*International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-8, August 2016*
***ISSN: 2395-3470***
***www.ijseas.com***

# A study on Optimization Modeling and Simulation in HVAC system - A Global Approach

**- Dr. Jen Jacob**
MEP Manager, Sinohydro Group Limited, Qatar.

## Abstract

Today, modeling and simulation are well-known techniques for resolving design concerns in numerous engineering and other disciplines. Extensive range of tools is available in field of design, analysis, and optimization of system performance. Design, test, operation, optimization and management of HVAC systems depend gradually on modeling and simulation techniques. Such techniques collectively with model-based analysis of HVAC systems afford an important tool smoothing the progress of the users to carry out thorough tests of the systems by following their performance. Similarly, abundant optimization programs are also being practiced in HVAC design problems. This paper deals with a brief study on optimization and control of HVAC system.

**Keywords:** HVAC system, Optimization, Simulation

## I. Introduction:

Modeling of HVAC systems is swiftly gaining more attention for system presentation assessment. Especially, at the intangible design stage, that often requires appraising various system substitutions to make a decision for the best system configuration. Modeling and simulation tools for HVAC system design and analysis might be categorized with respect to the tribulations they are meant to deal with it. For an example, tools for pipe/duct design, equipment sizing and range, energy performance analysis, system optimization, and control analysis and optimization. Every tool has its own boundaries and could only be functional for a certain range of applications. Therefore, accessible tools are not completely appropriate for modeling and simulation of all pertinent aspects and potential design analyses. In common, HVAC modeling approaches can be classified into three classes as, modeling approaches for HVAC components, modeling approaches for HVAC control and modeling approaches for HVAC systems. Dissimilar HVAC system modeling draws near requisites diverse levels of user skills, modeling resolutions, and user customization capabilities. To unravel dissimilar models, simulation tools have also been seen as hopeful solutions for launching the baseline presentation calculation which can be used during preliminary design stages of HVAC systems. Elucidation techniques for HVAC system simulation model can also be classified as simultaneous modular solution, self-governing modular solution, and equation-based solution using manipulation [1]. However, HVAC modeling and simulation is comparatively complex from a user and developer point of view. For a user, the complications cultivate with the stage of explicitness due to escalating prerequisite of user acquaintance of HVAC system and the number of system definition parameters. But the ease of use of data pertaining to those parameters from manufacturer is diminishing and analyses have become more complex. Similarly, the complexities increase with the explicitness and detail for a developer. This is due to the communications among the components of the HVAC system or HVAC system with the building. It is imperative that when system simulation is used for building performance assessment, the building features in terms of load demands and climate surroundings should be taken into account by modeling the by and large system using an integrated approach [2].

## II. Literature Review

Regardless of of numerous enhancements in HVAC system modeling and simulation tools/approaches, researchers consider that an assortment of work is still to be finished. New-fangled modeling techniques are being initiated facilitating salvage of component models and synchronized coupling of programs at run-time level. In the modern years, a mixture of modeling and simulation approaches have been comprehensively used in dissimilar research activities for HVAC system routine analyses. Numerous studies were connected to HVAC modeling at component, control, and system levels. At component level, models of air and water cooled chillers were developed to analyze their feat with various control strategies [3] [4]. Likewise, simplified models of cooling coil unit [5] and cooling tower [6] were developed for control and optimization of HVAC systems. In another study, component models of axial fan, air filter, and duct for a ventilation unit were urbanized to analyze the performance of the constant airflow control scheme [7]. At system level, a collective building-HVAC system model was accessible including models of building zone and HVAC equipment. The model was urbanized in Engineering Equation Solver (EES) and showed its effectiveness for the energy audit of commercial buildings [8].

Modeling and simulation approaches are also fairly encouraging for performance analyses of innovative and substitution HVAC systems employing low grade energy which includes solar air conditioning and desiccant cooling systems as shown in Fig.1. Desiccant wheel is the input component of desiccant cooling systems. Consequently, numerous desiccant wheel models were urbanized for presentation evaluation of desiccant and solar cooling systems. A desiccant wheel psychometric model was urbanized to forecast the presentation of three types of desiccant wheels manufactured by means of different kind of solid desiccants [9]. The modeling solutions were used to expand uncomplicated correlations for the outlet air conditions as a function of actually measureable input variables [10]. In an added study, simulation models of hybrid HVAC system were accessible combining conservative vapor compression system and desiccant cooling system. The models were used to evaluate the electricity reduction potential of hybrid system [11].

