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APPLYING CHP TO THE VENTILATION AIR OF BUILDINGS

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ABSTRACT

There is a strong industry focus on packaged CHP systems for small scale applications where the design time for unique installations cannot be justified. Distributed generators such as microturbines, reciprocating engines and fuel cells can all now be purchased as CHP products. The development of these products will bring the energy, environmental and economic savings realized in larger applications to the smaller consumers.

CHP systems traditionally operate most effectively and give the shortest payback when operated continuously at full output in a baseloading application. This is in conflict with a typical commercial building whose energy requirements vary extensively over daily, weekly and seasonal time periods. Just as CHP is not expected to supply the entire energy requirements of the industrial sector, so CHP should be looked at as merely part of the energy mix for the commercial sector as the capital cost of CHP equipment is typically higher compared to its alternatives and there are technical complications to supply a heating or cooling to power ratio away from design values.

An economic CHP system must therefore have a capacity much lower than the peak load of the building to ensure high utilization of the system so that the larger capital investment can be recovered through energy cost savings as quickly as possible. In the absence of a year round continuous demand for either hot or chilled water a commercial CHP system must offer a diverse range of outputs so that the waste heat from the generator can be utilized as much as possible particularly since the generator component is likely to dominate the capital cost of the installation. This paper proposes that the outdoor, or ventilation air stream into a building provides an excellent capacity match for CHP equipment packaged as a CHP Dedicated Outdoor Air System (CHPDOAS). Ventilation air has the largest temperature and humidity difference with indoor air of any stream of air in the building and so reduces the heat and mass transfer surface areas in the equipment.

Also since the ventilation air is only a fraction of the total air flow rate that is being conditioned the CHP system can overcool the air in the summer or overheat the air in the winter and the effect is simply to reduce the cooling or heating workload of the conventional equipment since the ventilation air is then mixed with the bulk of the air remaining in the building before being conditioned. This means that the CHP system can run its generator for longer hours and at higher loads than would have been possible if the outlet conditions were set at space neutral or space supply conditions.

NOMENCLATURE

RTU	Roof Top Unit
CHP	Combined Cooling, Heating and Power
HHV	Higher Heating Value
DOAS	Dedicated Outdoor Air System
CHPDOAS	Combined Cooling Heating and Power Dedicated Outdoor Air System

INTRODUCTION

Small scale packaged CHP systems can now be purchased from manufacturers of generating equipment such as microturbines and reciprocating engines which have heat recovery loops integrated into their designs to provide low temperature (typically below 100°C) process heat. Where there is a continuous or at least steady demand for hot water these packages can perform well and are as close to "plug and play" as any CHP system currently on the market.

Within the commercial market, where energy consumption is dominated by building heating and cooling loads there is much more diversity in the mix of energy products required from a CHP system, on a daily, weekly and seasonal timeframe. Since CHP equipment is typically more expensive than its conventional alternative in terms of capital cost, financial gain is achieved through maximizing the operating hours of the unit so that the cost saving achieved through the recovery of waste

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heat can help to repay the higher initial capital investment. The daily load fluctuations of a typical commercial building are great enough by themselves to severely reduce the operating hours of a unit sized at or close to the peak energy requirements of the building. An additional difficulty with supplying all of the cooling, heating and power from the same unit is presented by the fixed values for the electrical efficiency of the generator, the effectiveness of waste heat recovery and the COP of the absorption chiller or latent cooling device. These fixed values will determine the ratio of heating to cooling to power that the unit can efficiently provide to the building. Ratios away from this may be able to be delivered but will degrade the performance of one or more of the components within the system (Czachorski et al., 2002).

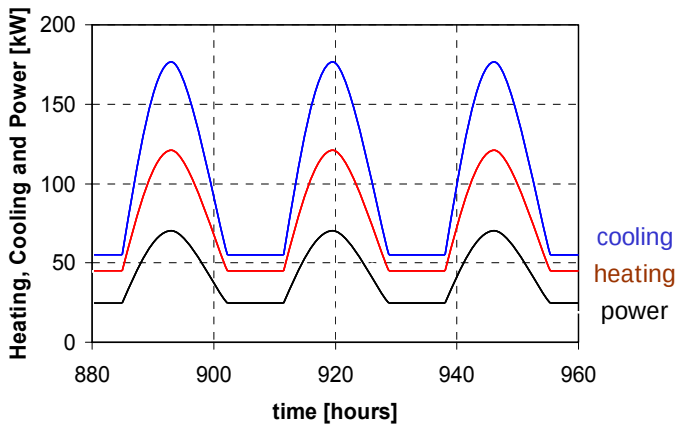

Figure 1. Load profiles for cooling, heating and power in an idealized application showing constant relationship between the three products.

