# Energy Consumption of Underfloor Air Distribution Systems: A Literature Overview

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ABSTRACT: The necessity of energy efficient HVAC technologies has been growing concomitant with the sustainable development conscience. In this context, Underfloor Air Distribution (UFAD) Systems appears as an air-conditioning technology that consumes less energy than conventional overhead systems. This paper is a literature overview of energy efficiency of UFAD Air-conditioning Systems, focusing on outdoor air and its influence on energy consumption. A global panorama of UFAD energy efficiency is given and possible directions for future researches are suggested. Airside economizer operations are emphasized in order to identify which can be their real contribution for the UFAD system energy consumption while keeping thermal comfort.

Keywords: underfloor air distribution (UFAD), outside air, energy-efficiency, air-conditioning

## 1. INTRODUCTION

Heating, Ventilation and Air Conditioning (HVAC) systems are responsible for great part of buildings' energy consumption. Several factors influence HVAC systems' operation and energy efficiency. These include not only the system itself but also local climate, building design, building materials, as well as the interior parameters, such as occupation density and nature of work developed.

The consideration of local climate is important to define whether to use or not air-conditioning systems to keep human thermal comfort, and how and when the system will operate. Solar radiation, particles concentration, air temperature, humidity and velocity are external parameters that also define the usability and operation of HVAC systems.

As the conventional mixing strategy for the environment air conditioning may be an unsuitable solution to solve this problem, the underfloor air supply system seems to be a more appropriate technology, as much for its characteristics of flexibility as much as the operational way. One is about a system that, introduced initially in Germany office buildings, in 1970's, supplies cooled air "low to top", by means of diffusers installed on the raised floor, as illustrated in figure 1. The system has as main characteristics the following: it promotes the exchange of heat with the environment more quickly, only the air volume of the effectively busy space is conditioned, it operates with higher air temperatures than the ones adopted in the conventional systems with ceiling air supply, and it promotes flexibility because allows changes of the air captation floor points due to the absence of ducts.

Until the end of 1990's, the use of this technology was limited to the data processing centres (CPD) areas and the greater contingent was found in the United States, South Africa, Japan, Germany, Sweden and Italy. Since its introduction, this type of system has aroused the interest of researchers, mainly in the United States, Europe, Japan and, more recently, in Brazil. Researches have been developed to define thermal comfort situations promoted by the underfloor air supply system in offices environments, which depend on the resultant thermal conditions in the environment and on the acceptance of these conditions by the users [1]. Also, researches have been developed to investigate its performance under energy saving point of view. These works are results of laboratory (climatic chambers) and field researches, including users. Indicators of the whole system performance are presented, mainly with focus in comfort and in the system operational conditions.

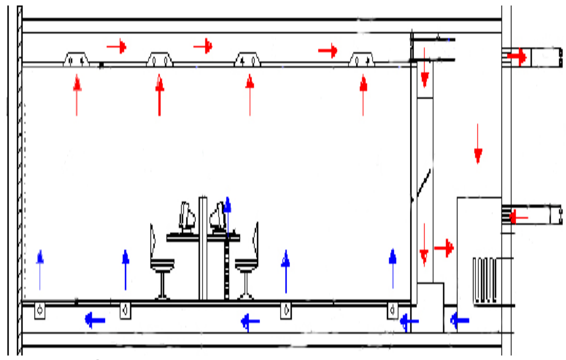

Fig. 1 – Schematic UFAD system – (Leite, 2003)

Underfloor Air Distribution (UFAD) systems have particular characteristics such as higher supply and return air temperatures that enlarge the use of outdoor air of specific climate conditions during its operation. Researches relating the use of outdoor air and UFAD systems are being developed in order to analyse possibilities of low energy consumption while keeping thermal comfort. However, more studies are required in order to quantify the real improvement provided by airside economizer strategies. In this context, this paper intends to give an overview about UFAD systems energy consumption, and how energy efficiency may be enhanced by the major use of outside air, based on papers chosen due to their significance on the related research.

## 2. UFAD ENERGY CONSUMPTION

Researches about UFAD system relate its energy consumption to: supply and return airflow and temperatures, thermal loads, stratification, plenum pressure, equipments (fan, chillers, diffusers), climatic influences, control strategies and design.

According to to Loudermilk [2 apud 3], Leite [4] and Bauman [5], the potential UFAD systems energy efficiency lay on: a) the fact that only the occupied zone is air-conditioned; b) convection thermal loads above the occupied zone are not considered to the supply air calculation; c) supply air temperatures are higher than in overhead systems. The following figure 2 represents the characteristic air temperature profile in the ambient. This profile justifies the above assertions.

