kind of seed, and, most importantly, length of the storage period.

Short to intermediate term storage (9–18 months) of the major field crop seed requires only a moderate amount of conditioning even under adverse tropical conditions. Basement-type dehumidifiers have been effectively used in Brazil, Honduras and other countries to reduce relative humidity sufficiently for reasonably successful short term storage. Dehumidifiers of this type add heat to the storage room but since water removal capacity is low and the rooms poorly insulated, the temperature does not rise much above the ambient condition. They are especially well suited for use in the higher altitude regions of the tropics and subtropics where day temperatures are moderate and night temperatures cool.

The conditioning system of choice for short to intermediate term storage should be the self-contained, window-type air conditioner. These are locally available in most countries, relatively inexpensive, installation does not require the services of refrigeration specialists, and repair and maintenance services are better than for other types of conditioning systems. Self-contained air conditioning systems that both cool and dehumidify are avaialable in capacities up to 48,000 BTU's (50,600 kJ). Some models or styles are more efficient in dehumidification, thus, those types should be selected

The storage warehouse of Costa Rica's Consejo Nacional de Produccion at Barranca is a very successful example of 'air conditioned' storage (Witte, 1971). CNP engi-

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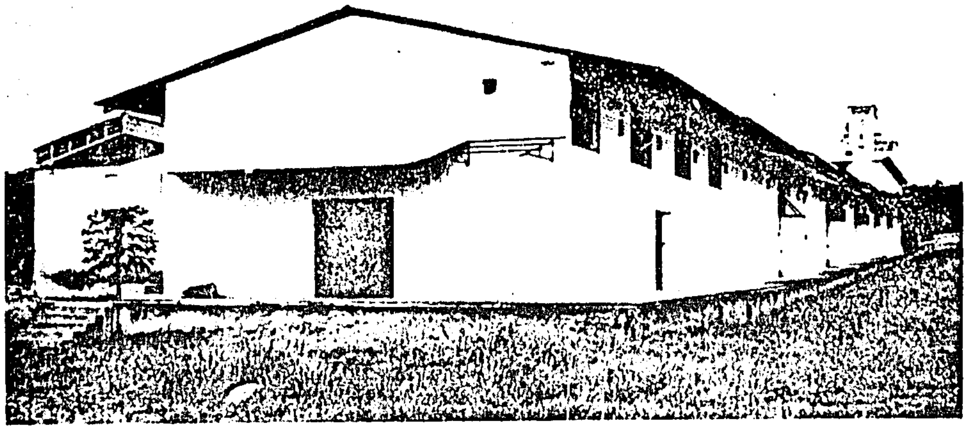

Fig. 7. Exterior view of air conditioned seed storage warehouse of Costa Rica's CNP (Witte, 1971).

neers renovated an unused concrete grain storage warehouse mainly by sealing cracks, repairing the roof, and installing tight fitting doors (Figure 7). The warehouse consists of nine individual storerooms each approximately 10 m × 20 m × 5 m (height) with a capacity of 5000 cwt (254,000 kg) bagged seed. Two 48,000 BTU (50,600 kJ) air conditioners were installed in each unit above door height in ports cut through the oppossing walls. The air-conditioners have satisfactorily maintained conditions of about 18°C and 45–50% relative humidity in the storerooms for more than three years with a minimum of mechanical failures, although ambient conditions at Barranca are humid-tropical. Rice, sorghum and maize seed stored in the facility maintains viability for 24–30 months.

Desiccant dehumidifiers can also be used to reduce relative humidity to a level satisfactory for short to intermediate term storage. In tropical countries, however, where ambient temperatures are high, refrigerated 'after-coolers', windowtype air conditioners or some other suitable heat removal system is necessary to prevent detrimental heat rise. In a system designed by our group for a seed operation in Brazil, the heat from desiccant dehumidification was removed by a recycling water after-cooler. The dehumidified air was blown over copper coils through which water circulated from an evaporative cooling tower (Figure 8).

The design and installation of conditioning systems for intermediate to long-term storage (3 to 10 years) is a very technical speciality. Therefore, the services of an experienced refrigeration engineer or specialist are essential. The various components of the system must be balanced, reheat provided or coils especially designed for efficient dehumidification (Munford, 1972). Because of technical problems in engineering of a low humidity-low temperature system, desiccant dehumidifiers are often integrated in the system to handle the major part of the moisture load.