## III. HVAC design optimization

Optimization techniques have been expansively deliberated and experienced on HVAC design tribulations. The regular simulation-based optimization, especially at HVAC system configuration level is a novel concept. HVAC design optimization tribulations can be classified into two types. The first type is optimization of stationary design parameters and the second type is optimization of the dynamic input variables, which typically encompass control scheduling and set points. The stationary variables are generally system design parameters that are unchanging in each simulation. Design of building envelopes HVAC system and components, ductwork and hydraulic systems, lighting is included in such type of problems [12] .

HVAC model-based optimization approach is widely studied during the preceding decade. An optimization of thermal performance of a building with ground source heat pump system was achieved to reduce building heating and cooling energy costs [13].

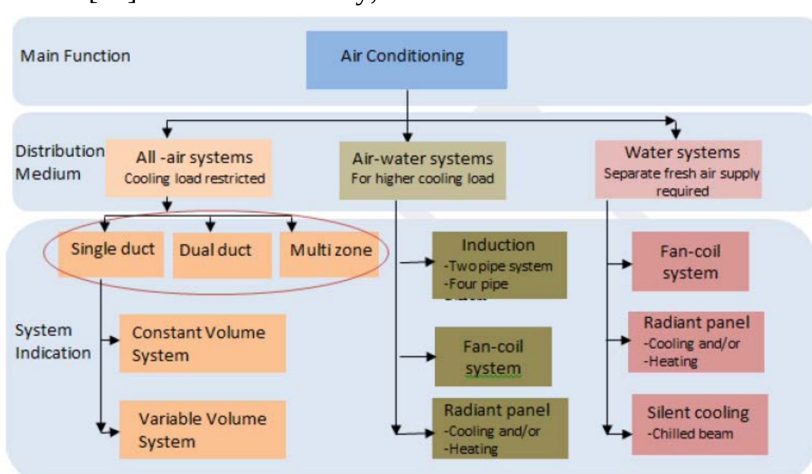


Fig.1 Generic Classification of Centralized HVAC Air-conditioning system

The urbanized models of cooling coil unit and cooling tower were also used for real time control and optimization of HVAC systems [6] [7]. Similarly, worldwide optimization of overall HVAC systems was performed using developed component models [14]. An additional optimization study was performed for optimal water-cooled chiller and cooling tower combination. Cooling tower approach and design wet bulb was determined as key parameters along with condenser water flow rate for optimal performance and to improve system life cycle costs [15]. Optimization research activities were primarily focused to the second type of optimization connecting optimization of HVAC control strategies. Dissimilar tools and strategies were pioneered for control optimization. For instance, in a study, optimization of chiller water condenser-pump system was performed in two steps. In the first step design conditions were optimized and in second stage control logic was optimized to take full benefit of equipment in the chiller system. It was shown that 5% to 8% improvements can be obtained by switching the basic controls to advance controls [16]. A tool called QuickControl was applied to perform the complex control simulations and 60% savings were predicted [17]. In toting up, an incorporated dynamic HVAC simulation process was proved as a viable practice for control optimization to progress the thermal management of buildings through resourceful system control [18]. In another study, a parametric analysis technique was presented to optimize the control sequence of chilled water plant. Theoretical Optimum Plant Performance model was applied to find the optimal control [19]. Similarly, a load-based speed control was introduced for the cooling tower fans and condenser water pumps to attain optimal system performance. The control strategy resulted in about 5.3% savings of annual system electricity use and 4.9% of operating cost [4]. Genetic algorithms (GA) are also broadly used in simulation-based optimization techniques for HVAC systems. A wide-ranging review of basics of GAs and their applications for optimization of design and control of HVAC system is presented [20]. GA was developed to optimize building envelope and HVAC system parameters. The aim was minimization of life cycle cost of a detached house [21]. Similarly, a district cooling system was optimized using GA. The case studies showed that the method was effective to give optimal or near-optimal solutions [22].

## IV. Modeling and simulation of HVAC system configurations

Optimizing HVAC system configuration is always an attention of system designers. Nevertheless, the configuration crisis for HVAC system design is a multi-level problem that includes both structural and design parameters. Selection of optimal configuration of HVAC systems, especially in routine way, is seldom studied. The task is reasonably complex in terms of time and effort because it requires evaluation of different system alternatives at the initial design stage. The promising modeling, simulation and optimization techniques could help to handle the task.

