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TECHNICAL ASPECTS OF CONTROLLED HUMIDITY STORAGE

Cooperative Research Program
University of Minnesota
Department of Mechanical Engineering
and
Department of Navy
Bureau of Yards and Docks

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FOREWORD

This report is based upon a comprehensive study by the University of Minnesota, Mechanical Engineering Department, covering the Preservation of Materials in Dehumidified Storage. The studies were sponsored by the Department of the Navy, Bureau of Yards and Docks, through a Cooperative Research Program Contract, NOy-79585, dated 17 June 1953.

The main objective of the program was to evaluate all data or information on the subject of preservation of materials in dehumidified warehouses available from Navy source, or any other source, and summarize the material into a series of reports.

This is a technical report covering a summation of material included in the project progress reports primarily of interest to engineers or technical personnel interested in the design, construction, or operation of dehumidified storage spaces.

INTRODUCTION

The prevention of the deterioration of materials has long been practiced by civilization with a great deal of concern and expense. The preservation of materials affects literally every person in all walks of life. Billions of dollars are expended annually to find and apply ways and means of extending the life of man's shelter, his tools and equipment, and the materials essential to modern civilization. Practically every product built or manufactured must comply with specifications intended to increase its resistance to deterioration.

Materials and equipment, particularly the type of equipment used by the Military, which are stored against a futured need are subject to deterioration even though they are not in use. Therefore, they should be stored under conditions which cause a very minimum of deterioration and thereby insure maximum reliability in time of need. There are many environmental factors such as oxygen, ozone, fungi, dirt, acids, etc. that must be dealt with but the most important factor is moisture since it predominates in almost all deterioration processes. Consequently, storage of material and equipment in a dry or controlled humidity atmosphere reduces or eliminates most of the deterioration which might otherwise occur.

To achieve a suitably dry atmosphere, dehumidification - the removal of water from the warehouse atmosphere - is required in most storage locations utilized by the Navy. Dehumidified storage reduces the need for expensive packaging and preservation treatment; reduces the damage from rust, corrosion, mildew, and rot; and reduces the need for frequent cyclic inspection and representation. Savings resulting from these reductions are frequently adequate or more than adequate to defray the cost of providing dehumidified storage. Furthermore, there is an added advantage in having the stored items in better condition for issue.

It is the purpose of this report to explain the need for application of dehumidified storage, to provide technical information for the accomplishment of dehumidified storage, and to recommend operating procedures for dehumidified storage.

I. PRESERVATION OF MATERIALS BY CONTROLLED HUMIDITY STORAGE

A. PRIMARY CAUSES OF DETERIORATION

1. **General** Deterioration is a loss in the value of a material or a decrease in the ability of a product to fulfill the function for which it was intended. Generally, deterioration is limited to impairment due to natural causes; such as moisture, moderate heat or cold, ultra-violet radiation, slow electrochemical reactions, and biological agents. Climate or environment determines which agents are present at a given location to shorten the useful life of materials. The intensity of the physical deteriorative agents - heat, sunlight, dust, and dirt - varies according to geographical location and the prevailing climate of the region. The chemical agents, moisture, salts, alkalies, and gases, are dependent on climate or industrial effluents for intensity of their action. The biological agents, fungi (molds), bacteria, insects, and marine organisms, are dependent upon the existence of optimum humidity, temperature, and nutrients to thrive in an active, destructive way.

2. Effect of Climatic Conditions. The intensity of the deteriorative attack by the physical, chemical, and biological agents of deterioration is, for the most part, dependent upon the prevailing climatic conditions for any given locality. The climatic variables most concerned with material deterioration are moisture, temperature, light, atmospheric oxygen and ozone, air contaminants, dust, dirt, and sand.

Each factor contributes to material deterioration; however, they never occur singly in the atmosphere. Many times it is the combination of these variables which determines the seriousness of attack. To facilitate this discussion, each variable will be discussed separately.

Much of the information available on the degradation of materials by exposure to climatic variables is in reference to extreme climatic conditions. The interpolation of data to the moderate climatic conditions, as experienced in warehouse storage, is quite difficult. The extent of deterioration caused by climatic factors not only depends upon the degree in which they appear individually but, more important, upon the degree to which they exist in combination with each other. Many materials are little affected by a single climatic variable but may be seriously affected when this variable is combined with another deteriorative agent.

3. Moisture Atmospheric moisture is the most common factor which is effective in accelerating the deterioration of materials. Secondary in influence is temperature, but, within the normal range of temperatures which usually occurs in warehouses, temperature is not of prime importance. Moisture will accelerate deterioration in varying degrees, depending upon the type of materials involved and the quantity of moisture available.

Moisture in the atmosphere occurs in the form of water vapor. The quantity of water vapor in the atmosphere varies according to the climatic conditions in the different areas of the United States. Air at high temperatures can contain more moisture at saturation than air at low temperatures; hence, air at 90°F, and saturation or 100% relative humidity contains an absolute quantity of moisture far greater than saturated air at 50°F. & 100% relative humidity. This moisture content of the air is referred to as humidity. There are two ways of describing humidity or the moisture content of air; absolute humidity, and relative humidity (RH). Absolute humidity is the actual weight of water per unit volume of air, usually expressed in grains of water per cubic foot of air. Relative humidity (RH) is the percentage ratio of water in the air as compared with the amount of water vapor the air could hold at saturation at that same temperature. A more precise technical definition of relative humidity compares the water vapor pressures rather than quantities. Within the range of warehouse temperatures the first definition of relative humidity is sufficiently accurate for all practical purposes.

Moisture alone is not considered a deteriorative factor, although, when in combination with other agents, it exhibits highly degrading properties. Moisture in either liquid or vapor form is a necessary agent for almost all forms of deterioration.

Water is one of the best chemical solvents known as it dissolves many chemicals and brings them into contact with the surface of the materials to cause damage. It may combine with an industrial air contaminants, such as sulfur dioxide, to form sulfurous or sulfuric acids, which are highly destructive to most materials. Although water itself is fairly stable, it is capable of promoting reactions between substances to cause other chemical reactions.

An electrochemical process, which is the principal cause of corrosion of metals, relies upon the presence of an electrolyte which is primarily water in combination with various chemicals. The absence of water from an electrolytic reaction will retard or stop the process. Rusting of iron and steel is an electrochemical process of economic importance.

Water is also a necessity in all life processes. Biological growth, a potential cause of deterioration in many materials, requires the presence of water. Biological growth in and around materials may be controlled to a varying degree by controlling the amount of water present. It has been found that very little fungal growth occurs at relative humidities below 70%. Therefore, it is important to control, within certain limits, the relative humidity of the air to obtain the optimum degree of preservation. Control of the humidity in a warehouse is the principal factor in the preservation of materials.

Water may be present on a material as either free water deposited by condensation or as absorbed or adsorbed water due to the hygroscopic properties of a material. The degradation due to moisture absorption may be of a physical nature resulting in shrinking or swelling as water is given off or taken on due to changing temperatures and humidities. Alternate shrinking and swelling may cause warping of some materials. In many cases, stresses are set up within the material which may cause fracture of the material at joints where adhesives are used.

Some hygroscopic materials take on water without a change in its physical or chemical nature and hence are said to adsorb moisture. These materials are termed desiccants, and their use in warehouse dehumidification will be discussed later in this report.

The water condensed on or absorbed by an organic material may be adequate to support microbiological activity and result in mildew or rot.

The water condensed on metals in sufficient quantities to establish electrochemical cells may cause rusting and corrosion. Water containing dissolved gases or alkalies may chemically affect the metals or stimulate the electrochemical action.

4. Temperature Tenperature affects material degradation in several ways. Temperature extremes may cause physical and chemical changes in the material, loss of the useful properties exhibited at ordinary temperatures, and by combining with the other climatic or atmospheric variables, control the rate of chemical reactions and biological activity.

As most composite materials are non-uniform heat conductors, temperature changes set up a temperature gradient throughout the materials which results in varied internal stresses. These internal stresses caused by dimensional changes may rupture the material depending upon its physical properties. This is true for a combination of materials having different coefficients of thermal expansion where a temperature gradient will cause a dimensional change in one material which in turn applies stress upon the others. Dimensional changes are generally of a temporary nature, unless the change is large enough to cause rupture or breakage of the material.

In the case of deterioration by a chemical process, the chemical reaction rate approximately doubles for every 10° centigrade (18°F.) rise in temperature. Therefore, most deterioration is increased upon heating and decreased on cooling, as most substances have increased solubility and are thus more susceptible to reaction with water and oxygen at elevated temperatures. Many organic materials may also undergo internal chemical changes at elevated temperatures.

Although temperature somewhat affects the degrees of biological attack, the range at which it retards growth is at the upper range of temperature encountered in normal storage conditions. The optimum temperature range for most fungal growth is from 50° to 90°F.

The important physical and chemical changes in the structure of a material due to temperature only are usually encountered either above or below normal warehouse temperatures. The important effect of moderate temperatures occurs when it combines with other physical agents of deterioration.

5. Light Sunlight is an important factor in outdoor deterioration and may also contribute to deterioration by its entry through openings or windows in warehouses. Its most important effect is that portions of the sun's spectrum alone or in combination with other agents may bring about chemical reactions in an irradiated material.

Absorption of a specific wave length of light by a material may cause an activation of molecules within the material. This molecular activation may result in a loss of energy through collisions and reradiation or a chemical change in the material composition. Loss in energy results in raising the temperature of the material. The effect of a temperature rise on deterioration has been previously discussed. The ultraviolet and visible portions of the spectrum are responsible for activation of molecules. Absorption of the infrared spectrum results in a temperature rise and no direct chemical action.

Sunlight, in addition to its heating effect and photochemical action, has an important influence on biological growth. Many organisms are destroyed by exposure to light, particularly the ultraviolet portion of the spectrum. However, some organisms depend upon light for their survival. Any organism which depends upon photosynthesis for the manufacture of starches, sugars, and other food products cannot live without the presence of light.

The amount of deterioration produced by sunlight depends upon the chemical structure of a material, the light wave lengths present, prevailing temperature, and the degree of reactive substances and agents of deterioration present. In summary, light has a deterioration effect upon materials by causing: (1) temperature rise, (2) photochemical reactions, and (3) biological growth.

6. Oxygen and Ozone. The normal constituents of air, except oxygen and ozone, are inert gases. At normal temperatures and pressures, the inert gases will not react with substances, however, deterioration by oxygen and ozone is well known. Degradive reactions by oxygen and its allotropic form, ozone, are chemically similar. Ozone, having a much higher energy content, is a more powerful oxidizing agent with the ability to attack many materials not affected by oxygen.

As previously mentioned, deterioration by oxygen is dependent upon other physical and chemical agents. Temperature is probably the most important agent as oxidation by ozone and oxygen are chemical reactions controlled by temperature. The tendency is to increase the rate of reaction with the increase in temperature.

7. Atmospheric Contaminants. Oxygen and ozone are the only constituents of the atmosphere that lead to deterioration. However, in various urban, industrial, and coastal regions, there are atmospheric contaminants present which seriously affect deterioration.

The atmosphere may be contaminated with sulfates and chlorides such as salt spray from the sea water in coastal regions. These salts react with water to form an electrolyte which facilitates the corrosion of metals.

Urban and industrial atmospheres contain various by-products of combustion from manufacturing processes which may cause degradation of many materials. The most common contaminants are oxides of sulfur, carbon and hydrogen sulfide. These oxides, when combined with water, may form acids which are detrimental to most materials. Sulfurous and sulfuric acid are more strongly ionized than carbonic acid resulting in a much stronger attack on many materials. Hydrogen sulfide is by itself, a strong reducing agent which reacts with most metals. Sulfur dioxide alone is a strong bleaching agent, as evidence by its use as an industrial bleach.

In conclusion, the general effect of atmospheric contaminants on the deterioration of materials is due to their combination with moisture with the resultant formation of acids.

8. Dust, Dirt, and Sand. Dust, dirt, and sand promote deterioration by their chemical, hygroscopic, and abrasive properties. The degree of deterioration, as is true of most agents, is somewhat dependent upon the presence of other physical or chemical agents.

Fine dust is a nucleus for condensation with the ability to hold moisture in close contact with a material surface. Because dust and dirt are hygroscopic, they will attract moisture from the atmosphere. Thus, a higher moisture level is maintained on the surfaces of materials with a tendency to establish electrochemical cells and thus increase degradation.

Dust, dirt, and sands are fine organic or inorganic particles having a definite chemical nature. Depending upon their origin, they may be either alkaline or acid and may provide a chemical reaction in the presence of moisture. An acid or alkaline reaction proves harmful to most materials. Highly abrasive characteristics are exhibited by dust, dirt and sand when present between moving parts or when impinging on stationary parts under other dynamic conditions, such as wind. This abrasive property is not important unless the material is subjected to a dynamic influence, usually not encountered in indoor storage of materials.

9. Summary Climatic factors, such as moisture, temperature, sunlight,

oxygen and ozone, atmospheric contaminants, dust, dirt, and sand promote deterioration. The degree of deterioration resulting from exposure to these elements can be determined only by defining a material in terms of its susceptibility to deterioration by any of the climatic factors. Outdoor storage of any material is the most severe exposure condition, and it can be expected that all deterioration processes will proceed at a maximum rate. Any steps taken to reduce the severity of exposure will result in less deterioration. In controlled humidity warehouse storage, the moisture is reduced to an innocous level, the daily temperature fluctuation is small, sunlight exposure is eliminated, and the impact of abrasive airborne sand and dirt is virtually eliminated. The remaining factors - oxygen, ozone, and dust - are of a secondary importance when the other factors, especially moisture, are controlled. Thus controlled humidity provides an optimum preservation condition for metals and many organic and inorganic materials.

B. CAUSES AND PREVENTION OF DETERIORATION OF MATERIALS IN STORAGE. The deterioration of materials in storage involves the same fundamental degradation processes that are involved with materials and equipment that are in day to day use. The principal difference betweeen a storage condition and a dynamic use condition is the degree of exposure to climatic and degradative factors of the environment. In considering the degradation of materials, they may be classified into two categories - metals and organic materials.

1. Deterioration of Metals There are many different forms of deterioration involved with metals but the predominant form encountered in storage is corrosion. This form of metal degradation is often referred to as "oxidation". The mechanism of the corrosion process is described in the technical literature as an electrochemical process.

a. Metal Corrosion The electrochemical process of corrosion is a complex phenonmenon and space does not permit a complete discussion of the entire subject. The general aspects of the corrosion process are discussed here and a brief technical discussion of the chemical aspects of metal corrosion is presented in Appendix I. When metals come in contact with water or some types of solutions, there is a tendency for electrically charge metal particles (ions) to go into solution. Because the solution must remain electrically neutral, an equivalent number of positive ions of another element must be displaced. In the case of a metal, such as iron in water, hydrogen is plated onto the surface of the metal as a thin invisible film.

The thin film of hydrogen can retard the reaction by insulating the surface of the metal from the solution. Further build-up of the hydrogen film will cause positive hydrogen ions to re-enter the electrolyte solution which results in reducing the entrance of the electrically charged metal ions into solution. For this reaction to continue, it requires that the hydrogen film be removed from the metal surface which is accomplished by its combining with oxygen in the solution to form water or escaping gas. Irrespective of the method by which the hydrogen is removed, the corrosion process on the metal surface continues as more metal ions go into solution. The removal of the hydrogen film is controlled principally by the concentration of dissolved oxygen in the solution which in turn depends on the degree of aeration, flow, and temperature of the water. The tendency of hydrogen to plate out as gaseous bubbles increases with the acidity of the solution. A specific example of the electrochemcial processes involving iron is discussed in Appendix I.

b. <u>Physical and Environmental Factors Affecting Metal Corrosion</u> In the electrochemical process of corrosion of metals, there are physical factors of the metal itself and environmental factors which affect the process. The physical factors are the nature of the metallic surface, oxide films, and electrode potential. Most metals are coated with an oxide film which in itself serves as an electrical insulator or barrier to the conduction of an electric current. This retards solubility and chemical reactions. An increase in temperature generally increases the rate of chemical reactions and reduces the solubility of gases in solution. Changes in temperature may also affect the solubility of reaction products in such a manner as to change the nature of the corrosion products. The effect of oxygen in metal corrosion is discussed in Appendix I. The effect of atmospheric contaminants have been discussed in the previous section.

c. Prevention of Metal Corrosion

(1) General. To prevent corrosion of metals, a control must be exerted over the influencing factors. Prevention of metal corrosion during indoor storage relies upon the use of various coatings, inhibitors, passivators, and atmospheric dehumidification or a combination of these methods.

Inhibitors, passivators, and coatings may reduce the corrodibility of the metals, the corrosiveness of the environment, or act merely as a mechanical barrier against the corrosive medium. Dehumidification relies upon the fact that moisture is required in the corrosion process and its removal will inhibit or completely retard the corrosion process.

(2) Metallic Coatings There are basically two types of protective metallic coatings used on corrodible metals, one type being cathodic, the other anodic to the base metal.

Cathodic coatings supply the metal surface with a more nobel metal resulting in reduced corrosion. Pinholes and discontinuities in a cathodic coating tend to cause an acceleration of localized corrosion. Corrosion is accelerated at points where the base metal is exposed, as a small anodic area is present in the electrolyte with the cathodic coating providing a suitable surface for the deposition of hydrogen. Care must therefore be used in the application of cathodic coatings and, in some cases, it may be advisable to apply an outer insulating coating.

Anodic coatings, being more anodic than the base metal, are preferentially attacked in the electrolytic process. In this manner, the anodic coatings exhibit their protective properties with eventual destruction of the coating. Unlike cathodic coatings, they will protect exposed surfaces of the base metal for some distance away depending upon the conductivity of the electrolyte and the metals concerned. This type of coating should be chosen where the protective coating is likely to be broken or contain pinholes.

There are many different methods of applying metallic coatings such as metal spraying, dipping, electro-deposition, deposition from a vapor, and metallurgical bonding by rolling, to name a few. Probably the most common methods are electro-deposition, sprayed and hot dip coatings.

The selection of the coating should consider durability, adhesion to the base metal, cost and ease of application, uniform density and continuity, and final appearance desired. In practical applications a compromise must be made after consideration of the cost and type of exposure as none of the coatings exhibit all desireable properties.

(3) Organic Coatings Organic coatings are widely used in the protection of metal surfaces from atmospheric corrosion. They act as mechanical barriers preventing the corrosive mediums from reaching the metal surface. The performance of an organic coating is therefore largely dependent upon its premeability to moisture and its ability to adhere to the metallic surface. In many cases, it is necessary to apply more than one coat to obtain satisfactory results.

The application of paint coatings is usually preceeded by an application of an undercoat or primer coating. Although the primer coat provides a base for the barrier coat, permitting maximum adhesion, it often supplies an inhibiting or passivating effect against any corrosive media which may permeate the barrier coat.

Other than selecting the proper coating, the most important means of assuring satisfactory results is the proper surface preparation and application.

Prior to application of the primer and protective coating, metal surfaces should be free of mill scale, oil, grease, corrosion products, and dirt. Cleaning of the metal surface may be accomplished through the use of acid and alkaline treatments, organic washes, and mechanical abrasion.

In many cases, a passivating treatment may be given the metal after cleaning. This is especially advantageous on very active metals such as magnesium, aluminum, zinc, and steel. An example of a passivation treatment is the use of a phosphate coating on steel which converts the steel surface to the less active metallic phosphate.

After cleaning, passivating, and priming of the metal surface the organic protective coating may be applied. The most commonly used coatings are greases, oils, lacquers, varnishes, enamels, and various special finishes such as baked resin finishes which are used without a primer coat.

(4) Inhibitors and Passivators An inhibitor is defined as any chemical substance or mixture that effectively decreases the corrosion rate when added in small amounts to a corrosive environment. Inhibitors tend to decrease the rate of current flow in the system by increasing anodic or cathodic polarization. Those inhibitors which increase anodic polarization are known as anodic inhibitors while those acting upon the cathodic are cathodic inhibitors.

The type of material to be protected and the environment to which it is subjected must be thoroughly understood before the selection of the inhibitor can be made. An inhibitor may effectively decrease the corrosion of a metal in one environment and actually promote corrosion of the same metal in a different environment. In some cases, an inhibitor may decrease corrosion and, at the same time, promote localized pitting.

Passivators are inhibitors which change the elctrode potential to a more noble value. The tendency of an anodic inhibitor to act as a passivator is greater than that of a cathodic inhibitor. The ability of an inhibitor to act as a passivator, as well as the amount of inhibitor required, is dependent upon the type of metal, the environment, and the temperature.

Various long-chain nitrites referred to as volitile corrosion inhibitors (VCI) have experienced limited use in the protection of metals, mainly ferrous metals. The compounds are used as either a powder or impregnated on a carrier such as fiberboard or paper. When enclosed in a space with the material to be protected, the molecules of the inhibitor migrate to the metal surface in a vapor phase thus resisting the access of water to the surface. The use of VCI requires tightly sealed containers impermeable to water and corrosion inhibitor transmission.

(5) Dehumidification Dehumidification is a method of preventing metal corrosion by reducing the amount of water vapor which is in the air. By proper humidity control, it is possible to keep the moisture content of air at a low level so that corrosion is not promoted. The term "controlled humidity" applies equally to both air-conditioning processes of humidification and dehumidification. These two processes are differentiated in that humidification adds moisture whereas dehumidification removes moisture from the air. Dehumidification is a conditioning process in which moisture is removed from the air to provide a desired relative humidity.

The recommended relative humidity for the storage of metals is in the range of 40 to 50% at temperatures normally found in warehouses. Where metals are subjected to extremely low temperatures and there is a sudden contact with warm humid air, the temperature lag in the metal due to its heat capacity may result in condensation of moisture on the surfaces. The literature devoted to deterioration of metals suggests relative humidities within the range of 30 to 60%. However, suitable protection is obtained in the range of 40 to 50% RH.

2. Organic Materials

a. General Materials of organic nature undergo degradation or deterioration by a means unlike that described for metals. The general theory covering the deterioration and corrosion of metals falls under the category of electrochemical process.

The basic unit of composition of many organic materials is either cellulose or hydrocarbon derivatives, and they can be affected by numerous chemical and physical factors. Upon exposure to combinations of the these factors, a chemical change takes place which results in some change in the physical properties of the materials. The changes brought about by these factors are not common to all materials and likewise the degrees of exposure to such factors produces varied results. The chemistry involved in the chemical changes taking place in the deterioration of organic materials is extremely complex and cannot be discussed in detail here; however, it is intended that this discussion will cover the highlights of most organic materials and the factors which are predominant in causing deterioration.

Organic materials, which are of primary interest, are wood, paper, textiles, plastics, rubber and leather.

b. Wood The deterioration of wood in general is defined principally by the end use of wood and the type of exposure to undesirable elements. The two principal phases of wood deterioration are those due to warping, cracking, crazing, and those due to fungi, micro-organisms, and insects. Cracking and crazing of wood results from improper seasoning and storage, while deterioration by fungi and insects is inherent in wood and its products.

There are two main types of wood harming fungi, the wood destroying fungi and the wood staining fungi. The wood destroying fungi are capable of disintegrating the individual wood cells which results in both physical and chemical changes in the wood. These changes are often referred to as decay. The wood staining fungi cause only discoloration in wood without causing a change in physical properties. Both the wood destroying and wood staining fungi are low forms of plant life which infect all types of wood. Fungi are unlike green plants in that they cannot make their own food but must have a supply available. In wood, this food supply is stored in the wood cell walls. The growth or development of fungi requires favorable temperature and moisture conditions, plus food supply and air. The food for growth comes from the wood itself while the other growth requirements are factors of the environment. In the absence of any one of the growth requirements, the fungi development may be retarded or even stopped for extended periods. However, when favorable growing conditions are provided, the dormant fungi will be revived. Generally, the most suitable moisture conditions for fungi growth in wood is a moisture content above the fiber saturation point (35% to 30%). The most favorable temperature for fungi growth is in the range of 75° to 90°F.

Wood at one time or another is exposed to infection by some type of fungi; and, deterioration can always take place when conditions are favorable. There is little that can be done in the way of sterilization to kill fungi because subsequent exposure will recontaminate the wood.

Insects are another cause of wood deterioration and, like fungi, are difficult to control. Again, the degree of exposure and the type of use defines largely the susceptibility of wood to attack by insects. The predominant insect causing deterioration of wood is the termite. It requires favorable temperatures and moisture conditions to sustain its life.

Powder Post Beetles will thrive on all types of wood in dehumidified storage. The dryer the wood, the more vulnerable to these types of beetles. Corrective treatment is that recommended by BuDock Publication NavDock TP-PU-2 "Insect and Rodent Control". Similar corrective treatment applies to termites if present in the area of the storage facilities.

Wood is relatively unaffected by normal variations in temperature. Temperature in combination with humidity determines the moisture content of wood but for this discussion, temperature is of secondary importance. The equilibrium moisture content of wood and other hygroscopic materials is shown in Figure 15. Light, like temperature, has little effect on wood other than being necessary for fungi growth.

c. Paper Paper, like wood, has cellulose as its basic unit of composition. Because of this, it is susceptible to the same types of deterioration as wood plus deterioration by other factors. In addition to deterioration caused by biological agents, paper is also deteriorated by physical agents, chemical agents, and manufacturing constituents. The biological agents consist of insects, micro-organisms, and rodents. The physical agents are sunlight, heat, dust, and moisture. Chemical agents consist of atmospheric smoke and gases. Manufacturing constituents are deleterious chemicals used in processing paper.

Paper, because of its uses, is not as vulnerable as wood to large scale infestation by cellulose feeding micro-organisms. Consequently, fungi is not considered a primary deteriorant because fungicidal treatments of paper are simple and effective. Paper is more susceptible to deterioration when exposed to physical agents. Changes in paper which take place upon exposure are photochemical, oxidative, hydrolytic, and other chemical changes. These changes are often referred to as "Natural Aging". They result from exposure to light, heat, moisture and acidic atmospheric gases. The rate of any chemical change depends largely upon the degree of exposure. Of the factors listed above, exposure to sunlight is probably the most harmful. Cellulose in paper is deteriorated by the ultraviolet portion of the solar spectrum, evidenced by discoloration, embrittlement, and loss of tensile strength. Heat and water vapor tend to increase the action of light on paper deterioration.

Paper exposed to moderate heat alone does not suffer appreciably. A more harmful exposure is in an atmosphere contaminated with sulfur dioxide. Paper exhibits an increase in acidity and a decrease in folding endurance when exposed to sulphur dioxide. The presence of deleterious materials in the paper from manufacturing is directly related to the quality of paper, the cheaper papers having more contaminants and consequently undergo more deterioration.

Ordinary paper may be differentiated from wet-strength paper on the basis of the effect of excessive moisture. Many types of untreated papers lose their structural strength and the fibers fall apart due to the solvency in water of the gelatinous bonding material. Wet-strength papers are more resistant to excessive moisture conditions.

The recommended storage temperature for paper is within the range of 65° to 80°F. and relative humidities from 40 to 55%. Paper is a material which is affected primarily by exposure to sunlight and acidic gases in the atmosphere. Normally, warehouse storage does not allow exposure to sunlight thereby eliminating one of the major causes of deterioration.

d. Textiles and Cordage For the most part textiles are composed of organic materials, and therefore undergo degradation in the same manner as other organic materials. The natural fibers used in textiles consist of cotton, wool, linen, and silk. The synthetic fibers consist generally of viscose, nylon, acetates, rayons, polyvinyl, and polyester. Another synthetic fiber is the glass fiber which is used in textile manufacture. Cordage is made largely from natural fibers of jute, hemp, sisal, and ramie.

Textiles deteriorate by either biological or chemical-physical agents. The biological agents are principally micro-organisms (fungi and bacteria) and insects. The chemical-physical agents are sunlight, oxygen, moisture, temperature changes, and other components of the weather including atmospheric contaminants.

It is impossible to evaluate the deterioration of textiles in terms of any one agent or by segregating the agents of deterioration into a class of primary or secondary causes. The action of biological agents and exposure to the chemical-physical agents constantly causes reactions. It is only the rate of the reaction that can be changed by environmental control. Organic reactions require two reactants. In the case of textiles, the fibers themselves are one reactant and any of the deteriorative agents previously mentioned constitute the other reactant. By altering the conditions required for a reaction to occur, the rate of reaction can be reduced and, if carried out to the limit, the reaction may be stopped entirely.

Textiles, like paper, are affected by exposure to light and, in particular, to the ultra-violet portion of the spectrum. Most textiles exhibit a loss in tensile strength on such exposure. Dyes are also affected by exposure to light with resulting change in color. Acidic contaminants in the atmosphere have a damaging effect on various textiles, and it has been found that the tensile strength of cotton varies with acidity of the atmosphere.

The storage temperature recommended for textiles is within the range of 40° to 80°F., and the recommended relative humidity is in the range of 40 to 50%. Textiles are predominantly affected by exposure to sunlight, atmospheric contaminants, fungi, and other biological agents. Inasmuch as sunlight is elimnated in warehouse storage, the control of biological agents is taken care of with a storage environment of normal warehouse temperatures and a humidity in the neighborhood of 45% relative humidity.

e. Plastics and Rubber The deterioration of plastic and rubber materials is difficult to describe without undertaking lengthy discussions of each individual compounding. Plastics and rubber are usually considered in the same material category as they have basically the same molecular construction. They are usually referred to as polymers of high molecular weight. Today most plastic materials, including some types of rubber, are synthesised and have properties much the same as materials made from natural sources. In the compounding of the various plastics and rubber, additives such as fillers, plasticisers, pigments, vulcanisers, stabilisers, and dyes are used. These materials must be considered along with the basic composition since they are, in many cases, involved in the overall deterioration process. It follows that each individual compounding must be separately considered for different exposures and extent of deterioration.

Chemical and physical deterioration of organic plastics results in cracking, reduced strength, warping and loss of transparency. The physical changes usually result from loss of plasticizer and exposure to cyclic humidity conditions. Chemical changes in polymers depend to a large extent upon the basic design of the polymer. Polymers are classified in two main groups according to their molecular structure: (1) linear or chain polymers and (2) branches network polymers. The linear polymers are often referred to as thermoplastics and the branched polymers as thermosetting polymers. The strength of linear polymers is dependent upon the size of molecule and interchain forms within the individual molecules. The number of cross-links in linear polymers is small compared with the branched network thermosetting polymers.

The linear thermoplastic polymers may deteriorate in any of three ways: (1) the chains may divide into smaller segments; (2) the chains may be tied together by cross-links; or (3) the nature of side groups may be changed. Since linear polymers are essentially long-chain molecular polymers, cutting the length of the chain is most important since this reduces the size of the molecule which in turn results in decreased strength. The second condition which results by introduction of cross-linkages is not as important although higher strength may be induced, and if carried to extremes, will cause a loss of elasticity, and consequent increased shrinkage and cracking. The third factor, a change in the structure of side groups can result in a degradation of certain properties such as electrical characteristics, moisture absorption, and others, although no serious effect is noticed in strength. Thermosetting plastics are not greatly affected by the first two types of molecular changes, but modification of side groups may cause surface deterioration on exposure to weather.