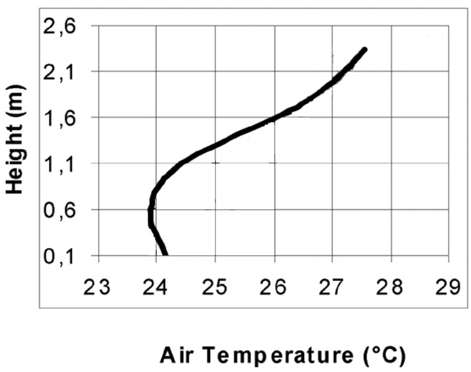


Figure 2 – Representative ambient air temperature profile (Leite, 2003)

UFAD equipments and operation influence systems' energy consumption. Researches such as Matsunawa et al. [6], McCarry et al. [7], Wang et al. [8] and Bauman and Webster [9] try to elucidate the real contribution of UFAD systems' equipments to reduce energy consumption. The main differences that alter equipments operation in UFAD systems are the plenum pressure and supply and return air temperature. According to McCarry et al. [7] energy consumption simulations indicate that operational UFAD systems costs are slightly lower than those from overhead systems, due to lower ventilation pressure and cooling loads. Pressurized plenum and passive diffusers may have energy efficiency diminished by leaks of air through raised-floor panels. On the other hand, zero-pressure plenum consumes energy by localized active diffusers working combined with central air-handling unit. Lower energy consumption of UFAD systems is a result from the reduced pressure provided by the system air distribution, since the plenum eliminates the need of ductwork and, consequently, reduces fan pressure required to air delivery [10, 5]. Bauman and Webster [9] recommends plenum pressures around or lowers than 25Pa; Leite [4] suggests plenum pressures between 8Pa to 12Pa. According to Wang et al. [8] the energy economy by mechanic cooling overlaps the higher energy consumption by ventilation necessary due to higher supply air temperatures. Webster et al. [11 apud 9] analyzed UFAD fan energy consumption, and results indicate around 48% economy generated by UFAD systems with variable air volume control (VAV) if compared to conventional overhead VAV systems.

Comparative researches of UFAD and overhead systems energy consumption have been developed, with results pointing better efficiency to UFAD systems. According to Bauman and Webster [9] UFAD energy consumption is lower than that from overhead systems due to reduction in energy for cooling by economizer operations and enhancement in chillers coefficient of performance, and reduced fan energy consumption. These result from: 1) extended economizer operations due to higher return air temperatures (77°F to 86°F (25°C to 30°C) against 75.2°F (24°C) for overhead systems); and 2) chiller delay start and reduction in energy for cooling due to higher supply air temperatures (62.6°F to 68°F (17°C to 20°C) against 55.4°F (13°C) for overhead systems). However, two scenarios may diminish these energy-cooling economies: 1) when humid climates require conventional coil temperatures; 2) when hybrid systems with a unique air handling system require conventional coil temperatures [9].

UFAD systems allow personal air distribution trough diffusers installed on the occupant desk. Researches such as Leite [4], Leite and Tribess [1], Bauman [12], Tsuzuki et al. [13], indicate that Task Ambient Conditioning (TAC) enhances both thermal comfort and energy efficiency. Quantitative and qualitative laboratory experiments [4] suggest that occupants are more tolerant to higher supply air temperatures when TAC is available, which would extend even more the use of outside air in specific climate conditions.

## 3. AIR –SIDE ECONOMIZER OPERATIONS

Economizer operations may be extended in UFAD systems. This is due to the fact that supply and return air temperature in UFAD systems are higher than that used in overhead systems. According to Bauman [5] UFAD supply air temperature extends the use of 100% free cooling, and the increased return air temperature extends integrated economizer operations. However, besides the need of mild outside air temperatures, two other subjects must be considered in order to keep human thermal comfort while reducing energy consumption: outside air humidity and room air stratification level.

The outside air humidity is decisive to define if economizer operations will be operable. Humidity must be controlled into acceptable human comfort levels and systems' workable boundary, so no condensation on plenum may occur. Humid climate requires enthalpy control or desiccant dehumidification so economizer operations can be used. Laboratory experiments [4] in altitude tropical climate (São Paulo City – Brazil) suggest that free cooling would be possible mainly during wintertime, due to outdoor air humidity, and that would be limited to dry-bulb temperatures under 66.2°F (19°C), which corresponds to absolute humidity lower than 10.5g/kg$_{dry\ air}$ (50% of relative humidity for 24°C of temperature). According to Spinazzola [14] some discomfort should be caused by high humidity levels if supply air from the cooling coil in the air-handling unit is at 63°F (17,22°C) (considered the best UFAD supply air temperature for thermal comfort according to researches in Europe [14]). Therefore, Spinazzola [14] recommends that most of the air should be cooled to 55°F (12.78°C) and some air bypassed and blended to the cooled one (coil face and bypass system), raising the temperature to the required 63°F (17,22°C). Spinazzola [14] also recommends that outside air should be pre-treated to remove humidity and make the face and bypass approach more effective.