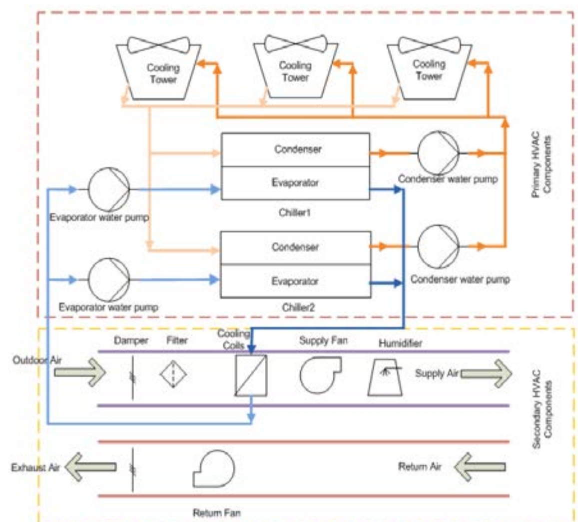


Fig. 2 Primary and secondary HVAC system components

Major and secondary HVAC system components (as shown in Fig.2) in a study, a simplified model were developed for evaluating chiller system configurations. A multiple chiller system consisted of two-ten equally sized chillers was analyzed. It was fulfilled that the energy efficiency of multiple-chiller system increases with a higher number of chillers, and the maximum saving was estimated to be 9.5% [23]. Four design options in terms of the number and size of chiller were assessed. The valuation showed that electricity savings of 10.1% can be achieved with six chillers of different sizes instead of four equally sized chillers [24].

In another study, four configurations for the heating system with a heat pump, condensing boiler, conventional boiler, and solar collector were analyzed. Solar collector-based heating system showed highest energy performance for the considered case study [25]. An optimization of solar cooling system was performed considering three different configurations in terms of number of heat pumps with different cooling powers [26]. Similarly, three different configurations of solar heating and cooling system with LiBr-H2O absorption chiller and evacuated tube collector were examined. The first configuration was designed for the maximum cooling load using an electric chiller as supplementary cooling system. The simulation model was urbanized for the detailed optimization of their energy performance. The results of the optimization suggested that the first configuration was able to achieve the best energy performance [27].

## V. Optimization of HVAC system configurations

In general, optimization is concerned with the minimization or maximization of the objective function(s) depending on what someone is looking for. However, normally optimization problems are defined as minimization and if a criterion is subjected to maximization, then the negation of the objective function is minimized. In optimization problems, the building simulation programs are increasingly being used to evaluate the objective function.

The current study is based on the minimization‘of the objective function in which the Dymola/Modelica overall HVAC system model is coupled with optimization program, GenOpt by using an appropriate optimization algorithm. Such an interaction provides automatic selection of optimal configuration. However, it requires suitable selection of optimization algorithm along with optimization variables in terms of system design and configuration parameters.

## VI. Optimization algorithms

A wide range of optimization algorithms is used in various HVAC optimization problems. However, decision about the selection of a suitable algorithm is vital for optimization of HVAC configurations. Generally, optimization algorithms can be categorized into two basic classes: deterministic and probabilistic algorithms. In deterministic algorithm, after each execution step, at most one way exits to proceed. The algorithm is completed if no way exists to proceed. Such algorithms do not contain instructions that use random numbers to decide what to do or how to alter data. In addition, deterministic algorithms are most often used if a clear relation exists between the characteristics of the probable solutions and their utility for a given problem. However, if the relation between a solution and its fitness is not so apparent or too complex or the dimensionality of search space is very high, then it becomes difficult to solve a problem deterministically. Therefore, Probabilistic algorithms are used to handle such problem. Most of the optimization research activities in various fields are implementing probabilistic algorithms mainly; the probabilistic algorithms are based on the Monte Carlo approaches that comprise numerous algorithms, such as Hill Climbing, Simulated Annealing, Evolutionary algorithms, etc. [28]. Generally, building simulation programs comprise code features, such as adaptive integration meshes, iterative solvers, and if-then-else logic. The feature can cause the failure of optimization algorithm that requires velvetiness of the objective function. However, if such simulation programs are used in conjunction with the optimization algorithms then tolerances of the adaptive solvers must be tight. Though, it is observed that in many building simulation programs the solver tolerances are so coarse that such algorithms can indeed fail far from minimum. Therefore, probabilistic optimization algorithms modeling and simulations (as shown in Fig.3) that do not require smoothness are frequently used to solve building optimization problems with small number of simulations [29]. Though, it is also to remember that no general optimization algorithm performs the best for all application and in addition no optimization