Figure 1 shows how the energy profile at a facility would ideally present itself for CHP if there were one generator or a series of generators matching the low voltage electrical loads in the building and the waste heat was recovered for cooling and heating. An even more attractive CHP application would be the provision of an absolutely constant electrical demand for the building, but this is almost never the case with commercial buildings. Building types such as hotels or hospitals may have a more continuous demand for hot water, even throughout the cooling season and therefore are a more attractive market for CHP technology and practices.

If Figure 1 is compared to a sample building that has been instrumented to record the energy profile, as in Figure 2, the problem of supplying all three loads from the same CHP system without having some conventional peaking capacity becomes apparent.

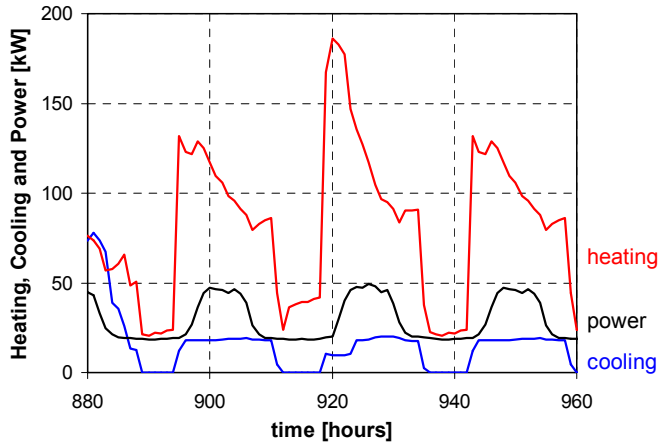

Figure 2. Real building load profile in the heating season showing the disparity between the three load profiles.

Figure 2 shows that not only are the heating and power requirements quite different in magnitude, they are also different in shape as well, with the peak heating requirement during the morning warm up and the peak electrical requirement in the middle of the day. As an example of the complexity in matching simultaneous cooling, heating and power loads in this building, consider just the heating and power loads in Figure 2. To match power with waste heat production the electrical efficiency of the electrical generator would have to be 8% (HHV) early in the morning of most days, but 27% (HHV) by midday.

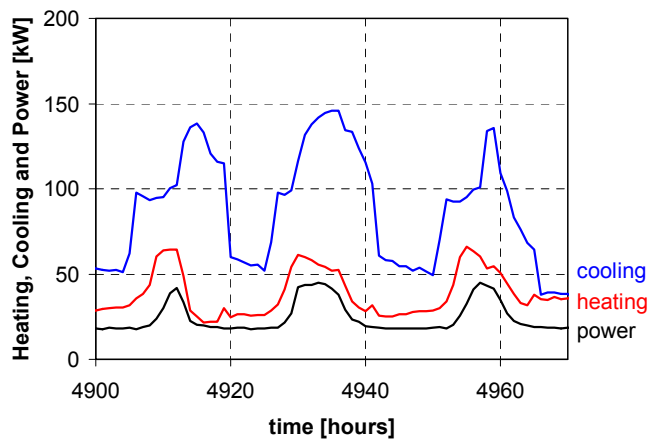

Figure 3. Real building load profile in the cooling season showing the disparity between the three load profiles.

Figure 3 is the same data for the cooling season. While the profiles of all three loads are in much better agreement with each other, with peak demand occurring in the middle of each day, the question becomes one of their magnitude. It is unlikely that a commercially viable generator will have enough waste heat from supplying the electrical load to drive waste

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heat activated cooling equipment to supply all of the buildings cooling load.

There are other important criteria to consider in this evaluation because the value of the heating and electrical outputs is likely to be drastically different from both an exergy and economic standpoint. There are large obstacles to the development of even a theoretically attractive CHP system that deals with the entire building energy profile in the absence of conventional peaking capacity.

