THESIS

THE DESIGN OF A MODERN APARTMENT HOUSE

WITH

CENTRAL HEATING AND

AIR-CONDITIONING SYSTEMS

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1948

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THE DESIGN OF A MODERN APARTMENT
IN BEIRUT
WITH
CENTRAL HEATING &
AIR-CONDITIONING SYSTEMS

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PREPARED & PRESENTED

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B.S.C.E

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P R E F A C E

The following thesis is an attempt to design an air-conditioning system for a modern apartment in Beirut.

Although very common in America and in Europe, air-conditioning is altogether new in this part of the world and it did not come into actual use until very recently, its application being restricted to theatres only.

This system gives an altogether new meaning to our old housing problems and it creates at the same time new opportunities for the engineers of the younger generation in tackling the more important needs of a modern house.

The tendency now is rather toward creating better inside living conditions within a house. More attention and care is devoted to the interior than to the exterior with a view of making it more attractive and comfortable. It is obvious therefore that it is the interior set-up which will contribute to the comfort and health of the individuals.

No doubt the construction of a modern apartment house in Beirut, equipped with an air-conditioning system will be a novelty. Once the advantages and benefits of such a system are seen, undoubted by people will come to realize its importance and will care to introduce them in their new designs.

This work is a study of the possibilities of applying such a system to an apartment house in Beirut. The various aspects of the problem are treated carefully and specific processes are proposed for their solution.

The proposed Lithium chloride absorption system is discussed as regards operation, capacity and economy and its relative merits and advantages will be pointed out in the conclusion, only after a careful study of the total heat load on the system. A real knowledge of the workability of this system can be brought out only when it is tried on a commercial scale.

In the preparation of this work, the author wishes to express his great indebtedness for the kind supervision of Professors J.R.Osborn, I.Rubinsky and K.Yeramian .

V.M. Keshishian

Beirut, Lebanon

March 1948

P A R T I

I N T R O D U C T I O N

A N D

G E N E R A L D I S C U S S I O N

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INTRODUCTION

In ancient times people warmed themselves during the winter by an open fire built at a convenient corner of the house which served for all of their cooking and most of their lighting at night at the same time and it had to be kept on burning day and night. This meant the gathering of the whole family around it, the roasting of a geme, the telling of stories in other words the center of their home lives.

Even in our own times the fireplace represents (represents) much the same thing and in most mountain districts in Lebanon and all villages in Syria an open fire is kept on burning in the so called dar (Hall) and is constantly fed with wood. At night it is carefully cowered to ease the building up of a new fire for the next day.

In middle ages the ordinary houses were provided, besides the chimney and the small windows which were probably never opened during the winter, with small circular openings situated near the roof called " oeil-de-boeuf " were intended to admit fresh air from the top. And in the big medieval castles this was done at the expense of much elaborate architecture on high towers provided with large windows.

awkward grammatical construction

All during winter people kept themselves locked in small sitting rooms with all openings closed. Beside the discomfort caused by the severe weather the fire had to be attended to prevent smoking and the ashes cleaned every now and then for regeneration.

This meant too much or too little heat and varying heat and then the ill effects of dry heat were severe.

Stores, theatres, restaurants and all public places became stuffy because in most cases they were closed as tightly as possible to keep out the cold. Heating systems caused damage to buildings and discomfort to people because of the circulation of coal dust, soot, gas and dust. The systems were usually so large that they required most of the available basement space for supply and return pipes, fuel, & ashes.

The discomforts caused by weather during the summer were of a different sort. Summer meant days, weeks and months of almost unbearable heat which had to be endured without hope of relief. Buildings were constructed of materials which offered little resistance to the intense heat of the sun. At night the walls would release the heat that they had absorbed during the day and thus the heat lasted through the nights preventing proper relaxation. Summer was considered as a time of poor business (saison morte) as it was almost impossible to get out.

Theatres were even more undesirable due to the increased heat caused by the large number of people gathered in one enclosure. Restaurants became deserted of hot cooking odours.

The result was unefficiency of work during the day and not much pleasant relaxation at night.

Buildings and residences are now being installed with mechanically and electrically operated central heating and air conditioning systems. They are constructed with many forms of insulating materials to check the inflow of heat during summer and to prevent the escape of the artificial manufactured heat during winter. The insulating materials are placed in such a way as to form an integral part of roofs, ceilings, walls and floors. In some cases they provide structural advantages in addition to insulating qualities.

Homes may now be perfectly ventilated and heated. The hot summer air may be cooled down to any desirable temperature, dehumidified and freed from all impurities. Days and nights can now be delightfully cool and refreshing. Stores, theatres, restaurants and trains enjoy these benefits with none of the old discomforts. Business goes on in summer as well as in winter. People feel better than they used to feel, they rest better, relax in comfort and are able to go about their business with full efficiency.

The early systems used in summer air conditioning aimed only at cooling the air from an outdoor temperature of 95°F for example to 70°F, which was then considered a comfortable temperature. This was first tried in theatres and it proved to be unsatisfactory and unhygienic, for cooling the air is not enough, its moisture content should be controlled to be perfectly comfortable. On the other hand, the abrupt change in temperature from 95°F indoor to 70°F outdoor proved too severe.

Now air conditioning units are designed and used with a more thorough knowledge of the hygroscopical conditions to give more comfort. Air is cooled and dehumidified and even heated sometimes after the removal of moisture content and is supplied in a purer form through large ducts aided by rotating fans.

In winter air conditioning supplies heat, humidity, ventilation and clean air. Heat of today is supplied in even and constant amounts as needed. Rooms attain gradually whatever temperature is desired. Heating is easy and perfect. All the difficulties of fuel handling, ashes,soot, dust are entirely eliminated. Modern units are equipped with electrically operated thermostats, regulators, valves and work almost automatically. The right amount of humidity is supplied to provide health, comfort and protection of furniture.

Apparatus for cooling, heating, dehumidifying, humidifying, cleaning and ventilating can now all be combined in one enclosed air conditioner which is small and can be placed in a convenient corner in the basement or utility room. Pipes, boilers and other equipment are smaller in size and can be entirely kept out of sight.

The advantages and benefits of air conditioning are innumerable in industry in addition to its comfort and health giving qualities, air conditioning has made possible the safe storage of large amounts of chemicals rendered the preserving of goods and foodstuffs safe and easy and has made possible the year round processing of many previously seasonable operations in industry.

Almost all forms of industry have benefited from air conditioning.

THE PROPERTIES OF AIR IN RELATION TO HUMAN COMFORT & HEALTH

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The object of air conditioning is to improve the quality of air in an enclosure to bring about human confort.

Some of the factors that affect human comfort are, temperature, humidity, motion of air, smoke, dust, odours, bacteria & several harmful gases, and ozone. Still other factors are ionization and pressure. The effects of the latter two are not yet clear and definite.

At present the simultaneous control of these first three factors is accomplished by air-conditioning.

Though complete specifications are lacking as regards comfort standards, yet, in all air-conditioning design, these factors must be considered carefully for successful operation of the machinary.

a. <u>Dust</u>:-

Particles of dust are always in the atmosphere. The quality of air to a large extent is affected by the amount and nature of these particles. Dust is sometimes classified as solid particles in air having a diameter of 1-150 microns. Though it lessens the effect of light and helps in the condensation of moisture, yet it is a bacteria carrier and when present in air in appreciable amounts, it becomes a menace to comfort and health due to its abrasive and toxic effects.

b. Fumes:-

Fumes are gases liberated from various chemical reactions in many industrial processes, such as distillation, metallurgy, etc. They are classified as particles between 0.2 and 1 micron in diameter.

c. Smoke:-

Smokes are gases resulting from incomplete combustion. They are finely divided and penetrate through filters easily and are hardly settleable. They are less than 0.3 microns in diameter. In most cases they are fairly toxic and injurious to health.

d. Ozone:-

Ozone is a form of the oxygen molecule O_3 - It is an active oxidizing agent because in breaking up it liberates nascent oxygen - O - which readily combines with most substances. Ozone is effective in destroying bacteria in air and it helps to offset fumes and mash odours. Its amount in air is very small. It is produced on a commercial scale for use in air conditioning systems by electrically operated ozonizers. The highest permissible concentration for air conditioning is 0.1 part per million parts of air.

e. Odours

Odours are caused by gaseous matter or suspended particles in the air which are repulsive to the sense of smell. Though, in general, they are not harmful, but they cause loss of appetite and give disagreable and unpleasent sensation and should be eliminated through air conditioning.

f. Bacteria

Bacteria is almost always present in the air. The bacteria content of the air may be determined by exposing culture plates to the air for 2 mins. followed by incubation at 98°F from 24-48 hours. The number may be counted on a slide under a microscope.

g. Air movement

Some motion of the air is desirable at all times. Stagnant air is neither comfortable nor healthful, no matter how pure it is and to what desirable temperature and humidity it is adjusted. From available data, it seems that 5 ft. per minute should be the minimum during the heating season and 50 ft. per minute the maximum during the cooling season. The total amount of air circulated in any system is the sum of the quantity taken from outside plus the quantity of air recirculated.

The more modern systems of ventilation maintain a set of minimum of outside air and vary the ratio of outside air and recirculated air, maintaining correct temperature conditions within the building. This applies to a heating and a ventilating system.

When considering a cooling and a dehumidifying system for summer air conditioning work it is desirable to plan to recirculate as great a portion of the air as practical, because of the relatively high cost of cooling.

There will always be a considerable quantity of outside air coming into a building by infiltration through walls and around windows and from opening of doors. In all places practically this infiltration supplies sufficient fresh air.

Ionization in air

Air, even after being conditioned and controlled for temperature, humidity and air motion, it lacks inherent freshness and is dead. Some experts ascribe this to the lack of ions. Experiments show that fresh outdoor air is rich in ions and that the ionic content is reduced in any enclosure due to human occupancy and is restored after the place is emptied. Though no direct physiological effects are observed, yet it is firmly believed by the majority that the presence of ions is essential for health.

Effects of Human Occupancy

Human occupancy produces the following changes in the properties of air.

