International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2019): 7.583

Active Chilled Beam (ACB) System, Solution with the Best Economic Life of High-Rise Buildings with High Thermal Mass and Low Cooling Capacity Load

Ramadan Alushaj[1], Flamur Bidaj[2]

[1]Professor, Mechanical Engineering Faculty, PUT, Albania

[2]Energy Department of Mechanical Engineering Faculty, PUT, Albania

Abstract: ***There are many studies that compare conventional Air-Conditioning (AC) systems and Chilled Beam Systems (CBS) for commercial high-rise buildings based on two criteria which are capital and energy costs without compromising on comfort. Actually, using those two criteria is not sufficient to define the best AC system for a high-rise building with the highest economic efficiency during a certain operational life. Taking this into consideration, this paper intends to describe the difference between the Active Chilled Beam (ACB) and other AC systems and which has the highest economic efficiency during a certain life and the reason why. The main purpose of this study was to analyze the capital costs, the energy consumption, Indoor Air Quality (IAQ), asset replacement and maintenance for the four possible mechanical systems required to implement in TID high-rise building of City of Tirana. During this study we have compared the properties of an ACB system, fan coils (FC), Variable Refrigerant Flow (VRF) system, and variable volume air volume (VAV) system. Based on the analyses and results of the study of property of four HVAC types of systems we came into conclusion that the energy consumption, asset replacement and maintenance have the most important cost in economic life of HVAC system. The capital cost of VAV and ACB system is higher than the capital cost of VRF and FC system, but the energy consumption, asset replacement and maintenance cost for economic life (25 years) are much lower for ACB system than for the other systems, which makes it the best system with an economic life of 25 years with a lower cost.***

Keywords: Energy, energy consumption, indoor air quality, heating, variable air volume, operation and maintenance, asset replacement, economic life, active chilled beam

1. Introduction

Albania, in the post-socialist era of market economy is undergoing a rapid development of the modern building constructions, where the main are the new residential buildings and high commercial buildings in the center of the city of Tirana.

The systems that have found application in tall commercial buildings have evolved over the past decades in response to the changes in the perceived goals of the entity that is constructing the building, the expanding needs of the potential occupants be they a corporate end user or a leasing party, and the concerns of the owner with the availability and the cost of energy and the resultant expenditures necessary to operate the building. More recently, the import of environmental concerns, including indoor air quality and the growing challenge to provide safer buildings, has further influenced the approach that is taken in the system selected for a modern tall commercial building.

High-rise commercial buildings are not only an engineering challenge to design the most suitable AC system to answer to the high thermal comfort requirements, but are also are also subject with the potential to contribute significantly to energy savings and CO2 emission reduction.
AC systems have many possibilities to achieve these tasks, which depend on many of factors of the system composition that mechanical engineers should analyze in accordance with the existing technology of the time in predesigning phase.

Air conditioning systems, taking into account the problems with the indoor air quality in the building, should be combined with the use of fresh air and mechanical ventilation, which are another important component in saving energy and reducing CO2 emissions.

On the other hand, many designers in their projects, usually start using the data and recommendations of the manufacturing companies for air conditioning equipment and systems, without deeper analyzing the effect that all components of the AC system have on its total performance in both full and partial load operation.

Therefore, in this study, we will consider the technical-economic analysis of combining an AC system with fresh and ventilated air as a fully functional system to achieve an energy saving and reduction of CO2 emissions at a vital cost of the system and sustainability, with the baseline of the building operation for 25 years.

2. General Considerations

Tall buildings intended for offices, constructed in the center of city of Tirana, based on ASHRAE Design Guide, require air conditioning systems with simultaneous heating and cooling as well as keeping high indoor air quality. Tall commercial buildings in particular present a series of design problems that set them apart from other functions.

This because people in offices, building occupants, today spend most of their time and therefore the air conditioning system should provide not only heating, cooling, humidification and drying, but also adequate ventilation, in accordance with the ventilation requirements for commercial and institutional buildings which are given in ASHRAE Standard 62-1. These ventilation rates were chosen to achieve an acceptable level of indoor air quality by control of carbon dioxide, particulates, odors, and other contaminants common to those spaces.

