The Updated Algorithm of the Energy Consumption Program (ECP) — A Computer Model Simulating Heating and Cooling Energy Loads in Buildings

F. L. Lansing, D. M. Strain, V. W. Chai, and S. Higgins

DSN Engineering Section

The Energy Consumption Computer Program (ECP) was developed to simulate building heating and cooling loads and compute thermal and electric energy consumption and cost. This article reports on the new additional algorithms and modifications made in an effort to widen the areas of application. The program structure has been rewritten accordingly to refine and advance the building model and to further reduce the processing time and cost. The program is noted for its very low cost and ease of use compared to other available codes. The accuracy of computations is not sacrificed however, since the results are expected to lie within ±10% of actual energy meter readings.

I. Introduction

The Energy Consumption Program (ECP), reported earlier in Refs. 1, and 2, was originally developed to satisfy the Deep Space Network needs in conducting complete energy surveys (audits) and to support the ongoing energy conservation project studies. The computer program proved to be a useful tool in evaluating many energy-saving suggestions and proposals presented by DSN personnel. Because of low running cost, ease of use, and accuracy of computations, the program has been accepted recently by NASA as a new technology item. The program applicability has also been increased since it was first put together in September 1977. Since its conception, experience with the program has been instructive as to both new ways to model and new fields of application. Accordingly, it has become essential, for many reasons, to enlarge the program structure, improve the coding techniques and make the necessary component additions or deletions that not only benefit the growing needs of the DSN but attract other NASA government or non-government users also.

The updated algorithm of the energy consumption program has a structure which can be divided into five parts:

(1) Calculation of space (zone) loads for the net heat gain or loss.

(2) Simulation of fan-coil (air handler) systems to meet above space loads.

(3) Simulation of primary equipment such as chillers (vapor compression or absorption types), heaters, boilers, and heat pumps.

(4) Design of proper air discharge, ventilation to each space, and capacity of primary equipment.

(5) A short economic analysis to evaluate the payback period of money spent on a specific modification.

The following sections describe the main additions, deletions or modifications made to the internal algorithms to widen

the applicability areas and, as a side benefit, shorten the already small processing time and running cost.

II. Program Structure

A. Dimensions

The dimensioning of the various parameters has been changed to be open-ended subject to the maximum limit of the local computer system memory. This means that there is no fixed limit on the number of zones, air handlers, or primary equipment to be handled in any problem. This open-ended dimension changes the size of program storage, which has the advantage of not only increasing the upper limit when handling high rise buildings or groups of buildings with a very large number of zones, but also reducing the problem size for buildings with a single zone or a small number of zones.

B. Namelist of Input Data

Program input data are presently contained in one namelist for user convenience. Many built-in default values are assigned to fill in for some input data unknown to the user.

Architectural and physical characteristics of the building (or zones) include latitude, elevation, wall areas and orientation, glass areas and orientation, shade factors, space volume, outside wall solar absorptivity and the physical properties of layers forming walls, roofs and floors.

Input data for the fan-coil (air handler) include the outside ventilation air, the zone-air handler circulating air rate, the heating and cooling set point temperatures, and whether or not these set points are automatically varying as a function of load (floating set points) or fixed. The use of outside air economizer cycles and time clocks can be identified. Also, the air-handlers field arrangement in feeding the various zones and the interconnection with the primary equipment (chillers or heaters) are needed. Besides the external weather data, the internal sources of heat gain, such as people, lighting, and mechanical, electrical and heat generating equipment are required. The rest of the input data in the namelist provides information regarding the cost of energy, interest rates and installation cost. More details are given in the new program documentation.