1) Amount of oxygen is decreased due to oxygen consumed in metabolism.
2) Carbon dioxide is given off a s a result
3) Surrounding temperature is increased due to the heat radiated from the body.
4) Humidity is increased due to the exhaled water vapor
5) Odors are produced
6) Ion concentration in air is decreased.

The old belief was that human discomfort was a result of an increased amount of carbon dioxide content of the air in enclosure. The modern theory is that it is caused as a result of the nonability of the body to keep a proper balance between the heat released by metabolism and the heat loss through evaporation, radiation, convection and conduction.

Effective temperature

From the above discussion it is evident that the three major factors (1) Temperature, (2) Humidity, (3) and air motion are closely interrelated in their effects upon human comfort and health. The combined effect of the three is called the " Effective Temperature " and is merely an index or a composite factor representing the state of air.

It is defined as the dry bulb temperature of saturated still air (with a velocity not more than 25 ft. per minute) producing the same feeling of warmth of cold as the air in any given state of motion.

Therefore all the different methods in air conditioning reduce ultimately to the provision and maintenance of a desirable uniform combination of temperature, humidity and air movement by mechanical means whereby the vitiated air of the enclosure should be replaced by clear, fresh outdoor air having all desirable qualities.

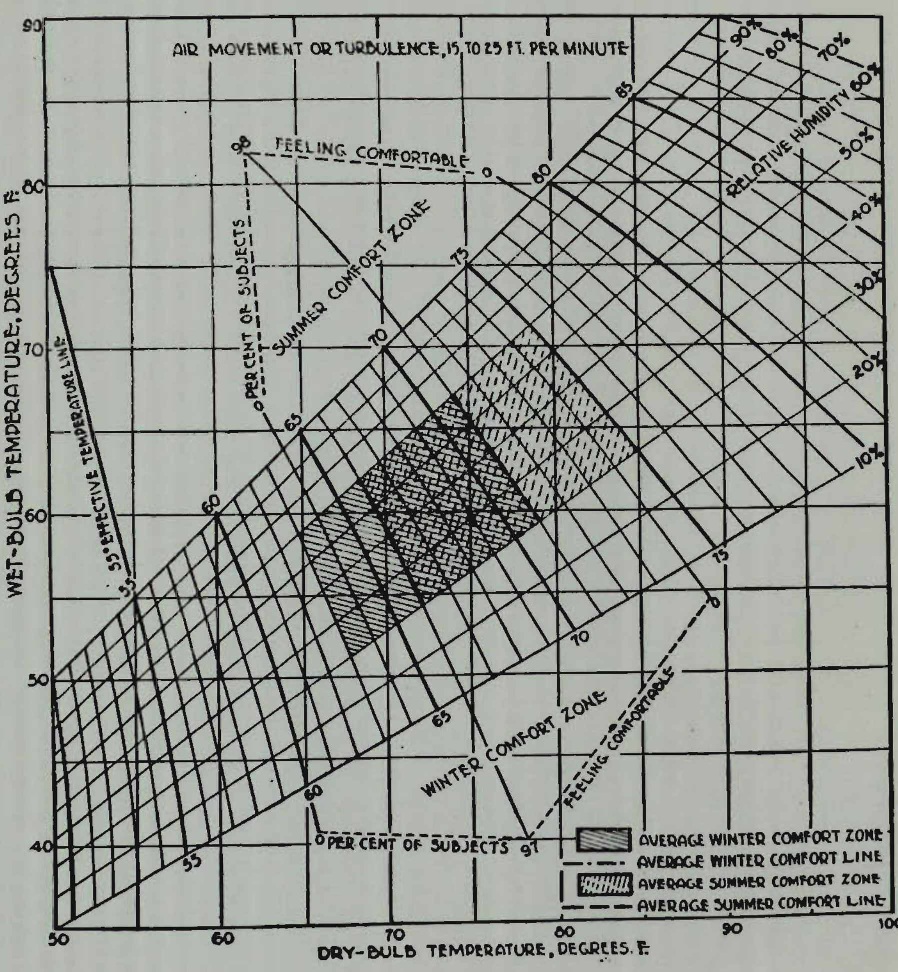


Fig. 1.

From Air-Conditioning Dalzell & Hubbard

There are no definitely set values of effective temperature which insure full comfort to any human occupancy as the latter may differ from person to person and also depends upon climatic conditions and other factors.

Yet there are certain temperature ranges and combinations of humidity and air movement which give comfort to an appreciably large percentage of the occupant of a place.

The comfort Zone

Comfort charts are elaborated both for summer and winter based on effective temperaturesfor different outdoor conditions. Dry bulb temperatures were once the only index for comfort. Now the effective temperature index has replaced it, and comfort now is interpreted in terms of effective temperatures.

In one type of comfort chart prepared by the American Society of Heating and Ventilating Engineers, the dry bulb temperatures are indicated on the horizontal axis and the wet bulb temperatures in the vertical axis. Straight lines running upward diagonally from left to right are for different percentages of relative humidity and those curves running from left to right downward are the effective temperatures.

The optimum effective temperature range both for summer and winter is distinctly marked out as the Comfort Zone where 98 % of the occupants are comfortable.

It is seen that in the first of the accompanying figures, the summer comfort zone is bounded by the 64°F and 79°F Effective Temperature lines, and the 30% and 70% of the Relative Humidity lines with an optimum of 71°F within the same Relative Humidity lines.

The winter comfort zone has practically the same Effective Temperature range, but bounded by lower effective Temperature lines. 60°F to 74°F with the same Relative Humidity Range, the optimum being about 66°F.

An air movement or Turbulence of 15 to 25 ft per minute is assumed in the preparation of these chards.

On another chart of comfort zone and normal effective temperature found in the " Refrigeration Data Book ", there are radial lines of Effective Temperature superimposed on a diagonally set rectangular matrix representing the wet bulb and the dry bulb temperature. Here the optimum effective temperature for winter is 70°F at 50 % relative humidity, and the optimum effedtive temperature for summer is at 76°F and 50°/o Relative Humidity. The corresponding dry bulb temperature is 71°F on the chart. This means that a 76°F dry bulb temperature with 50 % relative humidity gives the same feeling of warmth and cold as the saturated air at 71°F.

*" The optimum temperature of the environment most (most) conductive to human comfort and at which the body works most efficiently depends not only upon the type of work performed by the individual, but also upon other factors such as age, health and adaptability of the individual to climatic conditions. A moderate amount of fluctuation in temperature is beneficial to comfort and the accomplishment of physical and mental work "

* Refrig. Data Book

METEOROLOGICAL DATA FOR BEIRUT

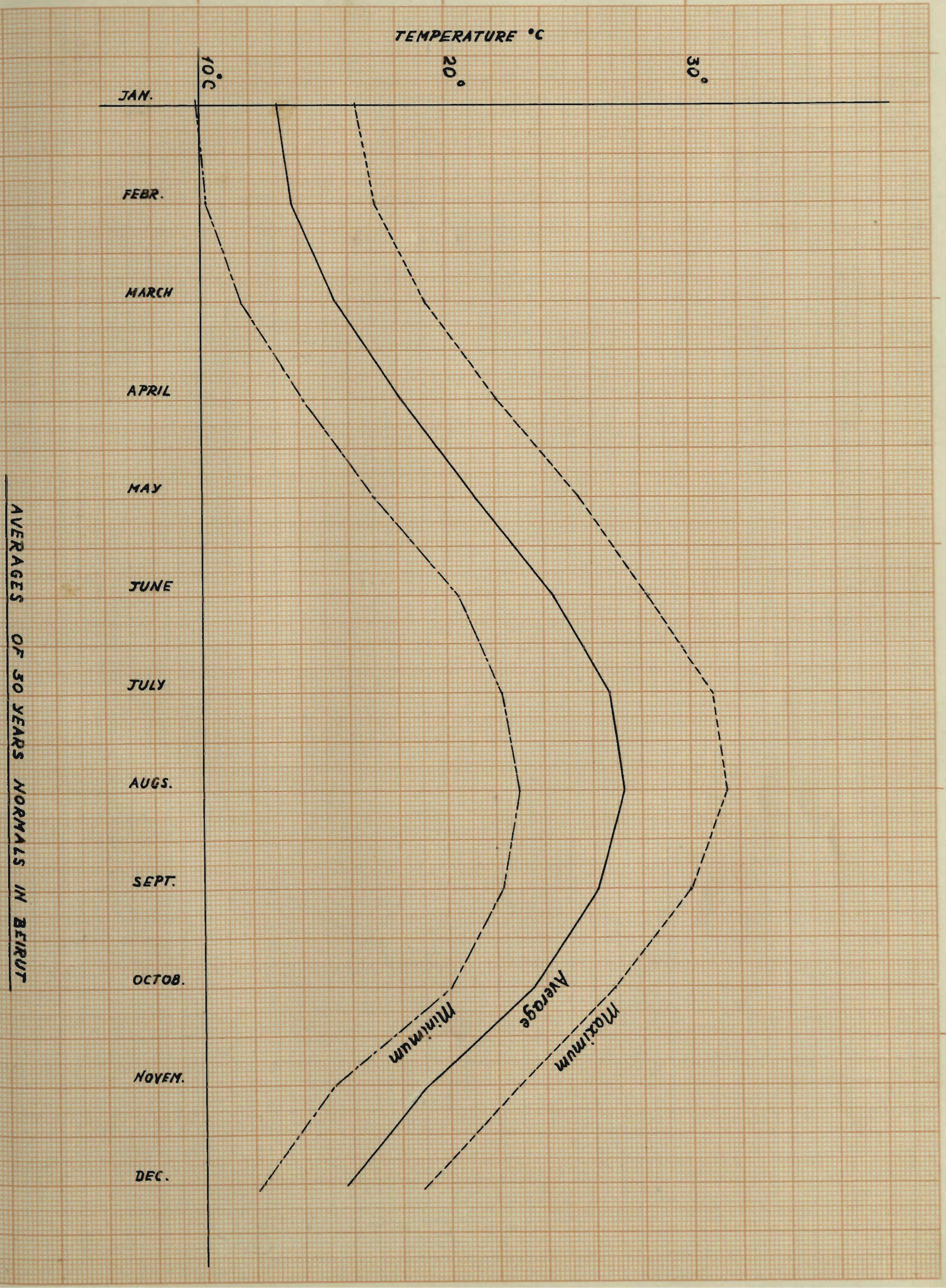
For the purpose of the design and calculations of an air conditioning system, fairly complete knowledgde of the temperatures variations, monthly and yearly, average temperatures, maximum and minimum temperatures and % relative Humidity are needed for the determination of Heat losses, total heat load, capacity of the unit and temperature range of machinery to be selected and so on.