As with other organic type materials, the organic compounds including plastics and rubber are susceptible to reactions with various factors of the environment such as water vapor, ozone, and oxygen. These agents, among others, cause a deterioration of plastics upon exposure to the weather. Of the three, the most important in the process of deterioration is oxygen, and second is ozone. These two elements will cause a change in the molecular structure which, in turn, results in changes in physical properties. The degree of exposure determines to a large extent the rate of deterioration. Also, the chemistry of the material determines to a large extent its susceptibility to deterioration by oxygen or ozone. Oxygen and ozone promote reactions which are irreversible; and, once the reaction has started, little can be done to activate any change in the opposite direction. The exposure of plastics to ultra-violet light results in cracking and crazing. Light in combination with other physical and chemical agents will cause discoloration, embrittlement, and a general loss of properties in plastics. The degree of deterioration depends largely upon the type of plastic.

The effect of water vapor on rubber has been found to be of secondary importance in its degradation, and, at present, there are diverse opinions as to which agent - oxygen or ozone - is the primary cause of rubber deterioration. The rate and degree of deterioration of rubber varies according to type and composition. Exposure of rubber to light is known to cause cracking and crazing. Recent use of antioxidents tends to indicate that ozone and heat are more important than oxygen in the degradation of rubber.

There is also a wide diversity of opinion concerning optimum storage conditions for maximum shelf life for rubber. Storage in a cool, dark atomosphere with temperatures in the neighborhood of 50 to 55°F. and humidities in the range of 50 to 60% is recommended. It is impractical to attempt any control over the ozone or oxygen content of warehouse air. However, indoor storage is beneficial to rubber in that sunlight, a factor promoting ozone deterioration, is eliminated; and rubber is not adversely affected by the lower humidities maintained in dehumidified warehouses.

No specific storage conditions for the various plastic compounds have been found in published literature. Organic materials in general are primarily affected by oxygen. However, they are also subject to microbiological attack and changes in physical properties due to extreme temperatures and humidity conditions. In view of this, it is recommended that plastics be stored at moderate temperatures, 40° to 80°F. and at humidities below 70%.

f. Paint The most degenerative source of moisture on paint films other than immersion in water is condensation which thoroughly wets a paint surface. Many paint vehicles are solvent in water, particularly cellulose derivatives, and others to a varying degree. Paint failure due to water has been eliminated through the development of highly insoluble pigments and very impermeable vehicles.

Low temperatures cause most paints to become brittle, however, paint films at low temperatures show better aging characteristics. Variation in the thermal expansion of paints and the painted surfaces may cause cracking and checking of the paint films under varying temperature conditions. Increased temperatures cause an increase in chemical destruction of paint films.

Like textiles, dyes, plastics and rubber, paints, and lacquers are seriously affected by photochemical activity of sunlight. Paints compounded of various zinc oxides and titanium dioxide exhibit chalking on exposure to light.

Besides the photochemical deterioration of pigments, radiant energy from sunlight acts as a catalyst in the chemical degradation of the various paint components. Oxidation of paint films is greatly increased in the presence of heat, moisture, and light. Although oxygen is required in the drying of paints, further oxidation results in brittleness, cracking, scaling, and chalking.

Paints containing pigments of white lead are highly reactive to sulfur dioxide and hydrogen sulfide. In the presence of moisture, the sulfur compounds react with white lead to form a dirty black lead sulfide. There are, however, many paints such as those using titanium or zinc pigments which resist such deterioration.

Warehouse storage, either normal or dehumidified, is adequate to give applied paint coatings ample longevity while in storage.

g. Leather Finished leather is an end product of animal skins which has undergone chemical and mechanical changes to improve its stability. The chemical and mechanical treatment of leather is known as "tanning". It is through tanning that leather derives its ability to withstand deterioration from different elements. The major deterioration of leather is due to a chemical process called hydrolysis. The chemical changes occuring during the process of hydrolysis involves water, and therefore, the moisture content of leather is an important factor in this type of deterioration. It is possible to more or less custom-make or tan leather to give resistance to various elements by altering the tanning process.

The recommended storage temperatures for leather are moderate temperatures, 40° to 70°F. and relative humidities below 70%.

h. Glass Glass is primarily an inorganic material. It is subject to deterioration by the same factors that cause other materials to deteriorate. Normally, glass is thought of as being very stable and relatively unaffected by moisture, heat, or light. Certain constituents of glass are, however, affected by moisture with resultant fogging of the surface. The surface of glass absorbs moisture, and a glass surface is also easily wetted. When water comes in contact with the surface of glass, certain water soluble constituents of glass migrate to the glass surface forming crystals of hydroxides and carbonates. The rate at which these deposits are formed is a function of relative humidity with the higher rate of formation being at the higher relative humidities. Test have shown that the rate of deterioration is extremely low at relative humdities of 60% or below.

The majority of cases of deterioration of glass surfaces has been noted on highly ground glass lens elements in optical instruments. Fungi and biological agents have also been found to deteriorate glass surfaces of this type. Since fogging and microbiological growth on glass surfaces are a result of high humidity, the recommended conditions for the storage of glass are moderate temperatures 40° to 80°F. and a relative humidity below 60%.

C. IN-STORAGE PRESERVATION METHODS USED BY MILITARY AGENCIES AND INDUSTRY.

1. General Following World War II the military agencies were faced with the requirement of preserving material and equipment for an indefinite period of time. The magnitude of this requirement had never existed previous to this time and consequently no established methods or practices were known to make such an undertaking convenient. Commercial business, by its nature does not store finished goods, such as military equipment, for any extended period of time particularly in a static or inactive state. It was known at this time, that for the long-term preservation of military material and equipment, methods would have to be devised to protect this material principally from exposure to high moisture conditions and other elements of the climate such as sunlight, dust, etc. The largest single factor in this long-term requirement existed with the U.S. Navy Bureau of Ships where surplus vessels of all types were to be deactivated. Studies were initiated immediately following World War II to devise methods of undertaking this program. Subsequent to this the U.S. Navy initiated studies to establish similar methods and procedures which would be applicable to warehouse storage. Concurrently the U. S. Army and Air Force initiated studies to determine methods of providing long term storage and preservation of equipment. All of the methods used had the single common denominator that they were in one way or another a form of controlled humidity storage. The principal difference, however, was in the type of enclosures that were required and used to accomplish this task. One of the predominant factors common to all of the programs was the type of containers used.

2. Sealed Containers There were various types of sealed containers utilized by all branches of the service for the preservation of material and equipment. In the sealed containers there were four basic types of preservation mediums used, such as inert atmospheres, dehumidified air, oil emulsion, and vapor phase inhibitors (VPI). These preservation mediums were incorporated in storage containers

ranging in size from small metal cans to gasoline storage tanks and ships. In containers filled with dry air only, a static desiccant was placed inside the container and allowed to absorb the moisture contained within. This type of container, however, had a disadvantage in that its internal temperature and humidity fluctuated widely throughout the course of a single day. The net result of this was a considerable amount of deterioration due to the continuous movement of water vapor within the container. Other instances were described where containers consisting of 50 gallon drums were filled with oil and such items as small arms and rifles were immersed and sealed. This method of long-term storage and preservation gave satisfactory results. However, the costs associated with such a program proved to be prohibitive.

Larger sealed containers, 250 to 1000 cubic feet in capacity, were constructed of steel plate and used for the long-term storage and preservation of artillery weapons. The results of this program were satisfactory, however, the maintenance required on these storage enclosures was excessive and the costs were high. This method of preservation does lend itself to the long term storage and preservation of such things as airplane engines for both shipment and outdoor storage. To alleviate the problem of pressure fluctuations due to temperature changes in the sealed containers, a method was devised whereby the container was provided with a breathing vent. This vent was so designed that during the day when the containers were exposed to heat from solar radiation, the enclosure was allowed to breathe through the vent and with the breathing taking place through a desiccant material which absorbed any moisture. The vent essentially acted as a two-way valve and upon cooling any outdoor air entering the container was dehumidified when passing through a desiccant. No extensive use of this type of container was used, but the results at least experimentally were considered to be favorable.

3. Strippable Films A container concept was developed for use in enclosing deck mounted armament and aircraft where the equipment was sprayed with a film to form a "cocoon". These films were formed of a coating of vinyl chloride and vinyl acetate. The outer coatings on these cocoons consisted of a combination of gilsonite and asphalt which dried to form a hard surface and which was subsequently coated with aluminum paint. The cocoons were generally dehumidified by placing a charge of desiccant within the enclosure and the moisture level was reduced to an acceptable level by replacing the desiccant as required. The results with these types of containers were not favorable and they were subsequently replaced with metal enclosures, particularly for the protection of deck equipment on ships.

4. Ships Following World War II the U. S. Navy was faced with the problem of preservation of the surplus Naval vessels. The basic idea was to use the ship as a container for its own equipment. The inactivation included preservation of the underwater hull, all surfaces and equipment exposed to weather, the interior structure and equipment exposed inside, and the internal surfaces of all equipment such as boilers, pumps, engines, etc. The exterior surfaces and equipment exposed to weather were preserved mainly by the application of paint as previously mentioned. Some of the outside equipment such as guns were enclosed by partially dehumidified cocoons. The interior of the ship was preserved by maintaining a low relative humidity, and this was accomplished by the use of dynamic dehumidification machines using the fire mains in the ships for the distribution of the conditioned air. Interior surfaces of the ship and its equipment not exposed to the atmosphere such as engines, boilers, etc. were also preserved by a combination of film preservatives and dehumidified air. The experience gained in this type of controlled humidity storage contributed the most information to the development of the controlled humidity warehouse storage program. It was initiated by the U. S. Navy and then followed by other governmental agencies such as the U.S. Army Ordinance and the

Air Force.

5. Caves and Mines Following World War II a number of limestone mines and caves were investigated as to their adaptability for long-term storage of equipment. In 1952 the U.S. Army ordinance obtained a large refrigerated underground storage space formally a limestone mine at Atchison, Kansas. The refrigeration system was removed and a dynamic dehumidification system was installed which maintained the humidity of this cave at approximately 45%. The use of this mine has been largely for the storage and preservation of machine tools and similar types of equipment. The results of this storage program have been very satisfactory Subsequent to the development of these mines by the U.S. Army, private industry has developed similar storage facilities at Nesho, Missouri near Kansas City. This cave storage provides a natural storage environment when dehumidified as the daily temperature fluctuations are negligible and the exposure to all factors of the atmosphere are excluded. Moreover, the economics associated with this type of storage over a long period of time has been encouraging..

II. FEATURES OF MATERIAL PRESERVATION BY CONTROLLED HUMIDITY STORAGE

A. EVALUATION OF CONTROLLED HUMIDITY STORAGE AND WAREHOUSE PERFORMANCE

1. General The main objective in the scope of work performed under Contract Noy 79585 at the University of Minnesota was a complete evaluation of controlled humidity storage as a method of preservation. It also included a technical evaluation of the performance of the dehumidified warehouses and equipment in use at four inland Naval Supply Depots - NSD's Clearfield, Utah; Mechanicsburg, Pennsylvania; Scotia, New York; and Spokane, Washington.

In the evaluation of dehumidified storage as a method of preservation a complete survey was made of all published literature, including government reports pertaining to the causes of material degradation, the effect of climate and environment on materials, and methods of material preservation. In this survey particular emphasis was placed on acquiring technical data pertaining to material preservation in a controlled humidity atmosphere in order that this method of preservation could be fully understood and properly evaluated. From the literature survey it was learned that considerable work had been done regarding the causes of material degradation and it was therefore possible to develop the recommended storage conditions presented in Section I. Also the survey provided information regarding the effect of climatic conditions on materials and its relationship to the design and operation of controlled humidity storage warehouses.

A comprehensive analysis of the operation of dehumidified warehouse facilities at the four inland Naval Supply Depots was also made to evaluate different types of building construction, the cost of operation, and the condition of material and equipment stored in these buildings. Each of the depots had maintained records of operating data which was of assistance in this evaluation. In the attempt to evaluate the performance of controlled humidity storage in the preservation of material, field studies were made at each depot where equipment was withdrawn from storage and examined for any evidence of deterioration. This examination consisted of visual inspections, and no evidence of material deterioration was found. The equipment inspected consisted of items such as pumps, compressors, electric motors, internal combustion engines, galley equipment, electronic gear, and ordnance equipment. A more comprehensive evaluation was desired but due to the fact that the original condition of the equipment when placed in storage was not known, active testing could not be done. The results of these field studies furnished the basic recommendations for a comprehensive controlled test program which is discussed in Part B. of this section.

2. Analysis of Warehouse Performance The warehouse buildings at the inland Supply Depots which were converted for dehumidified storage were all the same size (200 feet by 600 feet), but differed in the type of construction. Because of the different building construction it was of interest to the program to determine which type of building was best suited for use in controlled humidity storage. The criteria for the evaluation was the performance of the buildings in terms of the moisture loads which had to be handled by the dehumidification machines. In comparing building construction the buildings were grouped as follows:

Class I

Building walls of 12 inch concrete block, 6 inch concrete floor, wall and roof framing of either precast concrete or steel and a roof deck of concrete, wood or poured gypsum.

Class II

Building walls of 12 inch brick or 6 inch concrete extending from floor to window sill height - 4 ft. 3 in. above floor level, 6500 sq. ft. of framed wall with wood sheathing and cement asbestos exterior and 9700 sq. ft. of fixed and center pivot glass window sash from sill to eave height. Six inch concrete floors, wood beam and girder wall and roof framing and poured gypsum roof decks.

Class III

Building walls of reinforced concrete. In all other respects, the same as Class I.

Within each class of buildings slight differences existed with regard to sky lights, roof monitors, etc., but these were not segregated because when the buildings were converted, these items were treated in such a manner as to be ineffective.

Buildings of these construction classes were compared by calculating the average daily moisture load for each month of the year. The moisture load was determined by using the dehumidification machines as the source of reference. To facilitate a comparison of the calculated moisture loads the climatic conditions at the four inland depot locations are given in Figures 1, 2, and 3. Figure 1 gives the mean outdoor dry bulb temperatures. Figure 2 gives the monthly mean outdoor dew point temperatures and Figure 3 gives the monthly mean precipitation for each depot. The latter two, dew point temperature and precipitation, are the climatic factors which influence the building moisture load at each site.

The detailed sequence of this analysis was to calculate the daily moisture load, machine running time, and utilization of the dehumidification machine capacity. The calculation of these items was made using the stations' reported power consumption and machine timer settings for each building. The first step in the calculation of these items was to obtain a breakdown of machine running time on adsorption and reactivation power to the total power consumed. Manufacturers' machine ratings state that the dehumidification machines consume 2.3 Kwh/hr on adsorption and 22.2 Kwh/hr on reactivation. Using these ratings the following equation was set up to give the break down of operating time:

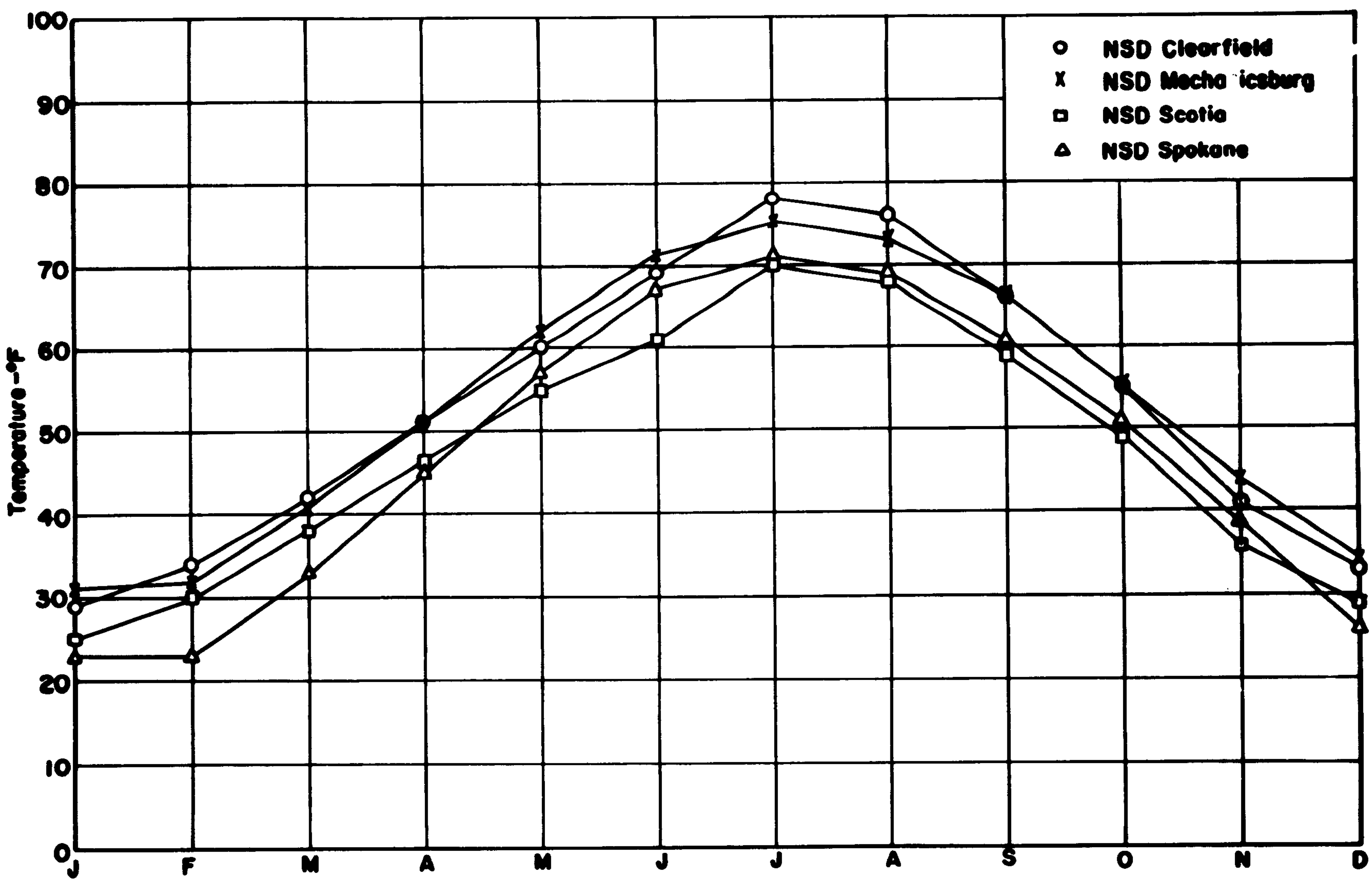


Figure 1

Monthly Mean Outdoor Dry Bulb Temperature - °F
at Four U.S. Naval Supply Depots

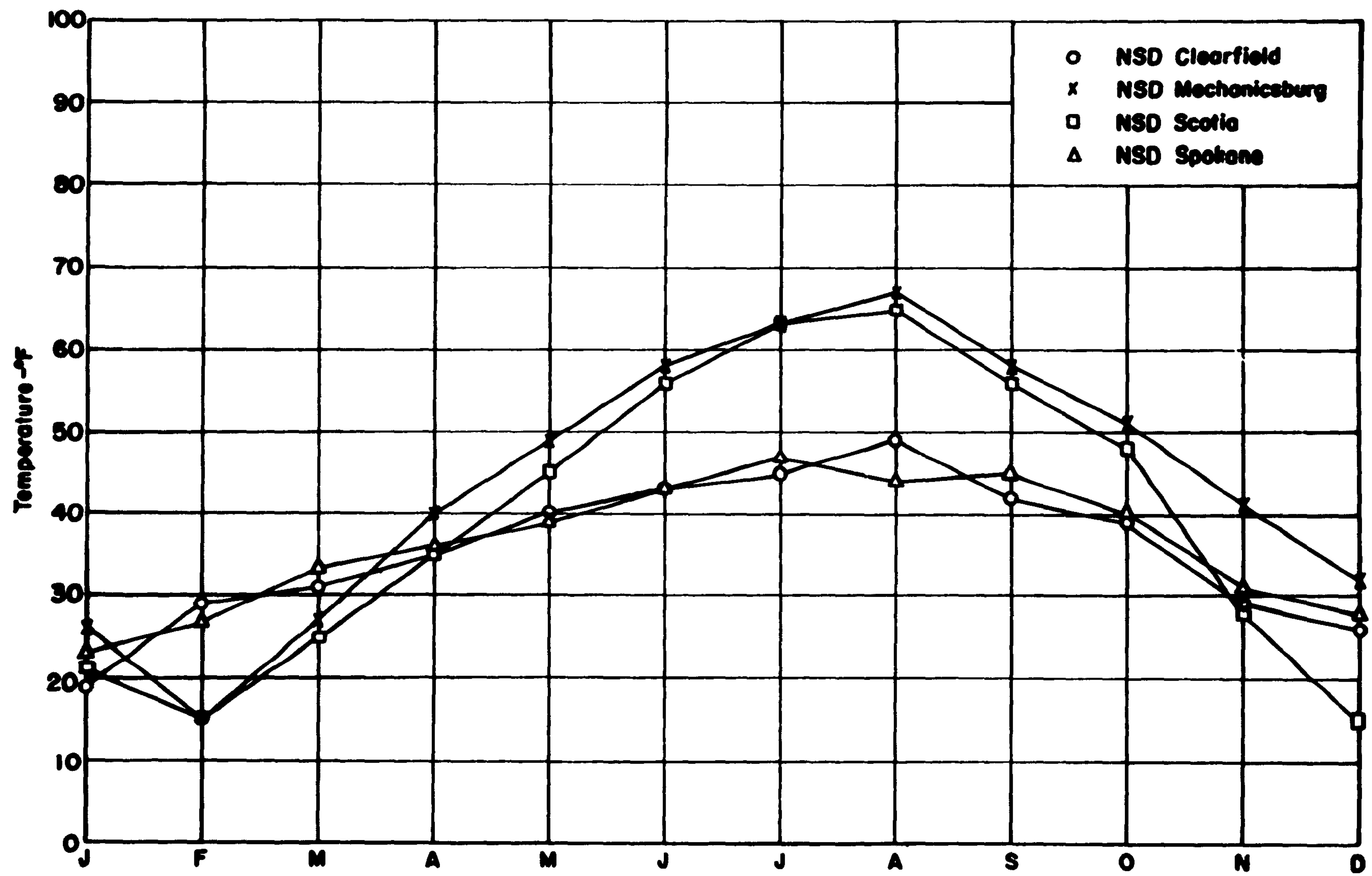


Figure 2

Monthly Mean Dew Point Temperature - °F
at Four U.S. Naval Supply Depots

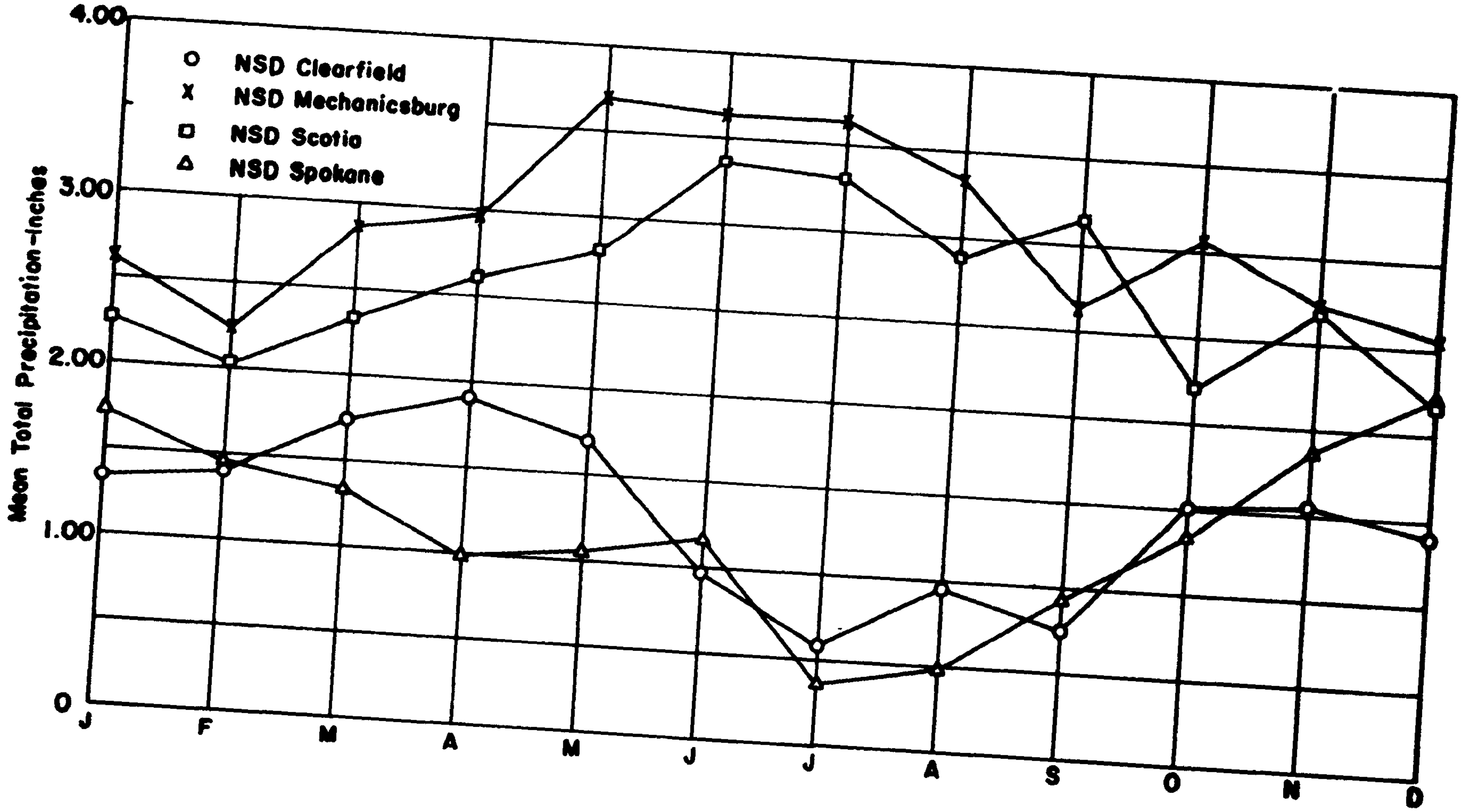


Figure 3

Monthly Total Precipitation
at Four U.S. Naval Supply Depots

$$2.3X + 22.2RX = \text{Power consumed per machine per day}$$

Where: X = Adsorption time, hours

R = Ratio of reactivation time to adsorption time

RX = Reactivation time, hours

The equation is solved for X to give adsorption and reactivation time. The adsorption time is the running time of the dehumidification machine which, when divided by 24 gives the per cent running time. Having determined the adsorption and reactivation time, the power consumption during these periods was determined by using the power ratings of 2.3 Kwh/hr on adsorption and 22.2 Kwh/hr on reactivation. Since the dehumidification machines are rated by the power consumed on reactivation per pound of water desorbed, it was necessary to construct the power performance curves shown in Figure 18 which covers the range of warehouse operating temperature and relative humidity. The moisture removed by one machine is obtained by dividing the power consumed on reactivation by the approximate rating value from Figure 18. To facilitate a comparison of the actual moisture removed and the available machine capacity, it was necessary to determine the actual machine capacity at the various operating temperatures and relative humidities given in the Monthly Station Reports. The available machine capacity was obtained from the curves in Figure 17. These curves, like those in Figure 18 were constructed from performance test data and the manufacturers' ratings of the machines. The comparison of the actual moisture load to the available machine capacity is termed "Moisture Removal Efficiency". An example of the detailed tabulation of this calculation procedure is shown in Table I where all data for Building 114 at NSD Mechanicsburg are shown. This table includes all operating data necessary to calculate the moisture load. The calculated moisture loads for all buildings at NSD Mechanicsburg are shown in Table II. The same calculation procedure was used for all four depots and the data shown in Figures 5 - 8 was developed for all controlled humidity warehouses at the four depots.

TABLE I
DATA USED FOR ANALYSIS OF
DEHUMIDIFICATION LOAD BLDG. 114 NSD MECHANICSBURG, PA.
PERIOD OF ANALYSIS

	NOV '50	DEC '50	JAN '51	FEB '51	MAR '51	APR '51	MAY '51	JUNE '51	JULY '51	AUG '51	SEPT '51	OCT '51
POWER USED-KWH	61508	31683	27374	33986	30720	30030	26102	42726	39008	54351	32952	27301
NO. OF MACHINES	4	4	4	4	4	4	4	4	4	4	4	4
MACH. TIMING-MIN.	90-40	90-45	90-40		60-44	50-35	50-35	30-28	30-28	40-35	40-35	40-35
DAYS IN PERIOD	34	29	27	35	28	28	35	28	28	35	28	28
AVG HUMIDITY-%	39.0	38.5	39.8	39.0	39.4	39.2	39	39	49	39	39	40
AVG TEMP-°F	54	41.0	38	39	46.0	54	66	74	81	82	74	65
OPER TIME-HRS/day												
Adsorption	37.2	20.4	20.8		14.8	15.0	10.8	16.6	15.1	17.9	13.5	11.2
Reactivation	16.5	10.2	9.3		11.6	10.5	7.5	15.5	14.1	15.6	11.9	9.8
Per Cent	155.0	85.0	86.6		61.6	62.5	45.0	69.1	62.9	74.5	56.2	46.6
POWER USED-KWH												
Adsorption	85.5	46.9	47.9		34.0	34.6	24.8	38.2	34.8	41.1	31.1	25.8
Reactivation	366.5	226.2	205.4		256.6	233.5	167.2	343.7	313.7	347.2	263.1	218.0
MACH RATING AT AVG TEMP KWH/lb	1.06	1.07	1.07		1.07	1.05	.98	.91	.84	.83	.91	.98
MOISTURE REMOVED lbs/day/bldg	1383.0	845.6	767.8		959.2	889.5	743.1	1510.8	1493.8	1673.2	1156.5	889.8
MACH RATING #H_2O/day/mach	435.	305	280	285	360	445	535	585	630	630	585	530
MOISTURE REMOVAL EFFICIENCY-%	51.2	81.5	79.0		108.1	79.8	77.1	93.3	94.1	88.9	87.9	89.9

TABLE II

CALCULATED DAILY MOISTURE LOAD IN CONTROLLED HUMIDITY WAREHOUSES

NSD MECHANICSBURG, PA.

