RIVERS STATE UNIVERSITY, PORT HARCOURT

THERMO-FLUID SYSTEMS AS DYNAMIC ELEMENTS IN STATIC STRUCTURES

AN INAUGURAL LECTURE

By

PROF. JOHN IRISOWENGIBIA SODIKI

B.Sc. (Hons), M.Sc., Ph.D, MNSE, MNIM, MACEN

Professor of Thermo-Fluids and Building Services Engineering

SERIES NO. 73

Wednesday, 26th January 2022

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The Vice-Chancellor

Deputy Vice-Chancellors

Registrar and other Principal Officers

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Directors of Institutes and Heads of Departments

Distinguished Professors and Emeritus Scholars

Staff and Students of Rivers State University

Distinguished Ladies and Gentlemen

PREAMBLE

God arranged four specific circumstances in my favour to enable me reach this height. Firstly, having done very well in the science subjects at secondary school; finishing with the highest possible grade A1 in the three subjects, mathematics, physics and chemistry; I was most inclined to making a choice of profession in Engineering. Secondly, even as young students, we had the understanding that Mechanical Engineering was the bedrock of most other engineering disciplines; hence my choice of this option at the university.

Thirdly, my first involvement in teaching came during the interregnum between my finishing the Advanced Levels at the then College of Science and Technology in December 1976 and my going to University of Lagos in /October 1977. I was engaged as an Auxilliary Teacher by the Rivers State Government and posted to Nyemoni Grammer School, Abonema where I taught Additional Mathematics (now Further Mathematics) and Physics.

Fourthly, my choice of Thermo-Fluids Engineering as a specialization was informed by my employment, following the N.Y.S.C. scheme, at the Central Engineering Workshop of Michelin Nig. Ltd, where we maintained the factory's utility services (i.e. the building services) of the central boiler, water supply and their distribution systems, cooling tower; as well as various air conditioning and ventilation systems.

As cited by Oguara (2001) in the 6th inaugural lecture of this university, Ogunye (1981) in his inaugural lecture at University of Lagos identified three possible forms of inaugural lecture:

1. To concentrate on the development of the department, if the lecturer is the occupant of an endowed chair attached to the department.
2. Be focused on the professor's own work within the general framework of his discipline.
3. Be on any general topic where the professor considers that he has something fresh and stimulating to tell his audience.

Vice Chancellor Sir, my lecture today will be more of form No. 2 above, with introductory concepts of the disciplines of my research interest (namely Thermo-Fluids and Building Services Engineering) and their inter-relationship.

1.0 INTRODUCTION

1.1 Definition

Thermo-Fluids (also known as Thermal-Fluids) Engineering is the combined study of heat transfer, mass transfer, fluid mechanics, thermodynamics and combustion; together with all the other relevant subjects that complete the engineering programme.

1.2 God's Creation in Thermo-Fluids

The Almighty God, the Great Engineer of the universe has created systems for us mortals, to protect, harness, utilize and learn from. In the human body, for instance, He created thermo-fluid systems which regulate body processes like blood circulation in veins and arteries (which form a pipe network) effected by the heart (which is a pump — a fluid machine).

Also, by a balance of the energy produced by metabolism (i.e. food oxidation), body work, respiration and evaporation heat loss from the body, as well as conduction, convection and radiation heat exchange with the surroundings, and some energy storage in the body, the body temperature is maintained at about 37^{o}C which is the ideal value for physiological processes. Other body thermo-fluid systems include urine plumbing and ventilation (i.e. breathing) via the lungs.

In all, God had created thermo-fluid and other engineering systems for our bodies to function continuously (without rest) for our entire lifetime which, in some well managed life-styles and circumstances, can be over one hundred (100) years. No such man-made systems exit, and so GLORY BE TO THE ALMIGHTY.

He had also created the ecosystem perfectly. In the thermo-fluids sector, he had made the rivers, the winds, the deep-sea temperature differentials, and the sun, which we harness to obtain hydro, wind, geo-thermal and solar energy sources, respectively. These energy forms are those referred to as renewable, as they are inexhaustible. They are also non-polluting to the environment. God has endowed us with these renewable energy forms and the non-renewable ones, such as the carbon-based fuels. We should be thankful to the Almighty. Human activities, however, oftentimes tend to destroy the ecosystem in the process of harnessing and utilizing these resources; with attendant issues such as the much-talked-about ozone layer depletion (with the associated global warming, sea level rise, etc.), acid rains and waste generation.

1.3 Applications of Thermo-Fluids Engineering

The applications of Thermo-Fluids Engineering range from efficient engine and power plant design to refrigeration, heating, ventilation and air conditioning (HVAC) to pipelines and renewable energy systems. Engineers in this field are found well prepared for challenges in a wide variety of industries such as aerospace, marine, automobile, manufacturing, oil and gas, power generation and construction (especially in building services). The subject areas of Thermo-Fluids Engineering also provide the foundation for analyses of such phenomena as blood flow in our veins, to ocean currents and atmospheric turbulence, to mention a few applications.

2.0 THE CONCEPTS IN THERMO-FLUIDS AND BUILDING SERVICES ENGINEERING

2.1 Thermo-fluids Subject Areas

Vice Chancellor Sir, a brief outline of these subjects is presented.

The fewer mathematical expressions stated here are not intended to adequately represent the gamut of expressions usually encountered in the subjects. They only serve to remind us that we are in attendance of an Inaugural Lecture in engineering.

2.1.1 Engineering Thermodynamics:

In lay terms, Engineering Thermodynamics is the branch of physics that examines the interaction of temperature, pressure and volume within a system to convert heat to work and vice-versa. This subject has three main purposes, namely to work out the flow of energy from one system to another, to determine the transformation of energy from one form to another, and to ascertain the utilization of energy for useful mechanical work (Hart, 2005). Its study is governed by some universal rules, the implications of which reach beyond engineering and even as far as philosophy. The first rule states that energy and matter cannot be created or destroyed; they can only be converted from one form to another. The second law states that all machines will lose energy from input to output (i.e. they have imperfect efficiency); and defines a system property called entropy.