C. Sequence of Computations

The program starts by converting all input data units to one standard, which is arbitrarily selected to be the English system. Zone sensible heat gain is computed hourly and summed with the internal heat gain, solar and transmission heat gain through glass and walls, infiltration and exfiltration. The net zone heat gain (or loss) is used next to determine the desired tempera-

ture of the supply air necessary to maintain the zone design conditions. Two-level zones are handled in a special manner throughout the program. The effects of outside air economizer cycles, automatic (or floating) set points, and zone "dead bands" are placed in the proper control sequence. The heating and cooling loads on the various air handlers are then computed and summed to the appropriate primary equipment (cooler, heater or reheater). The association of zones, air handlers and primary equipment is in a free form, whereby more than one air handler can feed a zone and vice versa. However, more than one air handler can be connected to a primary equipment, but not vice versa.

Once the primary equipment load is determined, the input energy necessary to operate the unit is computed according to the coefficient of performance (COP) subroutine. Moreover, the program includes special routines for designing new equipment to determine ventilation air, zone air flow rates, and capacity of primary equipment. The economics section is added at the end of the program together with all the necessary printing and plotting procedure. The results are then converted to either the English or SI (metric) unit system as the user desires.

D. Output Forms

The program output forms are tabulated and grouped mainly according to zone, air handler, and primary equipment. The output includes:

(1) Input data echo for the user to check all the entered data.

(2) Diagnostic messages.

(3) Hourly, daily, and monthly itemization of zone sources of heat gain/loss and zone-air handler heating and cooling loads, for two-day types each month.

(4) Hourly, daily, and monthly mixed air temperature, air handler heating/cooling loads and maximum and minimum supply air temperature of all zones fed by a given air handler.

(5) Hourly, daily, and monthly supply air temperature to each zone.

(6) Equilibrium zone inside temperature.

(7) Peak hourly heating and cooling loads for each piece of primary equipment.

(8) Hourly, daily, and monthly heating/cooling loads and the necessary thermal or electrical input energy for primary equipment.

(9) Design values of zone ventilation, conditioned air flow, and capacity of primary equipment.

(10) Hourly, daily, and monthly electric, thermal, heating and cooling load profiles for the building under study.

(11) Monthly itemization of energy consumed in lighting, mechanical, electrical and HVAC equipment and the corresponding cost.

(12) Money payback period for a given modification.

(13) Yearly thermal and electrical energy index for the building.

The program output is coded to be selective according to the user's needs. This means that the user will be able to print out only specific information to save printing costs.

E. Units

Input data can be entered either in English units or in SI (metric) units. Likewise, the program output can be printed in either unit system as the user specifies. The above feature is a new addition made to match the current worldwide trend of conversion to the SI units.

F. Data Plotting

This new feature is added to present the results graphically in 2-dimensional and 3-dimensional plots. Local plotting subroutines available at JPL-1108 computer system are used for this purpose. However, these subroutines are considered external to the program's main function.

G. Two-level Zones

The unique feature of ECP compared to other codes in this field is the ability to simulate two-level air-conditioned zones with two air streams. These two-level zones are commonly encountered in air conditioning electronic control rooms. The first air stream is cold air, which is provided through a common plenum floor underneath the electronic racks. The second air stream (comfort air) is provided to the second level to mix with the first air stream. A special zone index is defined in ECP for differentiation of two-level zones with simple zones. Each of the two-level zones is treated independently and special attention is given to their temperature equilibrium.

III. Description of Updated Program

The following subsections supersede those presented in Refs. 1 and 2 and describe the updated methodology used in each of the program steps, with special attention to the new points made. The program is written in FORTRAN V using the EXEC-8 codes of the 1108 machines at JPL. It requires approximately 32K of computer memory of 36-bit words.

A. Weather

Required weather information includes outside air dry bulb temperature, cloud cover factors and wind speed. For the outside air dry bulb temperature, 24-h values for each of the 12 typical days (one for each month) per year are needed. Twelve cloud cover factors are also needed: one for each month. A monthly cloud cover factor is determined by the ratio of accumulated daily, direct solar energy incident on site to that accumulated theoretically by ASHRAE model (Ref. 3). If no solar insolation data were available, the cloud-cover factors would be estimated from past site experience by the percentage of clear sky area. Hourly wind speeds for a representative day of the year are needed. The above weather data are considered the least information needed to obtain reliable results.