PERIOD OF ANALYSIS

BLDG NO	NOV '50	DEC '50	JAN '51	FEB '51	MAR '51	APR '51	MAY '51	JUNE '51	JULY '51	AUG '51	SEPT '51	OCT '51
3	632.5	452.8	271.8		266.0	591.4	961.2	1119.4	1226.7	918.0	526.4	590.2
4	689.4	367.24	464.4		630.8	631.1	733.5	1044.0	986.2	835.2	658.9	523.7
5	624.2	736.1	896.4		752.9	1315.0	1455.7	1833.6	1942.1	1670.5	1140.4	871.9
6	871.8	776.0	755.3		746.0	962.6	1322.6	1963.6	2130.2	1988.0	1015.8	1130.8
7	929.8	575.6	309.5		774.2	938.7	1070.9	1559.6	1667.0	1351.9	1027.0	793.8
11	625.2	460.6	521.1		657.2	840.4	702.3	1656.5	1508.4	1486.0	1557.3	
12	857.1				1010.6		741.1	1904.7	1541.0	1157.6	835.6	779.4
13	864.4	293.8	844.1		738.0	782.8	802.8	1127.0	1149.2	1204.7	840.0	578.4
14	1068.1	66.4			607.5	1070.8	1004.6	1862	2063.6	2224.5	1525.8	1334.9
114	1383.0	845.6	767.8		959.2	889.5	743.1	1510.8	1493.8	1673.2	1156.5	889.8
201	486.8	317.8	335.3		471.4	577.5	823.7	1007.0	926.2	732.1	768.8	382.6
202	537.7	370.1	335.3		573.4	590.5	790.8	982.7	1246.4	726.6	856.4	
204	595.3	361.1	406.0		640.0	594.3	861.2	1183.5	1250.6	1095.5	779.3	753.5
215	899.6	386.9	417.6		573.4	654.5	1098.6	1311.9	1148.0	1198.6	876.8	488.8
216	1032.8	573.4	568.6		654.4	589.6	1098.6	1220.0	1293.2	1008.0	798.2	851.3
302	799.2	346.2	426.6		467.8	689.7	1098.6	967.1	1015.6	992.5	724.6	775.2
303	415.5	260.6	285.6		361.1	370.2	433.0	787.3	1050.6	714.8	830.7	640.0
304	759.6	355.7	316.6		288.4	363.2	849.4	688.5	538.8	581.4	505.8	461.0
314	1007.9	621.7	665.4		676.6	772.2	857.7	1333.3	1155.7	1102.8	996.0	799.2
411	931.8	521.2	619.1		674.0	932.8	1047.4	1172.2	1147.6	1124.9	577.8	684.5
Calc. Avg Daily Load #/day	800.6	457.3	511.5		621.1	745.1	924.8	1311.7	1324	1194.8	900	740.5
Design Moisture Load #/day	537	435	423		487	536	658	943	1056	1101	905	706
Installed Cap. for Daily Moisture Removal Lb/day	1720	1264	1248		1540	1824	2200	2372	2528	2520	2384	2132

The calculated moisture loads in all dehumidified warehouses at the four inland Supply Depots are shown in Figures 4, 5, 6, 7, and 8. The analysis of buildings at NSD Mechanicsburg covers only a period of one year as a change in data reporting took place at the end of 1951 and machine time settings were not available to facilitate calculations. NSD Mechanicsburg is the only depot which has a sufficient number of buildings of different construction classes to facilitate a comparison of moisture loads. The curves show a wide variation of moisture loads in individual buildings, which is probably due primarily to warehousing activity. In general, this analysis did not reveal that any one construction class is best suited for controlled humidity storage buildings. The moisture loads for all buildings at each depot have been averaged and the data shown in Figures 9, 10, 11, and 12 show a comparison of the "actual" to the "original" design load. These curves illustrate the influence of local climate on the operation of controlled humidity warehouses. NSD Clearfield and Spokane have essentially the same type of climate and illustrate the effect of a "dry" dlimate on the building moisture load.

In addition to the analysis of the "total" moisture loads in the warehouses, further study was made to determine the contribution of each component of the total moisture load, such as breathing, stores turnover, transmission, and infiltration. In Figure 13, the breakdown of the moisture load as calculated from operating data is compared with the original design calculation of each component. Graph A of Figure 13 represents the average condition for a selected group of concrete block warehouses at NSD Mechanicsburg. This is a general comparison inasmuch as the transmission portion of the load includes both the transmission through the floor and walls and, likewise, the infiltration portion of the load includes the infiltration due to door openings. The primary purpose of this comparison is to show that the moisture load due to infiltration is the largest component of the total load and that its magnitude is considerably greater than that allowed for in the original design calculation. This comparison applies to the design month which, in this case, is August.

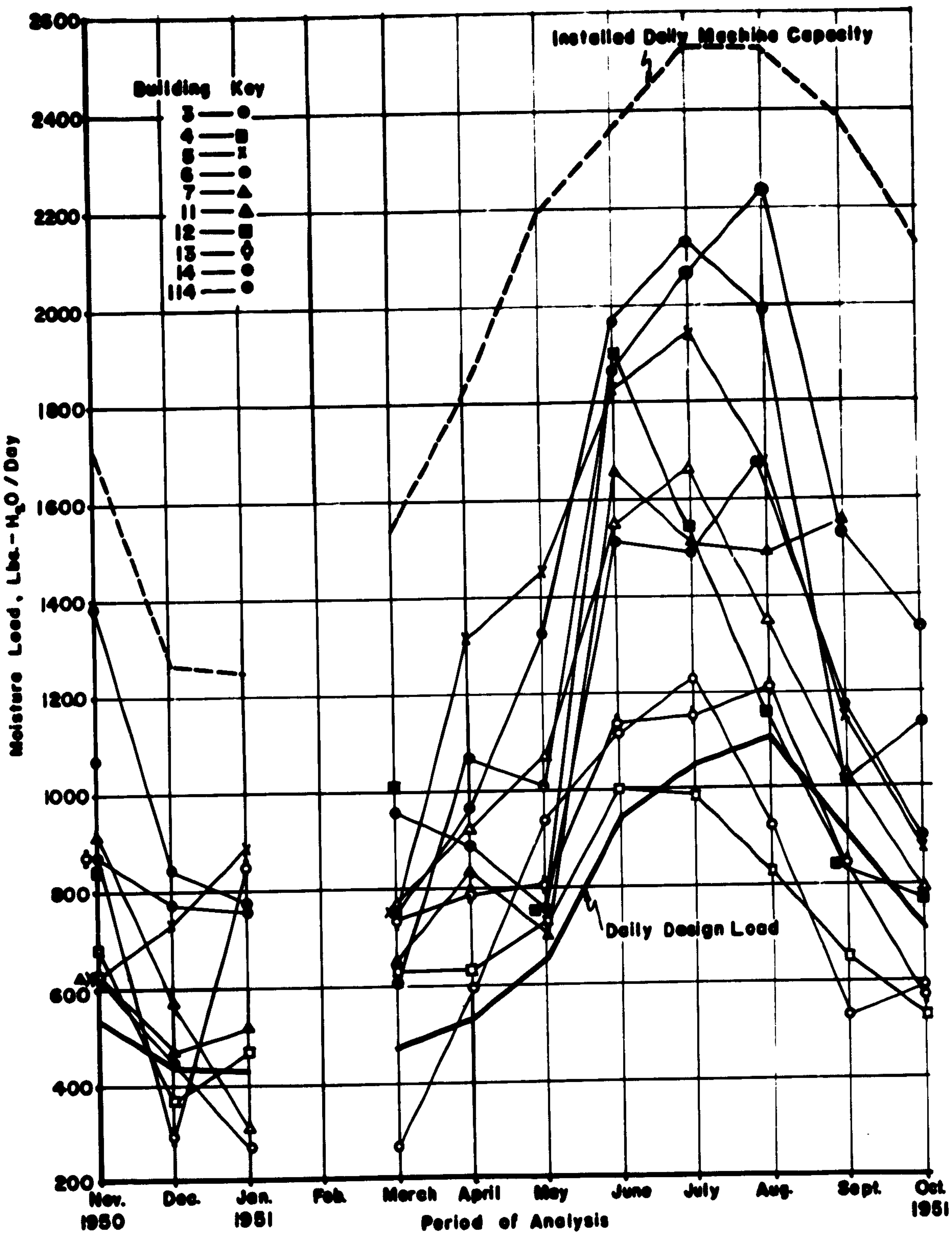


Figure 4

Design and Calculated Daily Moisture Load in Dehumidified Warehouses

Class I Construction

NSD Mechanicsburg, Pa.

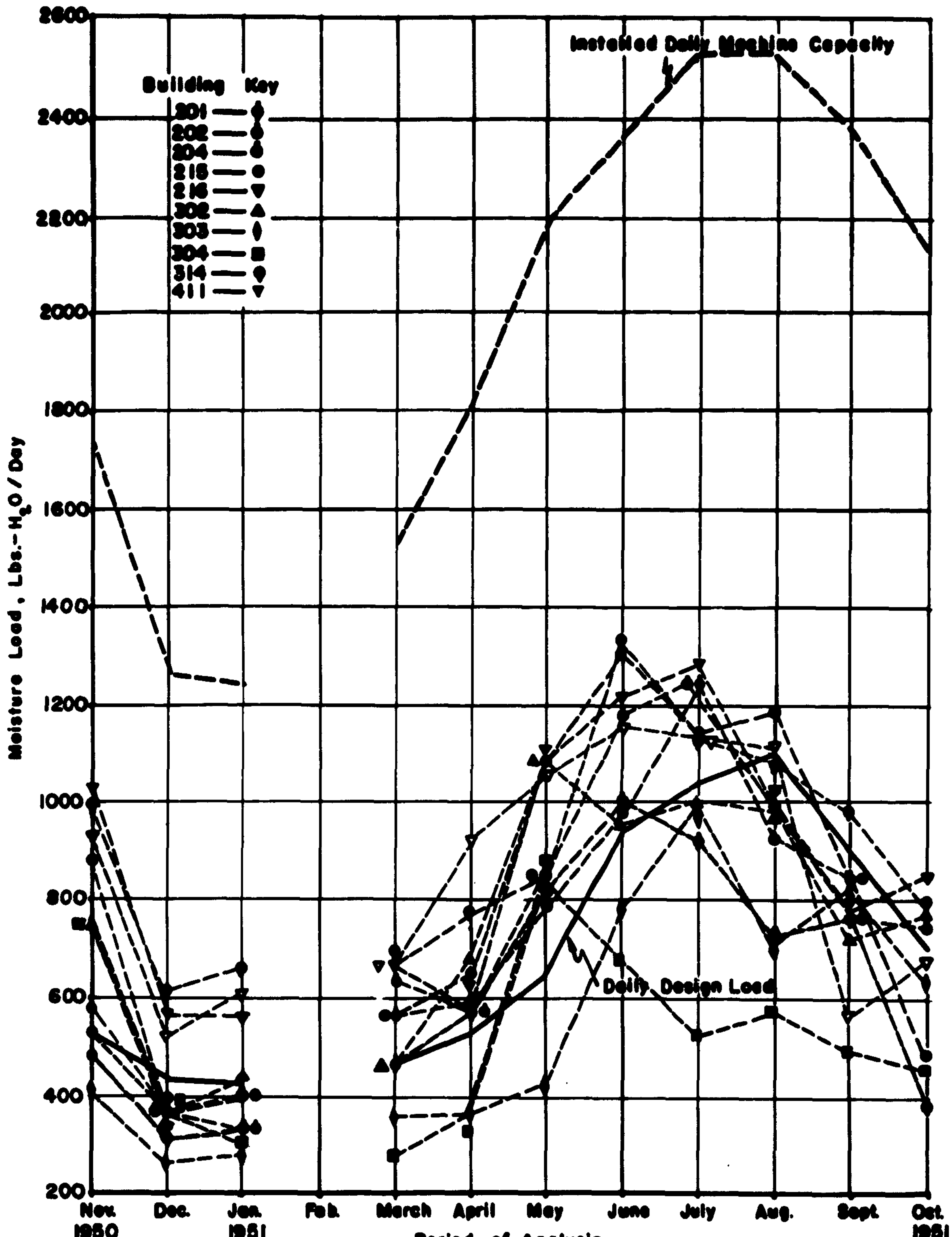


Figure 5
Design and Calculated Daily Moisture Load in Dehumidified Warehouses
Class II Construction
NSD Mechanicsburg, Pa.

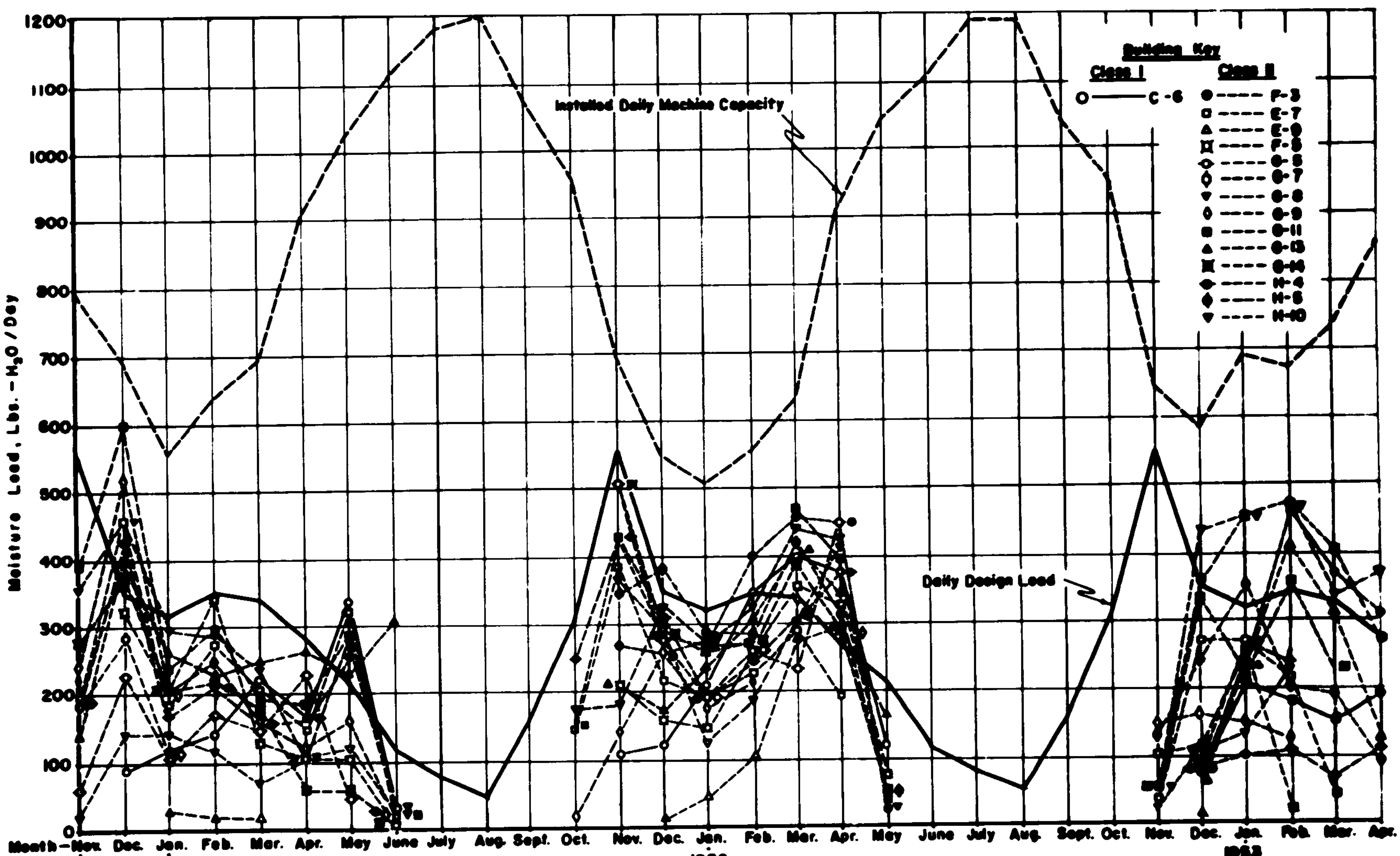


Figure 6
Calculated Daily Moisture Load in Fifteen Dehumidified Warehouses
NSD Clearfield, Utah.

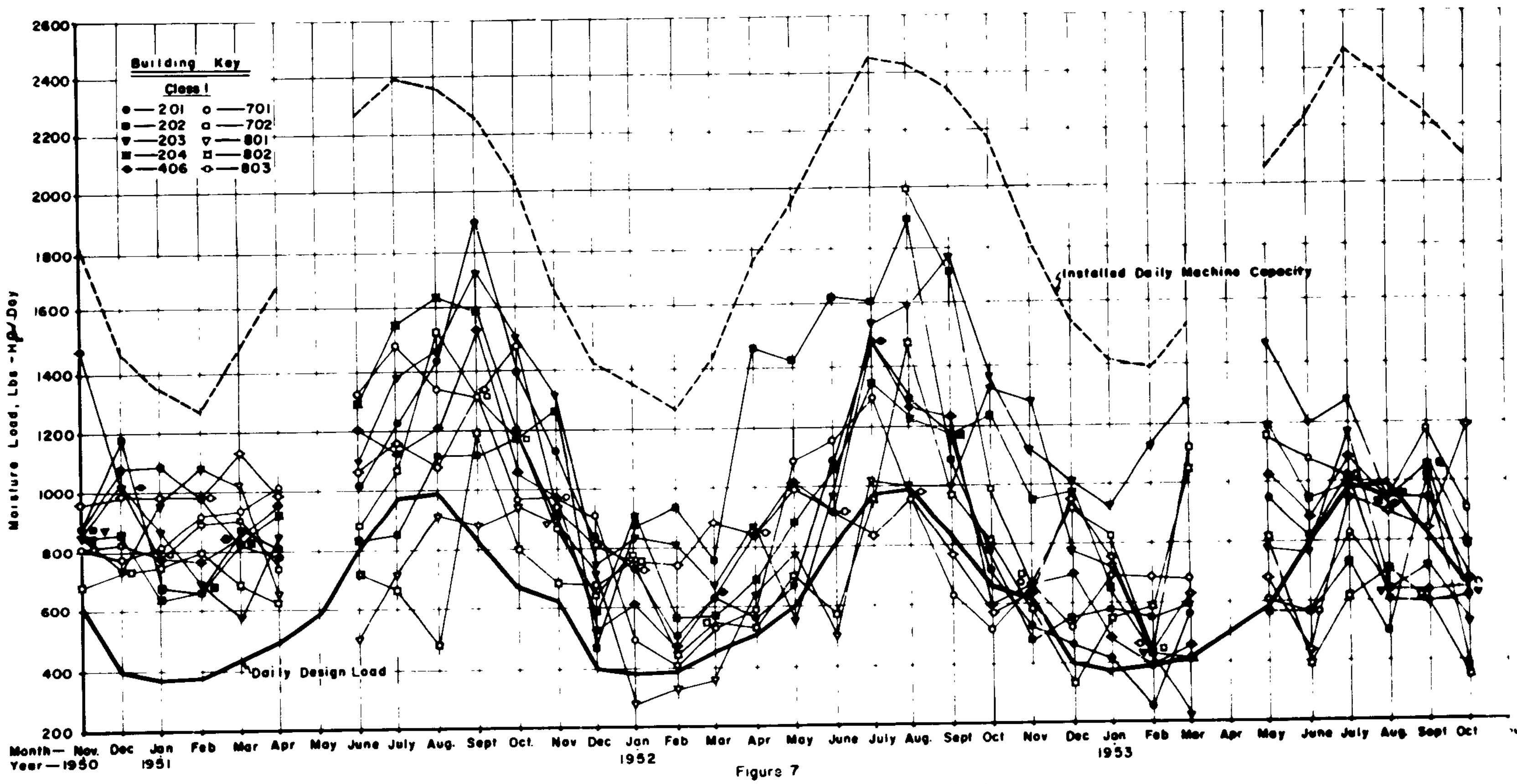


Figure 7

Calculated Daily Moisture Load in Ten Dehumidified Warehouses
NSD Scotia, N Y

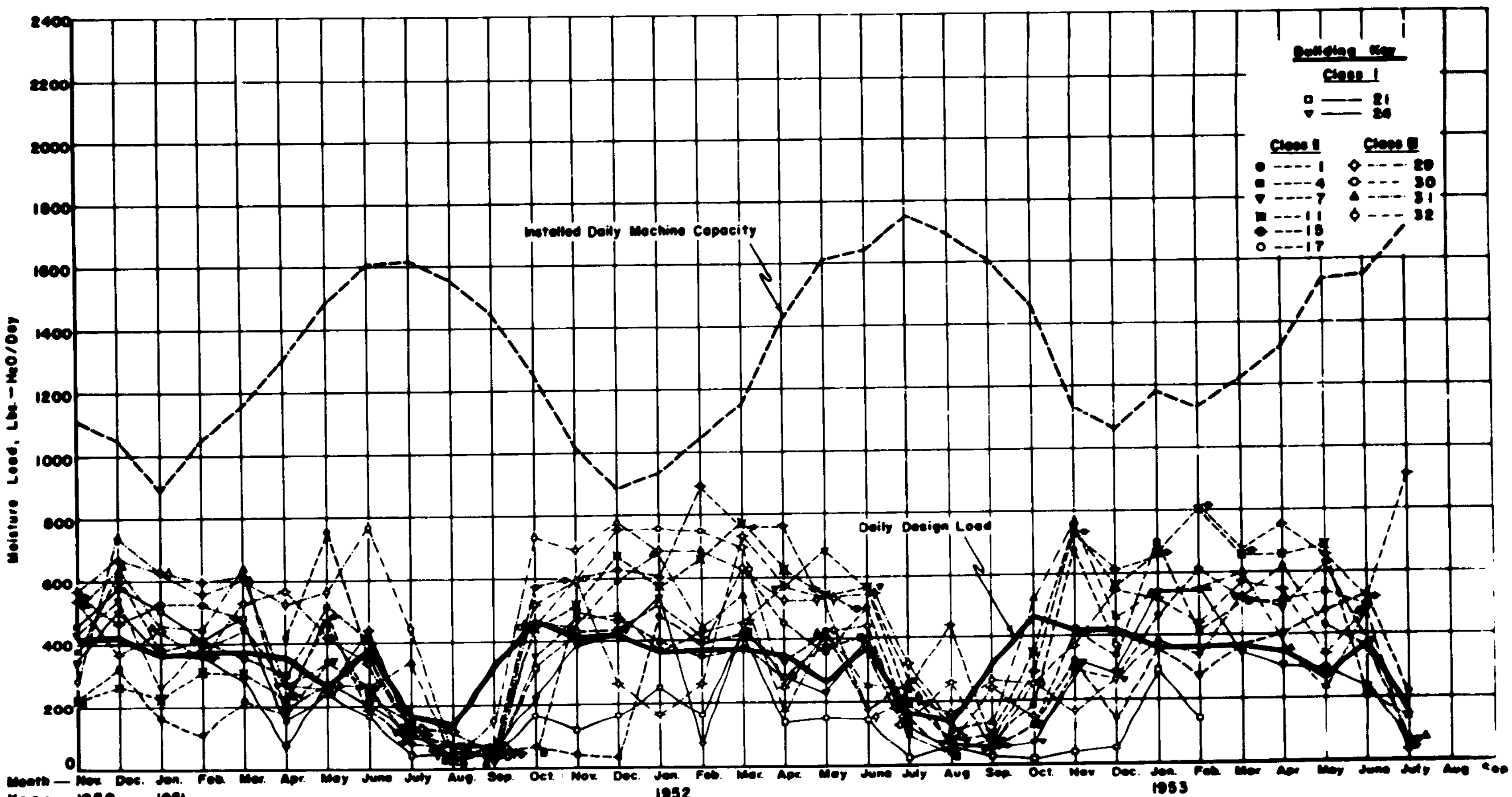


Figure 8
Calculated Daily Moisture Load in Twelve Dehumidified Warehouses
NSD Spokane, Wash.

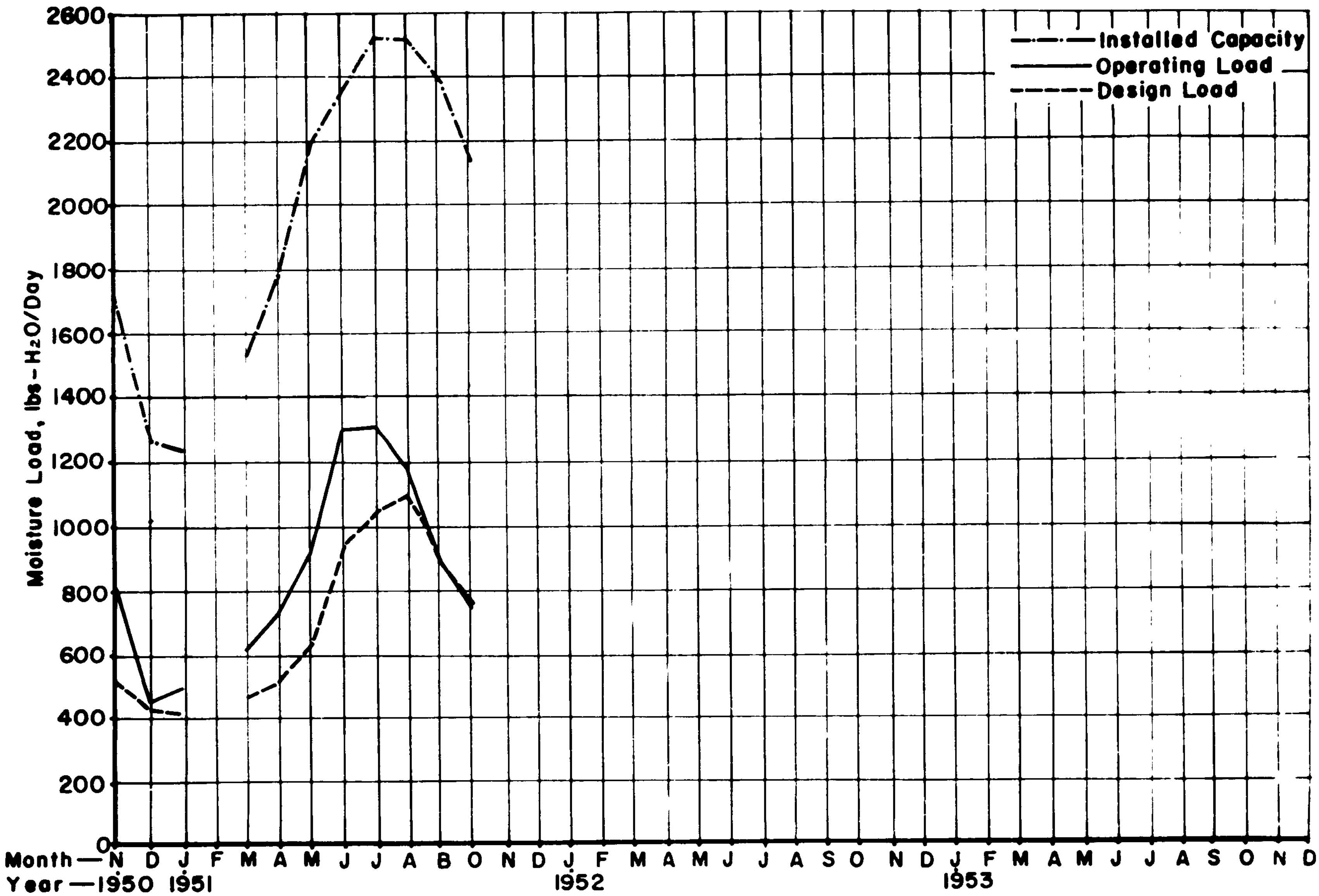


Figure 9

Average Daily Moisture Load in Dehumidified Warehouses-NSD Mechanicsburg, Pa.

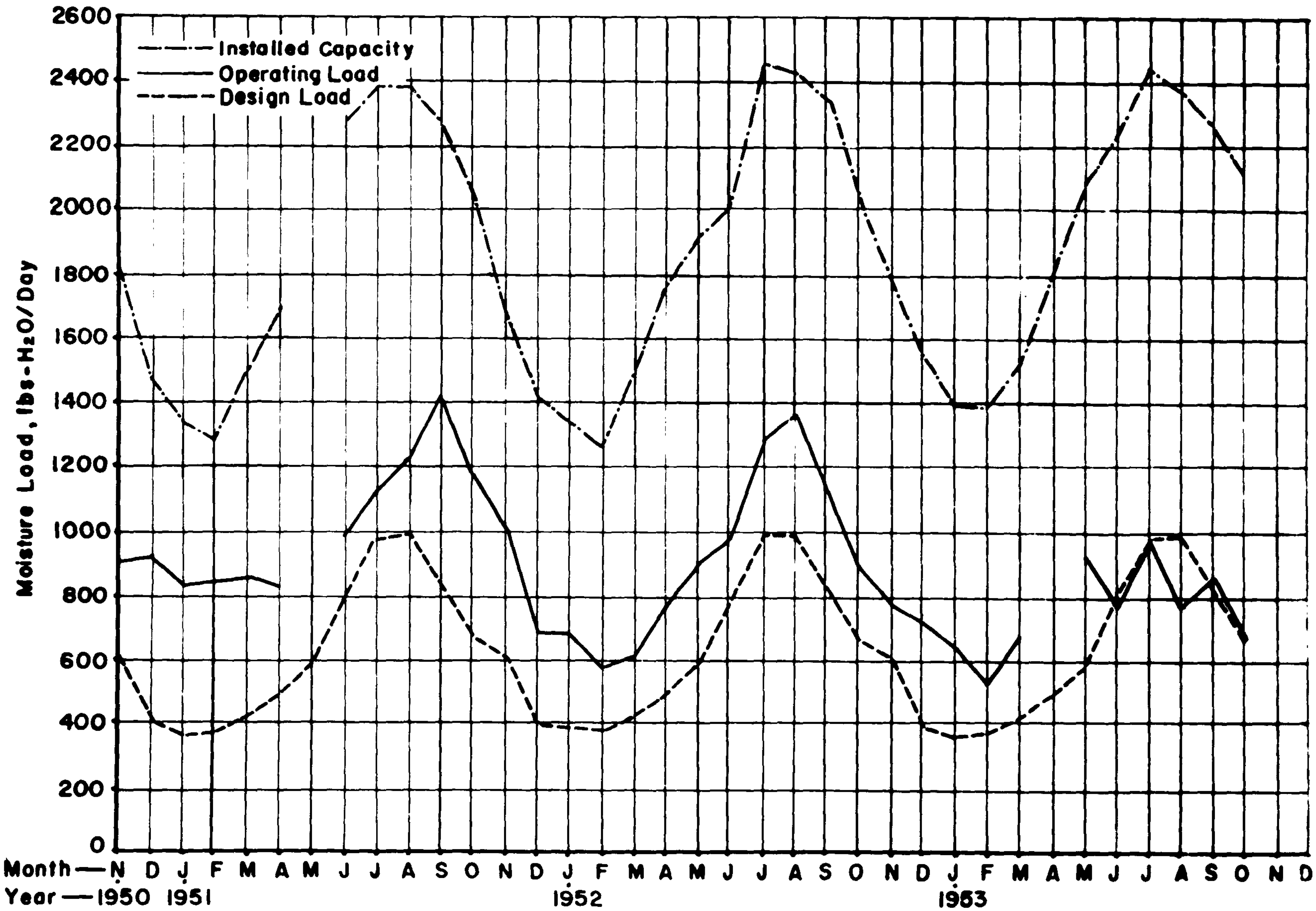


Figure 10
Average Daily Moisture Load in Dehumidified Warehouses - NSD Scotia, N.Y.

