2010

Air-Conditioning of Parked Aircraft by Ground-Based Equipment

Evgenia Sikorski
Offenburg University

Air-Conditioning of Parked Aircraft by Ground-Based Equipment

Evgenia SIKORSKI

Offenburg University, Mechanical and Process Engineering,
Offenburg, Germany
Phone: +49-(0)781-295-254, Fax: +49-(0)781-295-138, E-mail: Evgenia.Sikorski@fh-offenburg.de

ABSTRACT

Pre-conditioned air systems (PCA) represent the art of air-conditioning parked aircraft by a ground-based system, bringing outside filtered, cooled or heated air into the plane. The present report mainly addresses central PCA systems.

A description of special requirements, calculation of the overall cooling demand profile, and an explanation on the chilled water (brine) system design are given hereinafter for the central PCA system installed at the New Athens International Airport. The particularities of air handling units (AHU) for PCA are explained and relevant technical data given.

1. INTRODUCTION

Every aircraft – whether in the air, on the runway, or on the ground – needs air-conditioning and 400 Hz power supply. This paper addresses the air-conditioning issues only.

Naturally, air-conditioning of aircraft in motion can be done only by means of onboard equipment – an auxiliary power unit (APU). When parked, though, the means of supply depend on whether the aircraft stays in operation (during passenger boarding, disembarking, cleaning, etc.) or is out of operation (e.g. when it is parked for an overnight stay). The latter case is of little interest since no air-conditioning is required, except for some heating in northern climate countries to prevent freezing.

When in operation, a plane needs lots of outside air for the people on board (17 m³/h per person for normal operation and 5 m³/h per person for emergency operation). Mostly, it needs cooled outside air. Without any air being supplied to the cabin, the cabin temperature would rise up to 50°C within some 15 minutes (whereby the outside air temperature is of minor significance). After 5 minutes, the high CO_2 concentration and possible shortage of oxygen make the cabin air almost unbreathable.

The method conventionally used to supply air-conditioning to parked aircraft is by letting the APU continue to run. APUs, however, involve high levels of noxious emissions and fuel gas odors (e.g. 550 l/h of fuel are required for B 747-400) and cause a noise level of some 80 dB(A) at the airfield apron while their efficiency is between 10 and 12 %.

Pre-conditioned air systems represent the alternative method by using ground-based equipment. The electrically driven PCA systems do not require any fuel, their noise level is 70 dB(A), and their efficiency is up to 50 % (for central systems in terms of primary energy use). The noise level of 70 dB(A) at the airfield apron instead of 80 dB(A) corresponds to a 10-fold noise level reduction!

Two PCA versions are common: Point-of-use systems (mainly in US and Far East) and central systems (in Europe). Point-of-use system means a suitable air handling unit and pertinent air delivery equipment being mounted on a truck. Central PCA systems consist of several AHUs and air delivery equipment being installed on passenger-boarding bridges (one AHU for each bridge), one or two chillers, usually ice storage units, distribution piping, and controls.

Planes are parked either at a terminal or on a remote position. For remote positions, Point-of-use systems are the obvious choice. At terminals, both PCA versions can be used.

Which version is used at terminals is mainly determined by ownership conditions at the airport. In the US and Far East, modular airports are common; airlines own the gates and are entitled to install on their, mostly few, gates any additional equipment. In Europe, airports are built as functionally rigid areas; airlines merely lease gates, decisions on gate equipment rest with the Airport Authorities.

When PCA is to supply many or all gates at an airport, central systems are by far more energy-efficient than Point-of-use systems. Hybrid plants (central basic supply system with decentralized equipment for peak load demand) are also possible. This paper mainly addresses central PCA systems.

In this report, an explanation of the main issues regarding central PCA systems are given for the central PCA system installed at the New Athens International Airport.

2. CENTRAL PCA PLANT FOR THE ATHENS AIRPORT

2.1 General

The New Athens International Airport shall handle 15 million passengers yearly and 75,000 passengers at a Typical Peak Day. The selected PCA concept for the Athens Airport is a central cooling supply concept.