Indoor air quality (IAQ), with a minimum fresh air supply of 10 liters/s per person, has a major impact on the health, comfort and well-being of building occupants [14]. On the other hand, poor air quality has been linked to the problems of Sick Building Syndrome that reduced productivity in offices.

These functions in indoor conditions in offices require a close connection of heating, cooling and fresh air with ventilation. For all possible systems it should provide thermal comfort, acceptable indoor air quality and reasonable costs of installation, energy used, operation and maintenance.

To meet the challenge of providing systems that address these major issues, the commercially available equipment and the deployment of that equipment have also gone through a period of modification in some design details over the recent. But those systems have not the same operation, maintenance cost and economic life cost [1]. So, is important to compare systems that include IAQ for capital cost, the energy consumption, operation and maintenance cost for economic life (25 years. So this paper will consider the four possible systems to be applicable as technical solutions in example of TID tower Tirana.

3. Methodology

This article consider, by life-cycle cost analysis (LCC) to compare four different possible systems for application to the mechanical system for TID Tower Tirana HVAC solution, taking information and research from a variety material and in situ sources and in an independently way, tries to determine the benefits and drawbacks of using each system and also give e recommendation for the best efficiency system solution needed to apply in TID tower Tirana.

LCC analysis takes into account all the drivers as costs of purchasing, operating, maintaining and replacing equipment of a building system.

We have compared through a simulation model, four types of HVAC system regarding IAQ, Capital cost, the energy consumption, operation and maintenance cost for economic life cycle (25 years). The simulation model of the TID tower was developed using the HAP-Carrier software, which is design for building industry, to evaluate energy use and cost alternatives in building construction and associated HVAC systems.

4. System Modelling

Building Model

Building model used in this study was selected from the new commercial building in Tirana. This model presents the new generation of high-rise office buildings built in Tirana, Albania and thus serve as an appropriate baseline against which researchers can easily compare differing operational strategies.

It is difficult to fundamentally alter a large building, after it is finished and available for use by occupants. So the building usage and performance criteria should be defined at the outset of design.

The 24-storey TID Tower is part of the ambitious new master plan for the city of Tirana, which joins a project with about ten iconographic towers. The main destination of TID Tower consists of Offices (20 floors), and shop and restaurant facilities that are located at the basement of the building.

The TID tower architecture is based on a super ellipse shape starting as a perfect ellipse at the basement and ending as a rectangle on the top floor. The building has a windbreak envelope with shading covers of concrete slabs (Fig. 1)

The net-office area for each floor, which size varies from 510 square meters, starting on the fifth floor and gradually increasing to 626 square meters, on the 24-th floor (20 floors), wraps around the main core and makes perfect for all type of office divisions, letting natural light to come in from all sides. At 85 m height TID tower is the highest building in Albania. A circular, three-dimensional cut out of the base of the tower creates an almost ethereal aura for the tomb.

This Building is made of mixed glass and concrete sunscreens with façade by 50% + 50%.

The cooling capacities from North to West side of building are 55 - 120 W/m2 with 950 kW total cooling capacity.

This building is prefect to use certain HVAC systems, with lower capacity (55 - 120 W/m2) and high efficiency HVAC systems, like ACB system.

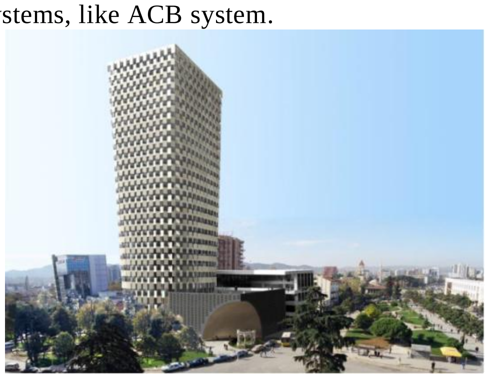


Figure 1: TID tower Tirana & façade type

HVAC System models

The active chilled beam (ACB) that is water-air system combining with dedicated outdoor air system (DOAS) 2-pipe, cooling only, or 4-pipe, that can be described as a “fan coil” unit with no fan and filter, working as a ceiling mounted induction unit, it provides ventilation cooling and heating into a space [5]. ACB have an integral constant air flow supply passing through nozzles (small holes) which induce air from the space up through the cooling or heating coil. Operating with supply water temperature 13-18°C no condensate forms, thus no drain pans are required [8]. Thus active chilled beams provide sensible capacity only. Dehumidification and up to 30% capacity are insured via an air handling unit AHU. It is totally reliant upon other factors such as chillers, ground source water, heat sinks etc. It is in these areas that the free cooling and energy efficiency of the systems is realized. As the baseline system the ACB 4-pipe system is selected.