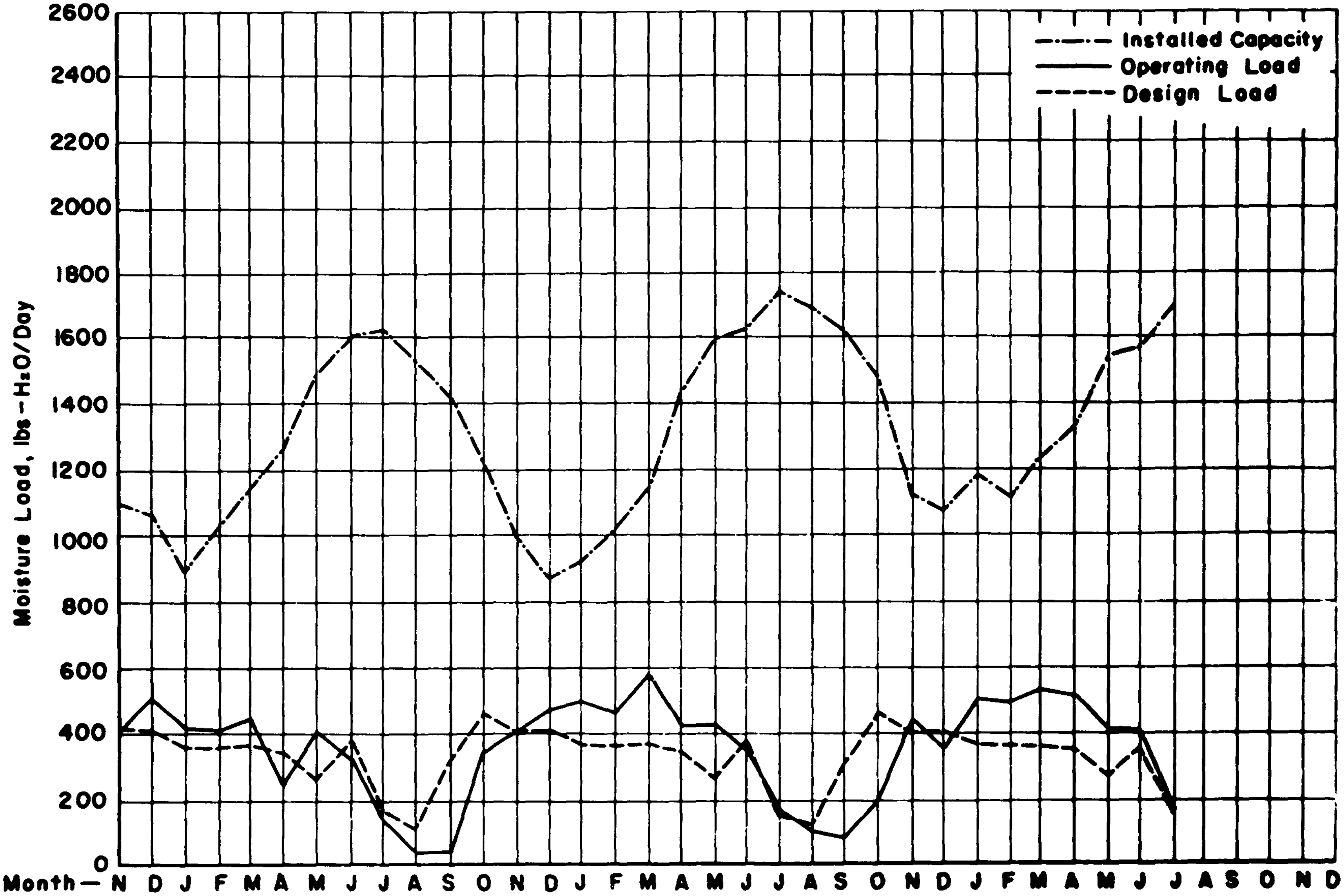


Figure II

Average Daily Moisture Load in Dehumidified Warehouses — NSD Spokane, Wash.

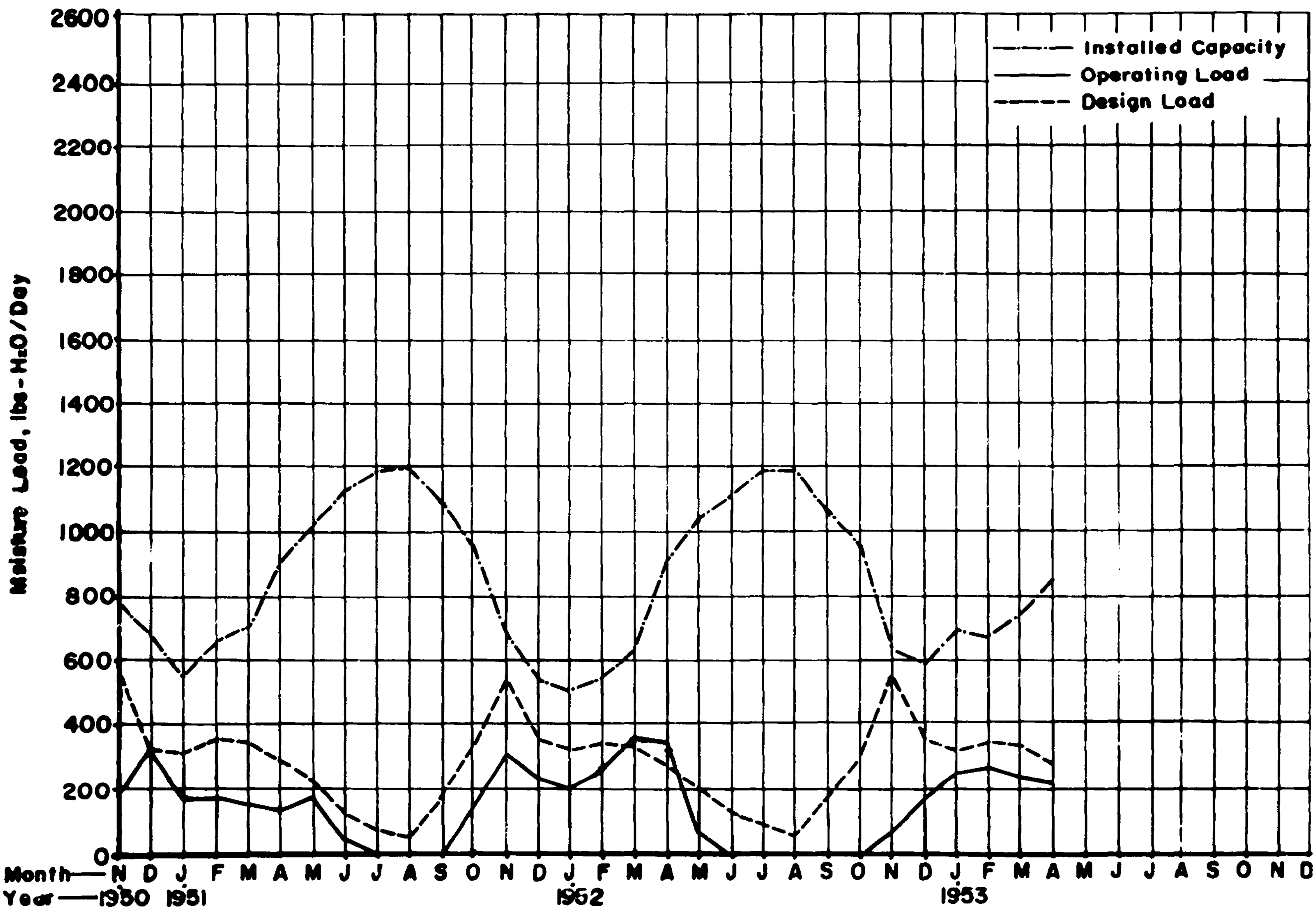


Figure 12

Average Daily Moisture Load in Dehumidified Warehouses — NSD Clearfield, Utah.

Following the general analysis of the design moisture load, further study was made on an individual building to determine the variation in each of the moisture load components throughout a year. Inasmuch as the total daily moisture load is largely dependent upon outdoor air conditions, it follows that parts of the total moisture load will vary accordingly. The results of the analysis on the moisture load components for different months of the year are shown in Figure 14. As infiltration is the largest component of the total daily moisture load, it is also the most intangible component to evaluate. To make this analysis, it was necessary to utilize certain data which were used in the original design calculations with actual operating data used wherever possible. The breathing component of the daily moisture load is dependent on the temperature change experienced within the building in a twenty-four hour period. The breathing component of the load was calculated from actual temperatures existing in the warehouse and it involved an eight degree maximum temperature variation throughout a day. This eight degree temperature variation was obtained from temperature measurements taken within the buildings. The wall transmission component of the total load was calculated by utilizing the recorded data giving actual stores movement into the building. The moisture component of floor transmission was one item which could not be directly calculated. It was necessary to utilize the same data used in the original design calculations. The rate of floor transmission was originally determined by tests which were conducted by Davison Chemical Corporation in a controlled humidity warehouse at the U.S. Army Signal Corps Depot, Lexington, Kentucky. The results of these tests were extrapolated to cover conditions at NSD Mechanicsburg, and these data were used in this analysis. The use of these data is justified in that the variation of floor transmission is not too great from month to month in any one building. Also, the magnitude of the floor transmission load varies from summer to winter; however, during the design month, the floor transmission is not of such a magnitude that assumptions made will greatly alter the magnitude of other components. The infiltration component of door opening was calculated on the basis

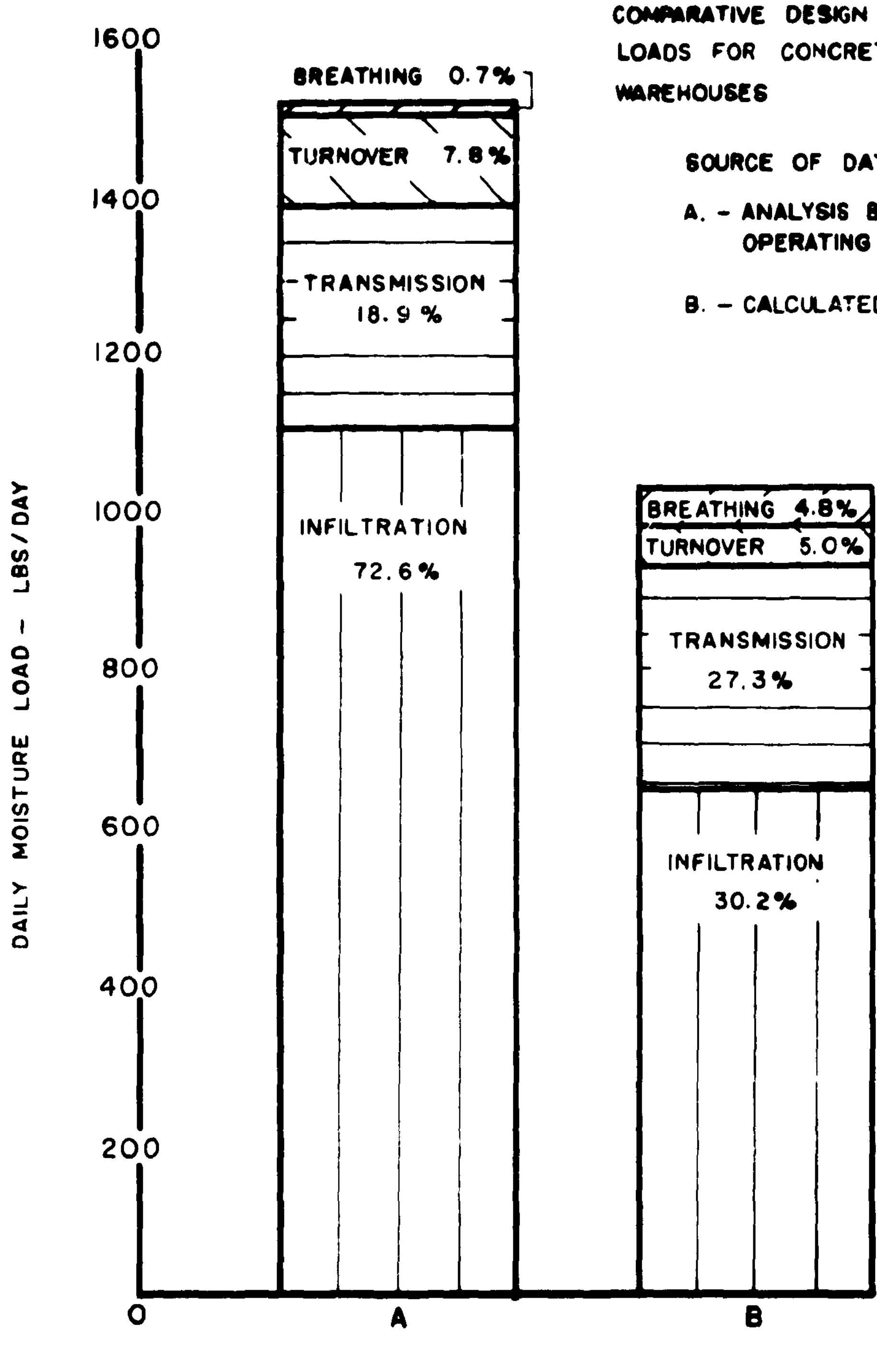
Figure 13

COMPARATIVE DESIGN MOISTURE LOADS FOR CONCRETE AND BLOCK WAREHOUSES

SOURCE OF DATA:

A. - ANALYSIS BASED ON ACTUAL OPERATING DATA

B. - CALCULATED DESIGN -- 1947



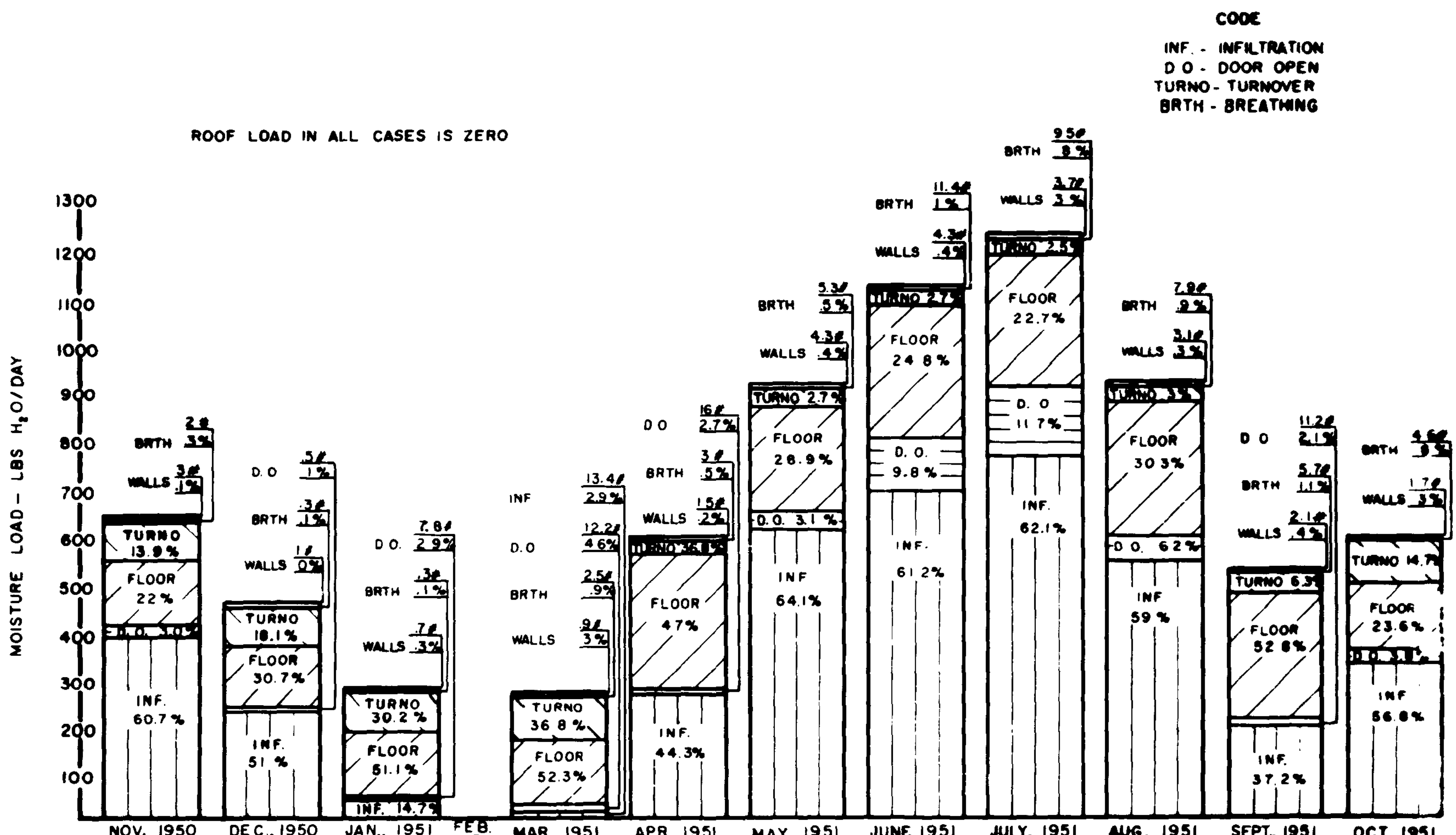


Figure 14

BREAKDOWN OF CALCULATED MOISTURE LOAD IN A DEHUMIDIFIED CONCRETE BLOCK WAREHOUSE of the actual door opening time recorded and the air admittance factor used in the original design calculations was applied to the actual door opening time. The calculation of these five components along with the previsou determination of the total moisture load for each month permitted the determination of the infiltration component by difference. It can be seen from Figure 14 that during the months of June, July, and August, the infiltration portion of the load is most significant and one which should be of main concern in the design of new warehouses or conversion of existing buildings. Also, the analysis shows that it is necessary, for calculating the total moisture load, to investigate different months of the year in order to determine when the maximum moisture load in the building will occur.

3. <u>Summary of Evaluation Program</u> In the entire evaluation of controlled humidity storage there were two primary objectives; (1) to determine the merits of controlled humidity storage as a method of preservation and (2) to determine the economics associated with this method of preservation. These objectives were satisfied to a large degree by the field studies at the various Naval Supply Depots. When the controlled humidity program was initiated in 1948 an evaluation was not anticipated to the extent that the program was operated on a test or trial basis. Consequently, the type of data required for a thorough and complete evaluation was not readily available. This was recognized early in the studies conducted under Contract NOy 79585 and recommendations for a controlled test program were made to the Bureau of Yards and Docks. A test program was initiated at the US NAVCERLAB, Port Huneme, California in 1955. This program was set up for a five year period and will in its conclusion give qualitative information which could not be developed in the field studies at the Depots.

From the above evaluation, the following conclusions concerning the two-fold primary objectives are presented:

(1) Controlled humidity storage is a positive and very effective means of preservation. By controlling the relative humidity to a level of 40% the predominant form of deterioration -

corrosion - is in all practical aspects eliminated. This method of long term storage gives a high degree of equipment readiness and reliability. It is a method of preservation which applies to any and all materials and it can be applied in many different ways to supplement other preservation methods which are required because of military mission requirements.

(2) The economics of this method of preservation are known in terms of providing and operating warehouse facilities. Direct cost comparisons with other methods of preservation cannot be made but it was found at each Supply Depot that cost reductions in the cyclic inspection and re-preservation of equipment stored in dehumidified warehouses amartized the cost of warehouse conversion in a period of three years of less.

B. PORT HUNEME TEST PROGRAM

The U.S. Navy Bureau of Yards and Docks continued the evaluation and investigation of preservation methods including dehumidified storage by initiating a test program at the Naval Civil Engineering Laboratory, Port Huneme, California in July, 1955. This test program was designed primarily as a field test program to evaluate the basic storage environments required for Military uses. The storage environments under test are open air, shed, standard warehouses, and controlled humidity warehouses. In order that this test program would yield as much information as possible on the effect of storage environments and costs associated with these different types of storage, equipment was selected from Navy Storage for simultaneous exposure in each storage condition. The items selected were jeeps, dump trucks, searchlights, steamboilers, pumps, welders, bake ovens, blades, and telephone switchboards. These items represented a cross section of different types of material. There are two controlled humidity warehouses in the program. One is maintained continuously at a relative humidity of 40% and the other at 50%. The purpose of these two different humidity levels is to evaluate the over-all effectiveness of each condition on the deterioration of materials. The test program has been under way for approximately three years and the results of the test, given in USNCEL Technical Report 075, after a 2 1/2 year period are as follows:

1. No rust or corrosion has been discovered on equipment stored in the 40% and 50% controlled warehouses.
2. Irrespective of preservation level, rust and corrosion occurred in most open air storage, less in shed storage and little in the standard warehouse, and none in controlled humidity warehouses.
3. Contact-preserved items in the open air and shed had 58% fewer rust areas than the domestic treated items. Contact-preserved items in the standard warehouse had 50% fewer rust areas than in the domestic-treated items.
4. Except for automotive and non-metal equipment, items that will be evantually removed from storage for shipment overseas are cheapest to store if contact-preserved and stored in a 50% dehumidified warehouse.
5. Except for automotive and non-metal equipment, items that will be eventually removed from storage for stateside use are cheapest to store if domestic-treated and in a 50% dehumidified warehouse.
6. Domestic-treated automotive and non-metal equipment can be stored cheapest in a standard warehouse. Contact-preserved non-metal equipment can be stored cheapest either outside or in a shed.
7. The Navy standard 40 ft. x 100 ft. rigid frame metal building has been satisfactory with limited modifications as a dehumidified warehouse during 2 1/2 years of use.
8. For the outside environment encountered in this test program, the dehumidification machine in the 40% RH building operated twice as long as the one in the 50% building, and thus used twice the power.

It is of interest in the design of controlled humidity storage facilities to have the benefit of the 2 1/2 years of the test program with actual time exposure of materials to the 50% relative humidity environment since it was found that this condition required only one half the amount of power required to maintain a building at 40% relative humidity. From the results of the above tests a relative humidity of 50% is satisfactory for at least a 2 1/2 year period, and it is to be expected that the materials in this storage condition will show no change at the end of the 5 year period because the major portion of any deterioration should be expected during the initial exposure period.

III. DESIGN OF CONTROLLED HUMIDITY WAREHOUSES

The implementation of a dehumidified warehouse storage facility requires that consideration be given to those factors which affect the economic and technical operation. Knowledge of the moisture loads as affected by climatic conditions, permeability of construction materials which affect the moisture load, along with construction features which may be incorporated into the buildings to facilitate economic operation will aid in the design of a warehouse facility.

A. RECOMMENDED CONSTRUCTION FEATURES FOR CONTROLLED HUMIDITY WAREHOUSES.

1. General The principal objective in designing dehumidified warehouses for the preservation of materials is to obtain a structure which is least affected by the surrounding climatic conditions. Therefore, a building having a maximum resistance to the transfer of moisture whether by transmission or infiltration is desirable. The economics of both first cost and operation of the dehumidification equipment is directly related to the building structure. To reduce both the initial cost of equipment and the cost of operation to maintain the prescribed humidity conditions, a warehouse having the minimum amount of air leakage and vapor diffusion is desirable.

Although it is preferable that the objectives are satisfied, the cost of constructing a warehouse must be maintained within certain practical and economical limits. Therefore, a considerable amount of ingenuity must be exerted in balancing all the factors involved without sacrificing one objective for the other. For example, there are many materials which can be incorporated in the design to provide the most efficient construction; however, such materials may be prohibitive in cost. On the other hand, cheaper materials may be used and yet obtain a satisfactory structure without materially affecting the initial cost or operation of the equipment.

Obviously, the first step to be considered is the location and orientation of the warehouse. With respect to location, soil conditions at the location of the warehouse is important in order to avoid excessive moisture from ground water and/or unsatisfactory sub-soils. The buildings should be located to provide the least amount of wall exposure to the prevailing winds. By reducing the amount of wall exposure, a reduction of moisture transmitted into the building by air infiltration is obtained. If possible, buildings should be orientated so that the largest dimension is parallel to the prevailing winds for the given geographical area.

2. Floors As warehouse floors will be subjected to extremely heavy traffic under certain conditions, reinforced concrete floors are most satisfactory. To insure that a minimum amount of moisture is transmitted through the concrete, there are certain precautions which must be taken. Six inches of high density concrete, as ordinarily recommended for heavy loading, is highly resistant to the transmission of water in the vapor state, the migration of moisture by capillarity may be extremely high. Capillary flow of moisture is caused by condensed or free water adjacent to the underside of the concrete floor. This moisture is absorbed by the concrete and transmitted by capillarity to the top surface and evaporated into the inside air. To avoid such transfer, precautions should be taken with the subsoils below concrete floors laid at or just above the surrounding grade.

Six inches of one inch gravel which is free of clay and sand should be used as a bearing course for the concrete slab. This will prevent free water from contacting the undersurface of the floor. Clay and fine sugar sand soils have the greatest capillarity. However, this is also dependent upon the depth of the ground water level.

A layer of heavy felt which is highly resistant to vapor is recommended between the gravel and the concrete floor. The felt may consist of 40 to 60 pound smooth rolled roofing which is highly vapor resistant and also extremely tough. If the gravel sub-base consists of sharp, crushed gravel, it will be necessary to provide approximately a one inch course of sand on top of the gravel to protect the felt from rupture or bruises by the sharp gravel. If there is danger of damaging the felt when laying the reinforcing steel or the concrete slab, it is recommended that an additional one inch layer of sand be placed over the felt to act as a cushion. The felt should be lapped approximately three to four inches, but need not be sealed. Since the gravel will prevent free moisture or water from contacting the surface of the felt, the amount of vapor which comes in contact with the undersurface of the floor will be negligible. This procedure has been used and found satisfactory in building construction however the water in the cement during placing of the concrete can be evaporated only from the top surface. This causes some delay in finishing the surface due to the slow rate of evaporation of the excess water. This may be overcome, to a large extent, by controlling the amount of water which is used at the time of mixing the concrete to a minimum.

The above procedure will also eliminate any excessive vapor or moisture leakage into the building through the expansion of joints of the concrete. It will also prevent excessive moisture flow through cracks which later develop in the concrete floor.

Unless it is absolutely certain that the soil is of a noncapillarity type and that the ground water level at all times is well below grade, the minimum specification should require at least six inbhes of one inch gravel devoid of any clay, sand, or other types of fine material. The additional cost of the felt as a barrier against any possibility of vapor movement is not a major cost factor.

Floors laid at truck floor height, some three of four feet above surrounding grade may be laid on compacted soil covered by a roofing felt or vapor barrier mentioned above.

3. <u>Walls</u> Many types of wall constructions can be used which are highly resistant to the migration of water vapor or free water. Local conditions dictate the type of material which is most economical and yet meet the necessary requirements.

The walls must be highly resistant to the transmission of moisture by capillarity which requires that the exterior surfaces of the wall should have low water absorption characteristics. The wall should also have a high resistance to air infiltration, since this has been found to be the greatest single source of moisture load, especially for a converted type warehouse. Air infiltration consists primarily of air leakages through joints, cracks, and door openings. For converted buildings, approximately 60% of the total moisture load is due to air infiltration. A wall should also be highly impermeable to vapor transmission. Materials should be selected to meet the above requirements, and yet be economical and practical to use.

a. Concrete or Concrete Block Walls. This type may be used if the exterior surface is covered with a water-cement paint. Such walls have been found to be resistant to air infiltration, water absorption, and vapor diffusion. The maintenance of such a wall may be considerably more than that of other types of walls due to the cracking of the mortar joints. Whenever cracking occurs, repairs should be made immediately. The openings at the top course of the cement blocks should be sealed to prevent the infiltration of air, vapor, or moisture at the intersection of the wall and roof. Light weight aggregate concrete blocks have a greater insulating value than sand and gravel concrete blocks. However, light weight aggregate blocks are considerably more permeable to air infiltration and vapor transmission, and also more highly absorbent to surface waters. As a result of their coarse textured surfaces, they are more difficult to seal with water cement paint and may require an application of a cement finish to obtain satisfactory exterior surfaces for the application of water cement paints.

b. Reinforced Concrete Walls These types have the advantage over concrete block in that they are less apt to crack and also are more easily coated on the exterior with water-cement paint. The economics regarding a comparison of costs between the two types of wall must be considered. This is dependent upon local conditions and the types of materials which are available. Labor conditions will also dictate the relative costs. Pre-cast concrete walls are easily installed and have certain advantages in reducing the cost of construction; however, panel joints require special attention in design and construction to insure that they are permanently tight against infiltration.

c. Brick Type Walls. This type of wall should require no supplementary exterior surface treatment. However, if it is a cavity masonry wall, the wall should have a coat of plaster on the inside surface. In certain areas, such walls may be costly depending upon labor conditions. They may also require a large amount of upkeep due to the possibility of leakages through the many joints.

d. Wood Frame Walls These walls should be provided on the outside with a tough sheathing paper or plastic membrane which is resistant to air infiltration and vapor transmission. Special precautions should be taken to seal the sill and top plates against air leakages.

4. Roofs There are many types of roof which can be used for a built-up roof consisting of either pitch and tarred felts, or asphalt and asphalt felts. Built-up roofing provides a high resistance to both air and vapor diffusion, providing that the eaves or periphery of the roof are sealed. The roof deck may consist of wood, concrete, steel, gypsum, or unit tile, with the type of deck selected depending upon the design of the building, availability of materials, and resulting economics in a specific location. Generally, it is recommended that roofs have an insulation value equivalent to at least one inch of insulation. However, to reduce the effect of solar radiation in the warmer climates and also the effect of sub-zero temperatures in the colder climates, the equivalent of at least two inches of insulation is recommended. The possibility of using aluminum paint or other heat reflecting materials for roofing surfaces should also be considered, although atmospheric contamination may negate the surface effect within a short period of time.

5. <u>Doors, Windows, and Auxiliary Building Components.</u> Freight doors should be vertical rising sectional doors because they are considerably easier to seal and maintain than hinge-type doors. They should wedge substantially air tight against gaskets when closed. Freight doors should be equipped with timing meters to record the door open time. Warning signals, either a red light or a buzzer alarm, should be provided to protect against the doors being left open for long periods of time. Walk-in or personnel doors should be weatherstripped.

Although it would be desirable to locate all doors, especially those utilized for stores movements, on a side other than the windward side, it is not always practical from a materials handling standpoint.

Windows should be reduced to a minimum and eliminated where possible to reduce air infiltration. Windows also transmit solar radiation which is detrimental to some materials. A large quantity of heat is also transmitted through windows resulting possibly in excessive indoor temperature conditions which can be detrimental to the preservation of materials.

Offices, laboratories, and similar areas should be provided outside of, but adjacent to, the dehumidified storage area. This will eliminate much of the traffic in and out of the warehouse by personnel not directly involved with warehouse activities. If personnel spaces or lavatories are provided in the warehouse, they should be vented to the outdoors and not to the storage space. All doors communicating to the storage space should be equipped with automatic door closers. Ceiling and wall construction separating the personnel and toilet areas from the storage space should be treated to provide a high resistance to the passage of water vapor.

B. **EFFECT OF CLIMATIC FACTORS**

1 General The dehumidified warehouse, as is true with all methods of preservation, relies upon the elimination or the reduction to a safe level of various undesirable climatic factors Climatic factors which are principle causes of deterioration are moisture, temperature, solar radiation, wind, and atmospheric contaminants The exposure of materials to these factors which are present in the atmosphere will result in some form of deterioration. The magnitude of deterioration depends upon the degree to which they exist singly or in combination with each other

As a dehumidified warehouse must provide protection from these variables to the stored materials, attention must be given to their degree of presence to properly design the warehouse The economy of construction and operation of the dehumidified warehouse is directly related to the amount of protection which it must provide.