Two terminals are served: the Main Terminal (14 gates) and the Satellite Building (10 gates). Both buildings are served from one central cooling system. The PCA plant room is located in the Main Terminal. Connection between the Main Terminal and Satellite is by way of an underground link.

Design conditions:

- Summer ambient design temperature: 35°C dry bulb / 35% r. h.
- Winter ambient design temperature: -1°C
- Aircraft cabin temperature: 24°C in summer, 21°C in winter

2.2 Contact Position Occupancy

"Aircraft contact parking interchangeability" is realized as specified in the Master Plan. There are three different scenarios of aircraft types to be accommodated at each gate: maximum (B 747-400, B 747-300, A 320, MD 11), minimum (MD 80 only), and simultaneous (B 747-400, A 320, MD 11). Simultaneous occupancy is the worst-case occupancy under consideration of all restrictions on neighboring positions.

Gate equipment – mostly AHUs – is designed on maximum position occupancy. There are three major types of aircraft: Jumbo, Wide and Narrow Body. However, distinction is made between two types of AHU only: AHU for Jumbo and AHU for Wide/Narrow Body aircraft. As a result, 11 aircraft positions are equipped with AHUs for Jumbos, the other 13 positions with AHUs for Wide/Narrow Body aircraft.

For typical gate equipment refer to Figure 1.

It is imperative that the central equipment design is defined by simultaneous position occupancy.

2.3 AHU Airflow and Cooling Capacity

The aircraft internal cooling load comprises four major components, which ratios are nearly equal for all types of aircraft. Considering the Athens design conditions and maximum occupation (seating load factor of 1.0 as determined in the Master Plan for non-scheduled flights), these are: cabin wall conduction (23 %), solar load on windows (11 %), electrical load of lighting and equipment originated by 400 Hz connection (22 %), and passengers and crew (44 %).

The individual cooling load and cooling capacity for all five types of aircraft mentioned under "Aircraft contact parking interchangeability" as calculated for the Athens environment considers a maximum seating factor of 95 % as listed in the Forecast Timetable. The calculations show that cooling load is approx. 30 % of the cooling capacity for all aircraft types; the cooling capacity varies between max. 96 % (from 13:00 to 15:00) and min. 76 % (from 3:00 to 5:00).

The cooling capacity of the pre-conditioned air when delivered to the aircraft is a function of airflow, outlet air temperature, and heat gain in the delivery path. The AHU outlet temperature is set to -5°C at design ambient temperature in summer, requiring the brine supply temperature to be -7°C. The required airflow is calculated under consideration of the heat gain in a standard air hose for normal passenger-boarding bridges.

The maximum required airflow is about 200 kg/min for Jumbo and 40 kg/min for MD80 aircraft. Due to the heat gain in the delivery path, the air temperature at the aircraft adapter rises from -5°C to -0.3°C for B 474-400 or 4.2°C for MD80 aircraft.

The maximum AHU cooling capacity for Jumbo and Wide/Narrow Body positions is 217 kW and 121 kW, respectively. With 11 Jumbo and 13 Wide/Narrow Body positions at the airport, the installed gate equipment capacity (all AHU cooling capacities) totals up to 3,960 kW.

For a Point-of-use PCA system refrigerating machines of exactly this capacity (at maximum contact position occupancy) would have to be installed. For central systems, the simultaneous position occupancy is decisive; hence the capacity to be installed is reduced to about 3,500 kW (diversity factor of 88 %).

Diversity factors have a direct effect on the central system investment costs. They also demonstrate the benefits achieved when comparing the calculations for any previous design step. In the end, a chiller capacity of "merely" 1,240 kW (see below) is sufficient (overall diversity factor 1,240 kW / 3,960 kW = 31 %), justifying the calculation and analysis efforts involved.

2.4 Overall Cooling Load Profile

The overall cooling load profile is defined by the loads of all flights at 5-minute-intervals for 24 hours of the Typical Peak Day. All flights from the Forecast Timetable and capable of docking at a bridge are included, corresponding to nearly 10 turn-rounds per bridge. Thus, the system is designed for the case that all flights that are capable of docking at a bridge actually are served there, as expected for the year 2025 due to environmental legislation.