In the study of Engineering Thermodynamics the simplest of the many variables which are usually analysed to provide tangible results are P, V, T, U, H, S, A, F and G defined, respectively, as pressure, volume, temperature, internal energy, enthalpy, entropy, availability function (sometimes called exergy), Helmholtz function and Gibbs function. For instance, the relationship between heat input Q and work output W of a system undergoing a non-flow process is given as (Rogers & Mayhew, 1980)

$$Q - W = U_2 - U_1 \qquad (1)$$

where 1 and 2 respectively denote initial and final states of the system; while for a flow process it is

$$Q - W = (H_2 - H_1) + \frac{1}{2} m\left(C_2^2 - C_1^2\right) + mg\left(Z_2 - Z_1\right) \qquad (2)$$

where, in the usual notation, the first term on the right is the enthalpy difference. The second term is the kinetic energy difference and the third term is the potential energy difference, between the two states.

Also,

$$\int_1^2 \left(\frac{dQ}{T}\right) = S_2 - S_1 = dS \quad \text{(Rogers \& Mayhew, 1980)} \qquad (3)$$

and dS = 0 for a reversible process, greater than zero for an irreversible process, and less than zero for an impossible one.

Furthermore, the non-flow availability function is given as (Rogers & Mayhew, 1980)

$$A = (U + \rho_o V - T_o S) - (U_o + p_o V_o - T_o S_o), \qquad (4)$$

while for steady flow, it is

$$A = (H - T_o S) - (H_o - T_o S_o) \qquad (5)$$

F and G are defined respectively as

$$F = U - TS \quad (6)$$

and

$$G = H - TS \quad (7)$$

2.1.2 Heat Transfer:

This subject is concerned with the exchange of heat between physical systems. It involves several mechanisms, such as conduction, convection, radiation, and the transfer of energy by phase changes. It always occurs from a region of high temperature to another region of lower temperature. Heat conduction, or diffusion, is the direct microscopic exchange of kinetic energy of particles through a system or across the boundary between two systems. Heat convection occurs when the bulk flow of a fluid carries heat long with fluid flow. The flow of fluid may be forced by external processes (forced convection), or sometimes by buoyancy forces caused when thermal energy expands the fluid (natural convection). An example of the latter process is a fire plume. Thermal radiation is the transfer of energy by means of photons in electromagnetic waves. Radiation heat transfer can occur in any transparent medium (solid or fluid) or through a vacuum. Even though these mechanisms have distinct characteristics, in practice they often occur together in systems.

The theory of conduction is founded on Fourier's Law which states that the rate of heat transfer per unit area across an area is proportional to the temperature gradient normal to the area.

i.e. $$\frac{Q}{A_x} \propto \frac{dT}{dx} \quad \text{or} \quad \frac{Q}{A_x} = -k\frac{dT}{dx} \quad (8)$$

in the usual notation, while the governing law for convection is Newton's Law of cooling of a solid surface in the usual notation.

$$Q = h\ A(T_w - T_\infty) \qquad (9)$$

The basic law of radiation heat exchange is Steffan-Boltzmann's law which states that the rate of energy emission by a 'black' body Q_e is proportional to the surface area A of the body and the 4th power of the temperature of the body.

$$Q_e \propto AT^4 \quad \text{or} \quad Q_e = \sigma AT^4 \qquad (10)$$

where σ = Steffan-Boltzmann constant
($5.669 \times 10^{-8} W/m^2K^4$)

2.1.3 Fluid Mechanics:

This studies fluids (liquids, gases and plasmas) and the forces on them, from the micron scale up to planetary scales. Fluid mechanics can be divided into fluid statics, the study of fluids at rest; fluid kinematics, the study of fluids in motion; and fluid dynamics, the study of the effect of forces on fluid motion. Fluid dynamics can be mathematically complex and is an active field of research with many unsolved or partly solved problems. Advances in computational science have facilitated effective implementation of numerical methods in this field; resulting in a modern discipline called computational fluid dynamics (CFD).

The properties commonly utilized in the study of Fluid Mechanics are density, viscosity, surface tension, pressure, compressibility, bulk modulus of elasticity and the specific heats. In the study of fluid statics considerations are given to pressure variations with height of fluid columns and static forces acting on surfaces, as in buoyancy forces acting on floating and submerged bodies.

Basic fluid dynamics studies consider uniform and non-uniform flows; steady, unsteady and quasi-steady flows; compressible and incompressible flows; one-, two-, and three-dimensional flows; rotational and irrotational flows; potential flows; source and sink flows; radial flow and vortex motion; and laminar and turbulent flows; considering such equations as the Colebrooke -White equation, namely (Douglas et al, 1995)

$$\frac{1}{\sqrt{f}} = -4\log\left(\frac{1.26}{\mathrm{Re}\sqrt{f}} + \frac{\varepsilon}{3.71d}\right) \qquad (11)$$

which is commonly translated into a graphical form, the so-called Moody Chart.

The boundary layer theory and pressure transcience analysis are also areas of interest in fluid flow studies.

Fluid dynamics forms the basis for the design of fluid machinery, such as rotodynamic and positive displacement compressors, pumps, fans, turbines and expanders.

2.1.4 The General Conservation Equations

In the study of heat transfer and fluid mechanics some basic principles that apply to a wide range of problems are those of conservation of mass, momentum and energy. It is usual to formulate governing equations based on these principles, and for a specific problem the engineer only needs to delete terms that are zero or negligible. These conservation equations in the Cartesian coordinate system are as follows, in the usual notation (Mills, 1998)

For mass

$$\frac{\partial\rho}{\partial t}+u\frac{\partial\rho}{\partial x}+v\frac{\partial\rho}{\partial y}+w\frac{\partial\rho}{\partial z} = -\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right) \qquad (12)$$

or

$$\frac{D\rho}{Dt} = -\rho\nabla\cdot v \qquad (13)$$

The operator *D/Dt* is called the substantial derivative and is the time derivative for an observer moving with the fluid.