As climatic conditions vary throughout the United States, so do the degrees of protection required. An area such as NSD Clearfield, Utah, approaches an ideal weather condition which provides for limited dehumidified operation while maintaining adequate protection. It is not always possible to locate a supply depot in areas having the ideal climatic conditions. If some latitude is allowed in the selection of a depot location, careful attention should be given to existing U.S. Weather Bureau records regarding the climate in the proposed areas. The data may be obtained from the U S Weather Bureau's Local Climatological Summaries for a specific area under consideration Other U S Weather Bureau data such as the "Station Meterological Summary" and "Special Meteclogical Summaries" along with the normal 5 to 10 year records will provide further information aiding in the designs of the dehumidified warehouse Information such as prevailing winds, precipitation, dew point, and dry bulb temperatures, relative humidity etc , should be used to establish design criteria and the design analysis of warehouse operating costs.

As previously mentioned the climatic factors most important from a preservation standpoint are moisture, temperature, solar radiation, wind and atmospheric contaminants. The variables and their effect upon warehouse design are as follows:

a. Moisture Moisture whether in the form of humidity or precipitation is the greatest single factor affecting the rate of material deterioration. Therefore, control of moisture is paramount in the preservation of materials. The warehouse, in most cases offers protection from precipitation, however, precipitation can and does add to the moisture in the form of humidity.

Moisture in the atmosphere is in the form of steam having a pressure called vapor pressure. This vapor pressure varies according to the dew point temperature of the air. When the outdoor dew point temperature is different from that maintained within the building, a vapor pressure differential between the inside and outside air will exist. When the outside vapor pressure is greater than that of the inside air, moisture will diffuse into the building. This diffusion takes place though cracks, door and window openings, and most types of building materials. Moisture also enters a building by air infiltration through these openings. The infiltration of moist air into the building is further aided by high winds and diurnal temperature variations which causes "breathing" of the building. Precipitation becomes a factor in that it ultimately gains entrance into the building by diffusion or capillary action through the floors.where precautionary measures have not been taken in the design of floors.

When climatic conditions for a given locality are at a low moisture level that is low dew point temperature and precipitation, considerable economy can be experienced in the construction and operation of the facility. Where outside dew point temperatures range below the level to be maintained within the building, the moisture within the building actually diffuses to the exterior air. Buildings being constructed in areas where the prevailing moisture condition is low, require fewer dehumidification machines, less operating time and considerable reduction in construction cost from the standpoint of vapor sealing.

The moisture conditions as experienced in any considered location must be carefully studied prior to construction so that the design relating to construction materials and dehumidification machine selection may be made. The effect of moisture on the selection and size of the dehumidification machine is discussed in Section V.

b. Temperature Dry bulb temperature, which varies considerably depending upon geographical location is an atmospheric variable which produces physical changes in almost all types of materials. These physical changes, which in most cases are detrimental, result from exposure to an extremely high or low temperature. The daily temperature cycle causes a greater degree of physical change than exposure to moderately high or low level of constant temperature. The greater the degree of cycling, the greater will be the effect of the physical change. Moderately high temperatures can also indirectly accelerate deterioration due to biological agents.

Outdoor air temperature conditions have varying effects upon the internal storage conditions of the warehouse. The magnitude of outdoor temperature changes and the rapidity with which these temperatures vary can have a considerable effect upon the stores located within the building. Normally, the thermal heat lag and the heat capacity of the stores will cause only a slight fluctuation in the indoor temperature. The maximum daily temperture variation measured in dehumidified warehouses at the Naval Supply Depots is approximately 14 to 16°F.

The construction of the building and its insulating properties will affect the temperature variation which may be expected inside the warehouse. Careful consideration of climatic temperature conditions must be used in selection of construction materials for designs of the warehouse. The use of various insulating

insulating materials for example, may be required where extreme temperature variation could be expected. Here again, existing U.S. Weather Bureau records should be studied for the design of the storage facility.

c. Solar Radiation The warehouse offers protection to materials from direct exposure to sunlight, however, solar radiation can and does cause daily temperature fluctuations within the building. Warehouse buildings have large roof areas exposed to solar radiation and consequently, a large quantity of heat is transferred to the building from the roof. This is desirable during winter months but undesirable during the summer months as it is reponsible for high indoor temperatures.

As most roof constructions include insulation or other building materials having a reasonable amount of thermal resistance, there is little that can be done to alter economically the effect of solar radiation. As mentioned previously, it is desirable to keep window areas as small as possible in order to restrict the entrance of direct solar radiation. Although areas having a high incidence of solar radiation generally have arid climates, precautions must be exercised to reduce the entrance of direct solar radiation.

d. Atmospheric Contaminants Atmospheric contaminants including airborne dust, dirt, and sand are factors which are undesirable from a preservation standpoint. They cause deterioration mainly through their abrasive or binding qualities. Airborne dust does, however, serve as a nucleus for the condensation of water vapor and when allowed to remain on the surface of a material it contributes to other forms of deterioration.

Gases in the atmosphere such as oxygen and ozone, plus contaminants consisting of sulfur dioxide, chlorides and sulfates are also instrumental in producing deterioration. Oxygen combines with many substances to cause deterioration. Sulfur dioxide is detrimental to metals as sulfurous acid or by its conversion to sulfuric acid on the corroding surface. Salts and chlorides present in sea water atmospheres form an electrolytic solution with water which aides in the corrosion of metals. The ambient atmosphere in industrial areas may also contain appreciable quantities of undesirable contaminants.

In spite of the objections to atmospheric contaminants from a preservation aspect, there is very little that can be done in the design of a warehouse to exclude these undesirable factors. A design permitting a minimum of air leakage is the most practical. It becomes impractical to exercise any additional control at the time the building site is selected. The dust generated within a building during normal use should be of more concern than, for example, dust and dirt from outdoors. Such control can then be better exerted during the operational phase of the building than in initial design.

e. Wind Wind velocity periodically or constantly is the driving potential for the infiltration of outdoor air into a warehouse. Transported with this infiltrated air is moisture and any atmospheric contaminants. If infiltrated air is more humid than the warehouse air, it adds to the moisture load of a dehumidified warehouse. If drier, it assists in the dehumidification effort as is accomplished periodically at NSD Clearfied, Utah. In such instances the moisture level of the indoor and outdoor air is the controlling factor and not the wind.

Through analysis of Weather Bureau data pertaining to the prevailing winds, information on the effect of building and depot orientation may be gained. It is desirable to locate a building such that the minimum wall areas is exposed to the prevailing winds. Infiltration is further reduced by locating windows and doors, wherever possible at points other than on the windward side.

2. Summary The best sources of information in reference to selection or design requirements for a selected area are the U.S. Weather Bureau records. Utilizing data on the climatic factors such as dewpoint, temperature, winds, and precipitation provides a means of calculating moisture loads; selection of building materials and the selection of the optimum type of controlled humidity system.

C. **MOISTURE LOAD** Up to this point there have been numerous references to moisture and its relation to deterioration of materials. The primary objective in prevention of deterioration is to maintain a humidity level within the warehouse which will either retard or prevent deterioration. The moisture load is, therefore, the amount of water which must be removed from the storage space to maintain a prescribed relative humidity.

The moisture load in a warehouse may be divided into two categories: the initial or "draw down" load where the original moisture is removed to bring the space and its contents into equilibrium with the humidity level to be maintained: and the "daily" load which is the day to day load which must be handled by the dehumidification equipment to maintain the desired humidity condition. Both of these loads must be considered from the standpoint of machine selection and warehouse design.

1. Initial or Drawdown Load The moisture load within a warehouse upon initial dehumidification is composed chiefly of the residual moisture within the stored materials and the warehouse construction materials. However, during this period the normal daily moisture load also contributes to the total load. The hygroscopic materials within the warehouse such as the wood in the structural members of the building, wood in pallets and storage containers and the dunnage inside the storage containers must be considered as sources of residual moisture during drawdown. When dehumidification of the warehouse is initiated, the materials are in equilibrium with the temperature and humidity conditions of the ambient air. Dehumidification causes the vapor pressure of the surrounding air to decrease which in turn allows moisture to evaporate from the materials. The drawdown process continues until equilibrium with the desired storage humidity is attained.

To calculate the amount of moisture to be removed during drawdown, careful examination of the hygroscopic properties of the existing materials must be made. Analysis of the building construction materials will provide a tabulation of the weight of various hygroscopic materials involved in the warehouse construction. Present day construction utilizing steel and gypsum roof decks along with steel framing contributes little to the initial drawdown load and can in most cases be neglected. In the case of the stored materials it is estimated from studies made by the Davison Chemical Co. that each measurement ton (400 cu. ft.) of stores contains an average of 200 pounds of wood equivalent. By utilizing the wood equivalent of the stored materials and the construction materials, the equilibrium moisture content for any given ambient condition may be found from Figure 15. The amount of moisture contributed to the drawdown load by these materials is found by subtracting the amount of moisture present in the materials at the warehouse design condition from the moisture present prior to dehumidification. The length of time required for the drawdown of the warehouse based on the calculated load, is dependent upon the number and size of the dehumidification machines. The combination of the residual moisture load and the normal daily load becomes the total drawdown load upon the dehumidification machines.

The previously mentioned capacity of the building and stores to hygroscopically retain water produces a flywheel effect upon the dehumidification cycle during periods of abnormally high or low moisture loads. This factor allows for stabilization of the humidity level within the warehouse.

2. Daily Moisture Load. The daily moisture load is largely dependent upon outdoor weather conditions and consequently, the daily load varies considerably throughout the year. The total moisture load must be determined for different months of the year to determine the period during which the maximum load occurs. The magnitude of each component contributing to the total daily load will vary accordingly with the outdoor weather condition so that an investigation of each component as affected by outdoor conditions must be conducted.

The sources of moisture to be considered in the daily moisture load are:

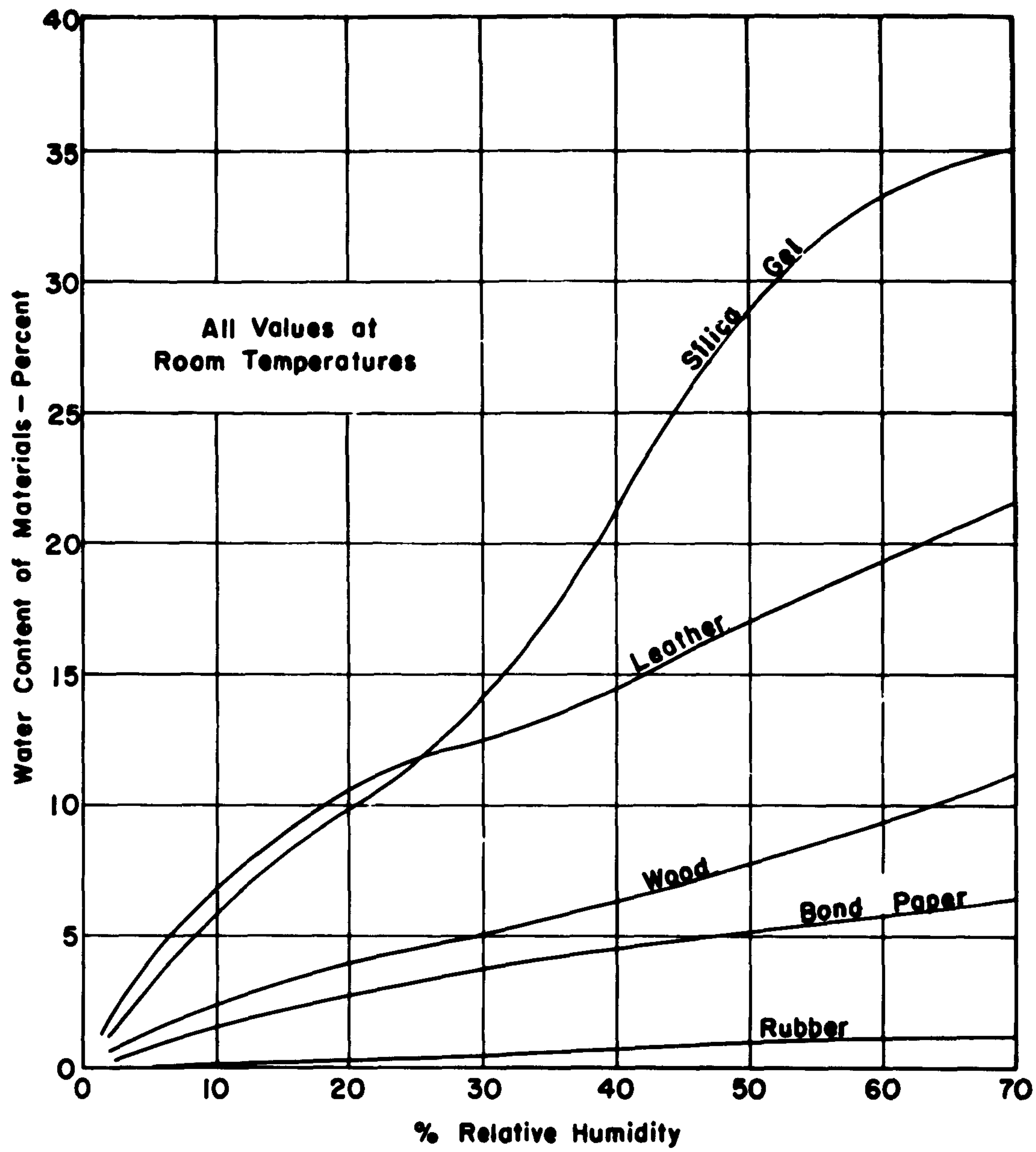


Figure 15
Moisture Content of Common Materials at Various Relative Humidities

(1) The transmission of moisture from outdoors into the building through the walls and floor.

(2) The entry of outdoor air through breathing which results from cyclic changes of temperature within the building.

(3) The residual moisture given off by stores which are brought into the building from a non-dehumidified area.

(4) The moisture brought into the building from outdoors by infiltration of air through building walls, doors and other openings.

These may be classified as: breathing load, wall transmission load, floor transmission load, stores turnover load, infiltration load, and door opening load. The moisture brought into the building through infiltration is of greatest importance, as shown through analysis of moisture loads, and should be considered accordingly in the design of the building and selection of construction materials. However, due consideration must be given to each of the other components.

a. Breathing The moisture load from breathing is actually a form of infiltration. This moisture enters the building with the outdoor air which is brought into the building as a result of the daily change of indoor air temperature which in turn causes a change in the volume of air within the building. As the air within the building is heated, it expands and, consequently, forces air out of the building. When the air within the building cools, there is a decrease in the volume of air within the building which results in air being drawn into the building from outdoors. It is the air draw-in from outdoors which contributes to the moisture load. Temperature measurements made in dehumidified warehouses indicate that there is approximately a twenty degree variation in air temperature near the roof and two to three degree variation near the floor. At the six to ten foot level, the daily temperature variation is approximately 14°F. For calculation purposes, eight degrees may be considered the average daily temperature variation in the building. In calculating the moisture load due to breathing, the first step is to determine the specific volume at the warehouse temperature plus or minus 4°F. Dividing the building volume by the specific volume of the air at each condition will give the pounds of air present in the building at the two temperature conditions. The difference in the weight of air at the two conditions is the weight of air expelled from or infiltrated into the building by breathing. The weigth of air multiplied by the specific humidity difference of inside and outside air gives the pounds of water per day admitted to the building by breathing. When a low outside moisture level exists, the specific humidity difference will be negative and, consequently, there will be a migration of moisture from the building to the outside. This results in a negative load or a dehumidification effect.

b. Wall Transmission Load The wall transmission load is the moisture which migrates through the wall because of a vapor pressure difference existing between the inside and outside air. The vapor pressure of the moisture in the air is determined from the dewpoint temperature, and the quantity of vapor flowing by transmission is calculated by the formula fiven the ASHAE GUIDE:

$$W = \frac{NAT(P_1 - P_2)}{7000}$$

Where: N = Permeance of the wall in perms expressed as grains per hour per square foot per inch of mercury vapor pressure difference.

A = Wall area in square feet.

T = Time, Hours (In this calculation the time period is one day or 24 hours.)

$(P_1 - P_2)$ = Vapor Pressure difference between indoor and outdoor air expressed in inches of mercury.

W = Pounds of moisture per day or 24 hours.

c. Floor Transmission Load The determination of the moisture transmitted through the floor is a difficult calculation to make since moisture transmission through a concrete floor in contact with ground includes a number of variables. The primary variable is the soil itself, since moisture flow in soil is dependent upon the type of soil, its moisture content, and its temperature. It is almost impossible to generalise on soil conditions and soil moisture content for any given location. Furthermore, the moisture content of any soil changes continually and may not be the same from season to season or year to year even under most ideal conditions.

The original studies on moisture transmission through warehouse floors conducted by the Davison Chemical Corporation included some field tests in a dehumidified warehouse at the U.S. Army Corps Depot in Lexington, Kentucky. In these field studies, measurement of water transmitted through the floor provided data showing an average transmission of 2.3 pounds of water per 1000 square feet of floor during the design month of August, and 1.1 pounds of water per 1000 square feet during the month of January, with the other months graduated uniformly between these values. The Naval Civil Engineering Laboratory, Port Hueneme, California (NCEL), recently completed similar tests on moisture migration through various types of floors. They reported extreme difficulties in establishing test procedure. Results of these tests conducted at 60°F. and relative humidities of 40%, 50% and 60%, are shown in Table III. Rates established are an average moisture migration rate for a 240 day test period. For design purposes these rates may be used in the calculation of the floor load component. The rates given in pounds of water per 1000 square feet per day a specific type of concrete mixture, slab thickness and soil bed and inside ambient conditions can be applied directly by multiplying the flow rate times the floor area involved.

d. Stores Turnover Load Where the original designs considered an annual turnover of 5%, Navy Supply Depot operating records show that depot warehouses have experienced an average of a ten percent turnover of stores each year. Some

TABLE III
WATER VAPOR TRANSMISSION RATES FOR CONCRETE FLOORS

Concrete Mix	Special Treatment of Concrete	Type of Soil Bed	Migration Rates - lbs/1000 sq ft/day Room Environment 60F - 40% RH	60F - 50% RH	60F - 60% RH
Portland 1:3:5 (2" thick)	None	Washed Sand	13.3	7.2	1.3
Portland 1:3:5 (6" thick)	None	Washed Sand	4.5	3.8	3.4
Portland 1:3:5	Darex	Washed Sand	8.1	8.6	16.2
Portland 1:3:5	Darex	Washed Sand	6.8	3.4	3.4
Portland 1:3:5	Plastiment	Washed Sand	3.5	2.6	0.8
Portland 1:3:5	Plastiment	Washed Sand	8.3	5.8	4.6
Portland 1:3:5	Formula 640	Washed Sand	3.2	2.3	1.7
Portland 1:3:5	Formula 640	Washed Sand	6.4	4.2	3.6
Portland 1:3:5	Magnesium Zinc-Silica Fluoride	Washed Sand	8.8	6.3	7.5
Portland 1:3:5 (8" thick)	None	Washed Sand	11.1	8.0	7.3
Portland 1:2.2:3.3	None	1" Coral	9.0	6.1	5.1
Portland 1:2.2:3.3	None	Beach Sand	4.7	3.2	2.9
Portland 1:2.2:3.3	Darex	Washed Sand	3.9	3.7	3.1
Portland 1:2.2:3.3	Plastiment	Washed Sand	4.7	3.4	2.1

(All Specimens 4" Thick Unless Otherwise Stated)

TABLE III
WATER VAPOR TRANSMISSION RATES FOR CONCRETE FLOORS

Concrete Mix	Special Treatment of Concrete	Type of Soil Bed	Migration Rates - lbs/1000 sq ft/day Room Environment 60f - 40% RH	60F - 50% RH	60F - 60% RH
Portland 1:2.2:3.3	Darex	Washed Sand	7.3	-	1.6
Portland 1:2.2:3.3	Plastiment	Washed Sand	3.7	4.0	2.2
Portland 1:2.2:3.3	Formula 640	Washed Sand	2.4	1.5	1.0
Portland 1:2.2:3.3	Formula 640	Washed Sand	7.3	4.6	3.4
Portland 1:2.2:3.3	Magnesium Zinc-Silica Fluoride	Washed Sand	13.7	8.0	7.5
Portland 1:2.0:1.9	None	Coral Sand	3.9	2.2	2.1
Portland 1:2.0:1.9	Formula 640	Washed Sand	4.7	4.8	4.1
Portland 1:2.0:1.9	Formula 640	Washed Sand	6.4	5.0	4.1
Portland 1:2.0:1.9	Magnesium Zinc-Silica Fluoride	Washed Sand	7.3	6.7	5.6
Asphalt	None	Beach Sand	3.2	-	-
Asphalt	None	Washed Sand	5.5	5.0	2.9
Asphalt	None	Coral Sand	-	0.0	0.21
Asphalt	None	1" Gravel	7.1		5.4
Asphalt	None	1" Coral		5.6	4.0
Asphalt (2" thick)	None	Beach Sand	4.7	1.5	1.0
Asphalt	None	Beach Sand	3.1	2.4	3.6

(All Specimens 4" Thick Unless Otherwise Stated) warehouses have had a turnover as high as 40%. The turnover rate is to a large extent influenced by the types of stores ivolved. As previously mentioned the Davison Chemical Corporation determined that each measurement ton of stores contained approximately 200 pounds of wood or wood equivalent which will change in moisture content when placed in a dehumidified warehouse. To determine the turnover load it is necessary to assume an annual turnover rate and, knowing the building storage capacity in measurement tons, it is possible to estimate approximately how many pounds of wood or wood equivalent will enter the building. Again utilizing Figure 15 the difference in moisture content of the wood at outside and inside conditions can be found. The difference in moisture content of the stores themselves multiplied by the weight of stores turnover will give the pounds of moisture from this source.

e. Door Opening Load For warehouses averaging a 10% turnover of stores, it has been found that the daily door open time averages one-half hour. In a survey of test data relating to air infiltration through doors, the Davison Chemical Corporation found that the average amount of air admitted per hour of door opening time was 27% of the building volume. Considering a half hour of door open time per building per day the calculation of the amount of moisture follows in the same manner as that for calculating the breathing load using the difference in specific humidity of the indoor and outdoor air. For each hour of door open time, outdoor air admitted will be equal to 27% of the building volume. This quantity of air expressed in pounds multiplied by the specific humidity difference will give the pounds of moisture from this source.

f. Infiltration Load From the analysis of the moisture loads within operational depots it was determined that the average warehouse similar to those in use at the inland supply depots have an infiltration rate of approximately one air change per day as compared with a 25% air change per day originally allowed in design calculations. The determination of the amount of infiltration to be expected in any given building is a rather intangible factor because it depends on prevailing climatic conditions, type of building, building design, orientation, building size, and the type of building materials involved. The analysis referred to in this report applies to concrete block buildings or wood frame and asbestos-cement sided buildings. There are, however, studies being conducted by the Bureau of Yards and Docks at its Civil Engineering and Research Evaluation Laboratories on the air permeability of different types of construction. When the results of these tests are availble, more reliable data on the air leakage which may be expected of different types of construction will be available. Until such a time as additional test data on infiltration rates are available, an estimated air leakage of one air change per day should be used. The calculation of the infiltration load is made in the same manner as that for breathing and door opening. This calculation requires an exchange of air equal to the building volume and, knowing the inside and outside specific humidities, the difference in moisture content multiplied by the quantity of air exchanged gives the quantity of moisture due to infiltration. In certain climatic areas where outdoor conditions prevail with a lower moisture content than that to be maintained within the warehouse, the infiltration load will be a negative and produces a dehumidifying effect. This is the principle by which selective ventilation accomplishes controlled humidity conditions in a warehouse. It is common practice in areas where favorable climatic conditions exist to open warehouse doors to allow the free movement of outside air whenever the outside air is at a lower moisture content than that maintained indoors.

The sum of these six moisture load components provides the total moisture load to be expected in a dehumdified warehouse. The moisture load by transmission through the roof has not been mentioned because the permeability of the built-up roofs in common use today for warehouses is so small that the resulting transmission load can be neglected. Breathing in a building due to a change in atmospheric pressure is also neglected because its magnitude is small.

3. Sample Calculations of Daily Moisture Load. A sample calculation of a daily moisture load is presented to show the steps involved in determining the average daily moisture load. The calculations are based upon a 30 day (1 month) period so the average daily moisture load is 1/30 of the total.

For this sample calculation the site selected for this dehumidified warehouse is in an area having climatic conditions similar to that of Cincinnati, Ohio. The first step is to examine the local weather bureau records over a five to ten year period to determine which month of the year has the highest average dewpoint temperature. (The dewpoint temperature is obtained from the Weather Bureau publication, "Station Meteorological Summary" W.B. Form 1001 C and "Special Meteorological Summaries" W. B. Form 1101 C - Supplement.) These are monthly summaries of weather data and are prepared for all first order weather stations. Other Weather Bureau data which are more desirable but not conveniently available are the "New Orleans Data". These data include a summary of dewpoint temperatures based on a frequency of occurrence, but unfortunately the data is not published or conveniently available for engineering design use.

For the Cincinnati area, the maximum outdoor dewpoint during July is approximately 64°F. The mean dry bulb temperature during July is 76.3°F. Past operating experience has shown that the warehouses operate (during the summer months) at a dry bulb temperature of five degrees higher than the outdoor mean temperature, so in this case, the indoor temperature for July is 81.3°F. Therefore, if the indoor relative humidity is to be maintained at 40%, the indoor dewpoint temperature is 55°F. The relationship between dry bulb temperature, relative humidity, and dewpoint temperature is found from any standard psychrometric chart.

The building to be dehumidified is a 200' x 600' warehouse with a wall height of 25 feet. The actual floor area utilized for storage is estimated at 70% of the gross area with the stores stacked to an average height of 16 feet. The calculated stores volume is 1,344,000 cubic feet or 33,600 measurement tons (40 cubic feet per measurement ton). The anticipated annual stores turnover rate is 10%. The 8" concrete block building walls have a permeance of 2.4 perms. See Table of Perms and Permeability, Table VI. The data and sample calculations of the design moisture load are summarized as follows:

Psychrometric Data

Conditions	Outside	Inside	Difference
Dry Bulb °F.	76.3	81.3	
Dew Point °F.	64.	55.	
Relative Humidity %	67	40	
Specific Humidity, W_s, lbs. H_2O/lb. dry air.	0.0128	0.0092	0.0036
Vapor Pressure, P, in. Hg.	0.6007	0.4356	0.1651
Moisture Content of Wood	12	7.4	4.6

Building Data

Wall area 40,000 sq. ft.

Floor area 120,000 sq. ft. (6" Portland cement over washed sand subsoil)

Building volume 3,000,000 cu. ft.

Wood content of the building - negligible

Breathing Load

Specific volume $(v_1) = .0252\ (81.3 + 4 + 460) = 13.78$ cu. ft./lb.

Specific volume $(v_2) = .0252\ (81.3 - 4 + 460) = 13.55$ cu. ft./lb.

$$\frac{\text{Building Volume}}{V_1} - \frac{\text{Building Volume}}{V_2} = \text{lbs. of air removed}$$

$$= \frac{3,000,000}{13.78} - \frac{3,000,000}{13.55} = 3700 \text{ lbs. of air removed.}$$

Daily Load:

$(3700) \times (0.0036) = 13$ lbs. H_2O per day.

Wall Transmission Load

Daily Load:

$$(\text{Wall permeance}) \times (\text{wall area}) \times (24 \text{ hours}) \times \frac{(P_1 - P_2)}{7000} =$$

$$(2.4) \times (40,000) \times (24) \times \frac{(0.1651)}{7000} = 54 \text{ lbs. } H_2O \text{ per day.}$$

Floor Transmission Load

Daily Load :

$$= (\text{floor transmission rate}) \times \frac{(\text{floor area})}{1000}$$

$$= (4.5) \times \frac{(120,000)}{1000} = 540 \text{ lbs. } H_2O \text{ per day.}$$

Stores Turnover Load

Daily Load:

=(daily turnover rate) x (building storage capacity) x (wood equivalent per measurement ton) x (difference in moisture content of the wood) =

$$= \frac{(.10)}{360} \times (33,600) \times (200) \times (.046) = 86 \text{ lbs } H_2O \text{ per day.}$$

$$= (.5) \times (.27) \times (3,000,000) \times \frac{(0.0036)}{13.5} = 108 \text{ lbs. } H_2O \text{ per day.}$$

Infiltration Load

Daily Load: =

(no, of air changes per day) x (vol. of bldg.)

$$= (1) \times (3,000,000) \times \frac{(0.0036)}{13.5} = 800 \text{ lbs. } H_2O \text{ per day.}$$

SUMMARY OF MOISTURE LOAD COMPONENTS

Component	Pounds of water per day	Percent
Breathing	13	.8
Transmission		
Wall	54	3.3
Floor	540	33.7
Stores Turnover	86	5.4
Infiltration - door open	108	6.7
Infiltration	800	50.0
Total daily load	1601	100

For purpose of comparison the calculated annual moisture loads for various Naval Supply Depots are shown in Table IV. The variation of the moisture load throughout the various months of the year are shown in Table V. Analysis of Table V indicated the importance of local climatic conditions on the dehumidification load.

TABLE IV
ANNUAL COMPONENT MOISTURE LOAD AT NAVAL SUPPLY DEPOTS

Pounds of Water per Hour

STATION	BREATHING	DOOR OPEN	INFILTRA-TION	FLOOR	WALLS ROOF	TURN OVER	ANNUAL TOTAL
Scotia	8,460	57,090	52,830	74,520	7,080	25,920	225,900
Mechanicsburg	9,820	66,450	61,560	74,520	8,040	25,920	246,310
Clearfield	1,650	10,770	10,050	37,170	1,470	25,920	87,030
Spokane	3,840	26,070	24,180	37,170	3,330	25,920	120,510
Total	33,970	230,070	212,580	290,850	28,230	124,560	920,260
PERCENT OF TOTAL LOAD	4	25	23	32	3	13	100

TABLE V

MONTHLY AND ANNUAL DEHUMIDIFICATION LOADS FOR MAINTAINING RELATIVE HUMIDITIES OF 40%

LBS. OF WATER TO BE REMOVED IN EACH PERIOD

Station	Mechanicsburg	Scotia	Clearfield	Spokane	Cheatham
*January	12,690	11,220	9,570	11,070	12,720
February	12,750	11,400	10,320	11,190	12,600
March	14,610	13,140	10,050	11,250	14,100
April	16,080	15,210	8,160	10,530	15,030
May	19,740	17,970	6,390	8,010	19,500
June	28,290	24,510	3,660	11,370	27,240
July	31,680	29,490	2,400	4,950	32,340
August	33,030	29,820	1,440	4,170	32,280
September	27,150	25,080	4,800	9,270	27,270
October	21,180	20,250	9,090	13,830	19,980
November	16,110	15,600	16,500	12,390	15,270
December	13,050	12,210	10,650	12,480	12,180
ANNUAL TOTAL	246,360	225,900	87,030	120,510	240,510

Note: 1. All months were considered as having 30 days, for simplification of comparison and calculation.