The aircraft turn-round times (TRT) have to be estimated for this calculation. The Timetable specifies arrival and departure times; however, mostly, planes do not remain docked all the time in-between. The TRT for each aircraft type is defined by averaging a couple of turn-rounds for that specific aircraft as listed in the Timetable and comparing the same with usual TRTs according to IATA-recommendations as well as on the basis of experience. The estimated TRTs vary from 120 minutes for Jumbos and 65 minutes for the smallest aircraft. For most flights (89 %), TRTs equal to 100 or 80 minutes.

Loads for individual flights are calculated with an average seating load factor of 70 %. This factor is generated as a mixed value considering various Master Plan requirements regarding scheduled and non-scheduled flights as well as international, domestic, and transit flights with their respective data about average seat capacity and seating load factor. Also included is the specified passenger movement at a Typical Peak Day of 75,000 passengers.

At arrival, the number of persons in a plane is calculated to be the scheduled number of passengers plus full crew. During disembarking (15 to 25 minutes, depending upon aircraft type), the number of persons declines to the cockpit crew while during boarding (20 to 30 minutes) it rises to the previous level again.

The overall cooling load profile (Figure 2) is calculated for a peak day at 5-minute-intervals and shows a peak load of 1,905 kW, various peaks, and frequently occurring strong capacity fluctuations originated by respective flow fluctuations at AHUs. Cooling demand exists also during the night.