This discussion on conditioning systems for seed storage can be best summarised

26

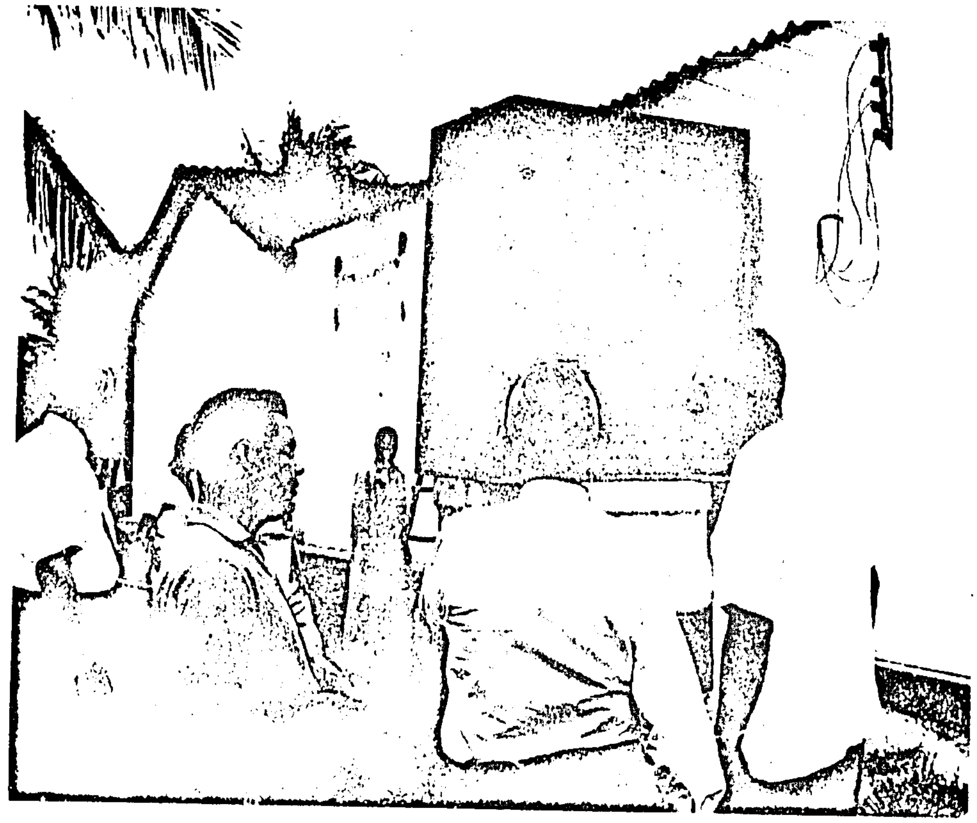

Fig. 8. Evaporative water cooler used in a recycling water after-cooling system in a desiccant dehumidified seed storeroom in Brazil.

with an expansion of the advice given above in connection with design and installation of storerooms for long term storage, viz., obtain expert assistance. The proper and economical design of structures and systems for all levels of conditioning requires experience and specialised knowledge of both environmental engineering and seed storage. If this experience and knowledge is not available within the staff of a seed company or programme, it should be obtained from other sources.

Acknowledgement

The drawings in this paper were made by Sra, Marlene Freire, graduate student in Agricultural and Biological Engineering from Sete Lagoas, Minas Gerais, Brazil.

We are especially indebted to Mr. R. S. Munford, Munford Engineering, Inc., Jackson, Mississippi, U. S. A. for generously sharing his vast experience and expertise in environmental engineering with us on many occasions over the past ten years.

27

The development work and adaptive research on which this paper is largely based are part of the technical services and assistance provided by the Seed Technology Laboratory, Mississippi State University, to the underdeveloped countries since 1958 under provisions of the contract AID/csd 2976 (and its predecessor, AIR-W-607) between MSU and the Agency for International Development, Department of State, Washington, D.C. Specific technical assistance projects – many involving seed drying and storage – have been completed or are in progress in more than 20 countries.

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78

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19'

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