For momentum (in a Newtonian incompressible fluid):

$$\left.\begin{aligned}
\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right) &= -\frac{\partial \mathrm{P}}{\partial \mathrm{x}}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho g_x\\
\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right) &= -\frac{\partial \mathrm{P}}{\partial \mathrm{y}}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho g_y\\
\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right) &= -\frac{\partial \mathrm{P}}{\partial \mathrm{z}}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\rho g
\end{aligned}\right\} \qquad (14)$$

These equations can be written in the compact form

$$\rho \frac{Dv}{Dt} = -\nabla P + \mu \nabla^2 v + \rho g \qquad (15)$$

These equations are often called the **Navier-Stokes Equations**.

For energy:

$$\rho \frac{Dh}{Dt} = \frac{Dp}{Dt} + \nabla \cdot k \nabla T + \mu \Phi + Q_v''' \qquad (16)$$

where Φ is a heat dissipation function, Q_v''' is a volumetric heat source term, and other variables have their usual notations.

2.1.5 Mass Transfer:

This subject is concerned with the net movement of mass (usually, meaning stream, phase, fraction or component) from one location to another; as a result of a difference in concentration of species. Thus, in the same way as heat transfer takes place due to a temperature gradient, so also mass transfer at the molecular level (i.e. diffusion) occurs as a result of a concentration driving force (or gradient). Furthermore, mass convection is essentially identical to heat convection: a fluid flow that transports heat may also transport a chemical species.

The similarity of the mechanisms of heat transfer and mass transfer results in the mathematics often being identical, a fact that can be exploited to advantage. For example, the solution to a problem of diffusion in a solid can often be written down immediately by referring to the analogous heat conduction problem.

However, there are some significant differences between the subjects of heat and mass transfer. Thus, unlike heat transfer at least two media are required for mass transfer to take place. There is a great variety of physical and chemical processes that require mass transfer analysis.

Some examples are the evaporation of water from a pond to the atmosphere, the purification of blood in the kidneys and liver, and the distillation of alcohol. In industrial processes, mass transfer operations include separation of chemical components in distillation columns, absorbers such as scrubbers or stripping, adsorbers such as activated carbon beds, and liquid-liquid extraction. Mass transfer is often coupled to additional transport processes, for instance in industrial cooling towers. These towers couple heat transfer to mass transfer by allowing hot water to flow in contact with air. The water is cooled by expelling some of its content in the form of water vapour.

The study of mass transfer is facilitated by basic theories such as Fick's Law of Diffusion for binary systems (Fick's first law) which relates to steady diffusion, namely (Mills, 1998)

$$j_1 = -\rho D_{12} \nabla m_1 \tag{17}$$

where j_1 [kg/m^{2}s] is the diffusive mass flux of species 1, ρ is the local mixture or solution density [kg/m^3], [m^2/s] m_1 is the mass fraction of species 1 and D_{12} [m^2/s] is the binary diffusion coefficient (sometimes called mass diffusivity). The equivalent molar form of the equation is

$$J_1 = -C\,D_{12}\,\nabla x_1 \qquad (18)$$

where J_1 [kmol/m^{2}s] is the diffusive molar flux of species l, C is the total molar concentration of species 1 and x_1 is the mole fraction of species l

For transient diffusion of mass species, Fick's second law of diffusion, namely (Mills, 1998)

$$\frac{\partial m_1}{\partial t} = D_{12}\frac{\partial^2 \mathrm{m}_1}{\partial z^2} \qquad (19)$$

in the usual notation, comes into play.

As in convective heat transfer, convective mass transfer (or mass convection) between a surface and a moving fluid may be forced or natural, internal or external, and laminar or turbulent; and there are good analogies between convective heat and mass transfers which are exploited in solving convection problems.

Simultaneous heat and mass transfer phenomena are common-place such as in wet- and dry-bulb psychrometry where the psychrometric charts widely used by air conditioning engineers are based on wet- and dry-bulb temperatures and the moisture content of the air.

The general conservation concept is also applicable to the subject of mass transfer in the form (in terms of moles) (Mills, 1998)

$$\frac{\partial C_i}{\partial t} + \nabla . N_i = \dot{R}_i''' \qquad (20)$$

where C_i is the molar concentration of species i, N_i is its molar flux and $\dot{R}_i'''$ molar rate of production.

2.1.6 Combustion:

The science of combustion, complex as it is, can be summed up simply as the study of the processes by which fuel is turned into energy through the application of heat. Combustion Engineering concerns the science of combustion as it applies to industry. The applications of combustion engineering range from home heating systems to car engines and power plants to various process and manufacturing industries. Combustion Engineering, among other considerations, utilizes the concepts of fluid flow, heat transfer, mass transfer and aspects of mechanical design of equipment.

The fluid flow, heat transfer, mass transfer equations are usually coupled and solved simultaneously. In diffusion - controlled combustion, for instance, the chemical kinetics are so fast that the mass transfer considerations control the rate of combustion, while heat transfer considerations control the rate at which the heat of combustion can be removed and hence the temperature of combustion controlled. Since the transport properties, such as the diffusion coefficient are temperature-dependent, the equations governing heat and mass transfer must be solved simultaneously. The interesting phenomena of ignition and extinction of combustion result in conflicting requirements of mass transfer, chemical kinetics and heat transfer.

As the global need for energy efficiency intensifies, due to the fact that the world's dependence on fossil fuels for energy cannot continue indefinitely, Combustion Engineering may well be at the forefront of developing new technologies in fuel consumption.