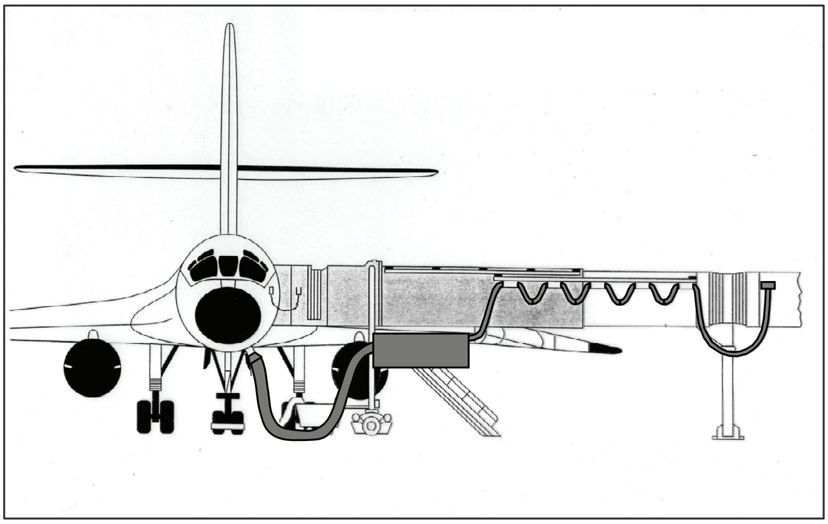

Figure 1: Typical gate equipment

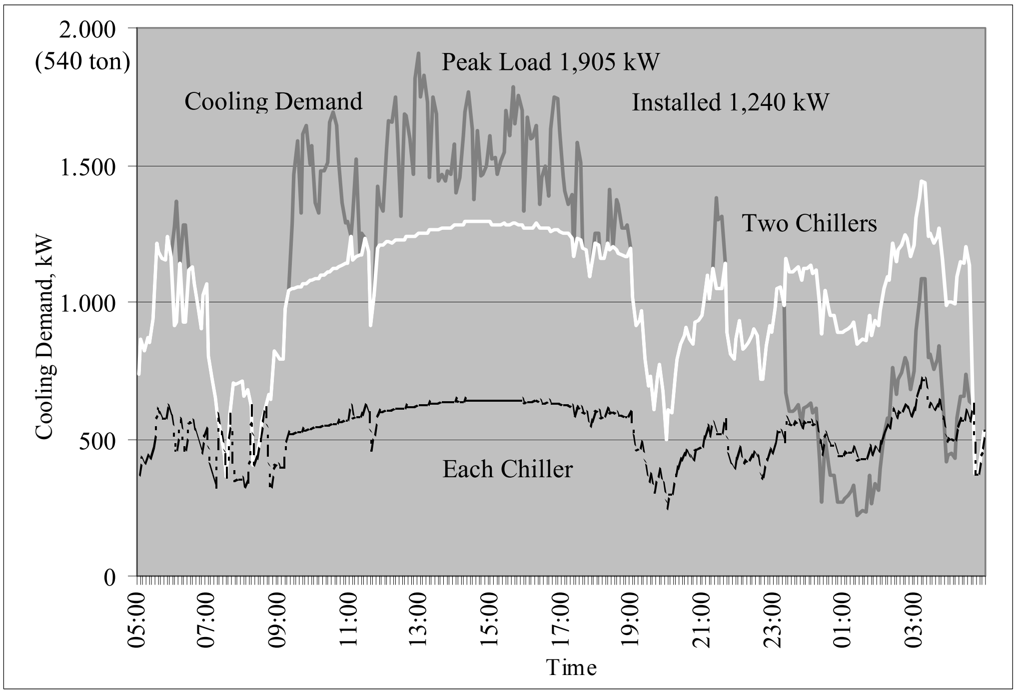

Figure 2: Overall cooling load profile

2.5 Central System Cooling Capacity and Control

To attain the minimum chiller and ice storage capacities, capacity control methods and hydraulic connection of all components are of high significance. The design process for such sophisticated systems is a highly complex and iterative task.

- To meet the peak cooling load of 1,905 kW (see below), two chillers are required. There is no air-cooled chiller on the market who can do this job alone at the required low supply temperature. Furthermore, the system will operate more safely with two chillers.

- The cooling system is divided into two circuits: primary and secondary. The secondary circuit supply temperature is set to be controlled proportionally to the outside air temperature:

$t_{outside}$ °C	35	10
t_{supply} °C	-7	+2

- To reduce electrical power peaks and to achieve highest possible overall equipment efficiency, the chillers are designed to cover basic load requirements, whereas the ice storage unit shall meet irregularly occurring peak loads. During low-load periods, the ice storage unit will be charged for the next peak period.

- The secondary circuit return temperature is set to +15°C at 35°C outside air temperature (summer design condition). With the supply temperature being -7°C, the secondary circuit (AHU circuit) operates at a temperature difference of 22°C.

- The primary circuit (chiller circuit) will not be able to cope with a temperature difference of 22°C. No chiller can operate at such a temperature difference – the max. admissible temperature difference is 12°C. Therefore, the ice storage unit is switched in series before the chillers. The warmed brine is pre-cooled in the ice storage unit to the set ice storage outlet temperature of +5°C and then enters the chillers to be cooled down to the required temperature.

- Ice storage charging and discharging are allowed during day and nighttime. However, both processes, charging and discharging, must continue for a certain period of time (e.g. 30 minutes), requiring the application of an auto-adaptive control algorithm.

- As long as the ice storage unit does not need to be charged, the primary circuit supply temperature (chiller circuit) corresponds to the temperature in the secondary circuit (AHU circuit).

- If, during a low-load period, ice storage is not fully charged, and the low-load period is expected to be long enough, the primary circuit will be split. One chiller continues to supply the AHUs at the required temperature level, which is almost always too high for charging. The other chiller operates at the charging temperature, which is set to -7°C. After the charging process is completed, the supply temperature in the respective chiller is adopted to the secondary circuit temperature.

- Cooling is not required when the outside air temperature is below 10°C. Then the pumps in the secondary circuit are switched off; one or both chillers run(s) as necessary to restore ice to full capacity only.

Evaluation of the overall cooling load profile – under due consideration of the capacity control and hydraulic connection method of all components – results in a minimum chiller capacity of 1,240 kW combined with an effective ice storage capacity of 3,800 kWh.