OUTDOOR AIR

The best CHP opportunities exist when the waste heat can always be utilized onsite. A significant continuous demand in a commercial building is conditioning the outdoor air to supply conditions for building ventilation. Systems that solely process outdoor air have become known as Dedicated Outdoor Air Systems (DOAS) (Mumma et al., 2001).

Focusing on this stream has two main advantages for CHP heating, cooling and dehumidification applications. The first is that the largest temperature and humidity differences between air streams exist in the processing of outdoor air. This reduces the surface area for heat or mass exchange that is required in the system. This also means that while the outdoor air stream may be as small as 15% of the total amount of air processed in the main air handling units, it contains a disproportionately high fraction of the buildings total conditioning load, providing a large sink for the products of any waste heat activated equipment in the system. Desiccants in particular will be more effective within the ventilation air stream than in the bulk of the return air due to its higher humidity.

The second advantage is that the output of a DOAS does not determine the building space conditions by itself. The majority of the conditioning load is typically in the air that stays within the building, although for spaces with high outdoor air requirements this may not always be the case. Since the air that the CHPDOAS is processing is only a fraction of the total, the outlet conditions of the air do not need to be as tightly controlled and the ratio of cooling to heating to power that has been shown to cause such difficulties for stand alone CHP systems in buildings can be relaxed and the operating strategy changed instead to focus on maximizing the waste heat utilization. A CHPDOAS is capable of running its generator at higher capacity factors without dumping waste heat as a result of this, even if this results in over heating (i.e. heating past supply or space conditions) in the winter and over cooling or drying in the summer. The excess conditioning will simply reduce the energy consumption of the main air handling unit.

The benefits of CHPDOAS also could be listed to include those provided by CHP and the on-site power production that it brings – peak load reduction, reduced dependence upon grid electricity, energy and energy cost savings.

REGIONAL PROFILE

To improve the payback, the system operating hours at full electrical capacity should be maximized, particularly since the generator is likely to be one of the expensive components of the CHPDOAS. The small capacity of a CHPDOAS compared to the peak cooling, heating or dehumidification load of the building helps to ensure this. The characteristics of the geographic region in which the building operates will also play a large role in the appropriate selection of the internal layout of the CHPDOAS. To investigate this, weather bin data from 6 representative cities in the US was compiled together to show the fraction of the year within which the CHPDOAS could be utilized by a commercial office building operating between the hours of 5am and 10pm Monday to Friday (4160 annual hours). A DOAS system allows the sensible and latent load to be separated.

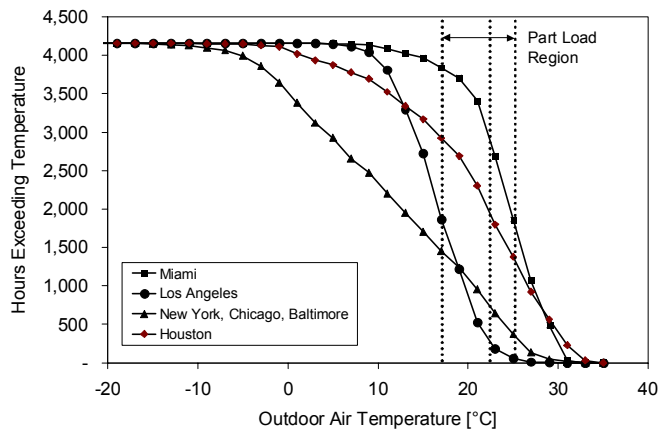

Figure 4. Annual office hours with outdoor air temperatures exceeding given temperature.

Figure 4 shows the outdoor air temperature distribution from four of these cities. Baltimore and Chicago were also included in the analysis, but their profiles were so similar to that of New York City that they were removed for clarity.

The central dotted line in Figure 4 represents the space temperature set point and the temperature (separated from humidity control entirely) at which no heating or cooling would be required as a result of external weather conditions. Internal loads such as people and office equipment will still need to be removed. As the outdoor air temperature approaches the space set point, from either direction, the sensible heating or cooling load will continue to reduce until the DOAS, or CHPDOAS will be unable to operate at full capacity.

Note that if the CHPDOAS were sized to meet the peak load of the building then it would operate at part capacity for the entire range of outdoor temperatures. The area in between the dotted lines in Figure 4 represents this concept of outdoor air temperatures within which the generator will have to dump excess waste heat or operate at part load. The actual width of this region will be determined by three factors – the fraction of outdoor air that the building uses, the capacity of the

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CHPDOAS and the limiting temperature (either in heating or cooling) the system can safely add into the space.