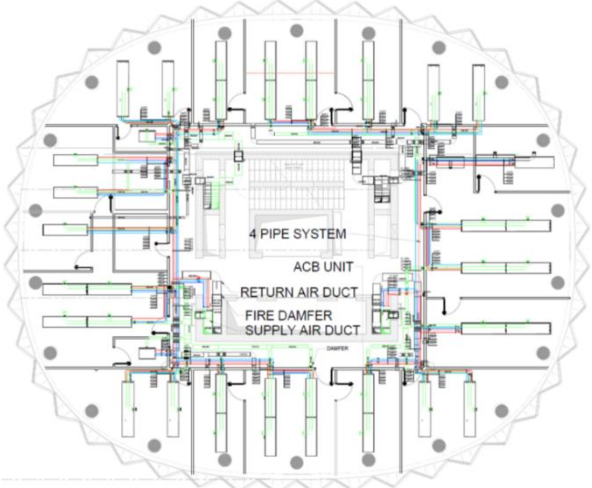


Figure 2: The Active Chilled Beam 4-pipe System (Floor-14)

ACB unit have not the fan so they are inherently more energy efficient than their main rivals – fan coil units [5]. An additional benefit is ACB use higher chilled water flow temperatures(13-18oC) than fan coil units, which means there is a significant part of the year when chillers do not need to be working and free cooling is available. The ACB units contain no moving parts and are therefore more reliable and less noisy, they are maintenance free, they have a long-life expectancy and no condensate containment provision is required. The economic life of ACB system, is given as 20-25 years.

Fan coil systems

Fan coil systems are assemblies of heat exchangers and ventilators and air filters for space heating or cooling, connected to two-pipe or 4-pipe hydraulic network systems. For our case study we have chosen as a preference the system with 4 pipes (simultaneous heating and cooling of all building). To ensure room air quality they usually use an AHU plant to supply the rooms with conditioned fresh air..

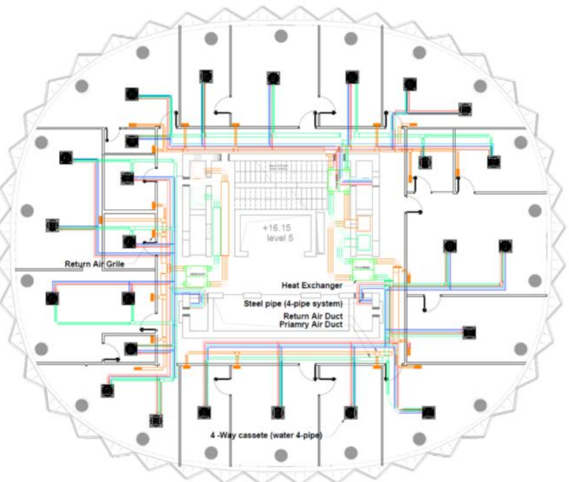


Figure 3: The fan coil 4-pipe system design (Floor-14)

For ensuring the required dehumidification, these systems are based on cooled water temperatures supply-return to values 6-12oC while in the heating function work at water supply temperatures 45-70oC. In terms of maintenance costs, these are considered relatively high as well as with not very long service life.

VAV systems

For our case study we have chosen as a preference the VAV system with an air duct and terminal heating devices (simultaneous heating and cooling). VAV systems consist of an AHU device with cooling/heating exchangers, air ducts and thermal load regulation terminal equipment with air flow variation and constant temperature and air supply to the room by means of air diffusers. The terminal regenerator serves to withstand the heating load.

A duct system distributes supply air to variable air volume terminal units located in the zones, which are identical to the zones supplied by ACB in the baseline system. However, VAV terminal can be equipped with reheats coils, especially if the required In a typical VAV system with temperature control need supply VAV terminal in supply air duct and extract VAV terminal in return air duct. VAV systems are systems that save energy in the mass of air flow reduction as a function of thermal load The economic life of VAV System is given as 20-25 years.