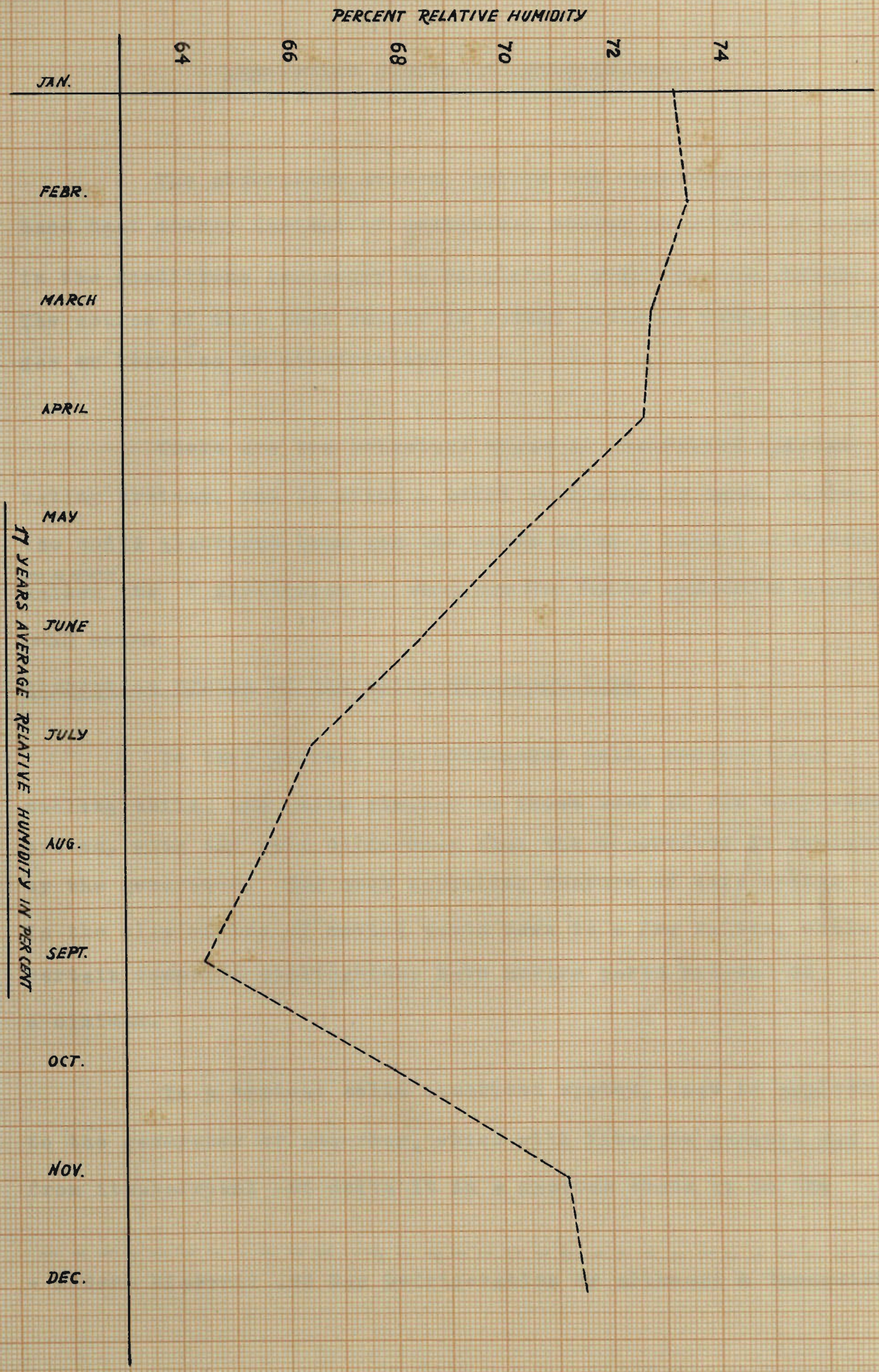
The data of the accompanying charts was taken from observations at the A.U.B. meteorological station.

In chart n°1, the temperatures plotted against the monts of the year are the averages for every month of the maximum and minimum temperatures of thirty years normals. The normals are the average temperatures of thirty years of the same month both for maximum and minimum temperatures of the day. In chart n°2 instead of the averages of the maxima of thirty years normals, the highest and the lowest temperatures reached during the consecutive months of the year are plotted. It is seen on these charts that the hottest month during summer in Beirut is August with an average maximum temperature of $31^{0}.56^{0}$ C(88.8^{0}F) and with an average minimum of 23.10^{0} (73.7^{0}F) As for winter the coldest month is January with an average maximum of 16.44^{0}C(61.6^{0} F) and an average minimum of 9.91^{0}C(49.85^{0}F)

In another chart prepared for the percent relative Humidities, the values plotted on the vertical axis represent the average humidity of seventeen year's averages for every month.

The highest humidity reached during the year is 73.31 % is in January and the lowest is 64.48 % in September. The year 1947 has had the highest yearly average percent relative humidity with a value of 74.13 %. The lowest yearly average is in the year 1945 with a value of 66.85 %.


TEMPERATURE °C
10°C
20°
30°
JAN.
FEBR.
MARCH
APRIL
MAY
JUNE
JULY
AUGS.
SEPT.
OCTOB.
NOVEM.
DEC.
Minimum
Average
Maximum
AVERAGES OF 30 YEARS NORMALS IN BEIRUT


PERCENT RELATIVE HUMIDITY
64
66
68
70
72
74
JAN.
FEBR.
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
17 YEARS AVERAGE RELATIVE HUMIDITY IN PER CENT

ABSORPTION SYSTEM OF REGRIGERATION

The absorption system, unlike the compression system, uses heat energy instead of mechanical energy to effect a change in the conditions necessary to complete a refrigerating cycle. The source of this heat supply is either ordinary fuels such as gas or kerosine or electricity.

There are two principal types of absorption refrigerating systems, one in which a solid absorbent is used, called the solid absorbent type and the other using a liquid absorbent, one of which is called the " Electrolux ", which may find future application in cooling small houses.

Absorption System of the Solid Absorbent type

In this system, the condensing coil, receiver and cooling coils, are quite similar to those used in the compression system, with the only difference that the compressor is replaced by the generator. The most appealing feature of this system is the elimination of moving parts down to a few valves, while certain domestic applications have moving parts reduced to a minimum.

In a typical solid absorbent system, heat is applied to the generator or absorber, which will liberate ammonia gas from its absorbent and drive it in a gaseous state up to the

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+ Modern Electric and Gas Refrigeration by Althouse & Turnquist.

condenser where the vapor is liquified by cooling.

The liquid refrigerant is forced from the condenser to the receiver or storage tank by the pressure of the vapor entering the condenser.

After sufficient ammonia is driven into the condenser and receiver, the heat is discontinued ~~and~~ to the generator or absorber coils. When the temperature of the absorber is lowered sufficiently, it begins taking back or reabsorbing the ammonia gas.

As the ammonia evaporates from the cooling unit it is replaced by liquid ammonia from the receiver. This operation continues until the proper amount of ammonia is reabsorbed by the generator, when heat is again applied and a new charge of ammonia is stored in the receiver.

From the description it is seen that the cycle is intermittent and that the complete cycle embraces both a generating period and an absorbing period.

LIQUID ABSORBENT SYSTEM (ELECTROLUX)

The liquid absorbent system seems to possess some very desirable characteristics. Water at ordinary pressures and temperatures will absorb great quantities of ammonia. Ammonia absorbed in water may be easily driven from the water by the addition of heat. Also liquid ammonia has a high latent heat of vaporization.

The water-cooled Electrolux is a very ingenious domestic refrigerator which is desighed to operate in a continuous cycle and has no moving parts or valves other than for the control of the burner flame and of the temperature of the circulated cooling water.

The regrigerant is ammonia, with water used as the absorbent; hydrogen gas is utilized to create a partial pressure to allow the ammonia to evaporate at a low pressure.W'

When the burner is lighted and its heat applied at the base of the generator, ammonia vapor is released from the solution. This hot vapor passes upward through the percolator tube and as the hot ammonia vapor rises through this tube it not only carries heat and a small quantity of water vapor, but actually forces the weak solution to the upper level of the generator.

Most of the water vapor in the strong solution condenses here, and the weak solution spills over the top of the percolator tube dropping back into the generator. The hot ammonia vapor, being light, continues to rise into the analyzer tube. As the hot ammonia vapor passes upward through the analyzer tube, more water vapor is removed while the hot ammonia vapor goes on into the rectifier.

The rectifier consists of a series of small steel baffle plates, surrounding one leg of a U-tube; because the hot ammonia vapor still has some traces of water vapor, which must be removed in order to have pure ammonia vapor, the hot ammonia vapor, (the hot ammonia vapor) is made to pass over these baffle plates, where the last of the water vapor condenses and flows back through the analyzer tube to the generator.

The heat from the gas flame has at this point completed its work. For the remainder of the cycle, the natural force of gravity is depended upon to create circulation.

The pure hot ammonia vapor now continues into the condenser. This condenser consists of two parts: A layer of steel tubing through which the hot ammonia vapor passes, and a layer of copper tubing through which cooling water flows. These two tubes are soldered together to obtain a solid contact for interchange of heat.

The cool water, passing through the copper tube, takes out the heat from the ammonia vapor, thus condensing the vapor. The ammonia now is in a pure liquid state and flows back into the U-tube.