2.6 Central Refrigeration Plant

The AHUs form the secondary (consumer) circuit. They are connected in parallel and require constant differential pressure. The circulating brine is pumped to the AHUs by three pumps (3*50%). The pumps are speed-controlled, providing a constant differential pressure at the consumers as required.

Two chillers, charged with R407C and each having a capacity of 629 kW, are installed on the roof of the Main Terminal building. Deviating from the Master Plan, air-cooled chillers instead of water-cooled chillers are selected because there is not enough make-up water available for cooling towers. Furthermore, chiller operation without vapor clouds is a requirement to be fulfilled. As each chiller requires a pump of its own (imperative constant flow), two chiller pumps are installed.

For ice storage, at least one pump is needed; for safety reasons, two pumps (2*50 %, with constant flow) are installed. They are in operation only upon ice storage discharge. The flow direction in the ice storage unit is the same for charging and discharging, i.e. the inlet ice storage connection serves as inlet for both, charging and discharging. The same applies to the outlet connection.

In case of chiller failure or power supply failure to the chillers, the ice storage unit is able to serve the AHUs on its own (emergency operation). Under such conditions, a supply temperature of as low as +3°C can be achieved. The operation time depends upon the ice storage charging level and cooling demand. When fully charged, the ice storage unit can serve the AHUs at least for 2 hours (calculated with regard to peak cooling demand).

Ice storage, pumps, and other equipment are located in the PCA plant room at basement level of the Main Terminal building.

The conveyed medium is brine, a mixture of water and 30 % (by volume) anti-freeze solution.

For illustration refer to the simplified flow diagram (Figure 3).

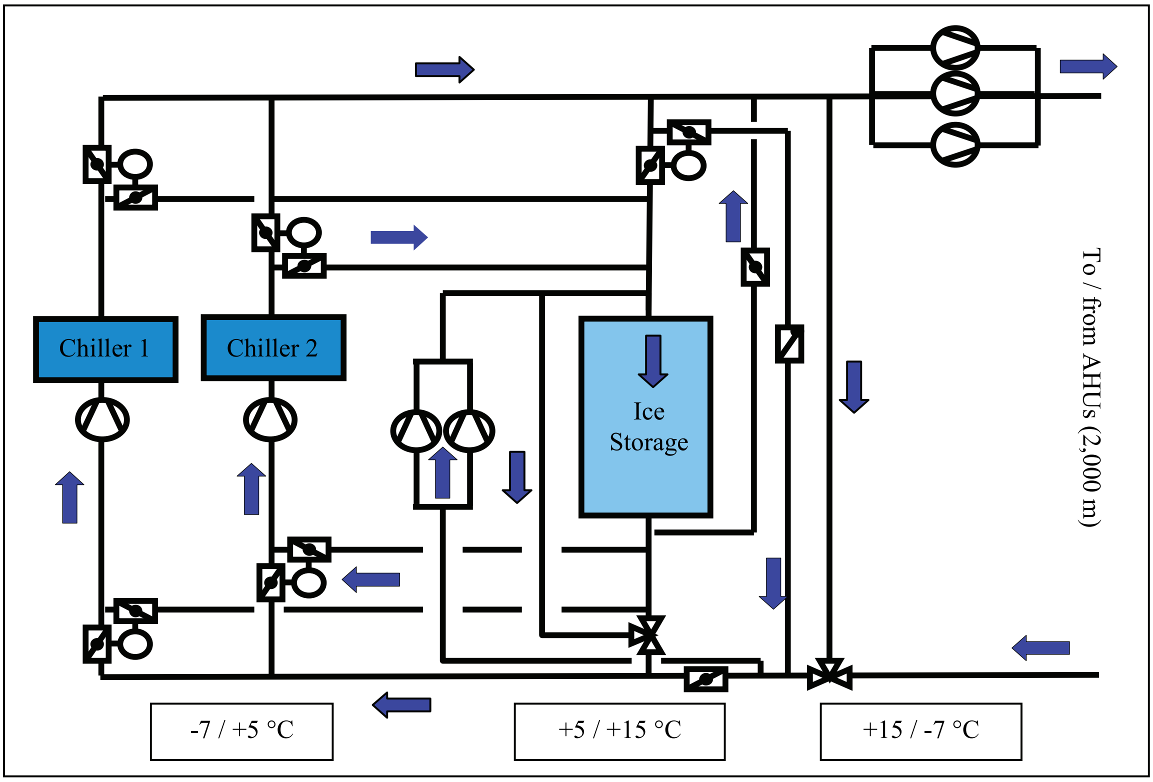

Figure 3: Simplified flow diagram

2.7 Operation Modes

Seven operation modes are defined.