B. Transmission Loads

The Total Equivalent Temperature Difference method (TETD), as described in Ref. 4, is used for its good accuracy and small computer memory requirement. Walls, roofs, and floors are assumed homogeneous, with average material properties that are determined internally using the data provided about their multilayers. Several additions are made in the computations of the steady-state heat transfer coefficients and the transient heat transfer coefficient amplitude and phase angle to make them zone-dependent. Since these heat transfer coefficients need to be determined only once for each zone, the program is coded to print the above coefficients and use them as input data for later runs of the same zone (or building) in order to save repetition time and cost.

C. Solar Heat Gain

Direct, diffuse and ground-reflected solar radiation values are generated internally using the known ASHRAE model described in Ref. 3. Cloud cover factors are applied to attenuate the theoretical ASHRAE values to yield the site-specific radiation values.

D. Infiltration/Exfiltration Loads

The effect of repetitive opening and closing of doors or windows and the leakage of outside air or conditioned air to or from the space through cracks, clearances or by buoyancy is calculated using the air change method. The corresponding sensible heat loss or gain is computed assuming quasi-steady-state.

E. Internal Heat Loads

Since the latent loads are often less than 10% of the total heat gain, only sensible heat gain is considered in ECP. The number of persons occupying the space and the wattage rating

of electrical, mechanical, lighting (incandescent and fluorescent) and heat generating equipment are entered hourly for two-day types representing repetitive events for the whole year. Day type (1) is a typical week day (approximately 251 week days per year); day type (2) is a typical weekend/holiday (approximately 114 days to include 10 official holidays). Heat gain due to the above internal heat loads is computed hourly based on quasi-steady state and no storage effects. Monthly variations of the magnitude of these sources of heat gain but not of their schedule are considered by zone multiplication factors.

F. Shading Effects

A zone shading factor due to overhangs, side projections, or adjacent buildings is considered as a fraction between 0 and 1, given by the user based on annual observations. Shading factors are used in the heat transmission computations to reduce the solar radiation falling on walls, windows, and roofs.

G. Loads Due to Neighboring Areas

When a neighboring zone is kept at a temperature different from that of the zone under study, the corresponding heat gain or loss is taken into consideration. The new program algorithm accounts for heat exchange through floors and ground floors not considered in the old version.

H. Fan-Coil (Air Handler) Types

Seven major classes of zone-air handler arrangements have been incorporated into ECP, which can be further divided into 18 different combinations as illustrated in Figs. 1 through 7. The seven classes are:

(1) Air handlers that provide cold air modulated by subsequent heating. Heating coils are located either in the air handler or at each zone supply air outlet as shown in Fig. 1.

(2) Air handlers that provide simultaneously two streams of hot and cold air (as shown in Fig. 2). Modulation is made by mixing different proportions of each stream to satisfy the zone needs. Mixing is done either in the air handler or in mixing boxes located at each zone supply air outlet.

(3) Air handlers that provide cold air mixed with bypassed mixed air as a first modulation, followed by heating as a second modulation. Heating coils are located either in the air handler or at each zone outlet, as shown in Fig. 3.

(4) Air handlers that operate either in heating or cooling modes at any one time with bypassed mixed air modulation. This is also the case of a heat pump/refrigerator unit with mixed air bypass control, as shown in Fig. 4.

(5) Air handlers that provide cold air mixed with a fixed ratio of bypassed return air as a first modulation and followed by heating as a second modulation. Heating coils are located either in the air handler or at each zone outlet, as shown in Fig. 5.

(6) Variable air volume air handlers that control, through restrictions, the air discharge to each zone while keeping the hot or cold supply air temperature fixed, as shown in Fig. 6.

(7) Air handlers that provide unmodulated cold air only year-round, as shown in Fig. 7.

These classifications are made differently compared to the old ECP version. For special two-level zones, each level is handled as a separate entity where a combination of the above air handler types is used. The new code provides greater flexibility in the analysis especially when a zone (single or two-level) is fed by more than one air handler, each of a different type. The program structure allows any future inclusion or modification of air handler configuration that the user desires, to include either special cases or new designs.