The U-tube is the receiving and storage compartment in the cycle when the liquid ammonia is allowed to build up to a predetermined level; then it flows into the liquid ammonia tube which passes through the heat exchanger. The ammonia is here cooled before it reaches the cooling unit.

Because a liquid will always seek its own level and since the U-tube is at a higher level than the cooling unit, the liquid ammonia flows by gravity through the liquid ammonia tube and spills into the cooling unit.

As the liquid ammonia falls into the cooling unit, it forms in large shallow pools on a series of horizontal baffle plates. The hydrogen that is being fed to the cooling unit permits the liquid ammonia to evaporate. During this process of evaporation, the ammonia absorbs heat from the cooled spaces. The ammonia vapor formed by the evaporating of liquid ammonia, mixes with the hydrogen. This mixture is heavier than hydrogen alone and therefore settles downward through the bottom of the evaporator into the gas heat exchanger. This circulation is continuous in the cooling unit.

The mixed gases then pass through the gas heat exchanger and are heated, which conserves energy by pre-heating the gases before they may pass into the absorber.

During this time a weak solution of ammonia and water is being carried from the generator to the top of the absorber where it falls upon the baffle plates. There it meets the mixture of hydrogen and ammonia vapor coming from the evaporator by way of the gas heat exchanger. The weak solution absorbs the ammonia vapor. The hydrogen is left free; since hydrogen is insoluble in water and is very light, it now rises to the top of the absorber and returns to the cooling unit.

The absorber is surrounded by the condensing water coil to cool the weak liquid. The cooling of the weak solution helps it to absorb the ammonia gas out of the mixture of ammonia and hydrogen. Also when the weak water solution absorbs the ammonia gas, considerable heat is liberated and the water-cooling coil must remove this heat to permit the regrigeration to continue.

The solution, now a strong solution of ammonia and water, drops to the bottom of the absorber and continues down through the liquid heat exchanger. The liquid heat exchanger carries the strong liquid, or refrigerant, back to the generator where it again starts its cycle.

SILICA-GEL AIR-CONDITIONING SYSTEM

This system which is adopted for ordinary household mechanical refrigeration uses silica gel as an absorption agent. This is SiO_2, silicon dioxide, a hard, hygroscopic crystalline substance which absorbs relatively large quantities of water vapor due to its capillary and porous nature.

When it is in contact with water vapor, it absorbs as much as 25% of its own weight.

After becoming fully saturated it can be reactivated by driving off the water vapor in the voids through heating.

The equipment used in a silica-gel house+ air-conditioning system consists essentially of two parts: 1) the silica-gel dehumidifying unit and (2) the air-circulating and cooling unit. The dehumidifier unit consists of heats of silicagel, air heaters for activating the silica-gel , a fan, a cooler, an air filter, and an automatic controlling system. In this unit, the fresh air is drawn through the filter to remove dirt and dust. The clean air then passes through the beds of silica-gel, which removes the moisture. The moisture free or dried air then is cooled in the cooler, from which it flows to the spaces to be conditioned. When the silica-gel has absorbed all the moisture it can, it is

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+ Moyer & Fittz Air-Conditioning.

reactivated of the addition of heat and then cooled for the next absorption period. This operation is entirely automatic.

In order to supply the spaces to be conditioned with cool dehumidified and pure air, a duct system must be provided for both the supplied and the recirculated air. In the case of a home heated by a hot-air furnace, this heating system adapts itself readily for air conditioning purposes. In some cases, the cooler is used as a heater during the winter, thus eliminating the hot air furnace. This heater may then be supplied with steam by a separate steamboiler.

In the summer months, the return air from the rooms is mixed with the fresh dehumidified air, the desired humidity and temperature are obtained for comfort.

The cooler is of the indirect-tube type. The cooling water flows through the tubes while the air passes over them. In cases where a refrigerating system is not used and deep-well water is not available, an alternative method is used to secure cooling. In this case the cooler is eliminated, and an excess quantity of air is dehumidified in the silica-gel unit. The excess quantity of air, having been made neerly moisture free, is now passed through recirculated water, which lowers the temperature of the air by so called evaporated cooling. The cooled air is now mixed with the recirculated air, and the mixture is then delivered to the supply ducts.

By such arrangements, it is possible to maintain a temperature of 82°F within a residence with a relative humidity of 45 % (grains of moisture per pound = 74) when the outside conditions are 95°F and 50 % relative humidity (grains of moisture per pound = I23).

The operating costs of such a system vary for different parts of the country. However, it is safe to estimate that the operating cost will not exceed 15 ¢ per hour of operation. A season of operation varies between 500 & 800 h. " .

COOLING BY DEHUMIDIFICATION WITH CALCIUM CHLORIDE

Calcium chloride has been most efficient and one of the cheapest dehumidifying agents. In relation with air conditioning it is used as a moisture absorbent as it has a strong affinity for water.

It is used most effectively as an anhydrous salt for drying purposes. It is also used in solution. The relative humidity of a saturated solution is only 28 %. Even for comparatively dilute solutions, the vapor pressures and the relative humidites are low. The product which is available for dehumidification purposes is 80 % of $CaCl_2$ and 20 % water.

In practice the circulated air comes in contact with the solution of calcium chloride and then passes out after dropping its moisture load.

P A R T I I

D E S I G N

&

C A L C U L A T I O N S

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ARCHITECTURE AND STRUCTURAL DESIGN

This is a double story signle apartment house of framed structure with walls built of 20 cms thick stone with 10 cms of back insulation. It consists of a large and comfortable living room or so called all purposes room opening to a veranda on the north East and leading from within to a dining room on the North-West.

There is a salon with a large veranda. Three bedrooms, a master bedroom and two smaller ones, are furnished with an oriental and a western bath. A small lobby divides this part from the kitchen and the maid's compartment.

Inner partition walls are of light concrete blocks with cement plaster on both sides.

The insulation for the outside walls and the roof slab is made of light porous concrete blocks Type A with dimensions 50 cm x 40 cm x 8 - 10 cms.

This type of insulation has been introduced into this country only recently and is commercially known here as " Celcrete " Type A is the lightest of the three types on market and it weighs only 250kgs/m3 and its crushing strength is 1 - 3 kgs/cm2.

Due to its cellular nature, it has remarkable heat insulating qualities and the coefficient "k" of its thermal conductivity may be favorably compared with that of cork, being 0.065 k.Cal.per meter, per square meter, per hour, per degree centigrade.

The windows will be of " Store-Roulant " type with shutters much similar to Venitian blinds and having ordinary sash made of double glass 3 mm thick. Though they are costy, but provide natural ventilation, lighting and awning simultaneously and moreover give a pleasing architectural effect from the outside.

The whole area below the maid's compartment in the basement leading down few steps from the landing, is divided into a large room for the installation of the air-conditioning unit and a smaller one for storage purposes.

The main duct leading from the basement to the conditioned space will pass from the lobby to the corridor and then branch out into smaller ducts to supply the various rooms infront and on both sides. The conditioned air will be admitted few feet below the roof slab in each apartment to provide for even distribution and circulation in each room.

The whole building will cover an area of 245 m2 or 2640 sq.ft. on a lot 400 m2 or 4300 sq.ft. on a site near the sea shore at Ras-Beirut.

(On the following pages enlarged plans are drawn of the living room, kitchen, etc)....

DESIGN CONDITIONS

Temperature, Humidity & Effective Temperature.

The outside design temperatures were chosen after the average of thirty years normals were worked out.

Following design recommendations, the outside temperature for cooling was chosen between the maximum and the average maximum. This is 87.44°F, the outside summer design

temperature .... 87.44°F
Relative Humidity ..... 66.82°F
Effective Temperature.. 67°F

In a similar manner the outside temperature was chosen between minimum and average minimum for heating and the valves are

Dry bulb temperature..... 50.I8°F
Relative Humidity .... 72.78 %
Effective Temperature... 49°

The inside temperature and humidity conditions for design are based on the comfort chart. The values selected from the middle portion of the " Comfort Zone " in each case, one on the average winter comfort line and another value on the average summer comfort line.

The comfort chart is reproduced here for purposes of reference. Page 12

The values selected are as follows:

Average Summer Comfort Conditions in Design

Dry bulb Temperature........ 76°F

Relative Humidity .... 48 % (Wet Bulb temp.)

Effective Temperature....... 71.5 °

Average Winter Comfort Conditions in Design

Dry bulb temperature .... 70.5°F

Relative Humidity........... 50% (wet bulb temp.59°F)

Effective Temperature ...... 67°

In the above conditions an air movement of 25 ft./minute is assumed.

Of course the design could have been based purely on effective temperatures, but this is a composite index which includes the effects of three factors: (1) Temperature (2) Humidity and (3) Air movement each of which should be treated separately in heat load calculations.

S U N - E F F E C T

* " Surfaces exposed to the direct rays of the sun will transmit more heat to the air conditioned spaces than similar surfaces shaded from the direct rays of the sun "

Different portions of surfaces will be sunlit during different times of the day, and all of the surfaces can not however be exposed to the sunlight at the same time.

The amount of the heat received is not definitely known and different authors give different values.

According to one an increase in the temperature differential between the inside and the outside air is given 30°F for roofs, and then the calculations for heat gains are done in the usual manner with the proper transmission coefficients.

The same author recommends for:

1) Skylights ... 300 B.t.u. per ft.2,per hour

2) Unprotected windows ... 180 B.t.u. per ft.^{2}, per hour

3) Protected a) WithVenitian Blinds 100B.t.u.per ft.^{2},per hour
b) with awnings 60 " " "

4) W a l l s ... 15°F increase in temperature differential.

* Moyer & Fitts Air-Condit.

In this design a difference in temperature between shaded and non-shaded portions of a wall is assumed 25 %, which gives a temperature differential for the sun effect of 33.3 degrees.

H e a t L a g

It takes several hours until the heat due to the sun effect is transmitted inside. The time varies from 3 - 10 hours being longer in thicker walls. For this reason the time of maximum wall transmission may not coincide with the time of peak load for cooling.

The effect of this lag is averaged by figuring sun effect on the exposure having greatest sunlit area of glass and wall.