From Figure 4, it is apparent that a CHPDOAS operating in Los Angeles will experience a much higher fraction of part load operating conditions than one operating in Miami or Houston.

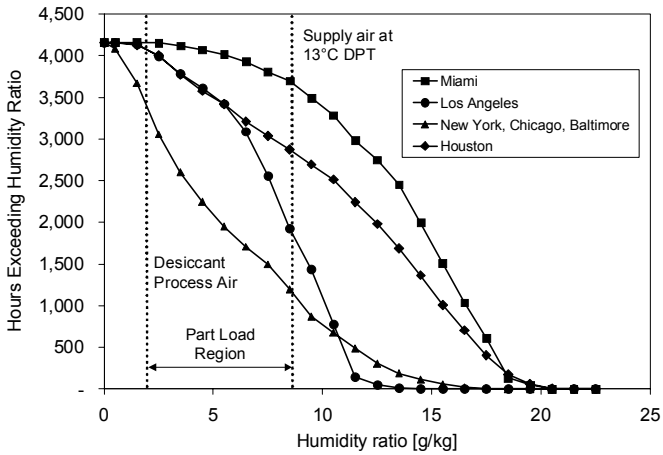

Figure 5. Annual office hours with outdoor air humidity ratios exceeding given humidity ratio.

In a similar manner as for temperature the relationship between operating hours and outdoor air humidity ratio is shown in Figure 5, along with the humidity ratio of supply air at 13°C dew point (9 g/kg) and the humidity ratio that an active desiccant could achieve when supplied with sufficient waste heat (2-3 g/kg). The area in between the two lines again indicates a region in which a CHPDOAS may not be able to operate at full capacity in a dehumidification capacity. Again the determining factors are the capacity of the desiccant relative to the quantity of moisture suppression required within the building. If the intent of the CHPDOAS is to only suppress the humidity in the outdoor air to supply conditions then only Miami and Houston have significant operating hours where the CHPDOAS could be run at full capacity. But if the supply humidity is used to reduce or eliminate the latent load inside the space then the operating hours at full capacity can be much higher.

The attractiveness of active desiccation in CHPDOAS is enhanced by the availability of waste heat that exists within the system as exhaust heat from the generator. Even if an absorption chiller already utilizes the waste heat the temperature is likely to be high enough to still reactivate either a solid or liquid desiccant.

HIGH OUTDOOR AIR FRACTIONS

The trend towards ever greater quantities of ventilation air, to ensure compliance with ANSI/ASHRAE 62-1999 (1999) both helps and hinders the implementation of CHPDOAS. A greater fraction of outdoor air use by a building means that more of the conditioning load is available to a DOAS to process rather than installing this capacity in the return air conditioning unit, which gives a CHPDOAS a much greater "sink" to cool, heat or dehumidify. The negative aspect of this is that in the extreme where a space requires 100% outdoor air is that the CHPDOAS must now deal with the peak loads of the building, leading to low utilization of the CHP equipment and high capital costs at installation.

The result of this is that a CHPDOAS is likely to be most suited to those buildings, such as commercial office buildings where the outdoor air is only a fraction of the total cooling load. A CHPDOAS may be a very effective method for a building owner to offset the cost of bringing distributed generation onsite as when the system both heats and cools the waste heat can be utilized for a substantial fraction of the buildings operating hours. The inclusion of an active desiccant wheel in locations like Miami where a high latent load exists all year round will also help to increase the value of the waste heat.

DUCTING CONFIGURATION AND SITING

A CHPDOAS can be configured for many different climates by changing the components within the system. The ducting arrangements for a CHPDOAS may differ from those of a DOAS (Figure 6).