I. Outside Air Economizer Cycles

To take full advantage of relatively cold outside air at times when cooling is needed, for example, the concept of outside air economizer cycle is introduced and included in ECP as an energy-conservation mode of operation. The logic of the controlling mechanism is embedded into ECP, whereby an hourly survey is made of the temperatures of outside air, return air, cooling and heating set points, and minimum and maximum supply air temperatures.

J. Temperature Bands and Automatic Set Points

As another energy saving feature, zone thermostat controls are set to vary between some lower and some higher limits, i.e., to a have a "dead band." The "dead band" limits are specified by the user. The controls logic is made such that the zone will not need active heating or cooling if its inside temperature lies between the "dead band" limits. Similarly, the set points for cooling and heating coils can be specified by the user to be fixed year-round or automatically adjusted. The recent advances in automatic temperature control allow the set points to vary within a practical range to match the zones requiring the most cooling and/or heating.

K. Time Clocks

The time clock on/off controls are only applied to air handlers and are not applicable to lighting, electronic or mechanical equipment since their effects appear under the internal heat sources schedule. Zone inside temperatures will

be assumed at ambient if air handlers are off under a time clock control.

L. Primary Equipment Performance

The primary equipment included in the new algorithm are:

(1) Electric-driven vapor compression refrigeration.

(2) Absorption chillers powered by fuel combustion, solar or other heat source.

(3) Electric-driven heat pumps.

(4) Heaters, reheaters or boilers powered by electricity or fuel combustion.

Default values built in for component efficiency and coefficient-of-performance can be superseded by user's input data. The capacity of primary equipment can either be entered as input data, if known, or given to the user as one of the design parameters. Vapor-compression chillers are assumed to have a maximum of four stages, and all other items of primary equipment are assumed to have only a single stage. Heaters, reheaters, boilers and absorption refrigeration equipment are assumed to have a constant efficiency at all loads. The coefficient of performance for heat pumps and vapor compression chillers is taken as a fraction (~50%) of the ideal Carnot's cycle working between the evaporator and condenser temperature. Partial-load performance takes into consideration the variation of outside air temperature and is assumed proportional from 100% full load till 40% of full load, below which the input energy is constant. The above approximation accounts for the inefficiency at very small partial loading caused by hot-gas bypass and electric motor.

M. Energy Consumed by Auxiliary Equipment

Auxiliary equipment is defined as equipment outside the air conditioning zone (or space) which is necessary to operate the building but does not affect the internal heating or cooling loads. For equipment located inside the air-conditioned zone, the data are entered into internal heat sources tables.

Electric auxiliary equipment includes external building lights and other outdoor equipment. Air-handler fans, condenser fans (air-cooled), condenser pumps (water-cooled) and boiler pumps are internally tied to the operation of primary equipment. Thermal auxiliary equipment includes fuel-consuming devices that are not located within any air-conditioned zone such as domestic hot water boilers. Auxiliary equipment energy consumption directly affects thermal or electric energy meters. Consumption is modeled for simplicity by using name plate capacities only. No allowance is made at this stage to partial load performance or flow pressure and discharge variations. However, monthly variations and schedules are considered.

N. Energy Cost and Payback Period

The economic part in ECP is designed to provide few parameters such as the monthly and yearly cost of electric and thermal energy consumed and the money payback period of a selected hardware modification. However, the program can be enlarged to include any detailed economic analysis as desired by the user.

A new documentation package is underway to include the updated guidelines for entering data, algorithm description, input and output formats and the program flow charts. The new documentation will supersede Ref. 2. The cost of running the program is still very low compared to commercial codes. The simulation accuracy, on the other hand, is under verification and is expected to be within ±10% range of actual watt-hour meters values.

References

1. Stoller, F. W., Lansing, F. L., Chai, V. W., and Higgins, S., "Energy Consumption Program — A Computer Model Simulating Energy Loads in Buildings," in *The Deep Space Network Progress Report 42-45*, pp. 288-293, Jet Propulsion Laboratory, Pasadena, Calif., June 1978.