In this design only half of the total exposed surfaces on two sides are considered as being sunlit, the North.East and the South-East.

Internal Heat

" In addition to the transmission and radiant heat gain, through walls, floors & glass areas, there must be added the heat given off by people and by various electric, gas or steam appliances. All these increase both the sensible and the latent heat load.

Quotation? If so, source?

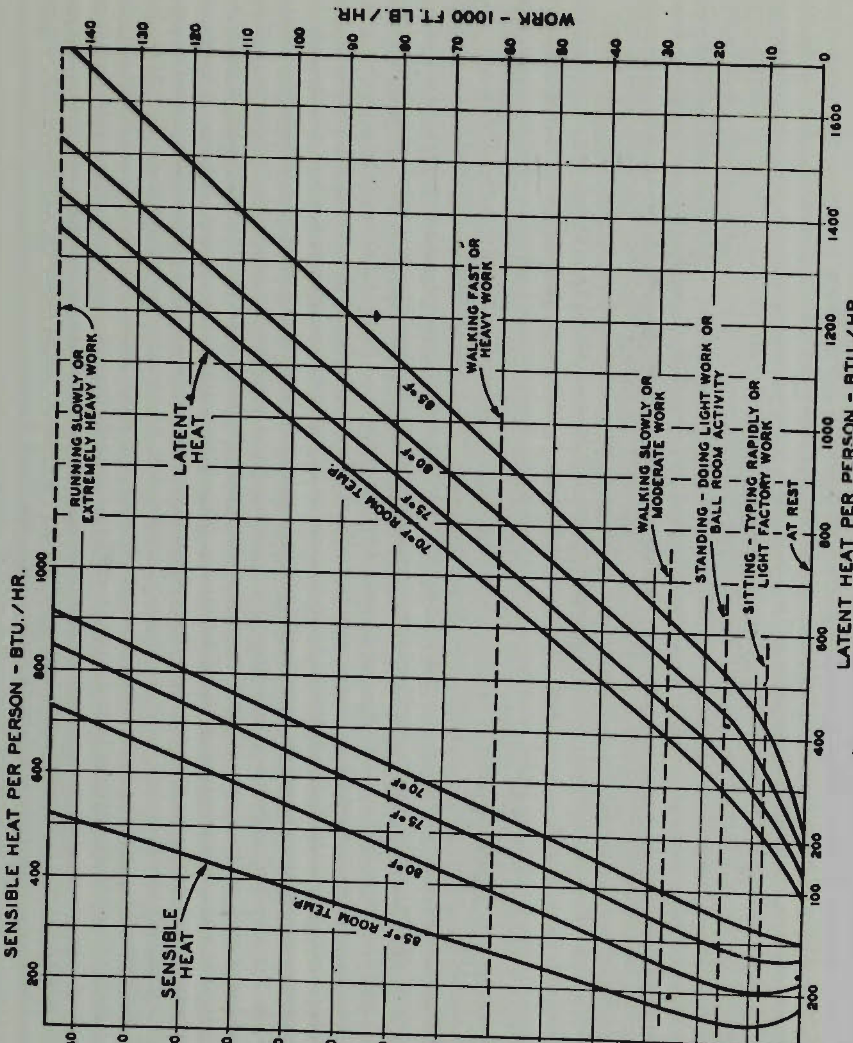


Fig. 2 Heat Gain from People, Btu. per Hour

From Refrigeration Data Book

The heat given off by persons doing average work is:

520 B.t.u. per hour at 76°F

543 B.t.u. per hour at 70.5°F

The number of persons assumed in each apartment is five.

Rather small for large apartment

The heat given off by lights and electric appliances per kilowatt is 3415 B.t.u. per hour. Often the electrical equipment will not be operating continuously and the proper time factor should be applied in such cases.

Infiltration

No matter how well the windows and doors are weather stripped, there will be infiltration of air through cracks and clearances depending upon the character and grade of the building construction and the velocity of the wind.

It is estimated here by measuring the periphery of the window casing assuming a 1/16 inch crack, with the wind blouring 15 m.p.h. An experimental coefficient of 0.148 cubic ft per minute per foot of 1/16 in. crack per mile velocity was taken. The infiltration through doors is assumed twice as much as that for windows.

The determinations for infiltration losses are approximate and there is no reason for going into refinements of calculation.

Air changes and Supply Air

An air change of once per hour is recommended for residences. According to ventilation requirements 10 cu.ft per minute of outside air per person should be figured,

and 25 to 40 cu.ft.per minute if there are smokers.
The quantity of supply air depends upon the sensible heat load and the difference between the temperatures of the room and of the supply air

$$Q = \frac{\text{Sensible Heat load}}{(t_1 - t_2)\ 0.24}$$

Internal Heat Calculations

Thermal Conductivities, K

(Btu. in per sq.ft. r.°f)

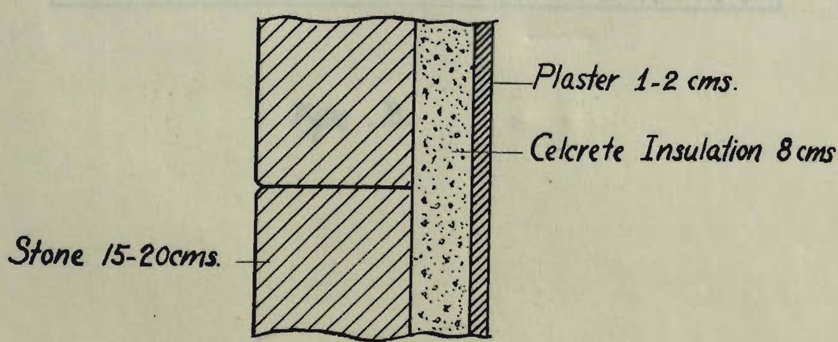
Cement Plaster	-	I2 - 8
Celcrête	-	4.84
Concrete	-	I2.0
G l a s s	-	5.5
Limestone	-	I0.8

COmposite Wall, Heat Transfer Factors

U = Heat transfer factor or overall transmission coefficient

t_1, t_2, t_3 = Thickness of various parts

k_1, k_2, k_3 = Thermal conductivities.



Cross Section of outside wall

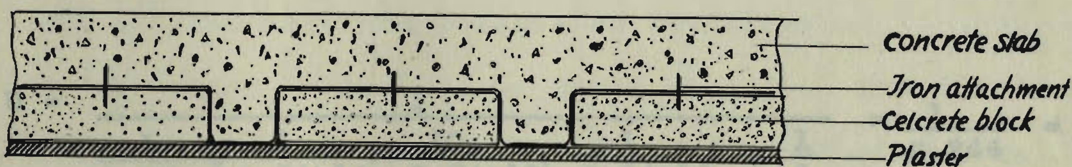
Determination of U-for Exterior Wall

Including airfilms on exterior surfaces

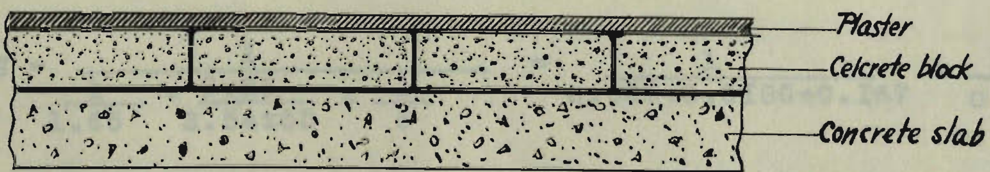
$$U = \frac{1}{\frac{1}{f_i} + \frac{t_1}{k_1} + \frac{t_2}{k_2} + \ldots \cdot \frac{1}{f_o}} = \frac{1}{\frac{1}{I.65} + \frac{1}{2.54x12} + \frac{8}{2.54x484} + \frac{15}{2.54x108} + \frac{1}{6}}$$

$$U = \frac{1}{0.606 + 0.0328 + 0.650 + 0.5480 + 0.I660} = \frac{1}{2.0028} = \underline{\underline{0.5}}$$

Determination of U- for concrete slab



Type - A -



Type - B -

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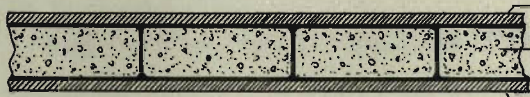
$$U = \cfrac{1}{\frac{1}{1.65} + \frac{10}{2.54x12} + \frac{10}{2.54x4.84} + \frac{1}{2.54x12} + \frac{1}{6}}$$

$$= \frac{1}{0.606 + 0.330 + 0.8I20 + 0.0328 + 0.I660} = \frac{1}{1.9468} = 0.5I5$$

Determination of U-For Partition Wall of Celcrete



$$U = \cfrac{1}{\frac{1}{I.65} + \frac{1}{2.54x12} + \frac{10}{2.54x12} + \frac{1}{2.54x12} + \frac{1}{6}} = \frac{1}{2.244} = 0.446$$

Determination of U-for Glass Windows

$$U = \cfrac{1}{\frac{1}{1.65} + \frac{0.25}{2.54x55} + \frac{1}{6}} = \frac{1}{0.606+0.0I80+0.I67} = \frac{1}{0.7944} = \underline{\underline{I.26}}$$

HEAT LEAKAGES

Heat leakages from walls or portions of walls exposed to the surface may now be determined fairly by applying the formula:

$$Q = A\,U\,(t_2 - t_1)$$

Q = Total Heat in Btu/h.

A = Net square feet of surface

U = Heat transfer factor

$t_2 - t_1$ = Temperature difference between inside and outside.

e.g.- The heat leakage from the North East shaded wall is

$A = 78\ f^2$ $U = 0.5$ $t_d = 11.4$ $Q = 445 = 78 \times 0.5 \times 11.4$ Btu/h.

and all the rest are calculated similarly as is seen on the result sheet. It is to be noted also that the difference in temperature between the shaded and the non-shaded walls is assumed as 25 % .

INTERNAL HEAT

Infiltration Losses

For an average window 1/16 inch crack and 3/64 inch clearance, velocity of wind 15 m.p.h., the experimental coefficient k = 0.147 - 0.148 w.ft/m/ft/mile veloc.