2. All warehouses have 121,200 sq.ft. of floor area with the exception of Cheatham which has 100,000 sq.ft.

* A near standard warehouse.

D. <u>Permeability of Construction Materials</u> The following Table VI contains a number of selected building materials for which permeability values under different conditions of relative humidity are given. The selected materials and permeability data are from a comprehensive survey of vapor transmission properties of building materials conducted by the Engineering Experiment Station, University of Colorado, under Contract No. 7-73244 which was sponsored by the Bureau of Yards and Docks through the U.S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California. The data are reported in the Final Report - "Survey and Analysis of the Vapor Transmission Properties of Building Materials" January, 1955. In addition to the data selected from the above report, additional permeability data on sprayed-on barrier materials was taken from the National Bureau of Standards report No. 2163 "Moisture Resistant Coatings for Walls of Structures Used for Storage" dated January 7, 1953. Experimental work on these coatings was conducted by the National Bureau of Standards and sponsored by the Bureau of Yards and Docks.

TABLE VI

WATER VAPOR TRANSMISSION COEFFICIENTS FOR

SELECTED BUILDING MATERIALS

Material	Permeance Perms-M	Permeability Perms - In.	Avg. Rh
PLYWOOD			
Various types of wood and glue		(Avg.) 1.6	65
1/4" Douglas Fir, Exterior Grade	0.2		25-35
1 coat shellac	Avg.5.9		65
1 coat asphalt paint	2.6-3.4		65
2 coats asphalt paint	0.4-0.9		65
1 coat aluminum paint	2.3-3.0		65
2 coats aluminum paint	1.3		65
1 coat primer plus 1 coat flat wall paint	2.6		65
1/2" Douglas Fir	Approx.3.2		65
1 coat asphalt paint	1.0-1.4		65
2 coats asphalt paint	0.4		65
1 coat aluminum paint	1.5		65
2 coats aluminum paint	0.8-1.2		65
1/4" Exterior type 3 ply	0.72		50-
1/4" Interior type 3 ply	1.86		50-
INSULATING FIBERBOARD			
Miscellaneous uncoated		12- 41	25-75
Structural insulating board (aspen fiber density = 17.3 lb. per cu. ft.)		31 - 34	35-73
Structural insulating board (hard pine, density = 18.1 lb. per cu. ft.)		10.7	85
Celotex (sugar cane fiber)		14.3,19.1	
Paper fiberboard		9.1,12.7	65
1/2" Insulating board lath (factory coated)	Avg.8.3		25
1/2" Interior finish insulating fiber board	Avg. 65		25
1 coat varnish	Avg.11.1		25
2 coats varnish	Avg. 4.6		25
1 coat sealer (linseed or veg. oil, resin board)	1.2-2.3		25
2 coats sealer	0.8-1.6		25
1 coat primer plus 1 coat flat wall paint	0.8-1.7		25
2 coats flat wall paint	2.9-4.8		25
1 coat water emulsion paint	37 - 48		25
2 coats water emulsion paint	Avg.47		25
25/32" Structural insulating sheathing (uncoated)	21 - 58		25
1 coat black paint (gilsonite, linseed oil base)	25.7		25

Material	Permeance Perms-M	Permeability Perms-In.	Avg. Rh
2 coats black paint	4.2		25
3 coats black paint	0.9		25
	1.5		85
1 coat metallic gray paint (synthetic resin, gilsonite, veg. oil base)	12		25
1 coat cream primer (processed drying oils, resin base)	3.1		25
1 coat thin asphalt paint (asphalt in mineral spirits)	22.4		25
2 coats thin asphalt paint	3.4		25
3 coats thin asphalt paint	0.5		25
	2.2		85
1 coat thick asphalt paint (asphalt pigment in petroleum naptha)	25.8		25
1 coat asphalt base plastic (asphalt pigment in petroleum naptha applied by troweling)	1.2		25,85
1 medium coat asphalt plastic (asphalt and volatile thinner, fiber pigment apply by troweling)	0.9		25
1 heavy coat asphalt plastic	0.8		25
	0.14		85
1 light coat asphalt plastic	0.3		85
Homasote			
1 coat aluminum paint	12.1		62.5
2 coats aluminum paint	0		62.5
COMPRESSED AND COMPOSITION FIBERBOARD			
Compressed fiberboard		0.9 - 1.9	65
Masonite Presedwood		1.4	37.5
		2.4	37.5
Masonite Presedwood, tempered		0.6	37.5
Cement-asbestos board		0.7 - 2.1	various
1" fiberboard, faced both sides with 1/8" sheet asbestos board	2.5		65
1/2" fiberboard, faced one side with 1/8" sheet asbestos board	0.8		65
1" Cemented wood fiber and 3/8" ground newsprint bound with asphalt	5.5		65
1" Cemented wood fiber and 3/8" ground newsprint bound with asphalt with a sprayed coat of aluminum paint	4.7		65
1" Cemented wood fiber and 3/8" ground newsprint bound with asphalt with a troweled coat of sand and cement asphalt emulsion plus 2 coats aluminum paint	0.6		65

Material	Permeance Perms - M	Permeability Perms - In.	Avg. Rh
CEMENT, PLASTER, CONCRETE, AND MASONRY			
Plaster		Avg. 13.5	40-75
Plaster on wood lath	11		100-30
Plaster on metal lath, 3/4"	15		40-X
Plaster on plain gypsum lath (with studs)	20		40-85
Gypsum, lime plaster on metal lath		17.9	30
Gypsum on wall board - plain- 3/8"	50		50-20
Insulating wall board (uncoated) 1/2"	50-90		40-X
Stucco		2.1	
Concrete		2.5	62-75
(1:2:4 mix)		3.2	
8" Cored block wall, limestone agrgt.	2.4		79-68
Brick wall with mortar - 4"	0.8		50-X
Tile wall with mortar - 4"	0.12		50-X
3/8" Plasterboard (plaster enclosed between sheets of heavy paper)	34.4		
3/8" Gypsum lath	29.1		57.5
Gypsum board, paper removed both sides	47.1		65
1/2" Plaster on 3/8" gypsum lath	20		60
Plaster on fiberboard lath	20.5		65
Plaster on wood lath	2.9-10.9		65-75
4" Brick and Mortar wall	0.8 1.1		75
8" Cement Block (limestone aggregate) and mortar wall	2.0-2.4		25-74
4" Tile and Mortar wall	0.12		75
7/8" Concrete plus 1 coat black asphalt type metal coating paint-application by troweling	0.3		49
Concrete plus 2 coats liquid asphalt coating	1.6		63
Concrete plus 2 coats aluminum paint	0.5		75
PLASTER WITH APPLIED COATINGS			
3/8" Plaster Board			
1 coat water emulsion paint	36.5		
1 coat rubber base paint	0.5		
1 coat aluminum paint	0.3-0.9		65
Gypsumboard, paper removed (thickness not specified)	47		65
1 coat interior primer and sealer	1.7		65
1 coat primer plus 1 coat lead and oil paint	2.0		65
1 coat primer plus 2 coats lead and oil paint	1.1-1.7		65
1 coat glue size plus 2 coats lead and oil paint	2.7		65

Material	Permeance Perms - M	Permeability Perms - In.	Avg. Rh
Gypsum lath with aluminum foil backing	0.08-0.4		65
1/2" Plaster	approx. 27		40-75
2 coats clear lacquer	4.7		42
1 coat spar varnish (veg. oil, synthetic resin base)	2.4		48
2 coats spar varnish	0.9		49
1 coat aluminum paint, applied by spraying	2.8		53
2 coats aluminum paint, applied by spraying	1.3		48
1 coat black asphalt type metal coating	0.3 -0.6		49
1/2" Plaster on 1/2" Fiberboard lath	14.4		25
1 coat sealer or varnish	2.4 -4.1		25
1" sealer, varnish or white primer plus one coat flat wall paint	1.5 -2.9		25
1/2" Gypsum, lime plaster on metal lath	7.9		25
2 coats flat white paint	0.6		25
1 coat seal coat paint plus 2 coats aluminum paint	0.4		25
3/4" Gypsum, lime plaster on metal lath	10.2		25
2 coats linseed, tung oil in mineral spirits	3.2		25
2 coats varnish	1.6 -2.1		25
2 coats flat or semi-gloss interior wall paint (linseed oil base)	av. 3.1		25
2 coats white enamel	1.2		25
1 coat aluminum paint	0.6- 2.1		
2 coats aluminum paint, aluminum bronze paint	av. 3.3		25
1 coat asphalt	2.4- 4.5		25
1 coat water emulsion paint	6.3		
1 coat rubber base paint	2.4		
MEMBRANE MATERIALS			
Single Sheet Papers			
Kraft paper, uncoated (30#)	138		
Parchment paper, lightly waxed one side	40.4		50
Kraft paper, wax saturated (20-25 lb./ 500 sq. ft.)	av. 20.8		65
Glassine, waxed both sides	av. 3.8		50
Brown waxed paper, waxed both sides	3.0		50
Kraft paper, wax coated	0.4- 0.7		25,37.5
Sisal kraft, plain	0.5		62.5
	1.2		75
Sisal kraft, treated	0.8		75
Kraft paper, asphalt infused and coated one side	0.6		

Material	Permeance Perms - M	Permeability Perms - In.	Avg. Rh
Kraft paper, asphalt infused on both sides	ave. 4.8		65
Sheathing papers			
Dry	135, 171		37.5
Rosin sized or "Red Rosin"	av. 66		60-75
Slaters felt, tarred	av. 42-48		65 high
Felt sheathing paper, tar saturated			
31 lb./500 sq. ft.	13.2		37.5
56 lb./500 sq. ft.	18.7		37.5
25-45 lb./500 sq. ft.	17.6		65
Sheathing felt, tar saturated asbestos (15 lbs.)	1.7		37.5
Sheathing paper No. 2 asphalt saturated (25 lb./400 sq. ft.)	1.4, 16		37.5
Kraft sheathing paper asphalt treated (25 lb./400 sq. ft.)	1.5		37.5
Felt sheathing paper, asphalt saturated			
22 lb./500 sq. ft.	3.3		25
25-35 lb./ 500 sq. ft.	20.2		75
	av. 8.3		65
40-50 lb./ 500 sq. ft.	3.4 -17.5		65
Sheathing felt, asphalt saturated asbestos 15 lbs.(70-75 lb./500 sq.ft.)	0.8		25
	13.1		37.5
	2.8		75
	1.1 - 5.3		high
50 lb. water proofing felt	0.4		37.5
	1.0		high
Felt sheathing paper, asphalt saturated and coated			
35 lb./500 sq. ft.	av. 0.5		65
43 lb./500 sq. ft.	0.3		25
	0.6		75
50 lb./500 sq. ft.	av. 0.4		
Heavy sheathing or roofing felt, asphalt saturated, and coated			
30 lb.(157 lb./500 sq. ft.)	0.15		65
40" (200-208 lb./500 sq. ft.)	0.03		25
	0.08		37.5
	0.26		65
	0.14		75
55" (255 lb./500 sq. ft.)	0.03, 0.08		25
	0.11		65
	0.12, 0.38		75
Sheathing felt, asphalt saturated and coated asbestos			
20 lbs. (93 lb./500 sq. ft.)	0.15		37.5
	1.1 - 2.1		high

Material	Permeance Perms -M	Permeability Perms - In.	Avg. Rh
60" (270 lb./500 sq. ft.)	0.08		25
	0.29		75
Duplex Papers			
(two or more sheets of paper bonded with asphalt or tar laminations)			
Untreated Kraft paper, asphalt laminations			
20-20-20(10,11 lb./500 sq.ft.)	0.8 - 1.2		25
	1.5 - 2.0		75
30-30-30-(14,16 lb./500 sq.ft.)	av. 0.8		25
	av. 3.2		37.5
	av. 2.6		75
30-70-30 to 30-100-30	0.3 - 0.8		25
30-50-60	0.4 - 6.1		65
40-55-40	av. 1.3		
60-50-60	0.5 - 6.2		75
50-60-50	av. 3.5		
60-60-60-, 40-73-40, 40-95-40-, 45-90-45 (22-30 lb./500 sq. ft.)			
30-110-30 to 30-193-30	0.2 - 0.4		25
60-80-60	0.2		46
50-130-50	0.5 - 1.8		75
30-100-60	0.9 - 2.3		65
60-150-60, 40-180-40, 60-180-60 (30-50 lb./500 sq. ft.)			
Asphalt saturated Kraft paper one side, untreated paper one side, asphalt lamination			
50-65-50 (28 lb./500 sq. ft.)	1.9		75
60-30-60 (30 lb./500 sq. ft.)	1.0		25
	6.1		75
Asphalt saturated Kraft paper both sides, asphalt lamination			
Waxed Kraft paper one side, untreated paper one side, asphalt lamination			
30-105-30 (32 lb./500 sq. ft.)	0.6		65
Coal tar saturated Kraft paper both sides, asphalt lamination			
30-75-30 to 30-85-30 (26-31 lb./500 sq. ft.)	1.6 - 2.1		65
Paper coated with metal oxides, asphalt lamination	0.5 - 1.9		65
Foils			
Aluminum foil surfaced papers 20 lb. bond paper, 0.00035 in. aluminum foil one side (16 lb./500 sq. ft.)			
aluminum foil on low humidity side	0.005		25
	4.4		75
aluminum foil on high humidity side	0.003		25
	1.07		75

Material	Permeance Perms - M	Permeability Perms - In.	Avg. Rh
Kraft paper, aluminum foil, one side	0.15		65
Kraft paper, aluminum foil both sides	0.12		65
Foil surfaced reflective insulation, double faced	0.08- 0.13		65
Corrugated asbestos on aluminum foil back paper (49 lb./500 sq. ft.)	1.0 - 1.7		75
Aluminum Foil, 0.004 in. thick	0.00		50
Paint Films			
Varnishes			
Clear air drying, insulating	0.0061		50
Orange shellac	0.0036- 0.0062		50
White lead, zinc oxide pigment - linseed, china wood oil vehicle	0.010		50
Titanium oxide pigment --linseed oil, ester gum varnish	0.007		50
AIR SPACES			
Air space, vapor flow downward		120	
Air space. vapor flow horizontal		258-399	
Air space, vapor flow upward		182-707	
1/16" vertical crack in 1/2" plaster, painted 2 coats gloss green enamel	2.55		
1/16" horizontal crack in 1/2" plaster, painted 2 coats gloss green enamel	2.04		
1/16" horizontal gap between steel plates, plates overlapped 1/2 in.	0.87		
1/16" vertical gap between steel plates, plates overlapped 1/2 in.	1.62		
SPRAYED-ON BARRIER MATERIAL			
GILSONITE			
Sike Seal, Heavy Consistency		0.1	
Gilsonite # 4010 Vaporseal		0.1	
Sike Seal Dampproofing Paint		0.2	
ASPHALT			
Hydrocide Mastic		0.1	
Protek-coat		0.1	
Semi-Mastic # 214		0.2	
KDS # 201 Vaporseal		0.4	
Dehydrantine # 10		0.1	
Uniflex Aluminum Roof Coating		0.1	
X2497 Mortel Vapor Barrier		0.1	
Flintkote Aluminum Paint		0.1	
Laykold Weather Coat		2.9	
C-13-C4		0.2	
C-13-NPC		0.3	
C-13-E		0.1	
10-16 Asphalt Emulsion		0.1	

Material	Permeability
ASPHALT AND RUBBER	
Laykold Cement	0.9
Asphalt Aluminum paint	1.4
PROCESSED FISH OILS	
XX Mica # 3911	0.1
FATTY-ACID GUM	
Waterlock	0.4
Plasticseal	0.3
Plasticseal	0.3
Redicoat	0.3
Plasticseal	0.2
CHLORINATED RUBBER AND TUNG OIL	
Paracrete	0.9
COAL TAR	
Processed Coal Tar - Bituplastic # 28	0.4
Bitumastic # 50	0.4
Bituminous Resin-Emulsion	0.7
BITUMINOUS RESIN	
Robertson Everplastic coat	0.1
Robertson Everplastic coat	0.1
VINYL COPOLYMER RESIN	
Vinyl Floor Enamel	1.7
SYNTHETIC RESIN	
Amercoat # 33	0.5
VINYL RESIN	
# 30-36 Sealfast	1.0

IV. CONVERSION OF WAREHOUSES FOR CONTROLLED HUMIDITY STORAGE

A. CONVERSION OF AN EXISTING WAREHOUSE.

1. General The principal objective in the conversion of any existing warehouse to make it suitable for controlled humidity storage is to seal the building against the entrance of moisture against vapor transmission and air infiltration from the outside air. The extent to which this sealing must be accomplished depends on the type of building and its construction. Essentially the same sealing operations are carried out in any building regardless of construction. However, certain details in each building will require individual consideration and, therefore, only the general modifications will be discussed here. Because of the individual details which occur in each and every building, the extent of "sealing" will vary as will the cost of conversion.

Since the primary source of moisture in a dehumidified warehouse is that carried into the building by the infiltration of outside air, the principal sealing objective is to minimize air infiltration. The parts of the building which admit most of the outside air are doors, windows, eaves, other building openings. There is a certain amount of air which infiltrates through the walls themselves, This is small in comparison to the air leakage through cracks and other building apertures. Many of the existing dehumidified warehouses which were converted for controlled humidity storage have a vapor barrier material sprayed on the interior side of the building walls to resist vapor transmission through the wall. It is now felt that the application of such a coating is unnecessary in view of the fact that the quantity of moisture entering the building by diffusion through walls due to the vapor pressure differences is small and may be neglected insofar as sealing is concerned. Eliminating this sprayed on coating will reduce the conversion cost considerably.

The steps necessary to seal various parts of the building are relatively simple; however, they must be given adequate consideration. Since each building requires individual consideration, it is impossible to outline specifically what materials should be used and how they should be applied. Rather, the steps discussed here cover the general points which should be accomplished in sealing the various components of the building. When considering various parts of the building to be sealed, the selection of a sealing method must give due consideration to the maintenance required to maintain the seal because it has been found from experience in operation of dehumidified warehouses that it is necessary to periodically recaulk and reseal buildings.

2. Wall Sealing For sealing walls of buildings having concrete block or reinforced concrete walls, it is recommended that the exterior of these buildings be coated with a cement-water type paint. Prior to the application of the cement-water paint, any loose mortar joints or cracks in the blocks or walls should be filled with mortar. The point where the floor intersects with the wall should be carefully caulked with a suitable non-hardening caulking material. The most important part of the wall which should be tightly sealed is at the eave line at the intersection of the wall and roof. At this point most of the outside air infiltration is admitted to the building. Also, this part of the wall is most difficult to seal. The construction details at this point vary depending upon the type of roof deck and the type of building framing used. Where the roof overhangs the wall, it is recommended that solid blocking be placed between the roof structural members which rest on the wall with all joints around the blocking caulked. Where the roof is capped at the point of intersection with the wall, it is recommended that the flashing be secured and caulked to the building wall. There should be additional caulking on the inside where the roof and wall join. The importance of obtaining a tight seal at the eaves cannot be overemphasized.

3. Window Sealing There are basically two types of windows, wood frame or steel sash, encountered in warehouse buildings. For steel sash windows, it is recommended that glazing be tight and any movable portion of the sash secured and caulked. The perimeter of the entire sash at the point of intersection with the wall should be thoroughly caulked. The window glass itself should be painted with light color paints so as not to permit any direct transmission of sunlight.

For windows having wood frames, it is necessary that the glazing be tight and any movable portions of the sash be securely fastened and caulked. The entire perimeter of the window frame should also be caulked.

4. Door Sealing When converting a warehouse for controlled humidity, all of the material doors will not usually be required for materials movement. The doors required for materials movement should be blanked off and sealed. These inactive doors should be securely fastened to their frame with all joints being caulked including the door frame at the point of intersection with the wall. Under these conditions, it is possible to inactivate the doors by sealing and yet readily reactivate them if required for future use. Non-active doors should be so marked. If blocked by stores on the inside, they should be so designated on the outside.

Doors actively used should be weatherstripped to make them as tight as possible. The frame itself should be thoroughly caulked at the point where it intersects with the wall. The bottom of the door should be provided with a rubber gasket seal at this point. If the doors are hinge type, they should be replaced with overhead sectional doors as this type can be made tighter than the hinge type doors.

All personnel doors are generally utilized when a building is used for dehumidified storage. These doors, like the active material doors, should be weatherstripped and the frame thoroughly caulked. Glass on these doors should be tightly glazed.

5. Vent Sealing All roof ventilators or similar openings in the roof or walls of the building should be sealed by blanking the opening with sheet metal. These openings should also be caulked with new sheet metal being painted.

6. Fire Sprinkling System In warehouses which have wet fire sprinkling systems, the fire system should be converted to a dry sprinkling system in order to avoid freezing during periods when the outdoor temperature may produce freezing temperatures within the warehouse if it is anticipated that the building will be unheated.

7. Miscellaneous Sealing Wherever office spaces, lavatories, utility rooms, or similar rooms are located within the building, it is necessary to seal these spaces from the interior space that is being dehumidified. All doors, windows, or other openings into the dehumidified space should be sealed in the same manner as recommended above. When only a part of a building is to be converted for controlled humidity storage, the exterior wall, etc., should be treated as previously discussed. The interior partitions separating the space should be made as tight as possible to reduce any air leakage from the non-dehumidified area.

A special point of importance, although not a sealing operation, is the need for eaves on buildings used for controlled humidity storage. Without eaves, external water from the roof tends to wet the wall. For masonry or concrete walls this may add considerably to the daily moisture load on the dehumidification machines. Moreover, the roof drainage from the eaves should be directly into storm sewers, or it should be drained away from the building so as not to create a moisture problem beneath the floor.

Other than sealing ventilators or similar openings in the roof, it is not necessary to treat a built-up roof to give added resistance to vapor transmission. A built-up roof has a high resistance to vapor diffusion and practically all warehouse buildings have this type of roof.

B. **CONVERSION OF EXISTING WAREHOUSES AT NAVAL SUPPLY DEPOTS.**

1. General At the inception of the controlled humdidity storage program at inland Naval Supply Depots in 1948 some 67 buildings having a gross floor area of 7,800,000 feet were modified for this type of storage. These buildings were the standard size (200' x 600') Navy warehouses consisting of General and Heavy Areo Equipment storehouse. For the purpose of comparison, the construction of these buildings is summarized into three categories, Types I, II, and III.

Type I Construction are buildings having 12" concrete block walls varying in height from 20 to 26 feet. Floors are 6 inch reinforced concrete. The wall and roof framing is either precast concrete or steel. The roof construction consists of a built-up asphalt or pitch surface on decks of concrete, wood or poured gypsum. These buildings have from fourteen to sixteen 12 x 16 foot overhead cargo doors.

Type II Construction These buildings are the same size as Type I but differ in the type of wall construction, wall framing, and windows. The wall construction consists of either 12" brick or 6" concrete base walls extending from floor to window sill height at a distance of 4 feet 3 inches above the floor level. The walls above this level consists of approximately 6,500 sq. ft. of wood frame wall, with wood sheathing and an exterior finish of asbestos cement board. The walls contain center pivot window sash comprising approximately 9,700 sq. ft. The roofs of these buildings are wood beam and girder frame construction with poured gypsum decks and built-up roofing. The Heavy Material and Aeronautical Warehouses have this type of construction and these buildings have a 60 ft. wide roof monitor in the center of the entire length of the building. The ceiling height in the monitor section is approximately 30 ft. and in the side lean-to sections approximately 15 to 17 ft.

The 9,700 sq. ft. of glass in the building walls is divided between the lean-to and monitor walls. General storehouses of this type have 28 sectional overhead type cargo doors.

Type III Construction consists of buildings the same size as type I and II excepting that the wall construction consists of poured reinforced concrete. Other building components such as floor and roof construction are the same as Type I.

The distribution of buildings by type at the four inland supply depots is as follows:

Station	Number of Buildings Type I	Type II	Type III	Gross Dehumidified Storage Area, sq. ft.
NSD Clearfield, Utah	1	18	----	2,280,000
NSD Mechanicsburg, Pa.	12	12	----	2,880,000
NSD Scotia, N.Y.	10	---	----	1,200,000
NSD Spokane, Wash.	2	6	4	1,440,000

2. Building Modification Although the warehouse buildings have different designs and construction features as described above, the modifications were essentially the same for all types of construction.

a. Walls The interior surfaces of all walls were sprayed with an asphalt emulsion sealer to a thickness of 1/16" to 1/8". This asphalt emulsion coating specification required a vapor permeability less than 7.0 perms. This spray coating covered the entire wall and was carried onto the ceiling surface for a distance of about 2 feet. Solid wood blocking was installed at the intersection of the roof and walls, and this was given a liberal emulsion coating. Interior office space partitions were treated the same as outside building walls.

b. Windows All movable windows were first secured and all joints as well as the window frames were caulked. The interior side of the windows were sprayed with the asphalt coating in the same manner as the wall surfaces. The exterior side of all windows were painted with aluminum paint.

c. Doors The overhead cargo doors not required for day to day operation of the dehumidified warehouse were rendered inactive by installing a 1 1/2 inch steel angle bar along the outside bottom edge of the door. This angle was secured to the floor and all joints between the exterior faces of the door and its wood frame at the base, head, and the joint of the frame and masonry wall were caulked. The horizontal joints between section of overhead cargo doors were caulked, and the face of each joint was covered with a vapor barrier type tape which in turn was covered with a bituminous paint extending the length of the joint. The exterior joints at the heads and jambs were closed with a 2 x 4 inch wood member which was secured and embedded in caulking material. The entire interior side of the door was than sprayed with the same type of asphalt emulsion coating as used on the interior wall surfaces. The exterior of these cargo doors was also painted with aluminum paint. All personnel doors not required in the use of the building were secured by this same procedure.

d. Sprinkling Systems. The fire sprinkling systems in these buildings were originally wet sprinklers, and they were converted to dry systems to prevent freezing during winter months. The conversion from wet to dry involved alterations in the valves and water supply mechanical equipment.

e. Miscellaneous In the building conversions it was necessary to install additional electrical power to accomodate the requirements of the dehumidification machines and the installation of the necessary electrical equipment required for automatic controlled operation of this equipment.

Consideration was given to some treatment to the floors of the buildings. Due to the fact that the buildings were completely stocked with materials, this was not done due to the cost of moving the stores. Certain floor sealers were investigated, and it was concluded that the life of such treatment was not sufficient to justify their use. However, the joints at the intersection of the wall and floor were sealed with an asphalt caulking material.

All roof openings such as louvers and vents were closed by covering the opening with either plywood or sheet metal. These closures were caulked and painted. Additional repairs were made to the roof where leakages were known as well as repairs to flashing and gutters to prevent rain and snow from entering at these points.

3. Warehouse Conversion Costs The cost of conversion of these buildings at the Inland Supply Depots varied from $0.27 to $0.38 per gross square foot of warehouse space with the average cost being $0.30 per square foot. The variation in unit cost is due to two primary factors: (1) the geographic location influenced the number of dehumidification machines required from two per building at NSD Clearfield to 4 per building at NSD's Scotia and Mechanicsburg; and (2) normal building repairs were made at the time the conversion was done and these costs are reflected in the overall costs.

The breakdown of the total cost on a percentage basis is as follows:

	Percentage of Total Cost
Vapor Proofing (Walls and Doors)	51
Controls and Wiring	18
Dehumidification Machines	13
Sprinkler System Conversion	18

As recommended previously in this report, future warehouse conversions do not require spraying of the interior of warehouse walls. However, this does not eliminate the cost of sealing doors, windows, and other building openings. The elimination of treating the walls should reduce the unit cost of converting the warehouses to less than $0.20 per square foot.

C. **OPERATING COSTS FOR CONVERTED CONTROLLED HUMIDITY WAREHOUSES.** Following five years of operation the annual operating cost for dehumidified warehouses at the four inland supply depots is summarized in Table VII. The annual cost of maintenance and operation in Column 2 is the direct cost associated with the dehumidification equipment. The table shows that the local climate directly affects the annual operating cost. NSD Clearfield and NSD Spokane are in a dry climate as compared with NSD Mechanicsburg and NSD Scotia.

The annual operating cost for warehouses at NSD Mechanicsburg were predicted to be $0.40 per square foot per year. The actual operating cost compares favorably with this figure.