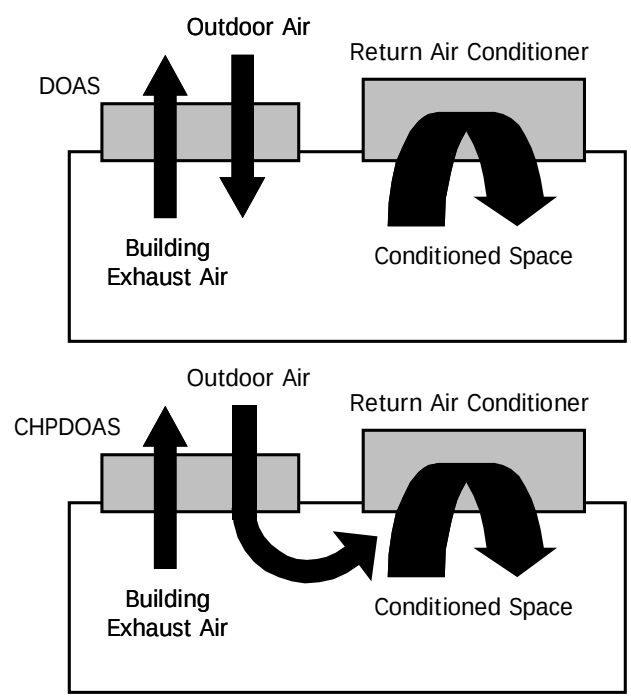

Figure 6. Ducting arrangements for DOAS as compared to a CHPDOAS.

A DOAS that has the capacity to process outdoor air even on peak heating or cooling days will be able to directly add air into the conditioned space continuously. Choosing the capacity of a DOAS can be as straightforward as knowing the maximum temperature or humidity difference that the unit

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should be capable of dealing with and sizing for this. The strategy for sizing a CHPDOAS can differ greatly from this as it is being sized not with the maximum capacity in mind, but maximum utilization, which may result in a unit that is under or over sized for the outdoor air stream, even at peak heating or cooling conditions. In any case the outlet conditions from a CHPDOAS will not always be suitable for adding into the space directly, but may need to be mixed into the return air stream.

EXAMPLE OF OPERATION

Consider two days in the heating season, one where the outdoor temperature is much colder than the other.

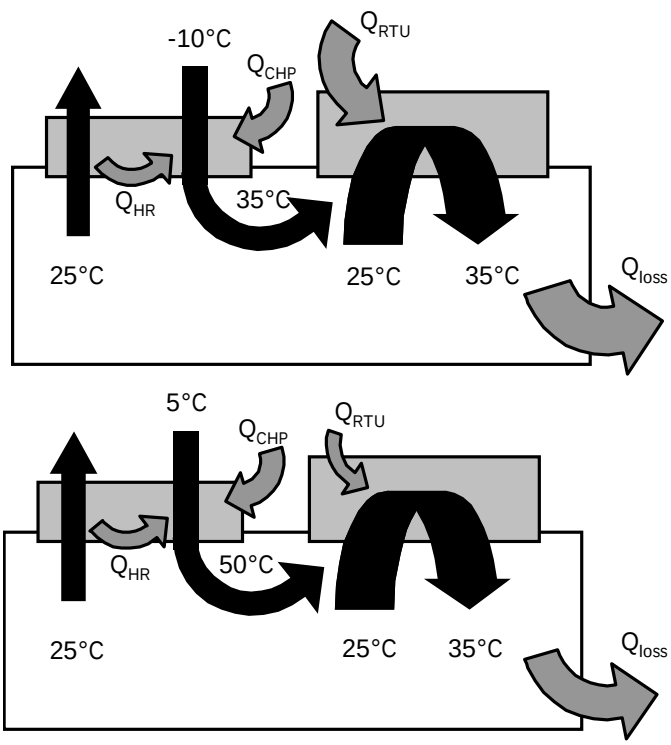

Figure 7. Example of the operation of a CHPDOAS on two days during the heating season for the same building, firstly at an outdoor air temperature of –10°C and then at 5°C.

Both sets of conditions in Figure 7 require heat to be added to the building, but the amount of heat required at 5°C outdoor air temperature will be much less than at –10°C. This means that the heating capacity of the space conditioning equipment in the building must have a capacity determined by the peak load requirements. However, while some component of the system must operate at part load, the use of a CHPDOAS will mean that the relatively expensive CHP capacity can still be fully utilized.

Considering Figure 7 in more detail, the heating supply conditions to the space from the RTU are set at 35°C. On the colder day, the CHPDOAS is sized to provide enough heat to just meet the entire conditioning load of the ventilation air stream. The CHPDOAS accomplishes this by recovering heat in the building exhaust air stream ($Q_{Heat\ Recovery}$ or Q_{HR}) with a total heat recovery wheel or other heat exchanger as well as adding heat rejected by the generator (Q_{CHP}) to the incoming air stream. In this case the air is then mixed into the return air and passed through the RTU where more heat (Q_{RTU}) is added from a conventional (non-CHP) source to make up the supply air conditions to the building. Heat is lost through the walls of the building (Q_{loss}) as well as that remaining in the exhaust air after the heat recovery step.