Air stratification room level is another important topic to define economizer operations. The greater the room air stratification the better will be the system energy efficiency. However, higher stratification level may cause uncomfortable conditions due to the temperature difference from ankle to neck. Bauman [5], based on laboratory experiments from Webster et al. [15 and 16], suggests that a flow rate of 0.6 cfm/ft² (3L/s/m²) would be a reasonable value to avoid excessive stratification, keeping a head-foot (0.3 to 5.6ft or 0.1 to 1.7m) temperature difference of 3.2°F (1.8°C).

Leite [4], Matsunawa et al. [6], McCarry [7], Architectural Energy Corporation [10], Chang et al [17] and Heinemeier et al. [18], indicate that in mild climates free cooling may be greatly extended during the year, promoting decreased energy consumption.

Free cooling is a strategy that reduces the hours required of the mechanical cooling equipment, using no cooling coil to keep supply air temperature. As the set point of the supply air temperature increases, warmer outside air can be used to meet the load. Besides that, warmer return air temperatures due to stratification also allow an increase in economizer operating hours [10].

According to Bauman [5] 100% free cooling in UFAD systems is extended up the 65°F (18°C), which corresponds to the system supply air temperature. According to Leite [4] laboratory experiments indicated that depending on humidity conditions, when UFAD systems deliver air through task ambient controls (TAC) the 100% free cooling operation would be extended to 74,3°F (23,5°C).

Integrated economizer operations may be used when the outside air temperature stays between supply and return air temperature. It means that when outside air is between these temperatures some free cooling may be used working associated with cooling coil. UFAD stratified systems may use integrated economizer operations when outdoor air is above 65°F (18°C) and below 85°F (29°C) [5].

Ghiaus and Allard [19] studied a method to indicate the potential for free cooling by ventilation. Although the research focus is the use of bin method as a good way to estimate cooling energy need and the potential of energy savings for cooling by using ventilation, the method and results should be analysed under the UFAD point of view. This research includes a measure related to the energy saved and applicability of free cooling, done through probabilistic distribution of degree-hours as a function of outside air temperature and time.

Pre-cooling strategies such as thermal storage and pre-cooling applications may reduce energy consumption and cooling peak demands; however, more studies about this subject are required [5]. Night purge strategy introduces outdoor air when it reaches a pre-defined temperature into the building during the night, in order to cool the building mass for offsetting the cooling load at the beginning of the occupied hours [20]. During evaluation of HVAC system operational strategies for commercial buildings, Ardehali [20] found out that night purge is not an effective strategy in buildings with low thermal mass storage. However, researches on night plenum ventilation using outdoor air to pre-cool building thermal mass with UFAD systems installed indicated peak demand reduction up to 40% [21] and 30% [22] during summer [12]. Badenhorst [23] indicates that pre-cooling strategy may cause condensation inside the plenum, mainly if cooled plenum suddenly is exposed to humid and warm air. Therefore, in humid climates, air dew point that enters the plenum must be controlled, leakage must be avoided and anti-macrobiotic materials should be used.

Researches about the use of outside air through natural ventilation combined with UFAD systems have been conducted. The stratification and displacement air flow that occur at the superior zone of rooms with UFAD systems installed transport efficiently the heat to be exhausted, resulting in better cooling efficiency [3]. This characteristic instigated researches such as Chang et al. [17], where energy consumption of hybrid UFAD air conditioning systems and natural ventilation have been investigated through Computational Fluid Dynamics (CFD) obtaining positive results depending on the climate conditions. Song and Kato [24] also analyzed the potential of natural ventilation combined with UFAD systems. They compared the energy efficiency of radiational panel cooling system with wind-induced cross ventilation and UFAD system with natural cross ventilation. The results indicated best energy efficiency for radiant panels.

## 5. CONCLUSION

The purpose of this work was to identify the main aspects that contribute to energy saving considering the system operation. Although the analysed bibliography indicates that UFAD systems have great potential to reduce energy consumption and that the use of outside air is extended in economizer operations due to UFAD system characteristics, it was observed that more researches are still necessary to prove and quantify the real contribution of economizer operations in energy consumption.

Also, there is a lack of studies about UFAD controls. More research is needed to identify strategies that monitor outside and indoor air temperatures and humidity, and maximize airside economizer operations. Studies of control strategies of pressure, airflow rate, air temperature, stratification and accurate estimation of thermal loads are essential to UFAD systems' performance. Methods that better indicate which climatic conditions are favourable to airside economizer operations are needed. The possibilities of combined system operation should be better investigated since recent researches indicate good possibilities of combining natural ventilation to UFAD systems. Measurements of energy consumption of mechanisms that control humidity should be analysed in order to indicate the viability of even more extended airside economizer operations. Researches about impact of airside economizer operations in equipment responses and function parameters are necessary, so energy efficiency should be enhanced by different operation parameters or innovative technologies.

Although researches conceptually indicate the energy efficiency of UFAD systems, few are the studies that present quantitative energy consumption data. Many efforts are still necessary to clarify which real contribution and consequences of airside economizer operations are and which favourable conditions to use them.

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