Vice Chancellor Sir, the inaugural lecturer started teaching and research of the mentioned subject areas and related ones, at undergraduate and postgraduate levels, since the year 1987.

2.2 Building Services Engineering

Building services engineers are responsible for the design, installation, and operation and monitoring of the technical services in buildings (including mechanical, electrical and public health systems) in order to ensure their safe, comfortable and environmentally-friendly operation. Building services engineers work closely with other construction professionals such as architects, structural engineers and quantity surveyors. Building services engineers influence the architectural design of buildings, in particular facades, in relation to energy efficiency and indoor environment, and can integrate local energy production (e.g. façade-integrated photovoltaic) with community-scale energy facilities (e.g. district heating, as in temperate environments). Building services engineers therefore play an important role in the design and operation of energy-efficient buildings (including green buildings, passive houses, plus-houses, and zero-energy buildings). With buildings accounting for about a third of all carbon emissions and over a half of the global electricity demand, building services engineers play an important role in the move to a low-carbon society, hence mitigate global warming.

In broad terms, the services in buildings encompass the following (Wikipedia, 2021):

2.1.1 Mechanical services:

- Energy supply – gas, electricity and renewable sources
- Vertical transportation (escalators and lifts)
- Heating, including low – energy (low-temperature) solutions
- Ventilation. This includes clean-room solutions (e.g. hospitals, labs) and industrial ventilation (factory spaces and processes)
- Air conditioning and other applications of refrigeration
- Sprinklers and other fire protection systems
- Irrigation systems
- Swimming pools, decorative pools and fountains
- Compressed air and vacuum air systems
- Gasoline systems
- Vibration isolation

2.2.2 Electrical Services:

- Energy supply - electricity
- Low voltage (LV) systems, distribution boards and switchgear
- Communication lines, telephones and IT networks (ICT)
- Building automation
- Lightning protection

- Fire detection and protection
- Security and alarm systems

2.2.3 Public health services:

- Plumbing solutions for water supply, both potable cold water and DHW (domestic hot water)
- Chilled-drinking water, water treatment as well as distilled water, reverse osmosis water, demineralized water
- Drainage of waste water (sewage) from inside a building and drainage/treatment of external surface runoff around a building. Increasing use of grey-water recycling and solutions to delay runoff (e.g. green roofs and infiltration beds). Radioactive and highly infectious waste-water drainage systems
- Solutions for hygiene and sanitation, including cleaning, indoor air quality, and health technology (e.g. isolation wards)

2.2.4 Others:

- Building-integrated features such as passive cooling
- Natural lighting, artificial lighting and building facades
- Building physics, especially related to heat and moisture transfer, daylighting etc.

The foregoing scope requires that building services engineers typically possess an academic degree in building services engineering, mechanical engineering or electrical engineering. Building services are the dynamic components in a static structure and, in spacial terms, the equivalent of one floor in six (i.e. over 15% of a building's volume) may be attributed to accommodating these services. As a proportion of the capital cost of construction a typical modern office building can require about 50% of the construction budget for its services.

The foregoing scope of building services makes imperative extensions to other built systems than houses, such as to automobile, aerospace and marine systems; and external environmental systems, such as communities and cities.

The two most notable professional bodies in this field are the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) founded in 1894, and the Chartered Institution of Building Services Engineers (CIBSE) which was founded in 1976 and received a Royal Charter in the United Kingdom. As there is not yet such a body in Nigeria, efforts are being put in place to establish one.

3.0 RELATIONSHIP BETWEEN THERMO-FLUIDS AND BUILDING SERVICES ENGINEERING

All the listed mechanical services are premised on the subject areas of Engineering Thermodynamics, Heat Transfer, Fluid Mechanics, Mass Transfer and Combustion; with added other mechanical engineering topics in machine design and mechanical vibrations relevant to such services as escalators and lifts, and vibration isolation.

Also, all the listed public health services are mainly premised on the subject areas of Engineering Thermodynamics, Heat Transfer, Fluid Mechanics and Mass Transfer; with added chemical and environmental engineering topics relevant to such services as water treatment and indoor air quality. Furthermore, the services categorized as **others** are premised in the subjects of Engineering Thermodynamics, Heat Transfer, Fluid Mechanics and Mass Transfer.

Vice Chancellor Sir, the inaugural lecturer has judiciously applied his Thermo-Fluids Engineering background to research in Building Services Engineering.

4. GENERAL ROLES (DUTIES) OF THE ENGINEER (CIBSE, 1995)

The professional roles of the engineer include the following:

4.1 Design

- Design work involving (or outside the scope of) established procedures and use of Engineering Standards and Codes of Practice to a competitive level of cost, safety, quality, reliability and appearance.
- Supervisory and managerial responsibility for an engineering design function or group
- Development of new design methods

4.2 Research and Development

- Evaluation of test results and interpretation of data. Preparing reports and recommendations.
- Managing, planning and execution of research and development effort in engineering resulting in the design, development and manufacture of products, equipment and processes to a competitive level of cost, safety, quality, reliability and appearance.

4.3 Manufacture, installation and construction

- Day-to-day organization and supervision of manufacturing, installation and construction functions from raw material input to finished product.
- The introduction of new and more efficient production techniques and installation and construction concepts.
- Managerial responsibility for a production, installation, construction or dismantling function.