TABLE VII

SUMMARY OF DIRECT OPERATING COSTS FOR CONTROLLED HUMIDITY WAREHOUSES

	NSD Mechanicsburg	NSD Scotia	NSD Spokane	NSD Clearfield
1. Average Annual Cost Power Required Per Bldg. for D/H	$3,395.00	$2,889.60	$ 758.75	$ 305.16
2. Average Annual Cost of Maintenance & Operation of D/H per building	1,250.00	1,950.00	1,310.76	1,047.78
3. Total cost of Operating D/H per Building	4,645.00	4,839.60	1,969.51	1,353.94
4. Average Unit Power Cost Dollar per Kwh	.0115	.010	.005	.006
5. Gross Area in Storehouse	120,000	120,000	120,000	120,000
6. Approx. Annual Cost of D/H per sq. ft. of Gross Storage Area	0.038	0.040	0.016	0.011
7. Approx. Annual Cost of D/H per sq. ft. of Gross Storage Area based on one cent per Kwh Power Cost	0.035	0.040	0.023	0.013

V. DEHUMIDIFICATION EQUIPMENT

A. DEHUMIDIFICATION MACHINES

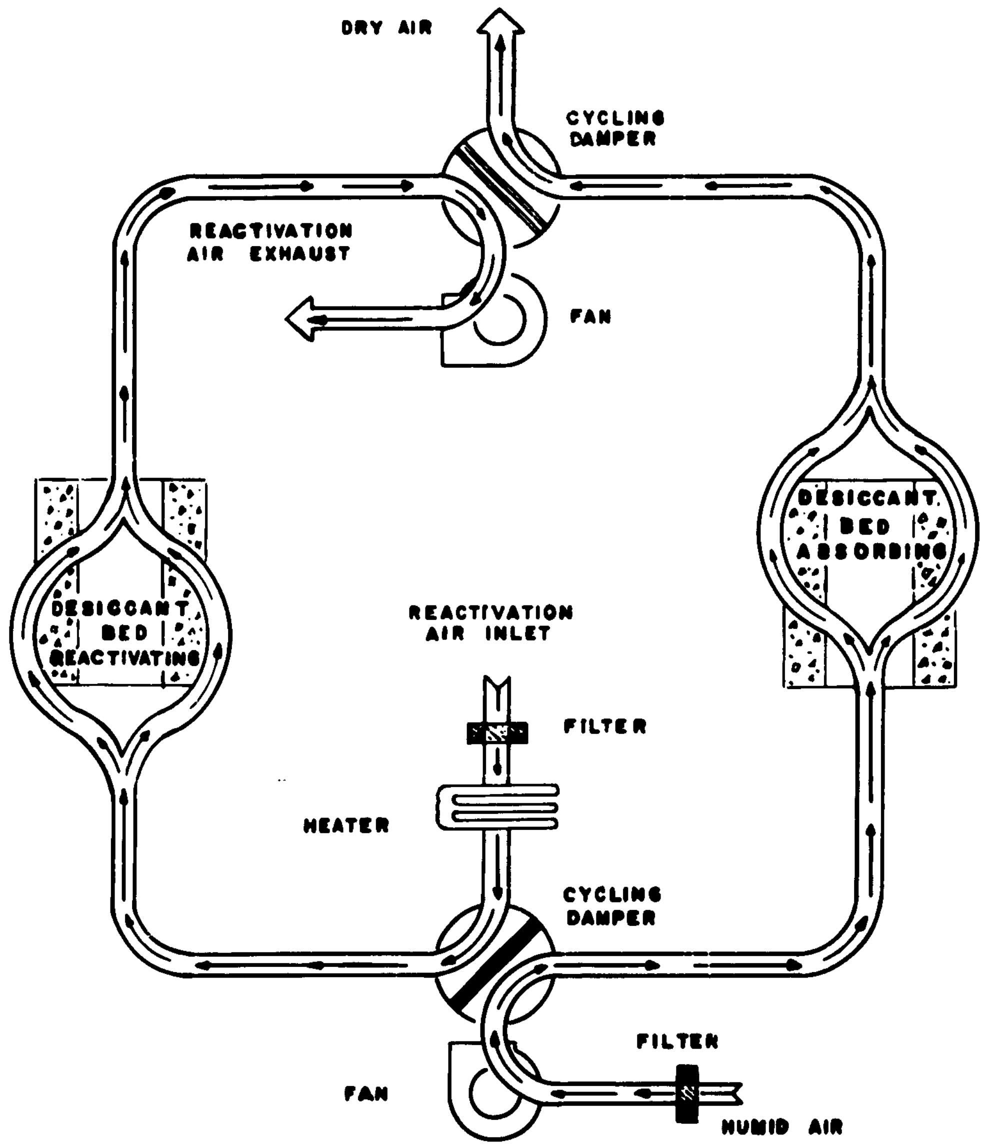
1. General The dehumidification equipment of specific interest is the type which is suitable for use in dehumidifying large storage warehouses. This equipment consists essentially of two basic parts: (1) a fan capable of moving large quantities of air; and (2) a moisture collecting media. Depending upon the principal of moisture collection used, the mechanical equipment will vary. The term "dehumidification" is commonly accepted and is a process by which the water vapor content of a given volume of gas or air is reduced. The amount of dehumidification which is to be accomplished in dehumidified storage dictates, to a great extent, the type of equipment which is suitable for this application. The process of dehumidification can be accomplished by either of two methods: (1) a combination of latent and sensible heat removal; or (2) the use of sorbents. Dehumidification by the removal of latent and sensible heat involves the use of refrigeration. Dehumidification with sorbents involves the use of a material which has the property of absorbing and retaining the water vapor which is brought into contact with it. All solid materials are sorbents to some extent as they absorb water vapor in varying degrees. The term "sorbents", however, is generally restricted to materials which have a capacity for holding large quantities of moisture in proportion to the volume and weight of the sorbent. Materials such as wood, paper, etc., all absorb moisture, but the quantity is small compared with their weight and volume. Consequently, they do not come under the general classification of a sorbent. There are two types of sorbents as defined in the American Society of Heating, Air Conditioning and Refrigeration Engineers Guide: (1) adsorbent - a material which does not change physically or chemically during the sorption process; and (2) absorbent - a material which changes either physically or chemically or both during the sorption process.

The degrees of dehumidification accomplished in dehumidified storage does not vary widely and should not be compared with industrial drying applications involving the removal of extremely large quantities of moisture. There are three main principles of dehumidification applied to dehumidified storage. These are (1) chemical desiccant, (2) refrigeration, and (3) selective ventilation. Each is discussed according to its application for the dehumidification of large warehouses.

2. Dehumidification with Chemical Desiccants Dehumidification with chemical desiccants may be accomplished with either an adsorbent or an absorbent. An adsorbent is often referred to as a dry desiccant and is a material such as activated alumina or silica gel. Absorbents are most often referred to as liquid desiccants which are solutions of lithium chloride or ethylene glycol. Both dry and liquid desiccants accomplish dehumidification or removal of moisture by the same principles. Sorbents have the ability of removing water vapor from a gas such as air due to the fact that the vapor pressure of the sorbent is less than the vapor pressure of the water vapor in the air surrounding the sorbent. Due to the vapor pressure differences existing when the air is brought into contact with the sorbent, the moisture in the air being at a higher vapor pressure will be adsorbed and continued to be adsorbed until the vapor pressure of the sorbent is raised and in equilibrium with the water vapor of the surrounding air. As this equililbrium condition is attained, the sorbent will increase in weight equal to the amount of water vapor which is removed from the surrounding air. When water vapor is removed from the air, its moisture content is reduced; consequently, there is a reduction in both specific humidity and relative humidity.

a. Dry Type Desiccants The most common dry type of sorbents are silica gel and activated alumina. The adsorption of water by these materials is commonly interpreted as a condensation process and, as such, the condensation process involves heat transfer in the form of latent heat of condensation and the heat of wetting. While the condensation or adsorption of water is taking place within the desiccant, the latent heat of condensation and the heat of wetting is transferred from the water to the solid desiccant. If provisions are not made to remove this heat, it is transferred from the water to the desiccant and eventually to the air which is being dried. The performance of dry type desiccants is affected by two factors: (1) the temperature of the air entering the desiccant; and (2) the moisture content of the air entering the desiccant. Dry desiccants have the capacity for holding a greater quantity of moisture at lower temperatures and therefore are more efficient in removing moisture when the entering air is at a combination of low temperature and high moisture content.

A schematic diagram of a dehumidification machine which utilizes dry type desiccants is shown in Figure 16. . For warehouse dehumidification, automatic equipment is most desirable when the moisture load is such that continuous dehumidification is required. This type of operation is accomplished by having two beds of desiccant such that one bed is adsorbing moisture while the other is being dried and reactivated. The dry type desiccants are reactivated by heating to a temperature within the range of 300° to 600°F. By heating either the desiccant or the air passing over or through the desiccant, the moisture adsorbed within the desiccant is removed. The warehouse air to be dried is passed through the desiccant and returned again to the space being dehumidified. The outside air required for drying and reactivating the desiccant bed is circulated through the heated desiccant bed and returned to the outside. The desiccant beds in these dynamic dehumidification machines are arranged so that each of the beds are switched on and off the adsorption cycle. The reactivation cycles are automatically controlled by four way valves and automatic timing and control devices. The preformance characteristics of the Pittsburgh Electrodryer Model J-150 and the Desomatic Model DOR-800 dynamic dehumidification machines are shown in Figures 17, 18, 19, and 20. These curves give the machine performance as a function of inlet air temperature.



Schematic of Solid Desiccant Dehumidification Machine

Figure 16

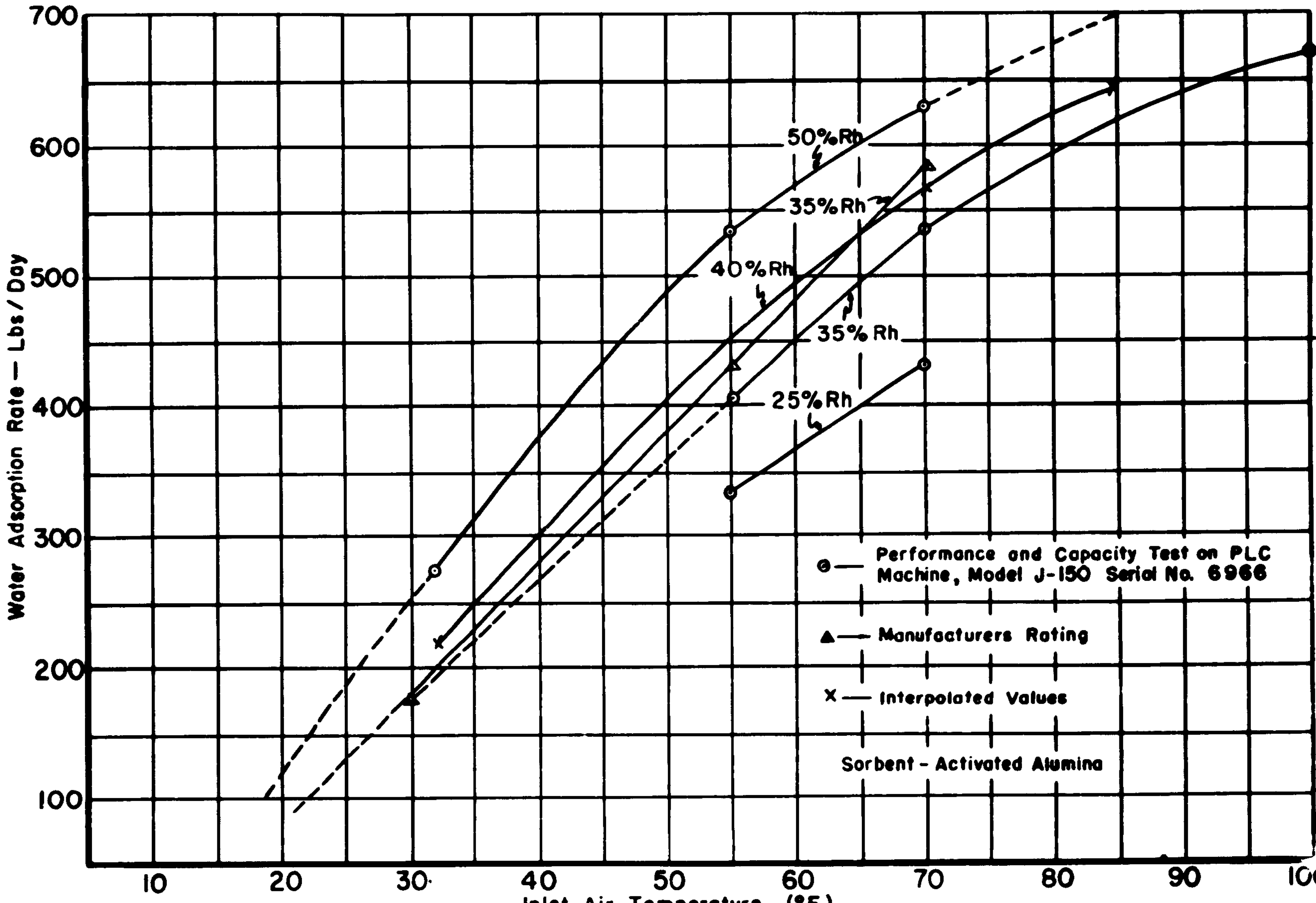


Figure 17

Water Adsorption Characteristics of Pittsburgh Lectrodryer Dehumidification Machine, Model J-150

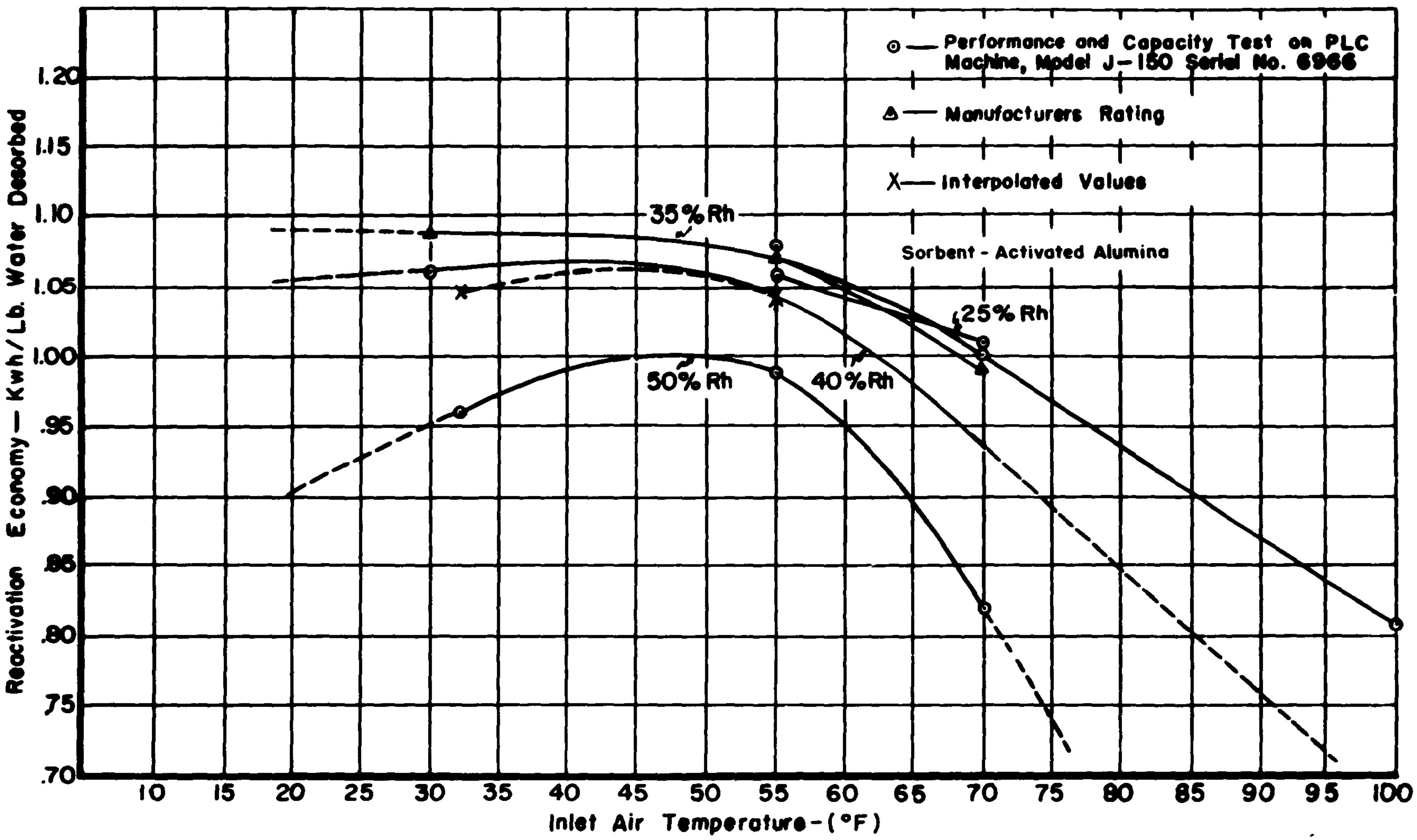
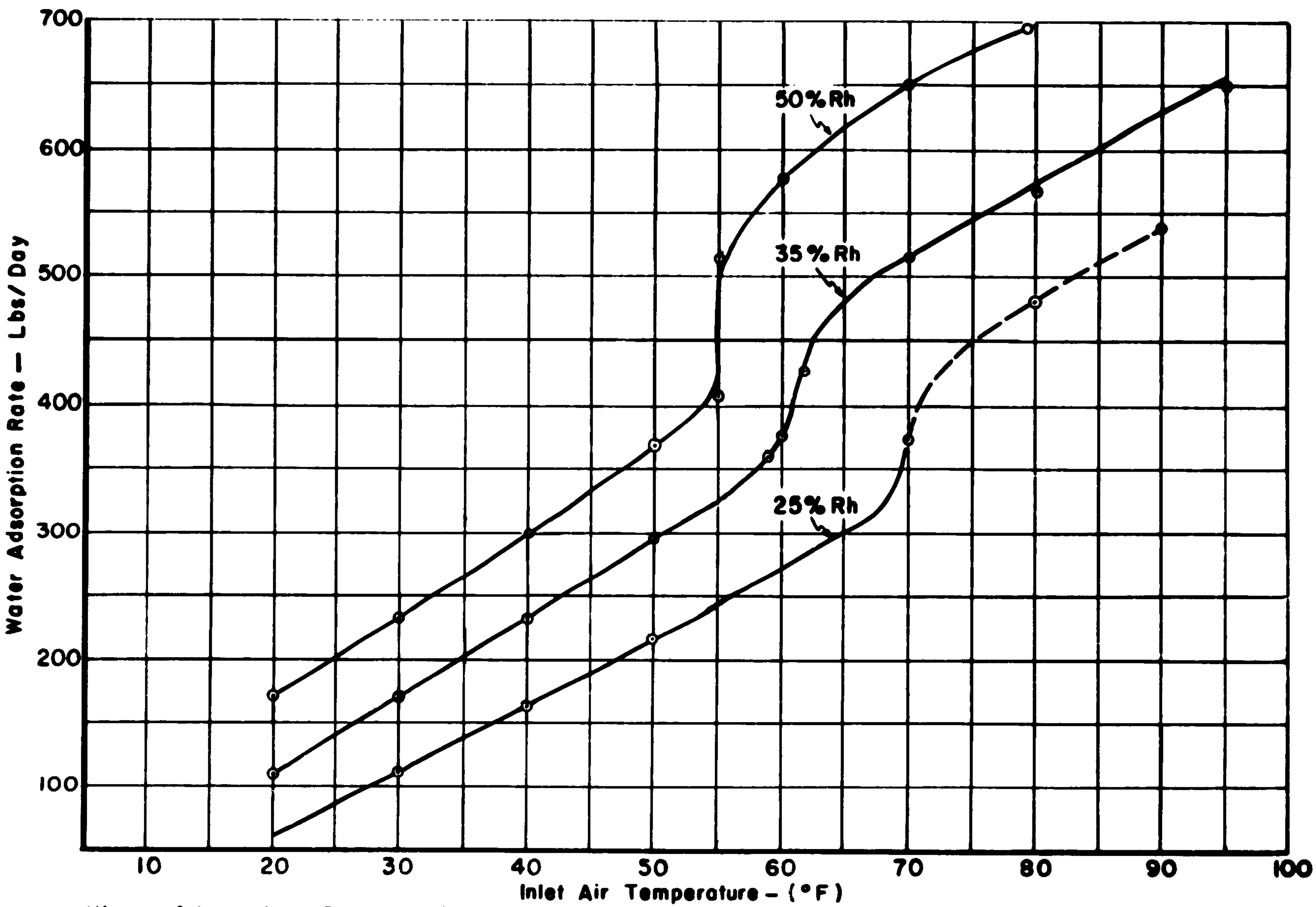


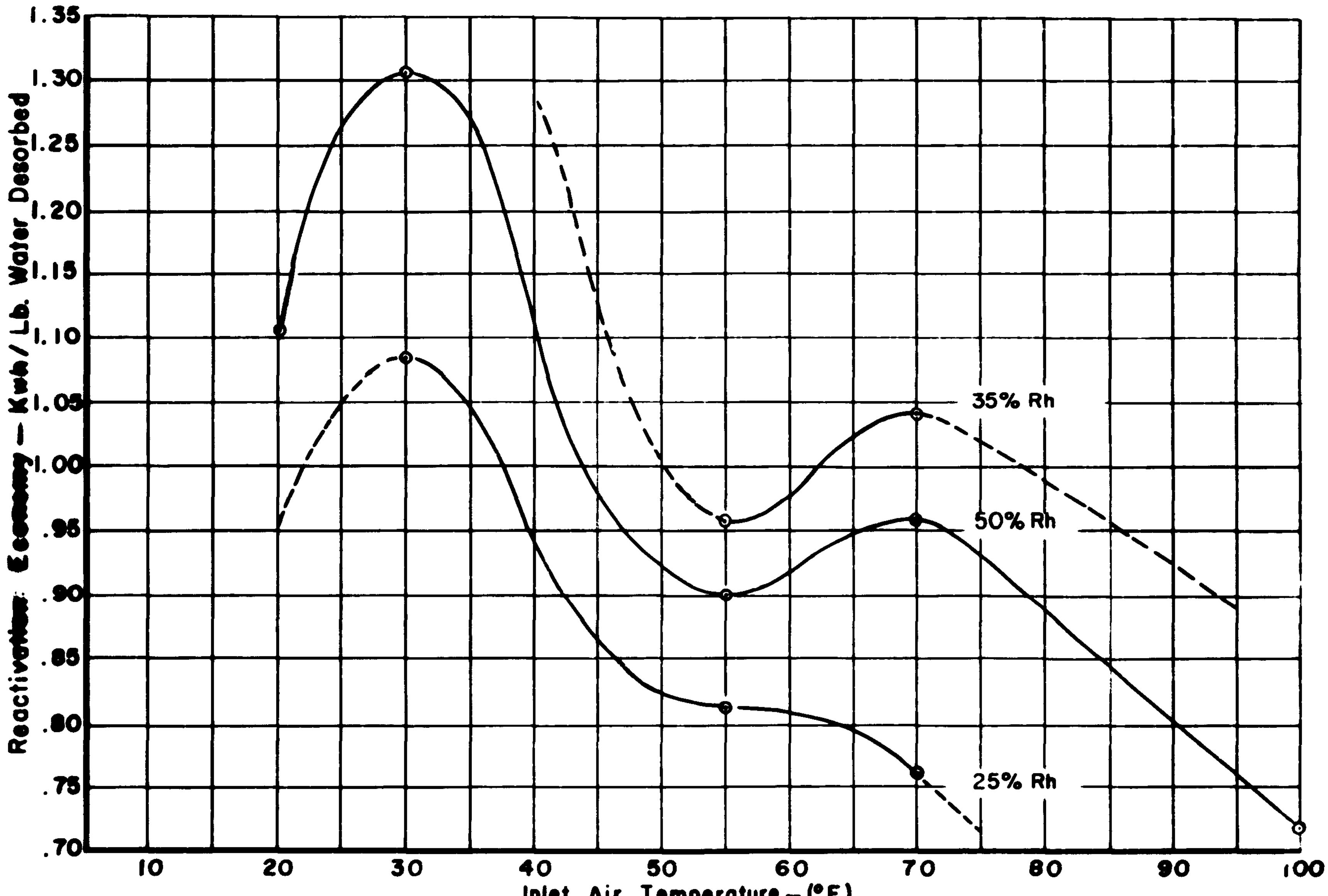
Figure 18

Power Performance Characteristics of Pittsburgh Lectrodryer Dehumidification Machine, Model J-150



Water Adsorption Characteristics of Desomatic Dehumidification Machine, **Model DOR-800**

Figure 19



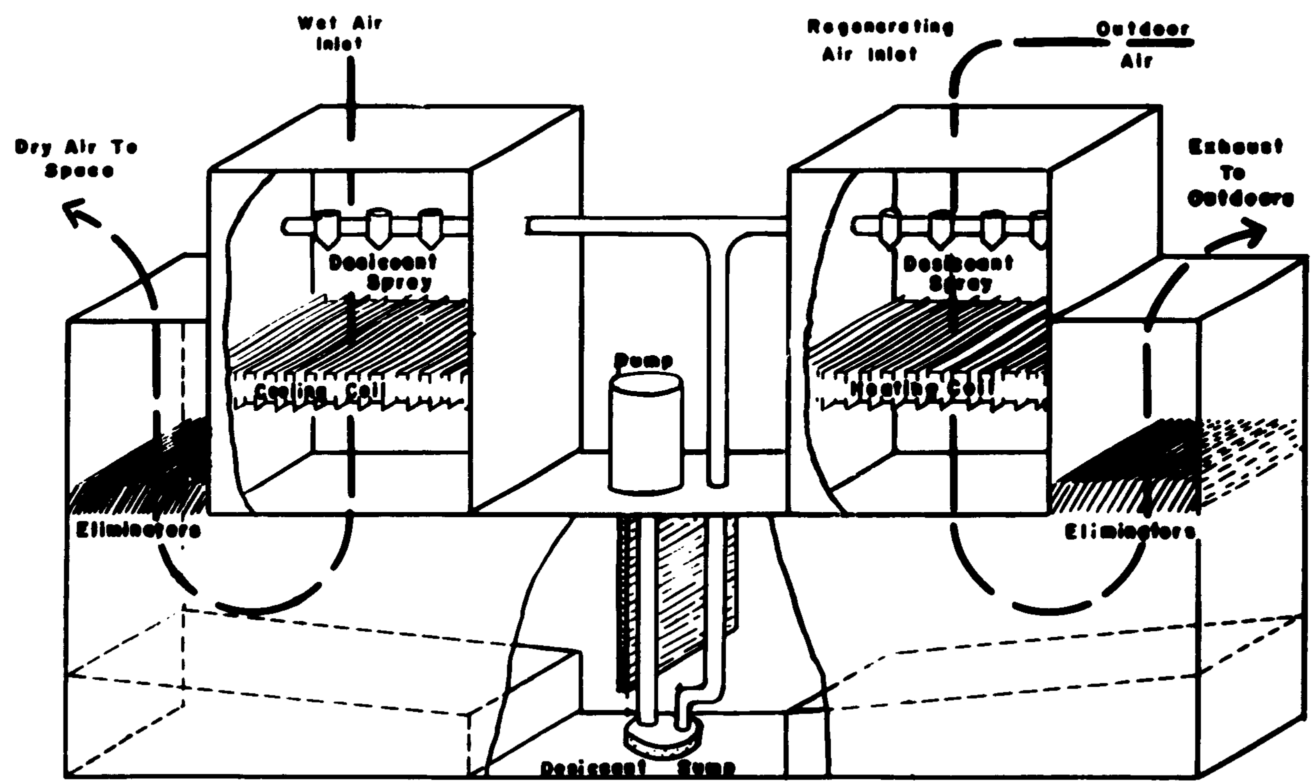
Power Performance Characteristics of Desomatic Dehumidification Machine, Model DOR-800

Figure 20

b. Liquid Desiccants The liquid type desiccants most commonly used for dehumidification are solutions of lithium chloride or ethylene glycol. The absorption of water by liquid desiccants requires the same process as for solid desiccants where moisture is removed from air in contact with the liquid desiccant due to vapor pressure differences. The moisture in air will continue to be absorbed by the liquid desiccant until equilibrium conditions are attained. A liquid desiccant dehumidification machine is shown in Figure 21. To accomplish dehumidification with liquid type desiccants, the air to be dried is brought into intimate contact with the absorbing solution by passing the air through a fine spray of the desiccant. This permits very intimate contact between the liquid desiccant and the air. As the moisture from the air is removed, the liquid desiccant absorbs the water and as the process continues the absorbing capacity of the desiccant decreases. The liquid desiccants, like the dry type solid desiccants, are regenerated by heating to a temperature which causes the moisture to evaporate. As the moisture is evaporated, the liquid desiccant solution becomes more concentrated and its moisture retaining capacity is restored. With the liquid type desiccants, the latent heat of condensation and the heat of solution is transferred to the absorbent solution and is either removed by regeneration or transferred to the air being dried. A diagram of a typical liquid desiccant dehumidification machine is shown in Figure 21.

The liquid desiccants, like the solid desiccants, have a greater capacity for holding moisture at low temperatures. They also have a higher efficiency when the entering air is at a low temperature and high moisture content.

3. Dehumidification by Refrigeration Although dehumidification by refrigeration has not been utilized in dehumidified storage to a great extent, it may have application in certain cases. Dehumidification by refrigeration is accomplished by passing the moist air over a cooled refrigeration coil where the temperature of the air is reduced below its dew point temperature. A typical layout of

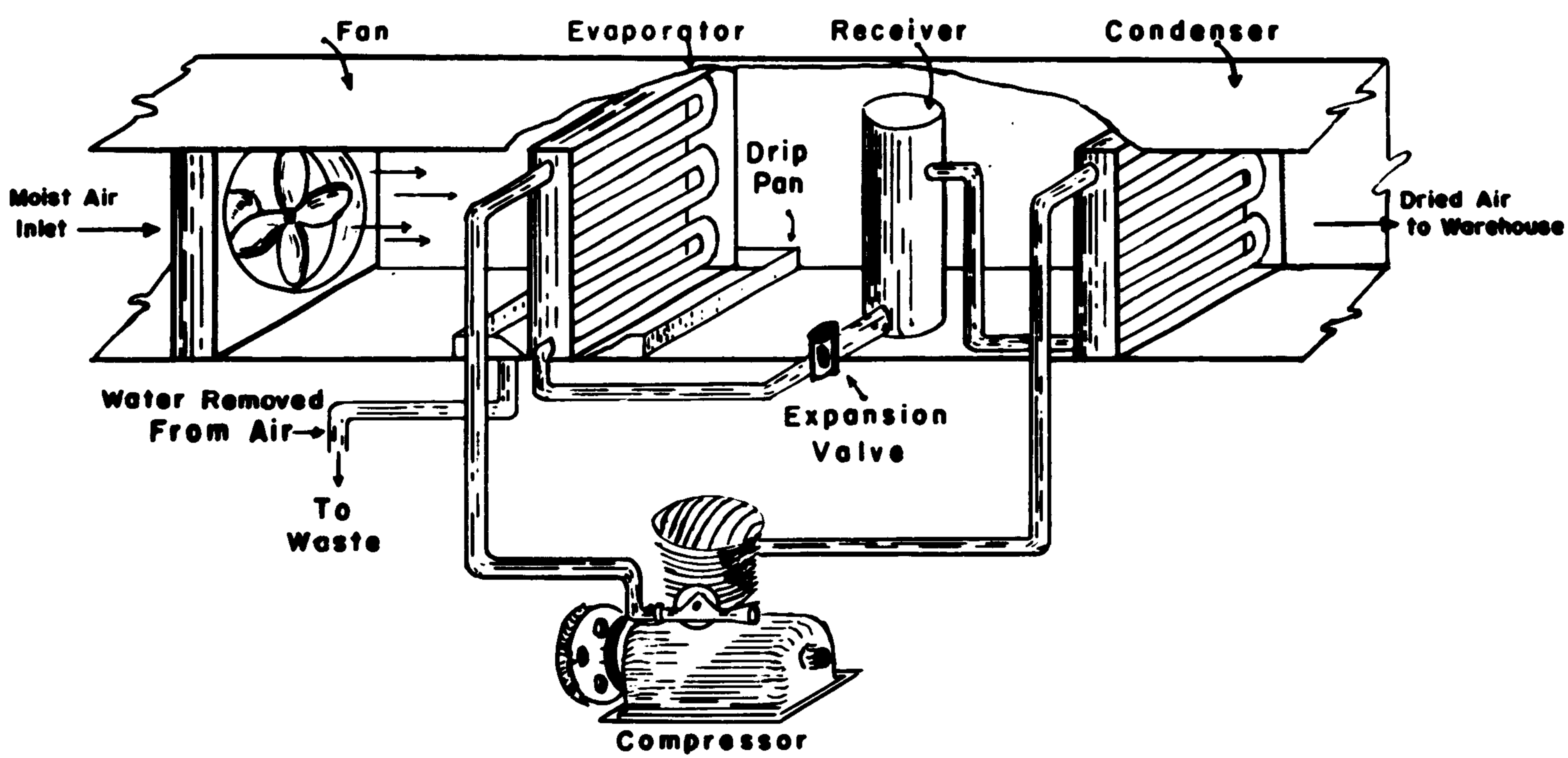


Dehumidification Machine Using Liquid Desiccant

Figure 21

equipment is shown in Figure 22. As the air leaves the refrigeration cooling coil, its temperature is lowered, and its relative humidity is increased with a decrease in specific humidity. The air may be passed over a heat exchanger which may consist of an auxilary heating coil or the condensing coil of the refrigeration system. As the air passes over the heating coil, the temperature is increased with a corresponding decrease in relative humidity with the air returning to the dehumidified space. The same basic principles of condensation are involved in dehumidification by refrigeration as with the solid or liquid type desiccants. However, the heat of condensation is removed by the refrigeration system and therefore is not transferred to the dehumidified air as in the case of solid or liquid desiccants. Consequently, there is an opportunity for better control of the air temperature leaving the dehumidification unit when the refrigeration system is utilized than with the other systems.