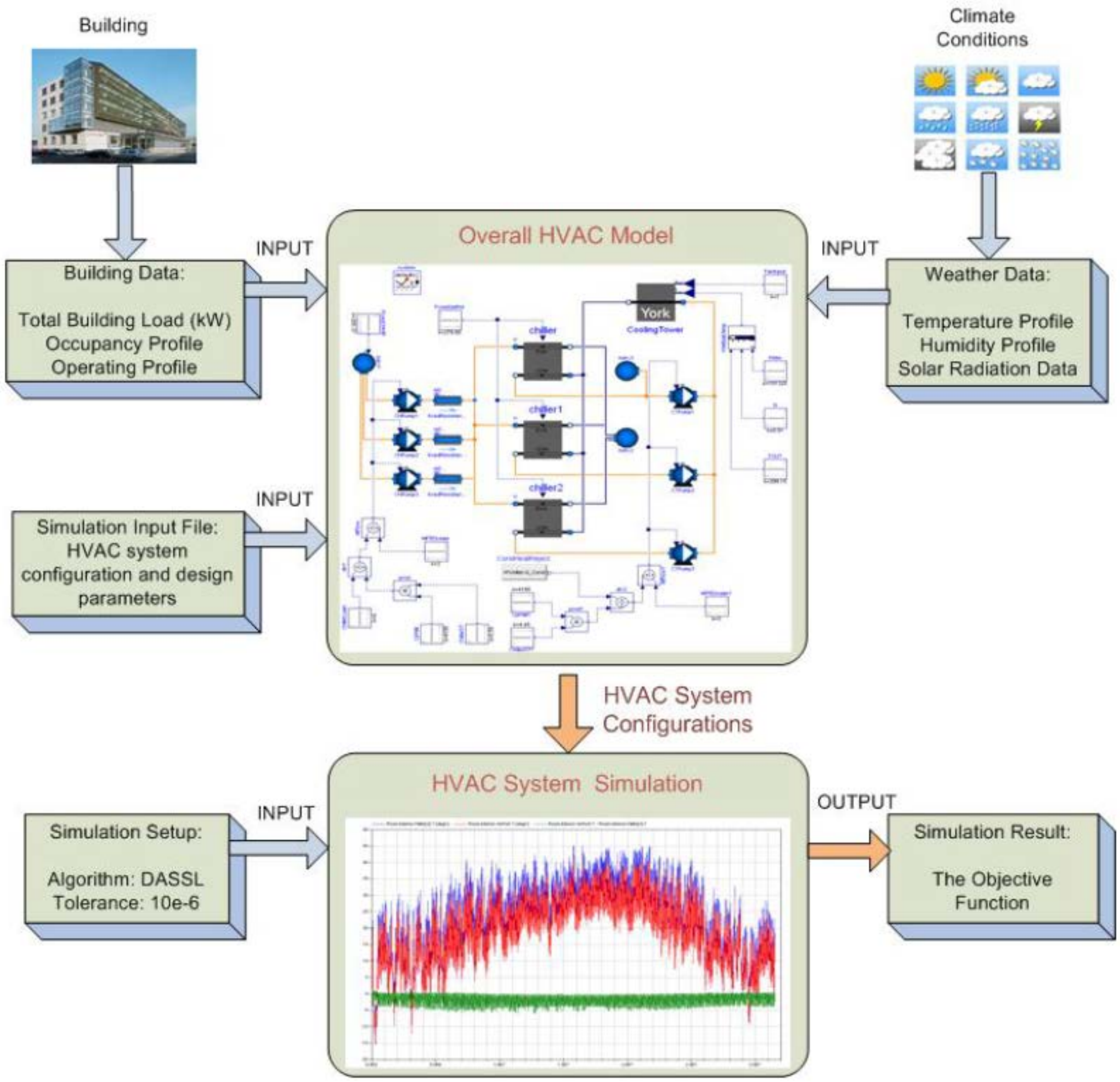


Fig.3 Modeling and simulations of HVAC optimization and system configuration

algorithm can guarantee finding the global minimum if local minima exits. In addition, the selection of a suitable algorithm for a particular application depends on a variety of factors, like structure of the objective function, availability of analytic first and second derivatives, number of self-determining parameters, and problem constraints. GenOpt is used in the current study for the optimization of HVAC system configurations. GenOpt optimization library consists of local and global one dimensional and multi-dimensional algorithms, as well as algorithms for parametric runs. Several optimization algorithms can be applied in GenOpt that include Generalized Pattern Search algorithms (GPS), Particle Swarm Optimization algorithms (PSO), Discrete Armijo Gradient algorithm, etc. Moreover, a hybrid global optimization algorithm can also be used in which PSO performs the global optimization and HookeJeeves achieves the local optimization. Beside existing algorithms, GenOpt superclass optimizer'can be extended to apply users defined optimization algorithms [30]. While the selection of a suitable optimization is based on the form of optimization variables involved in the study.

## VII. Results and Discussions:

It can be concluded from the literature review that several modeling and simulation tools based on various approaches are occupied for performance analyses of the HVAC systems. Available tools and approaches have their own prospects and constraints. Procedural modeling environment is mostly used in various studies. Equation-based object-oriented is an emerging modeling and simulation approach. Only few studies have utilized the approach for HVAC system simulation and optimization.

However optimization of HVAC system configurations has not yet been achieved. Therefore, there is need to apply the equation-based object-oriented approach because it offers significant benefits in terms of model development time, model reuse, and hierarchical model construction while handling the complexity of large systems. The model development duration often governs the time that is eventually spent for conducting numerical experiments. It can be noticed that most of the HVAC systems optimization studies were focused towards control strategies or optimization of a specific system or a component. Optimization algorithms, mostly genetic algorithms, were extensively used.