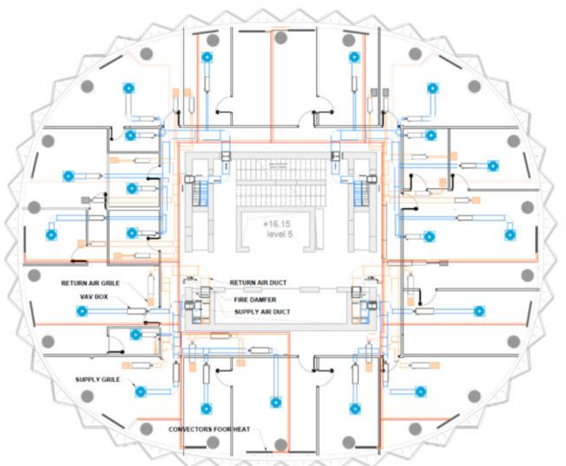


Figure 4: The VAV system cooling only + terminal reheat unit (Floor-14)

Variable refrigerant flow (VRF) system

Variable refrigerant flow (VRF) systems consist of a number of fan coils unit floor, wall, ceiling units or small AHU connected to an outdoor unit by refrigerant pipe work that work with variable refrigerant flow (or volume). The most prevalent alternative to the four-pipe fan coil is the variable refrigerant flow (VRF) 3- pipe system. This uses a similar type of terminal unit, consisting of a filter, fan and a single, refrigerant-filled heating/cooling coil. To compare with baseline system ACB 4-Pipes VRF system will be 3-pipe system. Maximum capacity of outdoor unit can be 50 kW and VRF system can generally be installed in paralel up to 150 kW. The economic life of a VRF 3-pipe system, given as 10 years.

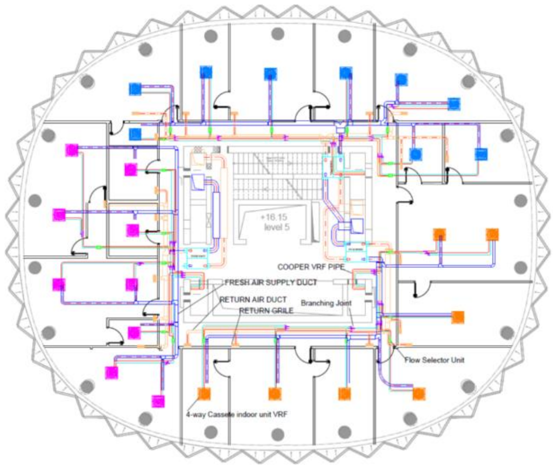


Figure 5: Typical VRF 3-pipe system project (Floor-14)

5. The Simulation Model and Results

Today, when we live in a time of energy crisis and global warming, it is of utmost interest for local and European investors to invest in EE buildings, which have to be analyzed based on the building life cycle (LCC). There is generally no exact study period for a project evaluation, but it is necessary to use the same study period in calculating the life cycle cost of each project alternative (12). Thus, for our analysis of the most suitable alternatives with the lowest cost of the building life cycle we will include: capital cost, cost of used energy, cost of capital replacement, maintenance costs, and repairs for a period of service 25- annual.

Mathematical model will be as follow:

$$LCC = \sum_{t=0}^{N} \frac{C_t}{(1+d)^t} \qquad (1)$$

Where is:

LCC – The total value of LCC in euro, for the actual value of the analyzed specific alternative

Ct – is the sum of all respective costs, including the initial and future costs, minus the positive monetary flux to happen

N = Years of the study period,

d = Discount value used to adjust cash flows at present.

t = Present year (where 0 is baseline year)

To use it for projects related to the building under our case study, according to the above LCC formula, we will adapt it to a more simplified formula as follows:

$$LCC\text{-}= Cc + Ec + Sar + Mar + OM\&R \qquad (2)$$

where is:

LCC – Total of LCC for the actual value in euro for the given alternative

Cc – Investment cost for actual value

Ec – Actual value of energy costs

Sar - Capital replacement costs at current value

Mar - Present value principal costs of capital replacement

OM & R - Current value of energy operation, maintenance and repair costs.