The heat equivalent of Infiltration:

$$H_i = 0.24\ Vd\ (t - t_o)$$

Air-Conditioning Dalzell & Hubbard.

H_i = Btu per hour required for heating the infiltration air

V = Volume of air in cu.ft.

d = Density lbs/ft^3 at outside temp.

t = Inside temp.

t_o = Outside Temp.

V = 0.I48 x I5 x 60 x I67.5 = 22.200 cu ft./hour

d at 50.I8°F = 0.0778 lbs/ft^3

$t - t_o$ = II4°F

H_i = 0.24 x 0.0778 x II.4 x 22.200 = 4720 Btu/hr.

<u>Heat given off by Persons.</u>

Assuming there are five persons in the house:

doing light work at 76°F Heat = 530 x 5 = 2650 B.t.u./h

moisture = I785 x 5= 8925 grains/h

at 70.5°F Heat = 543 x 5 = 27I5 B;T.u./h

Moisture =I350 x 5 = 6750 grains/h

TABLE I

AIR CONDITIONING CALCULATIONS

Heat Leakages	Net sq of surface	Heat Transf. factor -U-	Temp. Differ	B.t.u. per hour	Temp. differ	B.t.u. per hour
Walls or portions of walls exposed to the Surf.						
North-East shaded	78	0.5	II.4	445	20.32	792
North-East non shaded	860	0.5	33.3	I4300	20.32	8720
South East shaded	48	0.5	11.4	275	20.32	4.87
South East none shaded	590	0.5	33.3	9.820	20.32	6000
NorthWest shaded	408	0.446	II.4	2.080	20.32	3600
South West shaded	I235	0.5	II.4	7.000	20.32	I2.500
Glass in outside walls						
North East none shaded	100	1.26	33.3	4.200	20.32	2560
South East shaded	10	1.26	11.4	I45	20.32	256
South East none shaded	45	I.26	33.3	I.890	20.32	II50
North West Shaded	50	I.26	11.4	720	20.32	I280
South West shaded	I24	I.26	11.4	I.780	20.32	3I70
Ceiling or Portions of ceiling	1080	0.5I5	11.4	6.350	20.32	11200
Total Slab						
Total Heat				49005		5I7I5

Internal Heat	Unit	Number of units	Factor	B.t.u. per hour	Factor	B;t.u. per hour
Outside air infilt.losses	e.f.h	22.200	0.2I3	4720	0.352	7.850
Heat gain from people	pers;	5	530	2650		2.650
Heat gain from lights	watts	1200	1.338	1.370		1.370
Other sources of heat						
1-Large eledr.burners	watts	1	1.500	1.500		1.500
2-Ovens	watts	1	2.I25	2.I25		2.I25
3-Heaters 250 watts	watts	1	850	850		850
4-Heaters 500 watts	watts	1	1700	1700		1.700
5-Coffee urns	gals.	1	100	100		100
Total cooling load				60.I00 Btu/h		59.566 Btu/h

Tons of Refrigeration required = $\frac{60.I00}{12.000}$ = 5 tons

<u>The Lithium chloride absorption System-Servel Unit.</u>

This is the process used for regrigeration in the following design of air conditioning.

<u>Reasons for its selection.</u>

1- The unit is simple in itself having a minimum of devices for mechanical operation and control e.g. no rectifiers & analysers.

2- This results in minimum of repairs and the necessity for skilled supervision is done away with. This is important in this country for there is a lack of technical skill.

3- The unit is sealed having practically no exposed parts.

4- The materials used are cheap comparatively.

5- The unit is small and quite efficient and may be favorably used in residences of small sizes as single apartments.

Here water is used as the refrigerant and Lithium chloride as a solvent. There is no rectifier or solvent return provision and the machine can not be operated below a temperature of 32°F.

A characteristic feature of this machine is that the circulation of the refrigerent is not accomplished mechanically by means of a pump, but by a thermolight process whereby the vapor rising from the generator lifts the strong solution into the separator chamber. Here the pressure is nearly the same as in the generator (3 in.abs.) sufficient for returning the weak liquid back to the absorber which is located near the top. From there the liquid is delivered to the generator by gravity.

Steam jackets are provided around the evaporator tubes in the generator. The steam may be supplied under atmospheric pressure from a special boiler and may be used for feeding heating coils in a steam heating system.

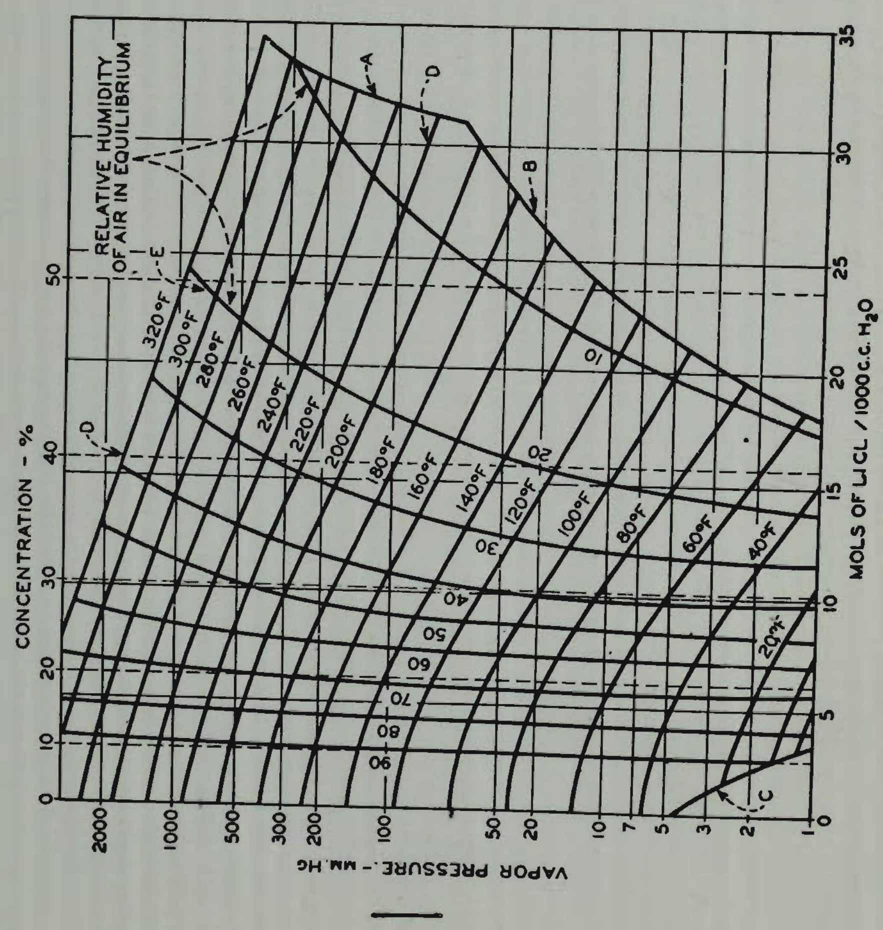
The evaporator is of the direct expansion type whereby water is evaporated inside extended surface coils with air passing on the outside of the surface.

The units found on market are of 3 and 5 tons capacity which may be regulated by the heat control of the gas burners.

The cycle efficiency is claimed to be 75 % by the manufacturers.

The conditions at the various point in the cycle will be more fully treated in the following design calculations.

Fig. 3. Chart of the Physical Properties of Lithium Chloride



From Refrigeration Data Book

Conditions and Design calculations in the Operation of the Refrigeration cycle

Conditions in the Generator

It is assumed that the concentration of the Li-Cl solution in the generator is 20 % or about 6.085 mols per 1000 cc of water. From the operating characteristics of the Servel Li-Cl air-conditioning unit the pressure in the generator is about 3 in Hg.abs. which is equivalent to 1.4736 p.s.i. From tables on physical properties of Lithium-chloride, the boiling point of the solution of this particular concentration having the same vapor pressure is 116.415°F.

Water vapor at this temperature and a pressure of 1.4736 p.s.i. is superheated and to calculate the total heat of 1 lbs of vapor the heat for superheating should be added to the total heat of the saturated vapor at that pressure.

Pressure	Temperature	Total Heat of saturation
1.4736# /in²	115.08	1110.8 B.t.u./lb.

Degree of superheat 116.415 - 115.08 = 1.335°F

S.H. of low pressure water vapor 0.44-0.45 B.tu/16/°F

Heat of superheat 0.45(1.335 = 0.6 B.tu.

Total Heat of superheated vapor 1110.8 + 0.6 = **1111.4** Btu.

Conditions in the Separator

From the generator water vapor mixed with the solution rises by a process of thermolift to the separator from where the vapor passes to the condenser, leaving behind a concentrated solution of Li-cl of about 40 %.

The pressure in the separator is about 3" of Hg absolute, lower than the generator pressure due to the gain in elevation which is about 1.5 m in ordinary installations, equivalent to an additional pressure of 2.I3-p.s.i.

Conditions in the Condenser

Here the hot vapor coming from the separator comes in contact with the surface of the cooling coils and condenses and returns to the liquid phase giving up its latent heat. This condensation occurs at 35°C or 95°F, the cooling water being at 35°C. The total heat of one pound of liquid at 95°F is 6I.3 B.tu./lb

Conditions in the Evaporator

There is an expansion valve between the condenser and the evaporator which controls the rate of flow of the high pressure liquid.

In passing through the expansion value the pressure is reduced and the liquid is cooled down.

The liquid comes now to the evaporator where the pressure is 0.299 p.s.i. This is the saturation pressure at I8°C or 64.4°F. The total heat of this saturated vapor is I087.2 B.t.u./lbs. But the vapor here may not be exactly saturated except nearly so in which case the total heat is nearly equal the corresponding value of the saturated vapor.

In evaporating the liquid takes up latent heat from the cooling space and then passes to the absorber.

Conditions in the Absorber

The concentrated liquid coming down from the separator passes through the heat exchanger where it is cooled to 35°c or 95°F to effect better absorption. This heat is utilized in warming the cool weak solution at the bottom of the absorber before it reaches to the generator.