4.4 Operation and maintenance

- Work involving the need to understand and apply analytical and technical skills and judgment and the use of a range of equipment, techniques and methods for measurement, control, operation, fault diagnosis, maintenance and for protection of the environment.
- Determining operation maintenance requirements in terms of tasks to be performed and time intervals between tasks.
- Providing specifications of operational maintainability standards to be achieved in design and production.
- Managerial responsibility for an operation of maintenance function or group

4.5 Health, safety and reliability

- Making the appropriate provision in engineering projects to ensure safety and the required standards of reliability, not only with employees and customers in mind but in the general public interest.
- Supervision and responsibility for health, safety, reliability in situations involving engineering plant, systems, processes or activities

- Accident investigation

4.6 Management and planning

- Short-range planning of engineering activities and functions
- Longer range and strategic planning of engineering activities and functions
- Supervision of engineering staff and resources and the associated legal, financial and economic practice at a level commensurate with the scale of the activity and size of organization within the constraints of the relevant environment
- Pioneering of new engineering services and management methods
- Management of the development and implementation of new technologies with estimation of the cost/benefit of the financial, social and political decisions taken
- Overall company/commercial responsibility as a director with engineering knowledge

4.7 Engineering aspects of marketing

- Preparing cost estimates and proposals
- Sales operations, efficient market coverage
- Market analysis, contract negotiations
- Customer technical advisory service
- Management responsibility for the dissemination of accurate technical information
- Territorial or market planning forecasts and targets

4.8 Teaching and career development training

- Academic (teaching) responsibility for engineering courses and activities at undergraduate and postgraduate levels
- Responsibility for training and the supervision of experience for those intending to become professional engineers, technologists and technicians
- Career development for professional engineers, technologists and technicians

The professional engineer usually finds himself engaged in one or more of the enumerated work areas. Vice Chancellor Sir, the inaugural lecturer has been engaged in Thermo-Fluids and Building Services Engineering in some of the enumerated areas.

5.0 CONTRIBUTIONS TO THEORY AND PRACTICE IN THERMO-FLUIDS AND BUILDING SERVICES ENGINEERING

The earlier employment, after the National Youth Service Scheme, as a maintenance planning trainee engineer at Michelin Nig. Ltd, Port Harcourt in the Central Engineering Workshop brought the inaugural lecturer close to the factory utility services (i.e. building services) of the central boiler, water facility, cooling tower and their distribution systems; as well as the various air conditioning and ventilation systems of the factory. This earlier experience later enabled the lecturer's contributions in maintenance planning: Sodiki (1997), Sodiki (1998b), Sodiki (1999a), Sodiki (2000b), Sodiki (2000d), Sodiki (2001a), Sodiki (2002c), Sodiki (2002d) and Sodiki (2005b). These contributions are in line with the operation and maintenance, as well as the management and planning roles of the engineer.

As in many engineering industries, major causes of failure of plant and systems also observed on that factory's building services (i.e. utility services) were the incidents of wear and corrosion. Inspired by his early background in empirical studies in the subjects of metallurgy and materials science, the lecturer later made the following useful contributions in this respect: Sodiki (1993b), Sodiki (1996), Sodiki (2002e), Sodiki (2005f), Sodiki & Ndor (2016), Sodiki et al (2016a), Sodiki et al (2016b) and Ameh et al (2021). Fig. 1 and Table 1 show the corrosion behavior of common engineering metals in selected laboratory environments, as reported in Sodiki (2005f) and Sodiki et al (2016a), respectively. These contributions are also in line with the operation and maintenance roles of the engineer.