Since this study is designed to compare HVAC system of the alternative to that of base case and focus on energy consumption, the other costs are simplified and omitted because they are identical in both cases in the comparison.

Figure 6 shows the scheme of how to calculate LCC, converting future costs to present values.

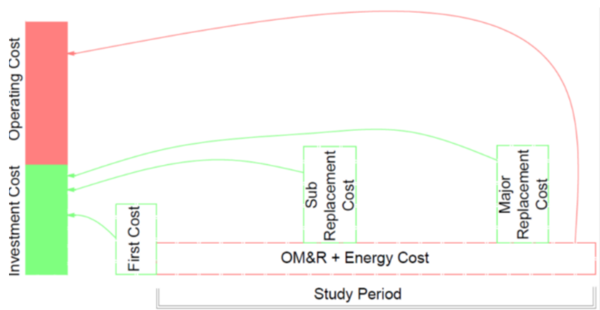


Figure 6: Concept Diagram of LCC Analysis for building-related projects

The simulation model of the TID tower for four type of HVAC system regarding the capital cost, the energy consumption, asset replacement, operation and maintenance cost for economic life (25 years) was developed using the HAP 4.80-Carrier software [11], which is design for building industry, to evaluate energy use and cost alternatives in building construction and associated HVAC systems. The simulation model, is designed as an hourly simulation tool to evaluate energy use for Annual HVAC and Non-HVAC (Lights and Electric Equipment) Energy Cost.

The baseline system is used the Active Chilled Beam with 950 kW total cooling capacity.

The modeling of the TID tower began with the specifications of the building plans from which the construction details and material specifications for the floors, walls, ceilings and windows were obtained. Internal loads were estimated based on operating schedules and by a study, instead of light fixtures, computers and other heat-generating devices in the building's internal vents.

The costs of installing the initial ACB system and the other three alternatives were estimated using the models produced to meet the energy loads seen in the HAP-Carrier simulation. In general, total costs were constructed from the individual costs of all system components including chillers, heat pumps, piping, valves, air ducts, air treatment units, controls, and electrical equipment plus installation costs and management costs.

In (Fig.7) below, is presented the energy consumption components for HVAC systems used in the comparative LCC analysis by simulation of model of the TID tower using the HAP 4.80-Carrier software.

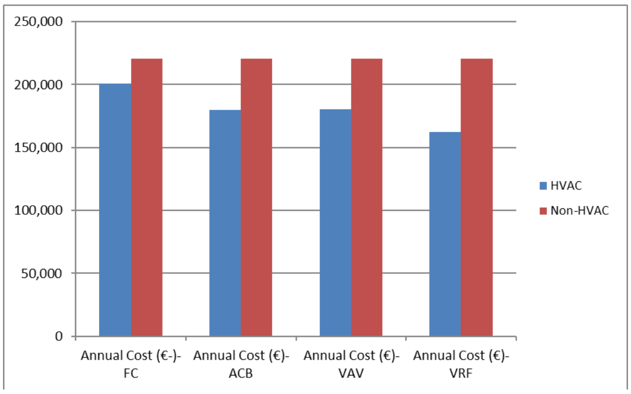


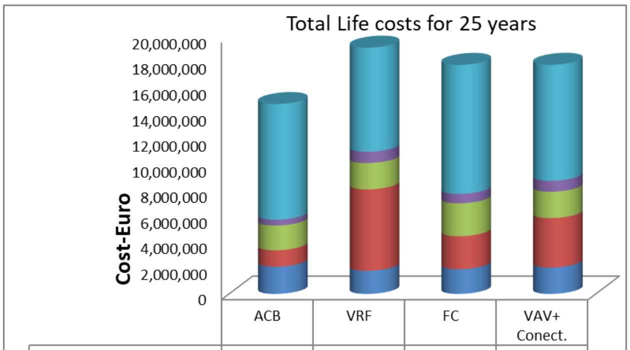
Figure 7: Annual HVAC and Non-HVAC Energy Cost – FC-ACB-VAV-VRF system analyze for TID tower

The cost estimation was examined by the Engineering Company in Municipality of Tirana, Albania, with extensive experience in design and cost estimating at baseline of Active Chilled Beam and other HVAC systems for Office building.