The pressure is the same as in the evaporator and is about 0.3 p.s.i.

Vapor passing over the concentrated solution of Li-cl is absorbed and it gives up its latent heat in condensation and raises the temperature of the weaker solution. The weak solution now returns to the generator and the cycle is repeated.

Efficiencies of the Cycle

Refrigerating effect = Heat per lb. of water entering the evaporator-

Heat per lb. of steam leaving evaporator

$Q_e - C_c$ = I087.2 - 6I.3 = I025.9 B.t.u. per lb.

The Refrigerating effect expressed in ton of refrigeration

$$= \frac{1025.9}{200} = 5.13 \text{ Tons of Refrigeration}$$

Heat imput to the generator = IIII.4 - 0.66 (II6.4I5- 95)

= IIII.4- I4.I5 = I097.25 Btu.

Ideal Thermal efficiency of the cycle =

$$\frac{\text{Refrigerating effect}}{\text{heat imput}} = \frac{1025.9}{1097.25} = 93.5\ \%$$

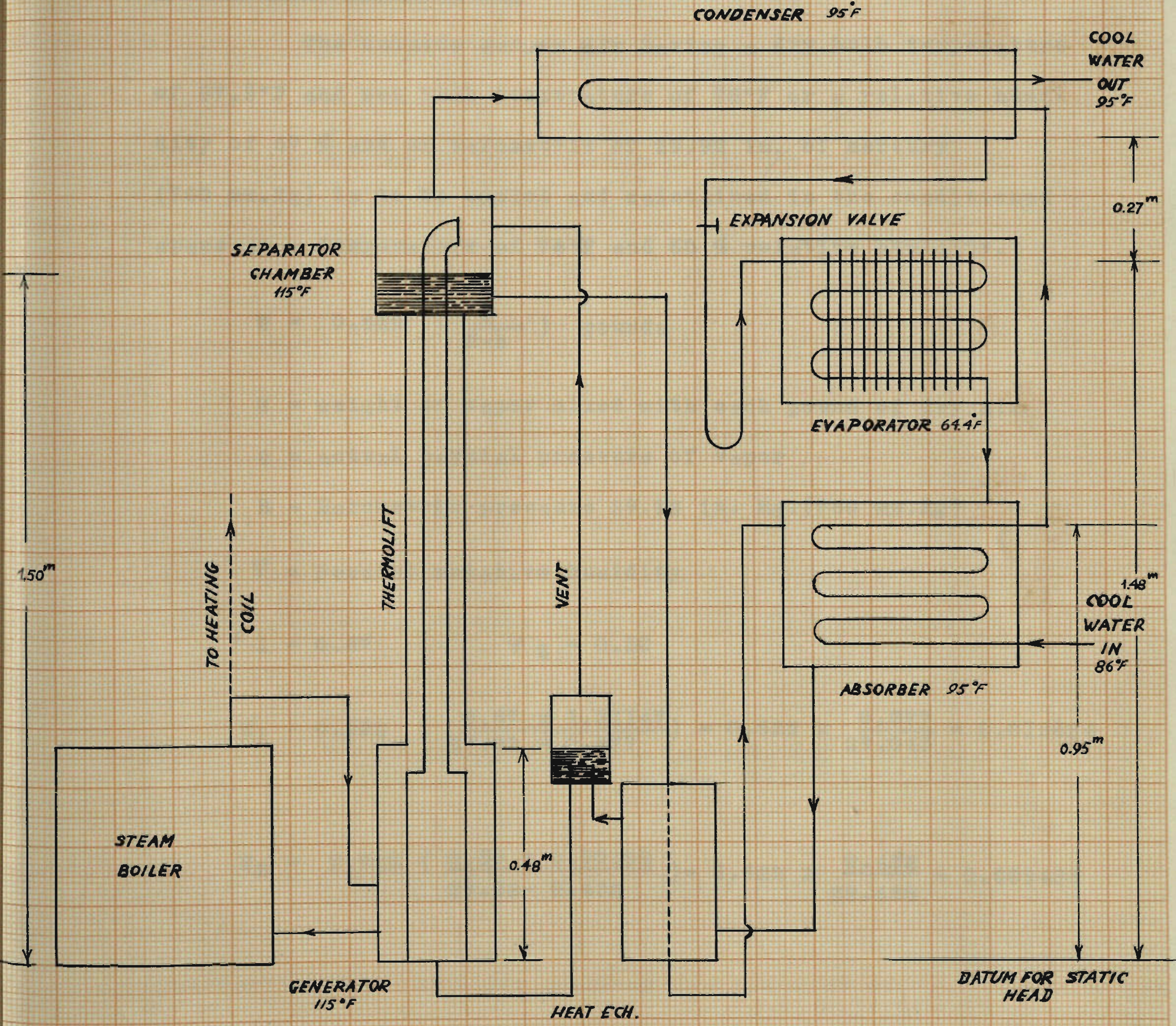
The efficiency of the generator being 80 % the practical efficiency of the cycle becomes .80x 0.935 = 74.8 %

The ideal cycle efficiency = $\frac{Qc}{Qg} = \frac{1087.2}{1111.4} = 97.8\ \%$

Due to the incomplete heat transfer & to heat leakages this is much less and is 0.76 x 0.978 = 74.34 %

TABLE II

	Temp. °F	Pres. #/in.²	pres. in. H_2O
Condenser	95°F	0.8149	22.60
Evaporator	64.4°F	0.299	8.26
Absorber	95°F	0.174	4.81
Generator	115°F	1.4736	39.20
Separator	115°F	1.4736-	39.2



SCHEMATIC ARRANGEMENT OF THE SERVEL

AIR-CONDITIONING UNIT

DEHUMIDIFYING AND COOLING

Dehumidifier Calculations

The outside summer air having a dry bulb temperature of 87.5°F and wet bulb temperature of 78°F or a relative humidity of 67 % and of barometric of 29.92 in. of mercury (760 mm.Hg) is to be cooled and maintained in the conditioned space at a temperature of 76°F and 50 % relative humidity.

$$W = 0.622 \left(\frac{e}{B-e} \right) \text{ pounds}$$

W = weight of vapor mixed with each pound of dry air

e = actual partial pressure of vapor

B = Barometric pressure 29.92 in. Hg.(760 mm.Hg)

φ = Percent relative humidity

$\varphi_1 = 0.67$ $\varphi_2 = 0.50$

$$W_1 = 0.622 \left(\frac{0.67 \times 1.31147}{29.92 - 0.877} \right) = 0.622 \times \frac{0.877}{29.043} = 0.018624$$

$$W_2 = 0.622 \left(\frac{0.50 \times 0.90398}{29.92 - 0.452} \right) = 0.622 \times \frac{0.452}{29.468} = 0.009486$$

+ Dalzell Air Conditioning

grains of moisture to be extracted from the humid air per pound

$W_1 - W_2 = 0.018624 - 0.009486 = 0.00913816$

$= \underline{\underline{63.96}}$ grains

about $\underline{\underline{64}}$ grains of moisture per lb of dry air extracted.

Dew point temperature of dehumidified air = 55°F

<u>Humidifying and Heating</u>

Air is to be maintained at 70°F with a relative humidity of 50% corresponding to a wet bulb temperature of 59°F, when the outside is at 50°F and 73 % relative humidity.

$$W_1 = 0.622 \left(\frac{0.73 \times 0.36241}{29.92 - 0.2646} \right) = 0.622 \times \frac{0.2646}{29.6554} = 0.00555 \text{ lb}$$

$$W_2 = 0.622 \left(\frac{0.50 \times 0.73866}{29.92 - 0.36933} \right) = 0.622 \times \frac{0.36933}{29.55067} = 0.00776 \text{ lb}$$

The water vapor added per pound of dry air must be

$W_2 - W_1 = 0.00716 - 0.00555 = 0.000221$ lb.

$= 15.47$ grains of moisture

should be added per lb of dry air.

Heating

The total heat load in heating is 60.000 B.t.u. per hour. Assuming the efficiency of the boiler to be 80 % the heat required is $\frac{100}{80}$ x 60.000 = 75.000 B.t.u. per hour.

Boiler Horsepower

The boiler efficiency is defined as the evaporation of 34 1/2 pounds of water from and at a temperature of 212°F. In this process 33.523 B.t.u., are absorbed, which is again given out when the steam is condensed in the radiators. This is taken as 33.000 in general practice to give a slightly larger boiler safety.

$$B.H. = \frac{75.000}{33.000} = 2.27$$

Since each B.H. is equivalent to the evaporation of 34.5 lbs of water, therefore 2.27 x 34.5 = 78.3 lbs of water.

Heating surface

For best economy in heating surface should be so proportioned to have about 1 ft.^{2} of heating surface for each 2 lbs of water to be evaporated.

Heating surface : $= \frac{78.3}{2} = 39.15$ ft.^{2} of heating surface.

<u>Grate Area</u>

$$S = \frac{hp \times 34.5}{E \times C} = \frac{2.27 \times 34.5}{8 \times 10} = \frac{78.3}{80} = \underline{0.98} \text{ ft.}^2 \text{ gr.area}$$

S = Total grate area in square feet

E = Pounds of water evaporated per lb of coal (6-10 usually)

C = Pound of coal burned per square foot of grate per hour (8 - 12 usually)

Selection of Pump-Motor for Circulating the Cooling Water

Cooling water entering absorber - 86 deg.F.

Cooling Water leaving condenser - 95 " "

Total heat to be removed by cooling coils- 60,1oo B.t.u./h

The quqntity of water to be circulated for

cooling - $\frac{60,100}{95-86}$ = 668 lbs/h

This is equivqlent to $\frac{668}{500}$ = 13.4 gallons/min.

It is required to pump 13.4 gallons per minute of water against an estimated static head of 32.8 ft. and a friction head of 6.56 ft. The overall efficiency of pump and motor is estimated 56 per cent; then the motor horse power is

$$H.P_m = \frac{13.4 \times 8.34 \times 39.36}{33,000 \times 0.56} = 0.237$$

The nearest commercial size will be 1/4 H.P. which will allow for increased loading due to any change in the operating conditions.