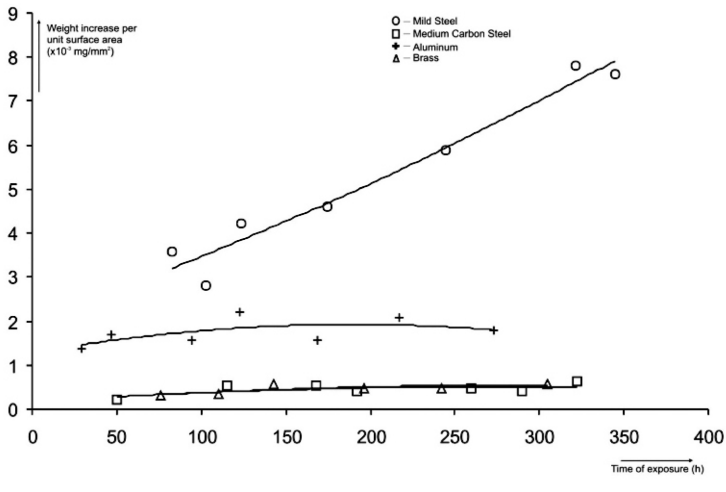


Fig. 1a: Corrosion-time graphs of test metals in the Laboratory atmosphere

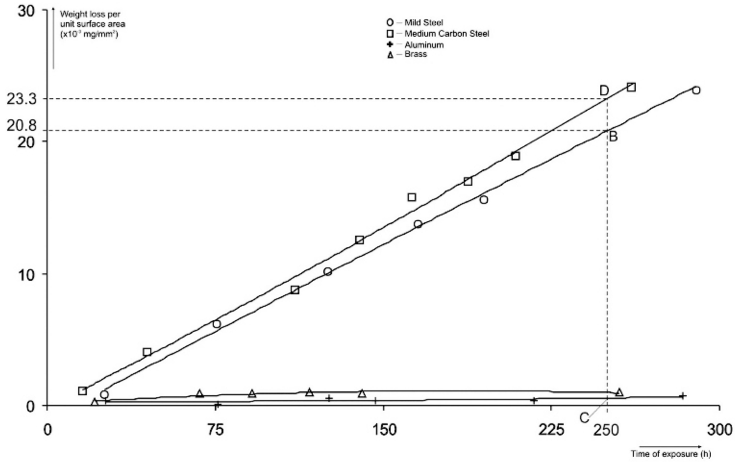


Fig. 1a: Corrosion-time graphs of test metals in 0.1M Ammonium Hydroxide

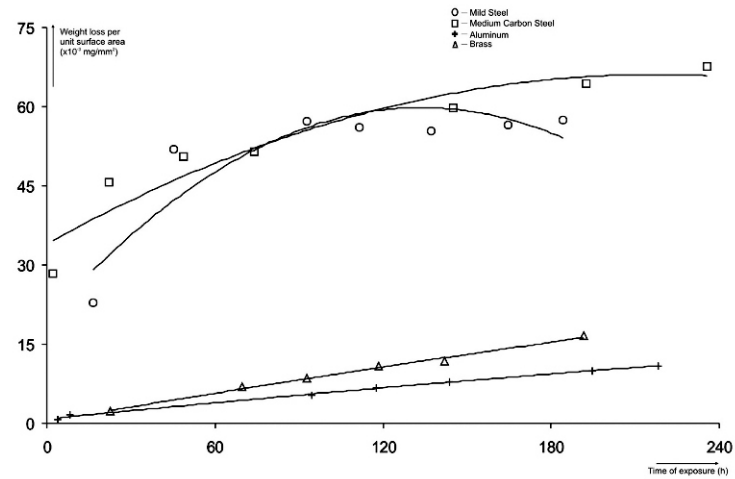


Fig. 1c: Corrosion-time graphs of test metals in 0.1M Hydrochloric acid

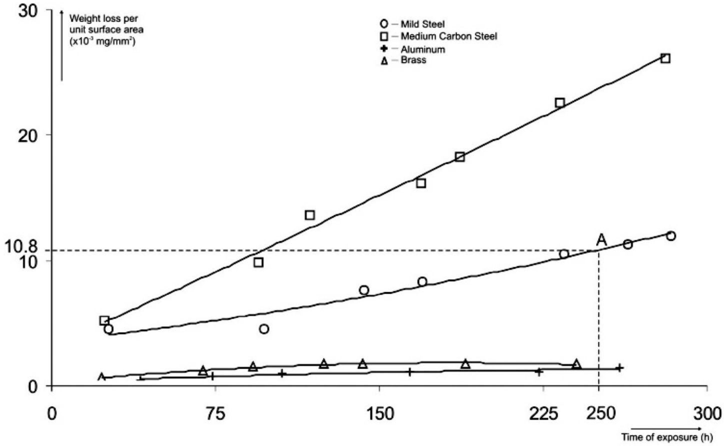


Fig. 1d: Corrosion-time graphs of test metals in 0.1M sodium chloride

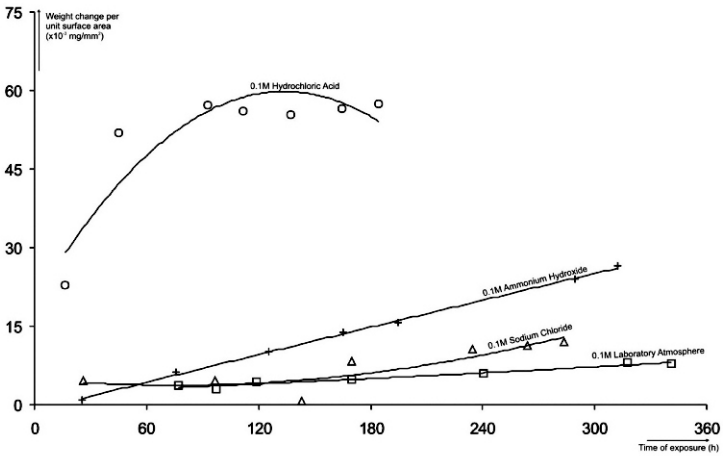


Fig. 1e: Corrosion – time graphs of mild steel in the different environments

Fig. 1: Corrosion-time behavior of mild steel, medium carbon steel, brass and aluminum in laboratory environments

Table 1: Regression Equation for Predicting Corrosion Extents and Rates of Selected metals and Environments (Sodiki et al, 2016a)

Corrosion Experiment	Regression Equation	Corrosion Rate Equation
M.S.* in Laboratory Atmosphere	$y = 2.270 + 0.0124t + 1.366 \times 10^{-5}t^2$	$R = 0.0124 + 2.732 \times 10^{-5}t$
M.S. in 0.1M NaCl	$y = 2.277 + 0.0416t - 2.980 \times 10^{-5} t^2$	$R = 0.042 - 5.960 \times 10^{-5}t$
M.S. in 01M NH_4OH	$y = -7.047 + 0.19t - 2.948 \times 10^{-4} t^2$	$R = 0.190 - 5.896 \times 10^{-4}t$
M.S. in 0.1M HCl	$y = 38.960 + 0.0293t + 6.079 \times 10^{-4}t^2$	$R = 0.029 + 1.216 \times 10^{-3}t$
M.C.S.* in Laboratory Atmosphere	$y = 0.297 + 2.403 \times 10^{-3}t - 4.376 \times 10^{-6} t^2$	$R = 2.403 \times 10^{-3} - 8.752 \times 10^{-6}t$
M.C.S. in 0.1M NaCl	$y = 3.225 + 0.076t + 2.245 \times 10^{-5} t^2$	$R = 0.076 + 4.490 \times 10^{-5}t$
M.C.S. in 0.1M NH_4OH	$y = -0.736 + 0.105t - 6.085 \times 10^{-5} t^2$	$R = 0.105 - 1.217 \times 10^{-4}t$
M.C.S. in 0.1M HCl	$y = 33.970 + 0.295t - 6.793 \times 10^{-4} t^2$	$R = 0.295 - 1.359 \times 10^{-3}t$
Brass in Laboratory Atmosphere	$y = 0.275 + 2.629 \times 10^{-3}t - 4.543 \times 10^{-6} t^2$	$R = 2.629 \times 10^{-3} - 9.086 \times 10^{-6}t$
Brass in 0.1M NaCl	$y = -1.666 \times 10^{-3} + 0.017t - 4.612 \times 10^{-5} t^2$	$R = 0.017 - 9.224 \times 10^{-5}t$
Brass in 0.1M NH_4OH	$y = 0.129 + 0.011t - 2.991 \times 10^{-5} t^2$	$R = 0.011 - 5.982 \times 10^{-5}t$
Brass in 0.1M HCl	$y = 1.561 + 0.065t + 7.145 \times 10^{-5} t^2$	$R = 0.065 + 1.429 \times 10^{-4}t$
Aluminum in Laboratory Atmosphere	$y = 1.726 + 8.286 \times 10^{-5} t + 3.775 \times 10^{-7} t^2$	$R = 8.286 \times 10^{-5} + 7.550 \times 10^{-7}t$
Aluminum in 0.1M NaCl	$y = 0.081 + 6.268 \times 10^{-3} t - 8.395 \times 10^{-6} t^2$	$R = 6.268 \times 10^{-3} - 1.679 \times 10^{-5}t$
Aluminum in 0.1M NH_4OH	$y = 0.281 + 1.332 \times 10^{-5} t + 4.670 \times 10^{-6} t^2$	$R = 1.332 \times 10^{-5} + 9.340 \times 10^{-6}t$
Aluminum in 0.1M HCl	$y = 0.288 + 0.059t - 4.528 \times 10^{-5} t^2$	$R = 0.059 - 9.056 \times 10^{-5}t$