2. Lansing, F. L. et al., *JPL Energy Consumption Program (ECP) Documentation*, Publication 78-76, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1978.

3. *Handbook of Fundamentals*, American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) 1972.

4. Threlkeld, J. L., *Thermal Environmental Engineering*, Prentice-Hall Inc., New Jersey, 1962.
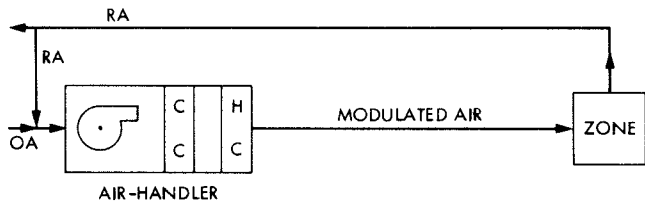
(a) A SINGLE ZONE AIR-HANDLER. COLD AIR IS MODULATED BY A HEATING COIL LOCATED AT THE AIR-HANDLER
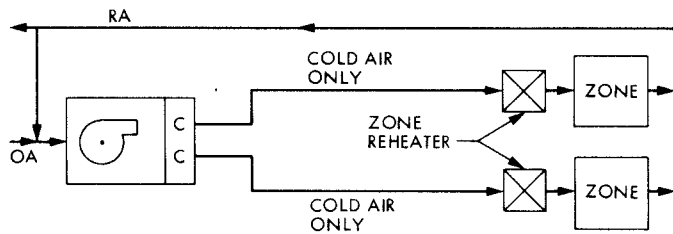
(b) A MULTIZONE AIR-HANDLER, PROVIDING COLD AIR DUCT(S). MODULATION IS BY TERMINAL ZONE REHEATERS
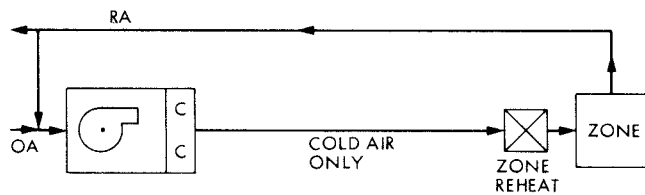
(c) A SINGLE ZONE AIR-HANDLER, PROVIDING A COLD AIR DUCT WITH TERMINAL ZONE REHEAT

Fig. 1. Type 1 air handlers: cooling followed by heating
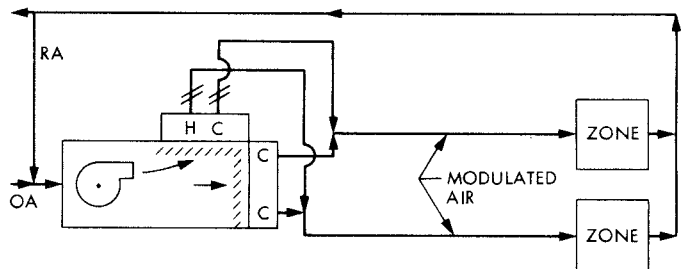
(a) A MULTIZONE AIR-HANDLER PROVIDING MULTI-FEED DUCTS. MODULATION IS CONTROLLED BY MIXING DAMPERS AT THE AIR-HANDLER
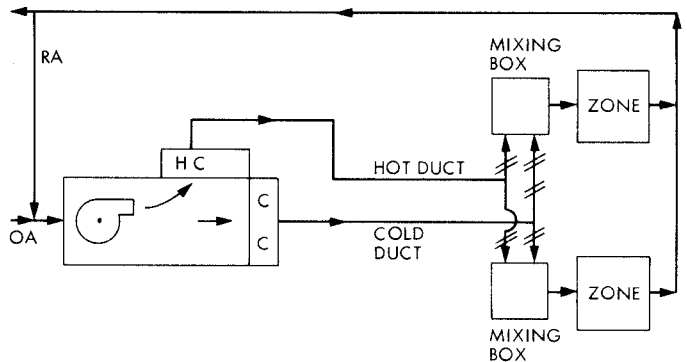
(b) MULTIZONE AIR-HANDLER WITH DOUBLE FEED DUCT (ONLY TWO COLD AND HOT DUCTS). MODULATION IS CONTROLLED BY ZONE MIXING BOXES