Selection of Fan

Each cubic foot of air per minute moved against a total pressure of one inch water gauge (equivalent to 5.19 pounds per sq.foot) represents energy expenditure of 5.19 ft. pounds per minute or o.ooo157 horsepower.

Therefore

$$* \; H.P. = \frac{(0.000157)(C.f.m.)(\text{Static Pressure})}{\text{Total Efficiency}}$$

$$H.P. = \frac{0.000157 \times 4830 \times \frac{1}{4}}{0.90} = 0.212$$

A ¼ H.P. Disk and Propellor Fan will used on account of low initial cost and small space requirement.

---

* Air-Conditioning, Dalzell and Hubbrard

Design of the Duct System

The " Friction Chart Method " is used in the design of the duct system. This method can successfully be used to size ducts for ordinary systems, especially in residences.

The total losses of heat are distributed in proportion to the floor areas. The percent of air supply is distributed likewise.

The total air supply to the apartment is

$$C = \frac{Hs}{1.08(t_2 - t_1)} = \frac{60.100}{1.08(87.5-76)} = \frac{60.100}{12.4} = 4.830 \text{ cu.ft./min.}$$

The percent of total air volume for each room is calculated by taking in the case of the living room 4830 x 0.15 = 725 cu.ft.

All other rooms are calculated in the same manner.

Size of Ducts & Inlet openings.

To determine the size of the ducts, the Friction Chart, Fig.300 in the Appendix of the Air-Conditioning book by Dalzell & Hubbard is used. For the living room duct, the process is as follows:

Locate the 725 cu.ft. of air at the lower part of the chart.

Refrigeration Data Book.

From this point, follow a vertical line upward to the intercepting point of the horizontal line representing pressure loss of 0.04 inch of water (See left side of Chart). From this point follow the slanting line, representing size of ducts in inches, upward to the scale at top of chart. It is noted that the size of duct is 15 1/2 inches. The same process is followed for all other rooms.

Then using the chart again, the velocity of air in the living room duct is found by following the slanting line, representing the air velocity per minute, from the intercepting point of cubic feet volume of air per minute and pressure loss of 0.04 to 580 feet per minute. All other rooms are calculated in the same manner and the results are shown on the following table.

In determining the size of the air inlet openings an air velocity of 300 ft.per minute is assumed & the sizes are determined from the chart as before.

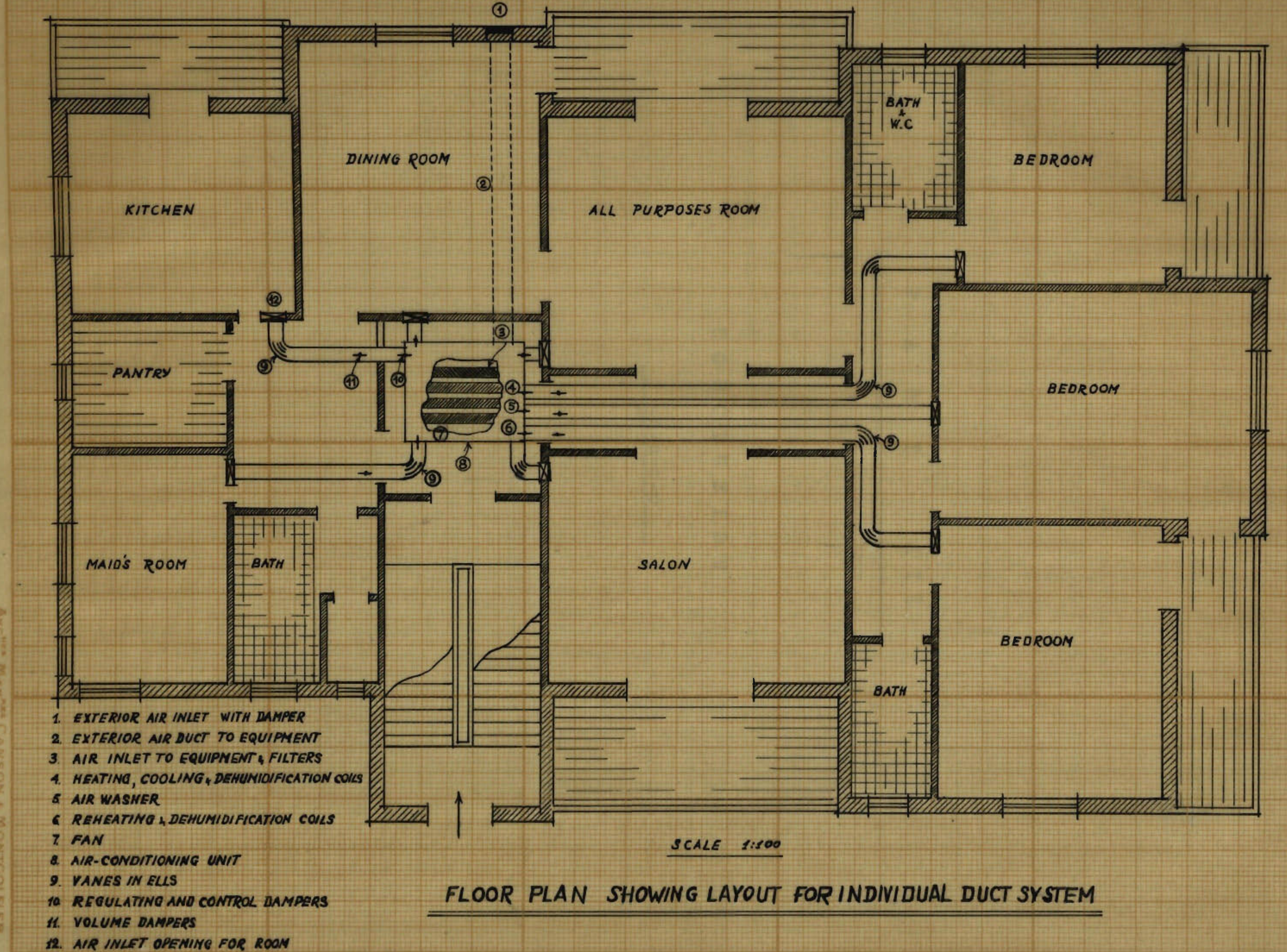
There is a special table in the appendix of the same book showing the sizes of the equivalent rectangular ducts are given.

T A B L E III

Design of Duct System

Room	Loss in Btu/h	% of total Air sup per m.	% of total Air.vol	Duct Size Inches	Veloc. of air in duct ft/m.	Size of Inlet Open. in inches	Size of Equiv. Rect. Duct in.	Size of Equiv. inlet open. in.
Entrance Hall	6300	I0.50	508	I3	535	I7 $\frac{1}{2}$	8x18	11x24
S a l o n	7.800	I3.00	630	I4 1/2	560	20	9x20	I2x28
Living Room	9.000	I5.00	725	I5 1/2	580	2I $\frac{1}{2}$	10x20	I4x28
Dining Room	7.450	I2.40	600	I4	550	I9	11x15	I5x20
Maid'sRoom	4.050	6.75	325	11	490	I4	10x10	11x15
Kitchen	5.250	8.75	422	12 1/2	520	I6$\frac{1}{2}$	10x13	13x17
Middle Bedroom	8.I00	I3.40	645	I4 3/4	565	20	I2x15	I7x20
Small side Bedroom	5I50	8.60	4I5	I2 I/4	5I5	I6	8x16	10x22
Large side Bedroom	7.000	II.60	560	I2 3/4	550	I7	12x15	I3x19
Total	60.I00	I00.00	4830					

Friction loss is 0.04 in. of water per 100 feet of duct length. The return air duct must have a total volume of 4830 cu.ft. per minute, with an average velocity of 300 ft. per min. A general layout of the duct system is shown on the accompagning plan.



SCALE 1:100

FLOOR PLAN SHOWING LAYOUT FOR INDIVIDUAL DUCT SYSTEM

P A R T III

C O N C L U S I O N

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C O N C L U S I O N

The preceeding attempt to design a modern apartment in Beirut equipped with an air-Conditioning system was initiated to meet the basic requirements of a modern house for the promotion of health and interior comfort.

This system has been successfully applied in public and industrial buildings and in particular to houses and residenses, and will no doubt become an essential need in modern living in this part of the world.

The particular choice of the Sevel Air-Conditioning unit offers great advantages in both method of installation and operation. This quiet, self contained, water cooled air-conditioner gives low operating cost, better performance and longer life; is available in 3 to 5 tons capacities and is easily and quickly installed without structural changes.

The cost of units of various capacities, specification, and Performance Data may be obtained from catalogs of Servel Inc., International Division.

A fair estimate of the operating expenses is as following:

<u>Electricity</u>

$\frac{1}{4}$ H.P. Motor	=	0.1865	kw
$\frac{1}{4}$ H.P. Fan	=	0.1865	kw
		0.3730	kw

0.373 kwh @ 21 P.S. per kw = 7.83 P.S./h

<u>Fuel Oil</u>

Quantity required = $\frac{60,000}{19,500}$ = 3.08 lbs

This is equivqlent to $\frac{3.08}{2.2}$ = 1.4 kg.

1.9 kg @ 10.8 P.S. per kg. = 15.12

Total 22.95 P.S. per runing/h

Expenditure per day is approximately LL 5.50

It is to be noted especially that neither the architecture nor the structural design of the apartment was influenced by the introduction of the system except in the provision of a basement room for the conditioner and provision in the walls and slabs for the rise, entry and exit of ducts and their inlet openings, with the only addition of celcrete insulation for the exterior walls from the inside which costs about LL 60 per cubic meter.

Recirculation is not considered, because first, the conditioned space is small and second the additional cost of installation of extra ducts more than offsets the small economy obtained from the decrease of the heating and cooling loads due to recirculation. Instead natural circulation is allowed on the outlet with store-roulant shutter acting as dampers.

The same duct system will be used for both heating and cooling on account of the equivalence of heating and cooling loads.

Although this design is made for an apartment house, it may well serve as example for similar designs when the general procedure and methods are extended to Stores, Shops, and Theatres with the proper selection of units.

The End

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