Only few research activities were related to the optimization of HVAC system configurations. Therefore, it is important to further investigate the optimization of HVAC system configurations, especially at the initial design stage.The main focus of the current research is to develop a systematic approach for automated optimal selection of HVAC system configuration. Here equation-based object-oriented modeling and simulation approach is used to further explore its prospects in the analyses of HVAC system configurations. This work also focuses on the coupling between simulation and optimization tools for automatic selection of optimal HVAC system configuration.

## References

[1] M. Trcka and J.L.M. Hensen, "Overview of HVAC system simulation," Automation in Construction, vol. 19, no. 2, pp. 93-99, 2010.
[2] Ir Jan Hensen, "Application of Modeling and Simulation to HVAC Systems," , 1996.
[3] FW Yu and KT Chan, "Modelling of a condenser-fan control for an air-cooled centrifugal chiller," Applied Energy, vol. 84, no. 11, pp. 1117-1135, 2007.
[4] FW Yu and KT Chan, "Optimization of water-cooled chiller system with loadbased speed control," Applied Energy, vol. 85, no. 10, pp. 931-950, 2008.
[5] Y.W. Wang et al., "A simplified modeling of cooling coils for control and optimization of HVAC systems," Energy conversion and management, vol. 45, no. 18, pp. 2915-2930, 2004.
[6] G.Y. Jin, W.J. Cai, L. Lu, E.L. Lee, and A. Chiang, "A simplified modeling of mechanical cooling tower for control and optimization of HVAC systems," Energy conversion and management, vol. 48, no. 2, pp. 355-365, 2007.
[7] Z. Wu, R.V.N. Melnik, and F. Borup, "Model-based analysis and simulation of airflow control systems of ventilation units in building environments," Building and environment, vol. 42, no. 1, pp. 203-217, 2007.
[8] S. Bertagnolio, G. Masy, P. Andre, and J. Lebrun, "Building and HVAC System simulation with the help of an engineering equation solver," , 2008.
[9] M. Beccali, F. Butera, R. Guanella, and RS Adhikari, "Simplified models for the performance evaluation of desiccant wheel dehumidification," International journal of energy research, vol. 27, no. 1, pp. 17-29, 2003.
[10] Fatemeh Esfandiari Nia, Dolf Van Paassen, and Mohamad Hassan Saidi, "Modeling and simulation of desiccant wheel for air conditioning," Energy and buildings, vol. 38, no. 10, pp. 1230-1239, 2006.
[11] K. Haddad, B. Ouazia, H. Barhoun, and others, "Simulation of a desiccantevaporative cooling system for residential buildings," , 2008.
[12] Yi Zhang, "Synthesis of Optimum HVAC System Configurations by Evolutionary Algorithm," Loughborough University , United Kingdom, Ph.D. dissertation 2005.
[13] O. Zogou and A. Stamatelos, "Optimization of thermal performance of a building with ground source heat pump system," Energy conversion and management, vol. 48, no. 11, pp. 2853-2863, 2007.