M.S*: Mild Steel, M.C.S*: Medium Carbon Steel

The M.Sc. and Ph.D research and engagement in building services engineering consultancy, inspired the lecturer to make contributions in the following aspects of Thermo-Fluids and Building Services Engineering, among others:

i. Computer Software Development for the Design of Building Systems: These are reported in Sodiki (1990), Sodiki (1993a), Sodiki (1999b), Sodiki (2004a) and Sodiki (2004c). Tables 2 and 3 illustrate such software. Many of these computer programs were the first of their kind developed in Nigeria.

Table 2: Fortran Program for Calculating Air Conditioning Cooling Loads and PsychrometricSodiki, 1993a)

```
      DIMENSION BF (5), SATEF(5)
      DATA RH, TRM, TOA, TWBRM/50.0, 25.0, 31.0, 0.010, 0.014, 18.0/
      READ (1,25) (BF(1), I=1,5)
 25   FORMAT (3X, 5F10.2)
      READ (1,22) (SATEF(1), I=1,5)
 22   FORMAT (1X,5F10.1)
      NPR = 1
      CALL ALOAD (TRM, TOA, WRM, WOA, CFMOA, RSHA, RLHA)
      CALL BLOAD (TRM, TOA, WRM, WOA, RSHE, RLHB)
      CALL SAFE (SUPSP, SUPLP, SUPGA)
      RSHI  =  RSHA + RSHB
      RLHI  =  RLHA + RLHB
      RSH   =  (100.0 + SUPSP) *RSH1/100.0
      RLH   =  (100.0 + SUPLP) *RLHI/100.0
      OASH  =  1.208*CFMOA*(TRM-TOA)
      OALH  =  2957*CFMOA*(WRM-WOA)
      TSH   =  RSH+OASH
      TLH   =  RLH+OALH
      GTH   =  (TSH+TLH)*(100.0+SUPGA)/100.0
      WRITE (3,1) RSH
      WRITE (3,2)RLH
      WRITE (3,3)CFMOA
      WRITE (3,4)OASH
      WRITE (3,5)OALH
      WRITE (3,6)GTH
  1   FORMAT (3X,'ROOM SENSIBLE HEAT IS',F25.2,3X,'KJ/S')
  2   FORMAT (3X,'ROOM LATENT HEAT IS', F27.2,3X,'KJ/S')
  3   FORMAT (3X,'OUTDOOR AIR REQUIRED FOR VENTILATION IS', F7.2,3X,'CU.M/S')
  4   FORMAT (3X,'OUTDOOR AIR SENSIBLE HEAT IS',F18.2,3X,'KJ/S')
  5   FORMAT (3X,' OUTDOOR AIR LATENT HEAT IS',F20.23X,'LJ/S')
  6   FORMAT (3X,'GRAND TOTAL HEAT IS', F27.2,3X,'KJ/S')

C     THE PSYCHROMETRICS NOW FOLLOW.  WE CHOOSE AN APPLICABLE PSYCHROMETRIC
C     PROCESS BY CHOICE OF NPR (1 UP TO 7)
      IF (NPR.EQ.1) GOTO 11
      IF (NPR.EQ.2) GOTO 12
      IF (NPR.EQ.3) GOTO 13
      IF (NPR.EQ.4) GOTO 14
      IF (NPR.EQ.5) GOTO 15
      IF (NPR.EQ.6) GOTO 16
      GOTO 17,
 11   ID  = 2
      BFD = BF(ID)
      CALL PSYCI (BFD,RH,TRM,TOA,RSH,RLH,CFMOA,OASH,OALH,GTH,ESHF,TADP,
```