The cost of dehumidification by refrigeration is higher than either the solid or liquid type dehumidifiers. Maintenance and operational costs are also higher than the desiccant systems. Dehumidification by refrigeration is not well suited to geographical areas where moisture loads are high or where the ambient air temperatures are low. At low ambient air temperatures, the refrigeration coil must be maintained at a low temperature. Below freezing temperatures frost accumulation on the coil is a disadvantage. It is not possible to generalize on the performance of dehumidifying coils used in connection with refrigeration systems because each coil or each design must be tested under a varied set of conditions in order to establish its performance. The process of dehumidification with a refrigerated coil depends, to a large extent, on the design of the individual coil. Therefore, in designing such systems it is recommended that the coil manufacturer be consulted before the equipment is selected.



Dehumidification By Refrigeration

Figure 22

B. OPERATION OF DEHUMIDIFICATION EQUIPMENT Much of the success in operating dehumidified storage facilities depends upon the personnel directly responsible for the operation of the equipment. The overall responsibility for operating the dehumidification equipment should be the responsibility of a technically trained person who understands the principles of vapor transmission and the processes involved with dehumidification machines. Also, an understanding of the instrumentation used for recording temperature and humidity data and humidity control instruments for the dehumidification machines is necessary. The staff of operating personnel should include mechanics capable of servicing any of the components of the dehumidification machines such as electric motors, fans, valves, controls, and recording equipment.

All personnel connected with the operation of the dehumidification equipment should be aware of the need for proper adjustment of the recording and control instruments. Millions of dollars of stores are entrusted to preservation in dehumidified storehouses. If the control instruments are not maintained in adjustment, the humidity level may rise above that specified and cause serious damage to the stores. Consequently, proper maintenance of these instruments and controls is of utmost importance.

The need for complete and thorough operating records is required as found from the studies which have been made in connection with the analysis of moisture loads in dehumidified warehouses and the performance of different types of building construction. Inadequately recorded data is one of the chief criticisms covering the data recorded by the different storage activities to date. The recording of data pertinent to the operation of the dehumidification equipment should include data on the following: (1) machine operation which includes timer settings etc., (2) machine maintenance, (3) outside weather conditions, and (4) warehouse tempertures and humidities.

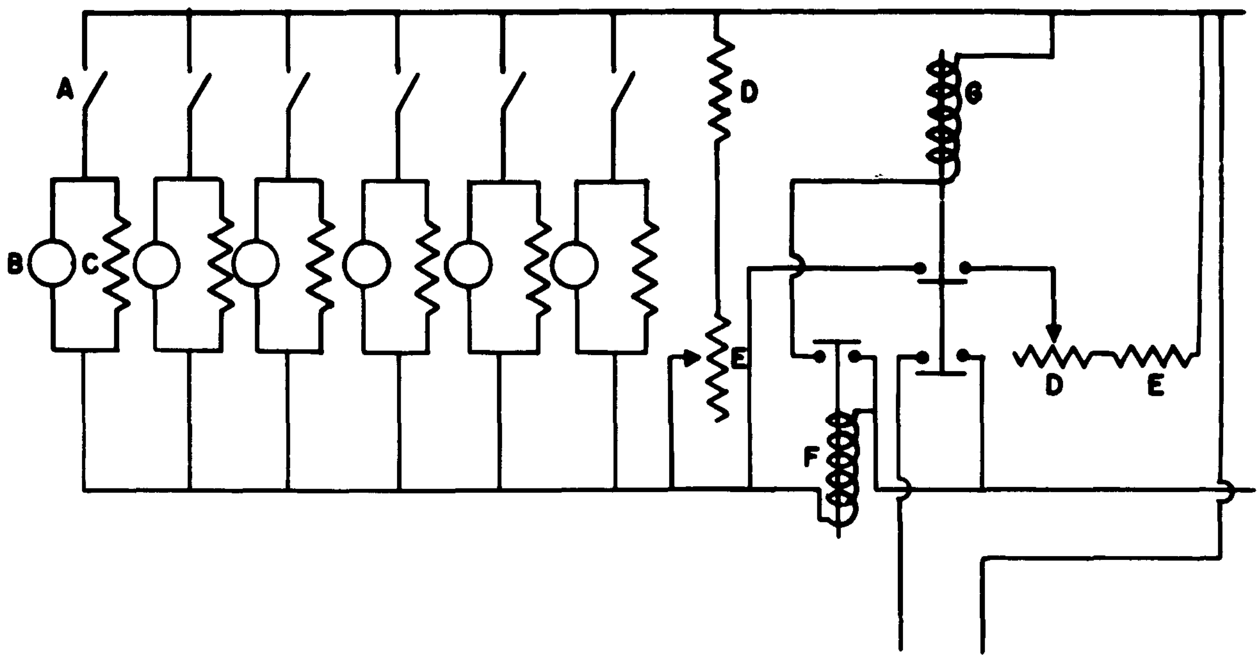
Naval Supply Depots operating dehumidified warehouses have, in the past, prepared monthly reports on the operation of these facilities, and it is recommended that the monthly station report form in Figure 31 be adopted at all activities in order that all reported data will be uniform and more complete than that which has been obtained in the past. A complete record of the data as outlined in this form will permit an analysis of operation from the standpoint of both machine and building performance. It is recommended that the data for the monthly report be collected as follows:

1. The inside dry bulb temperatures and relative humidities recorded on hygrothermograph weekly charts. The weekly average temperature and humidity may be obtained from this chart and converted to the weekly average dew point temperature. The conditions reported in the monthly station report would be the average of four weekly periods.
2. The machine timer settings to be recorded weekly. If settings are changed significantly during a monthly period, this change should be noted on the monthly report.
3. The machine running time on both adsorption and reactivation should be recorded monthly and reported on the monthly station report.
4. The power consumption is determined directly from the total machine running time.
5. The open door time to be recorded weekly and the four week total given in the monthly station report.
6. The stores movement in and out of the building to be recorded weekly and the cumulative total for four weeks reported on the monthly station report.

The operation of the dehumidification machines and associated controls requires that facilities be provided whereby the control elements can be checked and adjusted periodically. The U.S. Naval Supply Depots have such facilities in use at the present time and are equipped to adjust humidistats, exercise humidistats, and adjust recording hygrothermographs. The facility necessary for checking and adjusting the humidistats and hygrothermographs is a room, or cabinet, in which the humidity can be controlled at any desired level, and the humidity and temperature conditions cycled periodically. Suitable temperature and humidity recording instruments for maintaining records of outdoor weather conditions should also be provided.

C. DEHUMIDIFICATION CONTROL SYSTEMS. In the conversion of warehouses at the four Naval Supply Depots the operation of the dehumidification machines were controlled by a system which incorporated a twelve hair element type humidistats which were integrated with a master control panel. A schematic drawing of this control system is shown in Figure 23. This control system utilized six humidistats for the control of two dehumidification machines. The reason for the six sensing elements was to get a thorough sampling of warehouse air with respect to relative humidity. The control system gave satisfactory performance. However, in the course of operating these facilities, it was found that satisfactory and reliable control of the machines could be obtained with two humidistats per building or one in each fire bay.

The hair type humidistats require periodic exercising to remove any "set" which results from long term use at any setting. With the use of only two humidistats per building, the instrument maintenance is reduced considerably over the systems utilizing twelve units.



A - Humidistat Contacts

B - 1/4 Watt Neon Indicating Light

C - 2,000 Ohm - 25 Watt Fixed Resistor

D - 200 Ohm - 100 Watt Fixed Resistor

E - 2,000 Ohm - 100 Watt Variable Resistor

F - Sensative Close Differential Relay

G - Double Pole, Single Throw 110 Volt Standard Relay

Figure 23

Schematic Layout of External Dehumidification Machine Control System

D. SELECTION OF DEHUMIDIFICATION MACHINES The selection of dehumidification machines to handle the maximum daily moisture load depends, to a large extent, on the size of the building being dehumidified. The machines most commonly used at Naval storehouses today have a moisture removal capacity of 500 pounds of water per day. Sufficient numbers of these machines were installed to remove the estimated maximum daily moisture load to be encountered plus approximately 100%. The 100% excess capacity was intended to allow 50% operating time during the period of maximum load. Figures 9-12, show that loads were actually greater than estimated and that the excess capacity was less than expected. The capacity of the machines varies with the warehouse temperature, and the selection should be governed accordingly. That is, any excess capacity installed should be based upon machine ratings under temperature conditions existing during the period of maximum load. It is unnecessary to select machines having a capacity to handle both the maximum daily moisture load and the drawdown load when the building is first put into use. The capacity to be installed should be based primarily on the maximum load and allowing an excess capacity to permit intermittent operation. An excess capacity in the amount of 50% of the design daily moisture load is adequate. This will also give the capacity to handle a drawdown load providing the operation of the warehouse is not initiated during the design (maximum load) month. In the previous example, Section III, c., 6, where the design daily moisture is 1,601 pounds per day, it would be necessary to install four machines with moisture removal capacity of 500 pounds per day each, or a total capacity of 2000 pounds per day.

E. HUMIDITY CONTROL BY SELECTIVE VENTILATION The air conditions required for dehumidified storage may in some geographic areas be maintained by a process referred to as "Selective Ventilation". This is not a method dehumidification since it does not involve any condensation of water vapor. However, it is considered a method of accomplishing humidity control for storage purposes because the main source of moisture in dehumidified warehouses comes from the outdoor air. Where climatic conditions are such that the outdoor air is low in moisture content at certain intervals, it is possible that a warehouse can be ventilated with dry outdoor air to maintain the relative humidity level required for preservation of materials. In studies sponsored by the Bureau of Yards and Docks under contract NOy-70760 at NSD Mechanicsburg, it was found that dehumidification by selective ventilation is possible, and the factor which determines its application is the frequency of conditions where the outdoor air has a lower absolute moisture content than that maintained within a storehouse. In these studies, one warehouse was equipped with a fan capable of moving 12,000 cubic feet of air per minute into the warehouse. The fan was wired to a special controller which continuously sampled both indoor and outdoor air. When the control element senses that outdoor air is dryer than indoor air, the fan is automatically turned on and allowed to run until the outdoor conditions are more moist than that indoors, at which time the fan would shut off.

In principle, dehumidification by selective ventilation is accomplished merely by replacing the moist indoor air with dryer outdoor air. The extent to which dehumidification can be done by this method depends, as previously mentioned, on the frequencies which the absolute humidity of the outdoor air remains below the indoor air conditions, and also the duration of such periods. As an example, for a 3,000,000 cubic foot standard 200 x 600' Navy warehouse, a 12,000 cfm fan provides approximately 1/4 of an air change per hour. If the outdoor air conditions are such that the relative humidity in the building may be reduced to 35% by selective ventilation and, if the building is operated for a number of days at these conditions, there would be a considerable drying effect upon the materials within the building. The reason is that a standard Navy warehouse contains approximately 4,700 tons of wood and hygroscopic dunnage. The moisture content of wood and hygroscopic dunnage in a warehouse maintained at 40% relative humidity is 7.5% If the relative humidity of the ambient air were reduced to 35% and maintained at this condition for a certain period of time, there will be a reduction in moisture content of the wood and the hygroscopic materials to approach a moisture equilibrium content with the 35% relative humidity. The wood and hygroscopic dunnage in approaching equilibrium with 35% relative humidity which would result in a large quantity of water being transferred to the air. By reducing the moisture content of the materials a large reservoir of moisture is created to provide a "flywheel effect" whenever the humidity rises to 40% when selective ventilation is not possible. Through this combination of ventilation and moisture removal from hygroscepoic stores, it is possible to accomplish satisfactory operations of dehumidified storage in areas where climatic conditions permit the use of selective ventilation. In order that selective ventilation can be applied in any climatic locality, it is necessary that a very detailed study be made of weather records for the area. The weather records should be analyzed on the basis of number of hours per month in which the outdoor ambient conditions have a moisture content lower than that to be maintained within a warehouse. If the occurrence of dry outdoor conditions is frequent, it is recommended that selective ventilation be considered since it is the most economical method by which dehumidified storage can be accomplished. In areas where the occurrence of dry outdoor conditions is rather infrequent, it is still possible to utilize selective ventilation but it must be supplemented by mechanical dehumidification machines.

VI. OPERATING PROCEDURES FOR CONTROLLED HUMIDITY STORAGE

A. OPERATIONAL PROCEDURES FOR CONTROLLED HUMIDITY WAREHOUSES.

To assure that the program for the preservation of materials be effective, a relative humidity of 40% or lower was selected for ambient storage air. All dehumidified spaces at the U. S. Naval Supply Depots have been maintained at this humidity level since being placed into operation. To maintain this condition, the humidistats in the buildings are set at approximately 37% to 38% relative humidity and as a result the inside conditions have never exceeded 40% relative humidity.

In general, when the building is placed into operation all dehumidification machines are utilized. However, there have been cases where buildings have only been in partial use (partially filled with stored material) at which time only a part of the building has been dehumidified. When the entire building is dehumidified, all doors in the fire walls are left open to permit free circulation of air, and the opening of all active cargo doors is kept at a minimum.

The methods of storage used in dehumidified warehouses, has, generally, followed the normal non-dehumified storage procedures. In dehumidified buildings where cargo doors have been sealed, additional storage space was made available. Aisle space requirements were reduced, resulting in additional storage space. The only factor which distinctly differentiates a controlled humidity warehouse from an active uncontrolled warehouse is that the material movement time through cargo doors be maintained at a minimum. This requirement should be rigorously stressed to reduce to a minimum the infiltration of outside humid air.

The warehouses are operated as preservation storage facilities with complete awareness of the factors affecting the dehumidification moisture loads. The operation of gasoline driven equipment such as fork lifts, etc. has been closely controlled to prevent carbon monoxide concentrations of attaining concentration levels which are harmful to personnel. In only a few instances has it been necessary to provide ventilation to counteract this problem. However, electric lift trucks are utilized considerably for materials handling within controlled humidity warehouses.

The operating personnel required for the 3,000,000 square feet of controlled humidity warehouse space at NSD Mechanicsburg originally consisted of seven persons consisting of one group leader, two mechanics, and four operators. The group leader has overall charge of the operation and maintenance of the dehumidification machines and the test room and its allied operations. The mechanics are responsible for performing the maintenance work required on the dehumidification machines, controls and accessory equipment. The operators are responsible for the periodic checking of machine operation, humidistat performance, and the operation of the hygrothermographs. The operators also collect data regarding door open time, machine running time, the number of machines cycles, and other pertinent data regarding the operation of the building. They are also required to report the maintenance required on machines, control system, doors - both active and inactive, and other building deficiencies which will affect the machine operation.

Since the operation of controlled humidity warehouses has become routine, during the past two years it has been possible to reduce the number of assigned personnel from seven to three people on the subject type warehouse.

B. OPERATION OF GASOLINE AND DIESEL DRIVEN HANDLING EQUIPMENT.

The operation of gasoline and diesel engine powered equipment inside a warehouse should be limited to a period not to exceed one hour unless cargo doors are open and remain open for fifteen minutes of each hour of operation. Past experiences indicates that in the large sections of dehumidified buildings with two cargo doors open, gasoline engine equipment may be safely operated without increasing the concentration of carbon monoxide above safe limits. Operators of gasoline equipment should be instructed to shut off the engines when not in use and under no circumstances permit the engines to idle for more than thirty seconds. Self-power exercising of gas or diesel fuel engine operated equipment in storage should not be permitted within any warehouse.

Carbon monoxide is one of the most dangerous and yet one of the most common hazardous gases encountered in daily life. It is a product of incomplete combustion of all common fuels. It is colorless, odorless, and slightly lighter than air and is one of the chief constituents of exhaust gases produced by internal combustion engines. Gasoline engines on materials handling equipment should be adjusted and maintained in such a condition for its maximum combustion efficiency. An improperly adjusted or worn piece of equipment may produce twice the amount of carbon monoxide as an engine that is properly adjusted. The average idling automobile engine, if properly adjusted, produces carbon monoxide at the rate of 0.6 cubic feet per minute. Consequently, warehouses in which gasoline engines operate can present a serious health hazard unless the operation is controlled and the working area suitably ventilated by simple and common procedures.

Stockmen should be instructed to contact the Safety Division if they have any problem concerning carbon monoxide in a building. All stockmen in the dehumidified buildings should receive instructions in the use of a simple carbon monoxide detector which should be provided. If 100 parts of carbon monoxide per million parts of air or .01 on the scale of the tester is detected, the Safety Division should be notified to double-check the atmosphere.

Tests conducted at NSD, Mechanicsburg, Pennsylvania, show that operating a gasoline engine lift truck in a <u>closed</u> section of a controlled humidity building produced a carbon monoxide content of 0.03 (3 parts of carbon monoxide per 10,000 of air.) This concentration produces headaches, mental dullness and nausea in one and one-half to two hours. Experimenting with two gas engine lift-trucks in the same section for one hour with the doors open for fifteen minutes after one-half hour operation showed a concentration of .02. With one machine in operation, the concentration was slightly below .01, or one part per ten thousand. Employees can work without perceptible effects or discomfort in a concentration of .01 carbon monoxide for eight hours.

C. RECORDS MAINTAINED FOR DEHUMIDIFICATION OPERATIONS

There are a number of record forms which are used in collecting data relative to the operation of the dehumidified building, machines, and the test room. A brief description of these forms is as follows:

Form 440 - Shown in Figure 24 is a check sheet located at the control panel in the warehouse buildings which have a humidity control system utilizing 12 Humidistats. This form is used by the dehumidification machine operators in their daily check of the building. The illuminated indicating lamps on the control panel reflects the number of humidistats which are calling for dehumidification and are noted upon the form. This serves as a daily check on the operation of the control system and also on operation of the humidistats located throughout the building. In the daily check, if a light is observed to be on continuously the operator can assume that either the humidistat is out of calibration or that there is an inoperative relay in the control panel. However, experience has proven the reliability of the dehumidification machines so that in recent installations, control boards have been omitted in favor of daily visual inspection of each machine by operating personnel.

Form 690 - Shown in Figure 25 is a record maintained at each machine and filled in during the operators' daily observation of the machines. In the columns provided, the readings of the cycle counter, reactivation timer, and absorption timer are recorded. The purpose of this running log is to show the number of cycles completed in a 24-hour period along with the corresponding absorption and reactivation time. Any irregularities which arise between the absorption and reactivation timer can be noted if the time observed and recorded on this sheet is not in accord with the time settings on the absorption and reactivation timers.

Form 627 - shown in Figure 26 is used to record the operating conditions of the master hygrothermograph and the combined dry bulb and dew point recorder used in the test room. The principle purpose of this record is to show any discrepancies which may exist between the master hygrothermograph and the condition within the test room.

Form 734 - shown in Figure 27 is used by the machine operators to summarize data collected during the week. The absorption and reactivation time settings are observed and recorded in this table on Mondays along with the door open timer meter readings. On Wednesday and Thursday, psychrometer readings are taken in three locations (one in each fire bay) in each building and are recorded in the columns headed NS, CS and SS. On Friday, the check is made on the resistance of the heating elements in the dehumidification machines and these resistance values are recorded in their appropriate columns.

Form 243 - shown in Figure 28 is a report form used to summarize the operations in each dehumidified building at the Depot. One sheet is prepared for each building and the weekly operations are summarized to give pertinent information regarding machine operation, door open time, and power consumption.

Form 731 - shown in Figure 29 is a monthly report which is used to record preventative maintenance performed on the dehumidification machines. Its contents are self explana .

Form 239 - shown in Figure 30 is a form used in collecting data on the movement of stores in and out of buildings. This form is provided to each stockman in each building and it is filled in at the end of each week to record the tons of materials moved "IN" and "OUT" of the warehouse. At the end of the month, a summary is made in the space provided. The report summarizes this operation for inclusion in the monthly report covering all buildings.

Form S&A 4450 - 4 shown in Figure 31 is the monthly station report presently used at Mechanicsburg, Pennsylvania, to report the humidity and temperature conditions within the dehumidified warehouse, the power consumed in each building, the door open time, and material handled in and out of the buildings. This breakdown is very desirable and should be initiated at the time buildings are placed in operation.

In addition to the preceding forms, the hygrothermograph charts in use in all buildings and in the outside weather station are filed in the Depot for a permanent record. The test charts taken from a four-pen temperature recorder used in field checking the operation of the dehumidification machines are also filed with the hygrothermograph charts.

Form No. 440

Humidity Indicator Light Record of **Humidity Indicator Light Record of**

Building No. ____________ **Building No.____________**

Humidistat Setting:__________%R.H. **Humidistat Setting:__________%R.H.**

Date	Hr.	1	2	3	4	5	6	7	8	9	10	11	12	Date	Hr.	1	2	3	4	5	6	7	8	9	10	11	12

Figure 24
Humidity Indicator Light Record

Daily Timer Check Sheet
Form No. 690

Date	Cycle	React.	Adsorp.	Date	Cycle	React.	Adsorp.

Navy - NSDMech., Pa.

Figure 25
Daily Dehumidification Machine Timer Check Sheet

Master Hygrothermograph Chart Against Foxboro Recorder

Semi-Weekly Dry Bulb and Relative Humidity Check Sheet No.

Covering Period Form To

Time	Foxboro			Master	
	D.P.	D.B.	R.H.	D.B.	R.H.
	F	F	%	F	%
12					
2					
4					
6					
8					
10					
12					
2					
4					
6					
8					
10					
12					
2					
4					
6					
8					
10					
12					
2					
4					
6					
8					
10					
12					
2					
4					
6					
8					
10					
12					
2					

Time	Foxboro			Master	
	D. P.	D.B.	R.H.	D. B.	R.H.
	F	F	%	F	%
4					
6					
8					
10					
12					
2					
4					
6					
8					
10					
12					
2					
4					
6					
8					
10					
Total					
Aves					

Remarks

Form No. 627 NSD Mech., Pa. 9/29/52-300

Figure 26

Test Room Condition Log

Weekly D/H Machine and Building Log
Form No. 734

Week Ending ________

Bldg. No.	Mach No.	Time		Cycles	Door No.	Meter Reading	Resistance		N.S.		C.S.		S.S.		Timers		Remarks
		Adsorp.	React.				No.1	No.2	W.B.	D.B.	W.B.	D.B.	W.B.	D.B.	Ads.	Rea.	
	1				1												
	2				2												
	3				3												
	4				4												
	1				1												
	2				2												
	3				3												
	4				4												
	1				1												
	2				2												
	3				3												
	4				4												
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	1				1												
	2				2												
	3				3												
	4				4												
	1				1												
	2				2												
	3				3												
	4				4												
	1				1												
	2				2												
	3				3												
	4				4												

Navy-NSD Mech, Pa.

Figure 27

Weekly Dehumidification Machine and Building Log

Form No. 243 **Dehumidification Equipment Data Log**

Station Mechanicsburg, Pa. __________ Building No. ____________________

Nominal Month of ____________________ No. of Machines ____________________

Covering Period of ______________ to ____________________________, Incl.

Week End'g	Door Opening Meters			Mach. No.	Cycles		Adsorpton			Reactivation			Power		
	Dr. No.	Meter Rdg.	Hrs. Oper		Meter Rdg.	Cycles	Meter Rdg.	Hrs.	Time/Cycle	Meter Rdg.	Hrs.	Time/Cycle	Ads KWH	React KWH	Total KWH
Totals															
Totals															
Totals															
Totals															
Totals															
Month Totals															

Figure 28

Dehumidification Equipment Data Log

Dehumidification Machine Log
Form No. 731

Station - NSD, Mechanicsburg, Pa. **Building No.** ________________

	Mach. No.	Date	Comments	Date	Inspection Notes
4-Pen Recorder Temp. Charts	1				
	2				
	3				
	4				
Oiling & General Service	1				
	2				
	3				
	4				
Filters	1				
	2				
	3				
	4				
Desiccant Added	1				
	2				
	3				
	4				
Repairs					

Navy-NSD Mech. Pa.

Figure 29
Dehumidification Machine Log

Measurement Tonnage In and Out D/H Warehouses
Form No. 239

Building No.

Date	Tons in	Tons out
Totals		

Signature (Stockman-in-Charge)

Navy-NSD Mech. Pa.

Figure 30

Stores Movement Record

Monthly Station Report
on
Dehumidified Warehouses

Report S & A 4450-4

Station ______________________

Nominal Month of ______________ **19** ______ **No. Houses** __________

Covering the Period ______________ **To** ______ **No. Machines** __________

Bldg. No.	Ave. D.B. Temp °F	Ave. R.H. %	Power Used KWH	Door Time Hrs.	Tonnage Material Handled		Tons per Hour of Door Time	Notes
					In	Out		
Total								
Average								
Total Last Month								
Average Last Month								

Comments:

Figure 31

Monthly Station Report on Dehumidified Warehouses

APPENDIX I.

ELECTROCHEMICAL PROCESS OF METAL CORROSION

The process of electrochemical corrosion can be illustrated by reference to the simplest case, that of iron. The process of electrically charged particles (ions) of iron going into solution and displacing hydrogen may be illustrated by the chemical equation:

$$\underset{\text{metal}}{FE} + \underset{\text{ions}}{2H^{+}} \quad \underset{\text{ion}}{Fe^{+++}} + \underset{\text{atoms}}{2\ H}$$

This shows the formation of the hydrogen film which forms on the metal surface. This hydrogen is free to combine with any dissolved oxygen in a water solution to form additional water:

$$\underset{\text{atoms}}{2H} \quad + \underset{\text{dissolved}}{1/2O_2} \quad \underset{\text{liquid}}{H_2O}$$

or the hydrogen can escape from the surface as gaseous bubbles.

$$\underset{\text{atoms}}{2H} \text{ --- } \underset{\text{gas}}{H_2}$$

As the hydrogen is removed from the metal surface the reaction proceeds with the accumulation of ferrous ions (Fe^{++}) which are oxidized and precipitated as rust. This reaction is: $2Fe^{++} + 1/2O_2 + H_2O$ - - $2Fe^{+++}$ + $2OH$ which yields insoluble ferric hydroxide (rust). In this process the hydrogen acts as a metallic element with positive ions being displaced and plated out.

The electrode potential present at any instant between the metal surface and its ions in solution is proportional to the initial tendency of metal to corrode. Because the electrode potential may vary with the concentration of metals ions in solution, it is necessary to establish a base concentration. A standard concentration is an ion concentration of 1 mole per 1000 grams of water. With this in mind and arbitrarily establishing the potential of hydrogen as zero, the electrochemical series of elements has been arranged. Theoretically, each element in the electrochemical series should displace the elements below it. However, this may be varied by changes in ion concentration and temperature and composition of the electrolyte.

The placing of metal in contact with water will cause a continuous evolution of hydrogen if the hydrogen were always at a potential corresponding to its position in the electrochemical series. This is not always the case as hydrogen on most metal surfaces has an added resistance to overcome before it can be liberated as a gas. This added resistance is termed "overvoltage" and its magnitude depends upon the nature or condition of the conducting surface, the temperature, pressure, nature and velocity of the solution, and the size and number of hydrogen bubbles formed.

Overvoltage is then the potential which acts against the liberation of hydrogen at the cathode. Low hydrogen overvoltage in the absence of oxygen may lead to an increase in the corrosion rate. Various organic inhibitors along with other substances which are strongly absorbed by the cathode tend to increase overvoltage with a reduction in the rate of reaction.

The importance of hydrogen in the corrosion process is evident from the primary equation. Variations in the hydrogen-ion activity have an important effect upon the rate of corrosive reaction. The general conclusion is that the more acidic, greater hydrogen-ion activity, the greater is the corrosive attack. This, however, is not always true as many metals have a tendency to become passive upon oxidation in concentrated acids. Aluminum and many alloys are unaffected by variations in acidity as a result of their inherent passivity. Although most metals are more strongly attacked by acids, the amphoteric metals (aluminum, lead, zinc, etc.) are corroded in alkalies.

INFLUENCE OF OXYGEN IN SOLUTION

As the rate of corrosion is dependent upon the success in the removal of the hydrogen film from the cathode, the importance of oxygen in the solution can be understood. Oxygen in solution will remove the hydrogen by combining with it to form water. The rate of corrosion is therefore controlled by the amount of dissolved oxygen adjacent to the metal surface. Although an increase in oxygen concentration usually increases corrosion some metals require an excess of oxygen to remain more passive. This is true of such metals as aluminum and many of the stainless steels which may corrode when the oxygen concentration is small. Corrosion of metals may take place in low oxygen concentration when conditions exist that will cause removal of hydrogen or attack by other ions.

The presence of ions other than the metal or hydrogen ions can affect the rate and degree of corrosion. Probably the most important influence of other ions is the resulting nature and distribution of corrosion products. An example of this would be the protective coating formed on deposition of calcium carbonate from hard water. Secondary effects could be the modification of metal and hydrogen-ion concentration by the presence of other ions or direct metal oxidation by the other ion itself.

SUPPLEMENTAL INFORMATION

Technical Report 131 - "Moisture Migration Rates Through Building Materials" dated 12 May 1961 by U. S. Naval Civil Engineering Laboratory, Port Hueneme, California provides data on the migration rates of moisture entering dehumidified warehouses through walls and floors as evidenced by tests on laboratory samples. Report available from Armed Services Technical Information Agency. (Successor agency - Defense Documentation Center, Cameron Station, Alexandria, Virginia.)

Technical Report R221 - "Warehouse and Preservation Methods and Economics for Storing Materiel" dated 27 Dec 1962 by U. S. Naval Civil Engineering Laboratory, Port Hueneme, California is the final report of test program mentioned on page 57 of University of Minnesota's "Technical Aspects of Controlled Humidity Storage", and in the Foreword and page 11 of University of Minnesota's "Preservation of Materials in Controlled Humidity Storage". Report available from Defense Documentation Center, Cameron Station, Alexandria, Virginia, or from Director, Technical Services, Department of Commerce, Washington, D. C.

ERRATA

Page 36 - 15th line
"The wall transmission components of the total load was calculated by utilizing the recorded data on conditions maintained within the warehouse and outside weather data for each particular month. The moisture load due to stores turnover was calculated from recorded data giving actual stores movement into the building."

Page 38 - B - Port Hueneme

Page 53 - 5th line - "400 cu. ft." should read "40 cu. ft."

Page 63 - Under "Stores Turnover Load" a second heading should be added to the second load calculation as follows:

<u>Open Door Load</u>
Daily Load:

Page 68 - Table VI - added asterisk to heading as follows: Perms - M* and add footnote as follows:
*Perms - based upon thickness indicated.

Page 78 - 12th line - "The doors required for materials movement..." should be "The doors not required for materials movement should be blanked off and sealed."

Page 84 - 9th line - "$.40 per square foot per year" to be changed to "$0.04 per square foot per year."

Page 94 - 3rd line - delete the work "a" before "twelve hair element...."

Page 96 - 3rd line - Insert "of" between "method" and "dehumidification."

Various - Minor errors of typography and spelling are not corrected.