To provide reliable data on life cycle cost analysis, we decided to use current maintenance cost data from Twin Tower Tirana which is in use on 2005-2013- and maintained by Profesion Klima (l.t.d.) [10] as maintenance database. This influenced the choice of the alternative systems, which are described below.

The final cost by LCC Formula (2) estimates for the baseline active chilled beam system (ACB), and the three conventional alternatives are presented in Fig.9.

The Fig.8 present results by the formula (2), in table & graphics bars, describes an in-situ comparison result of four different HVAC systems (active chilled beam system (ACB), fan coils (FC), VRF, and VAV system) for TID tower regarding the capital costs, the energy consumption, operation and maintenance of the mechanical systems for total life costs over 25 years applied to 12000 m2 new offices TID tower Tirana.



	ACB	VRF	FC	VAV+ Conect.
Energy cost(€)	9,008,400	8,111,850	10,049,200	9,034,800
Maintenance(€)	453,582	873,942	728,490	851,270
Sub asset replacement(€)	1,926,000	2,054,400	2,568,000	2,054,400
Major asset replacement(€)	1,284,000	6,346,000	2,568,000	3,852,000
Capital cost(€)	2,118,600	1,797,600	1,926,000	2,054,400

Figure 8: Annual HVAC and Non-HVAC Energy Cost – FC-ACB-VAV-VRF system analyze for TID tower

6. Conclusions

A comparative analysis of ACB system as alternative for tree other conventional HVAC systems is presented. This study investigates four aspects of ACB system: the capital costs, the energy consumption, operation and maintenance of the mechanical systems for total life costs over 25 years. The analysis leads to the following conclusions.

The energy consumption and asset replacement have most important cost in economic life of HVAC system. Those are 7 to 8 time of capital cost. The energy consumption is lower for VRF systems. The capital cost of VAV and ACB system is higher than VRF and FC systems, but the energy consumption, asset replacement and maintenance cost for economic life (25 years) it is cheaper for ACB system. The asset replacement cost is higher for VRF systems.For economic life of 25 years, in total cost of the VRF system is the highest.

This study confirms what preceding research has shown, i.e. that for economic life of 25 years, in total cost, the cheapest system and the best solution for application in TID tower is ABC system. This is particularly true for building with high thermal mass and low cooling capacity load.

References

[1] VAV Reheat Versus Active Chilled Beams & DOAS- By Jeff Stein, P.E., Member ASHRAE; and Steven T. Taylor, P.E., Fellow ASHRAE, May 2013
[2] Understanding Chilled Beam and VAV Systems- John Murphy, LEED® AP BD+C, Trane, 2010
[3] Modern chilled beam technology, Mikhail Surudo, 2011
[4] VRF Life Cycle Cost Analysis, Brian Thornton P.E., PNNL-2011
[5] Virta M. et al. 2004. “Chilled Beam Application Guidebook.” Brussels: REHVA Guidebook
[6] Chilled Beams & Pinnacle Application Guide, A Fläkt Woods Company- 2009

[7] An Introduction to Chilled Beams and Ceilings, CBCA-2012
[8] Design Considerations For Active Chilled Beams, Darren Alexander, P.Eng.; and Mike O'Rourke, ASHRAE Journal, September 2008
[9] CIBSE Guide M: Maintenance Engineering and Management, The Chartered Institution of Building-Services Engineers, 2008
[10] System data base of Twin Tower Tirana, 2005-2013-ProfesionKlima.sh.p.k.
[11] Hourly Analysis Program HAP v 4.80i- Carrier software.
[12] Fuller, S. K., & Petersen, S. R. (1996). Life-cycle Costing Manual for the Federal Energy Management Program.
[13] Fuller, S. (2013). Life-Cycle Cost Analysis (LCCA), 1–7. Federal Energy Management Program, Dept. of Energy. Washington.
[14] ANSI/ASHRAE Standard 62.1-2010, Ventilation for Acceptable Indoor Air Qual-ity, ASHRAE, Atlanta, 2010.
[15] Energy Design Resources, Advanced Variable Air Volume System Design Guide,2