- **Operation mode 1 – Full Load Operation**: AHUs require a cooling capacity between 1,905 and approx. 1,200 kW.
  Both chillers are operating at sliding supply temperatures; excess demand is met by the ice storage unit. Brine returning from the AHUs is pre-cooled in the ice storage unit and afterwards cooled-down in the chillers to the required temperature.

- **Operation mode 2 – Part-Load Operation**: AHUs require a cooling capacity between 700 and 1,200 kW; high cooling demand is expected.
  Both chillers are operating at the supply temperature of -7°C; any excess capacity is supplied to the ice storage unit to restore ice.

- **Operation mode 3 – Low-Load Operation and High Demand Expectation**: AHUs require a cooling capacity of less than 600 kW, high cooling demand is expected.
  One chiller is operating at sliding supply temperatures and serves the AHUs. The other chiller is operating at the supply temperature of -7°C for ice restoration. Chillers are interchangeable (sub-modes 3A and 3B).

- **Operation mode 4 – Low-Load Operation and Low Demand Expectation**: AHUs require a cooling capacity between 800 and 600 kW, expected cooling demand is lower than 2/3 of the max. cooling capacity.
  Only one of two chillers is running and operates at sliding temperatures to serve the AHUs. Brine returning from the AHUs is pre-cooled in the ice storage unit and afterwards cooled-down in the chillers to the required temperature. Chillers are interchangeable (sub-modes 4A and 4B).

- **Operation mode 5 – Very Low-Load Operation and Very Low Demand Expectation**: AHUs require a cooling capacity of less than 600 kW, expected cooling demand is lower than 1/2 of the max. cooling capacity.
  Only one of two chillers is running and operates at the supply temperature of -7°C. AHUs are served with sliding temperature medium (mixed flow). Any excess capacity is supplied to the ice storage unit to restore ice. Chillers are interchangeable (sub-modes 5A and 5B)

- **Operation mode 6 – Low or Very Low-Load Operation, Low Demand Expectation, Ice Storage is Fully Charged**: AHUs require a cooling capacity which does not exceed the capacity of one chiller or both chillers.
  One chiller is or both chillers are in operation at sliding temperatures (sub-mode 6A and 6B, respectively). Chillers are interchangeable (sub-modes 6AA and 6AB).

- **Operation mode 7 – Emergency Operation**
  In case of chiller failure or in case of power supply failure to chillers, the ice storage unit is able to serve the AHUs on its own.

The flow diagram (Figure 3) allows for all listed operation modes.

It can be seen in the flow diagram that the secondary circuit (AHU circuit) return flow is never passed directly to the primary circuit (chiller circuit). The AHU return flow fluid is

- either pre-cooled in the ice storage unit (modes 1 and 4) or
- mixed with the return flow from the ice storage unit when it is being charged (modes 2, 3 and 5) or
- mixed with some part of cold brine bypassing the secondary circuit (mode 6).

Nevertheless, an additional bypass connection with a 3-way control valve is installed to ensure that the temperature difference at the chillers does not exceed the set value. This valve functions in all modes with sliding supply temperatures. It also protects the chillers during start-up and similar phases.

Bypassing of some cold brine occurs in all modes where the chiller(s) operate(s) at sliding temperatures (i.e. modes 1, 3, 4, and 6), because the primary circuit always requires constant flow conditions, while strong flow fluctuations are typical for the secondary circuit.

2.8 Heating

Due to the climatic conditions prevailing in Athens, the AHUs are equipped with electric heating (30 kW for both types).