Now take the same building in an outdoor air temperature of 5°C. There is now less heat lost through the walls and the overall heat requirement is therefore reduced. The amount of heat required by the CHPDOAS to raise the temperature of the outdoor air stream to supply conditions is also reduced. If the outlet conditions from the CHPDOAS to the RTU were maintained this would normally result in curtailing the electrical output of the generator or wasting available waste heat, but since the outlet temperature can be raised (in Figure 7 it is shown as 50°C) the heat input from the generator can be held constant and the waste heat fully utilized. The heat input from the RTU will be reduced when the hotter than supply air from the CHPDOAS is mixed into the return air stream from the building, displacing electrical or fuel consumption.

While this example describes operation during the heating season, cooling and dehumidification operations will be similar in effect where RTU load is displaced by the CHPDOAS operating as close to full capacity as feasible.

RETROFIT INSTALLATION

A retrofit installation of a CHPDOAS, while still undesirable compared to designing it into a new building can be achieved with a couple of simple duct additions, namely a duct that brings exhaust air to the CHPDOAS and one that then takes processed supply air to mix with the return air stream from the building. Some damper operations inside the RTU will have to be adjusted and new control logic used, but there will be very few hardware changes required beyond the ductwork additions and the installation of the CHPDOAS itself.

UNOCCUPIED BUILDINGS

If the CHPDOAS were installed exclusively to process outdoor air then there would be no opportunity to run the system when the building was unoccupied since there would be no ventilation air requirement, although there may still be heating or cooling demand to maintain night setback levels. RTUs are not traditionally able to control both temperature and humidity in the absence of ventilation air flow (Henderson et al., 2002). Since the CHPDOAS has building exhaust air ducted to it and a return duct to carry supply air into the space the unit will be able to continue to process air by treating exhaust air and then returning it to the space, as shown schematically in Figure 8.

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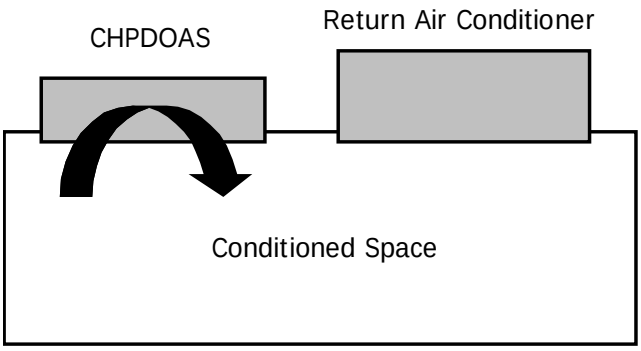

Figure 8. CHPDOAS operating when ventilation air is not required.

Maintaining a night or unoccupied set point could also be achieved with the same CHPDOAS, as long as a couple of additional control dampers were installed in the unit to redirect the flow through the heating or cooling coils.

CONCLUSIONS

There is a direct conflict between the requirements of many types of commercial buildings which experience highly variable daily and seasonal load profiles and ideal operating conditions for CHP applications where the initial larger capital investment is normally recovered through continuous or very high operating hours in a base loaded condition.

Other sinks aside from hot water heating will need to be found if CHP is to make significant penetration into the commercial market outside of building types such as hospitals and hotels as the electrical generators waste heat needs to be used as continuously as possible. By focusing solely on the ventilation air a much more attractive application for CHP can be found than attempting to condition inside the main air handler. The ventilation air in a commercial office building makes up only 15-20% of the total air flow through the air handler and can provide a good match for CHP equipment. Additionally the ventilation air can be over-cooled, over-heated or over-dried since it will be mixed with the bulk return air, furthering increasing the utilization of the waste heat.

The configuration of a CHPDOAS can be arranged such that cooling, dehumidification and heating can all be provided by the same piece of equipment resulting in high operating hours and/or utilization of the waste heat from the generator almost regardless of the season. However, since a CHPDOAS should be configured for the climate in which it is to be installed, not all heating, cooling and dehumidification components need be included.

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