Fig. 2. Type 2 air handlers: mixing cold and hot air streams
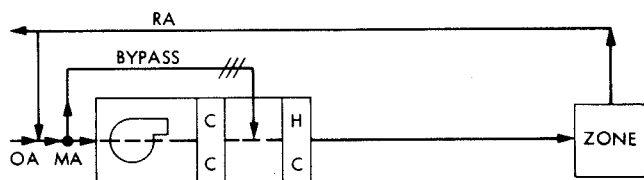
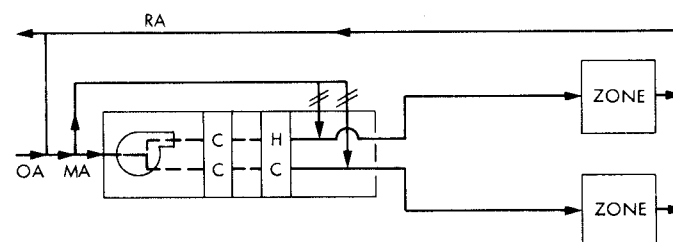(a) A SINGLE ZONE AIR-HANDLER WITH COOLING COIL, BYPASS MIXED AIR CONTROL AND HEATING COIL

(b) MULTIZONE AIR-HANDLER WITH COOLING COIL, MIXED AIR BYPASS DAMPERS AND ZONE LOCATED REHEATERS. BYPASSED AIR IS ZONE-DEPENDENT
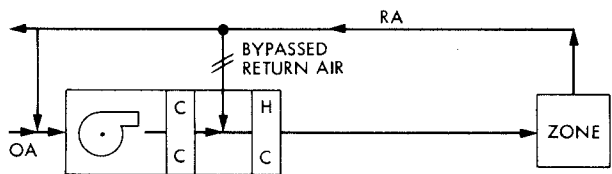

(c) A SINGLE ZONE AIR-HANDLER WITH COOLING COIL, BYPASS MIXED AIR CONTROL AND A HEATER LOCATED AT THE ZONE

Fig. 3. Type 3 air handlers: cold air modulated by bypass mixed air followed by heating

(a) SINGLE ZONE AIR-HANDLER WITH HEATING AND COOLING COILS USING BYPASS CONTROL. EITHER HEATING OR COOLING IS ON AT ONE TIME

ONE COIL ACTING EITHER AS HEATER OR COOLER AS NEEDED
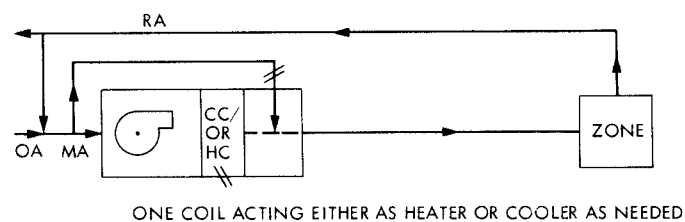
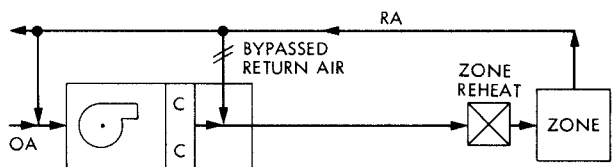(b) SINGLE ZONE HEAT PUMP WITH BYPASS CONTROL

(c) MULTIZONE AIR-HANDLER WITH HEATING AND COOLING COILS USING BYPASS CONTROL FOR EACH ZONE. EITHER HEATING OR COOLING IS ON AT ONE TIME

Fig. 4. Type 4 air handlers: alternate heating and cooling with mixed air bypass control for each mode