[14] L. Lu, W. Cai, Y.S. Chai, and L. Xie, "Global optimization for overall HVAC systems----Part I problem formulation and analysis," Energy conversion and management, vol. 46, no. 7, pp. 999-1014, 2005.
[15] James W Furlong and Frank T Morrison, "Optimization of water-cooled chillercooling tower combinations," CTI JOURNAL, vol. 26, no. 2, p. 14, 2005.
[16] Hoge Crowther, "Optimizing Chillers and Towers," ASHRAE Journal, pp. 3438, 2004.
[17] EH Mathews, CP Botha, DC Arndt, and A. Malan, "HVAC control strategies to enhance comfort and minimise energy usage," Energy and buildings, vol. 33, no. 8, pp. 853-863, 2001.
[18] EH Mathews and CP Botha, "Improved thermal building management with the aid of integrated dynamic HVAC simulation," Building and environment, vol. 38, no. 12, pp. 1423-1429, 2003.
[19] M. Hydeman and G. Zhou, "Optimizing chilled water plant control," ASHRAE Journal, vol. 49, no. 6, pp. 44-55, 2007.
[20] L.G. Caldas and L.K. Norford, "Genetic algorithms for optimization of building envelopes and the design and control of HVAC systems," Journal of solar energy engineering, vol. 125, p. 343, 2003.
[21] M. Palonen, A. Hasan, and K. Siren, "A genetic algorithm for optimization of building envelope and HVAC system parameters," Proc. IBPSA'09, 2009.
[22] TT Chow, A.L.S. Chan, and CL Song, "Building-mix optimization in district cooling system implementation," Applied energy, vol. 77, no. 1, pp. 1-13, 2004.
[23] WL Lee and SH Lee, "Developing a simplified model for evaluating chillersystem configurations," Applied energy, vol. 84, no. 3, pp. 290-306, 2007.
[24] FW Yu and KT Chan, "Strategy for designing more energy efficient chiller plants serving air-conditioned buildings," Building and environment, vol. 42, no. 10, pp. 3737-3746, 2007.
[25] M.T. Balta, I. Dincer, and A. Hepbasli, "Performance and sustainability assessment of energy options for building HVAC applications," Energy and Buildings, vol. 42, no. 8, pp. 1320-1328, 2010.
[26] C. Sanjuan, S. Soutullo, and MR Heras, "Optimization of a solar cooling system with interior energy storage," Solar Energy, vol. 84, no. 7, pp. 1244-1254, 2010.
[27] F. Calise, M. Dentice d'Accadia, and A. Palombo, "Transient analysis and energy optimization of solar heating and cooling systems in various configurations," Solar Energy, vol. 84, no. 3, pp. 432-449, 2010.
[28] Thomas Weise, Global Optimization Algorithms- Theory and Applications., 2009.
[29] M. Wetter and J. Wright, "A comparison of deterministic and probabilistic optimization algorithms for nonsmooth simulation-based optimization," Building and Environment, vol. 39, no. 8, pp. 989-999, 2004.
[30] M. Wetter, "Generic Optimization Program User Manual Version 3.0. 0," 2009.

**Author**

Dr. Jen Jacob is a United Kingdom registered (licensed) MEP Chartered Engineer and he has gained professional competencies through training and monitored professional practice experience. He is also fulfilled the MEP requirement established by the United States of America, international commission. Consequently International accreditation Organization USA has accredited as a MEP Certificate Engineer for the MEP engineering works. He is specialized in different kind of Infra & Building service MEP system through multinational projects, such as Lusail Infrastructure project - Qatar, Hamad international Airport - Qatar, Durrat Al Bahrain Project – Bahrain,also worked with many of presumed MEP projects such as, commercial projects, large type of hospitals, large type of warehouses, High rise towers, Group of villas in one compound, etc.