According to Airport Handling Manual AHM 973, there are two heating modes:

- "Technical" heating, maintaining the cabin in an "anti-freeze" condition at a temperature of +5°C during night stop; this kind of heating is not required in Athens with a winter ambient design temperature of -1 °C.
- "Passenger comfort" heating, providing for a cabin temperature of +15°C. Taking into account the electrical load originated by the 400 Hz connection (some 30 kW for B 747-400), no aircraft in Athens – even when empty – needs significant heating. Actually, it is ventilation that counts. However, to ventilate the cabin, cold outside air may have to be heated.

2.9 AHUs and Other Gate Equipment

The AHUs for PCA differ to a great extent from AHUs used in normal HVAC applications. The main differences are the very high velocity in the air delivery path (up to 45 m/s in the aircraft adapter), the very high air pressure (up to 11,000 Pa), and the much lower supply air temperature (-4°C).

Two AHU types are used, one for Jumbo and one for Wide/Narrow Body aircraft with rated airflows of 200 and 110 kg/min, cooling capacities of 217 and 121 kW, and electrical power supply of 22.4 and 44.8 kW, respectively.

In contrast to Wide/Narrow Body aircraft, Jumbos are equipped with two air input connections and are supplied with air through two flexible service hoses. For this reason, Jumbo-suited AHUs are equipped with dual air delivery facility as accessory. They serve smaller aircraft in single hose operation mode.

The AHUs consist of air filter, fan (with frequency transformer), two cooling coils, electric heater, outlet plenum, and digital controls.

Icing may occur at the first cooling coil only (seen in flow direction), which has much wider fin spacing than the second coil. Defrosting is achieved by controlling a built-in brine valve. The timer on the valve is set to around 90 seconds every approx. 17 minutes of operation. During the defrost cycle brine bypasses the cooling coil, so that any ice accumulated on the coil will melt by the hot outside air (as mentioned before, defrosting is required in summer only).

The AHUs are installed under the passenger-boarding bridge cab and connected to the terminals using so-called “services transportation units” (STU), being a telescopic device to carry the brine and condensate water piping as well as cables and wires from the terminal to the front end of the bridge.

The AHUs and STUs move together with the bridge cab some 10 times a day whereby bridge length, cab height, and bridge position vary depending upon the aircraft served (normal bridge length about 17.5 m retracted and 33.5 m extended, cab height between 4 and 7 m, bridge rotation by 180°). The mounting brackets and the STUs are provided with some constructional technicalities to meet such high requirements.

Supply air is delivered to the plane via a service hose. The service hose and its aircraft adapter are stored in a basket attached to the bridge.

3. CONCLUSIONS

- Compared with conventional APU-based systems, central PCA systems feature higher energy efficiency, lower levels of noxious emissions, fuel gas odors, and a 10-fold lower noise level at the airfield apron.
- For air-conditioning of parked aircraft, it is outside air and cooling supply that count. Heating is of minor importance.
- For Point-of-use PCA systems, the design of all equipment is determined by the maximum aircraft position occupancy. For central PCA systems, the maximum position occupancy is decisive only for the design of gate equipment. The design of central equipment is determined by the simultaneous aircraft position occupancy involving the beneficial application of diversity factors.
- The overall diversity factor for the central PCA plant at Athens Airport (ratio between central system cooling capacity and total gate equipment capacity) is as low as 31 %.
- The overall cooling load profile for the central PCA system shows various peaks and frequently occurring strong capacity fluctuations originated by respective flow fluctuations. Cooling demand exists also during the night.
- For central PCA systems, the method of capacity control is of high significance. The central cooling system requires sophisticated hydraulic connection of its components and as many as 6 operation modes.
- The AHUs for PCA differ to a great extent from AHUs used in normal HVAC applications.

ACKNOWLEDGEMENT

Thanks to the courtesy of caverion GmbH (formerly Krantz-TKT), especially to Dipl.-Ing. Detlef Makulla of the R&D Department, for having made available to me related material.