114

RA

OA MA | C C | H C | RESTRICTION | ZONE

(a) SINGLE ZONE AIR-HANDLER WITH EITHER HEATING OR COOLING ON AT ONE TIME

RA

HC | C C | HOT | COLD | ZONE | ZONE | RA

OA

(b) MULTIZONE AIR-HANDLER WITH BOTH HEATING AND COOLING COILS ON. MODULATION IS BY VOLUME RATE CONTROL

Fig. 6. Type 6 air handlers with both heating and cooling coils on: modulation is by volume-rated control

RA

BYPASSED RETURN AIR

OA | C C | H C | ZONE

(a) SINGLE ZONE AIR-HANDLER WITH FIXED BYPASS RETURN AIR, COOLING AND HEATING COILS

RA

BYPASSED RETURN AIR

OA | C C | ZONE REHEAT | ZONE

(b) SINGLE ZONE AIR-HANDLER WITH FIXED BYPASS RETURN AIR AND COOLING COIL. HEATING IS LOCATED AT THE ZONE

RA

BYPASS RETURN AIR

OA MA | C C | REHEATER | ZONE | ZONE
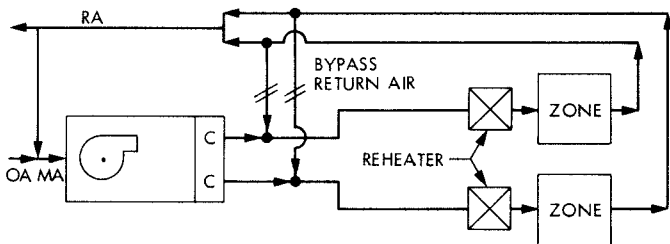
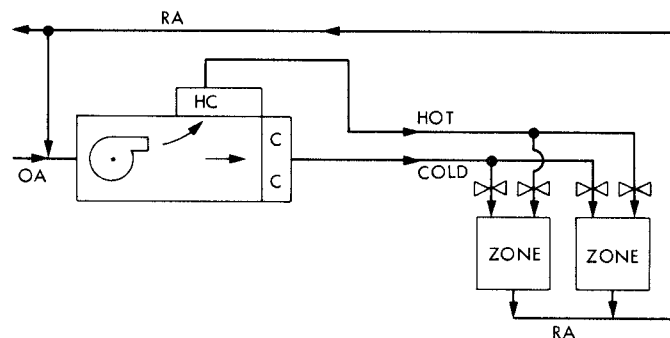(c) MULTIZONE AIR-HANDLER

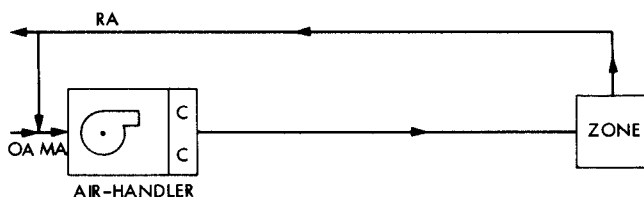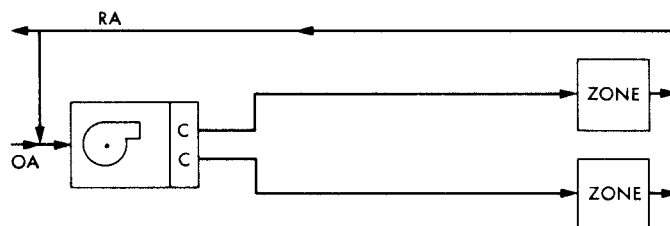**Fig. 5. Type 5 air handlers: cold air modulation by fixed position bypassed return air followed by heating**

RA

OA MA | C C | ZONE

AIR-HANDLER

(a) SINGLE ZONE AIR-HANDLER PROVIDING UNMODULATED COLD AIR ONLY

RA

OA | C C | ZONE | ZONE

(b) MULTIZONE AIR-HANDLER PROVIDING UNMODULATED COLD AIR ONLY

Fig. 7. Type 7 air handlers: cold air all year-round; no modulation by any heaters or air mixing