Table 2 Cont'd

```
    6CFMDA, CFMSA, FEDB, TLDB, REHT)
    WRITE (3,7)
    WRITE (3,8)
    WRITE (3,9) BFD,GTH,ESHF,TADP,CFMDA,CFMSA,TEDB,TLDB
 7  FORMAT (3X,'SELECT EQUIPMENT USING THE FOLLOWING PARAMETERS')
 8  FORMAT (2X,'BFD',4X,'GTH(KJ/S)',1X,'ESHF',3X,'TADP(C)',4X,
    6'CFMDA (CU.M/S)',4X,'CFMSA(CU.M/S)',1X,'TEDB(C)',1X,'TLDB(C)')
 9  FORMAT (F5.2,F15.2,F5.2,F10.2,2F14.1,2F8.2)
    GOTO 111
12  ID  = 5
    BFD = BF(ID)
    CALL PSYC2 (BFD,RH,TRM,TOA,RSH,RLH,CFMOA,OASH,OASH,OALH,GTH,ESHF,
   6 TADP,CFMDA,CFMSA,TEDB,REHT)
    WRITE (3,7)
    WRITE (3,28)
    WRITE (3,29)BFD,GTH,ESHF,TADP,CFMDA,CFMSA,TEDB,TLDB,REHT
28  FORMAT (1X,'BFD',1X,'GTH(KJ/S)','1X,'ESHF',1X,'TADP(C)',1X,'CFMDA(CU.M/S)',
   61X,'CFMSA(CU.M/S)',1X,'TEDB(C)',TLDB(C)',1X,'TLDB(C)',2X,'REHT(KJ/S)')
29  FORMAT (F4.2,F12.1,F5.2,F8.2 2F11.1, 2F8.2,F13.1)
    GOTO 111
13  ID  = 2
    BFD = BF(ID)
    CALL PSYC3 (BFD,RH,TRM,TOA,RSH,RLH,CFMOA,OASH,OALH,GTH,ESHF,TADP,CFMDA,
   6CFMSA,TEDB,TLDB)
    WRITE (3,7)
    WRITE (3,38)BFD,GTH,ESHF,TADP,CFMSA,TEDB,TLDB
38  FORMAT (3X,'BFD,GTH,ESHF,TADP,CFMSA,TEDB,TLDB',3X,'ARE',3X,F4.2,F15.1,
   62F5.2,F10.1,2F5.2,3X,'IN THAT ORDER')
    GOTO 111
14  ID  = 5
    BFD = BF(ID)
    CALL PSYC4 (BFD,RH,TRM,TOA,WRM,WOA,RSH,RLH,CFMOA,OASH,OALH,GTHD,
   6ESHF,TES,CFMDA,TEDB,TLDB)
    WRITE (3,7)
    WRITE (3,48)BFD,GTH,ESHF,TES,CFMSATEDB,TLDB
48  FORMAT (3X'BFD,GTH,ESHF,TES,CFMSA,TEDBTLDB,ARE RESPECTIVELY', F4.2
   6F15.1,F4.2,F10.1,2F5.2)
    GOTO 111
15  ID  = 2
    BFD = BF(ID)
    CALL PSYC5 (BFD,RH,TRM,TOA,RSH,RLH,CFMOA,OASH,OALH,GTH,ESHF,TADP,
   6TEDB,TLDB,WEDH,TWBRM.AD)
    WRITE (3,7)
    WRITE (3,58)GTH,ESHF,TADP,TEDB,TLDB,WEDH,TWBRM,AD
58  FORMAT (3X,'GTH,ESHF,TADP,TEDB,TLDB,WEDH,TWBRM,AD,ARE',F15.1,4F5.2,
   63F10.2,'RESPECTIVELY')
    GOTO 111
16  CALL PSYC6 (TOA,RSH,SATEF,TRM,CFMSA)
    WRITE (3,7)
```

Table 2 Cont'd

```
      WRITE (3,68)TRM,CFMSA
68    FORMAT (3X,'TRM AND CFMSA ARE RESPECTIVELY',F10.2,' AND',F15.2)
      GOTO 111
17    CALL PSYC7 (TRM,TOA,WOA,WRM,CFMOA,SATEF,TSA,WSA,TEDB,WEDB,WEA,WLA,WSAT)
      WRITE (3,7)
      WRITE (3,78) SATEF,TSA,WSA,TEDB,WEA,WLA,WSAT
78    FORMAT (3X,'SATEF,TSA,WSA,TEDB,WEA,WLA,WSAT,ARE RESPECTIVELY',7F10.2)
111   CONTINUE
      STOP
      END

      ROOM SENSIBLE HEAT IS                                260.23 KJ/S
      ROOM LATENT HEAT IS                                   17.04 KJ/S
      OUTDOOR AIR REQUIRED FOR VENTILATION IS                       0.24 CU.M/S
      OUTDOOR AIR LATENT HEAT IS                              2.69 KJ/S
      OUTDOOR AIR LATENT HEAT IS                              2.69 KJ/S
      GRAND TOTAL HEAT IS                                  311.88 KJ/S
      APPARATUS DEWPOINT =                                  13.89 C
      SELECT EQUIPMENT USING THE FOLLOWING PARAMETERS
      BFD  GTH(KJ/S) ESHF TADP(C) CFMDA(CU.M/S) CFMSA([illegible]) [illegible]EDB(C) TLDB(C)
      0.25  311.88   0.93  13.89  15.3         15.3         25.64   16.53
```

Table 3: Program for Calculating Total Heads of Submersible Pumps (Sodiki 2004a)

```
*        Program:          PUMP.Prg
*        Description:      Program to Calculate Total Heads of Submersible
*                          Pumps for Various System Parameters
*        Language:         Microsoft Visual Foxpro Version 5.0

SET TALK ON
SET SAFE OFF
CLOS DATA
USE PUMP
ZAP
LO = 100
HA = 0
QO = 1
FOR LO = 100 TO 300 STEP 50
        FOR HA = 0 TO 50 STEP 5
                LT  = HA + 25
                HS  = LO + HA
                QT  = QO/3600
                OO = 1.8182 * LOG(QT)   + 5.9556
                MO = 2.0002 *  LOG(QT)  +  6.1785
                HO  = 10**00
                HM = 10**MO
                HT  = (QT**1.85)  *  ((39962.44  *  LO) +;
                        (132874.89  *  LT)) + 2466703.54  *  (QT**2)+ HO + HM + HS
                APPEND BLANK
                REPLACE BOREHOLE WITH LO
                REPLACE STORAGE  WITH HA
                REPLACE DISCHARGE  WITH QO
                REPLACE HEAD  WITH HT
                ENDFOR
        ENDFOR
ENDFOR
LIST TO FILE PUMP
CLOSE ALL
RETURN
EOF
```

ii. Novel Improvements in Design Equations and Methods for Building Services: Reported in Sodiki (1995), Sodiki (1998a), Sodiki (1998c), Sodiki (1999c), Sodiki (2000a), Sodiki (2001b), Sodiki (2001c), Sodiki (2002a), Sodiki (2002b), Sodiki (2003a) and Sodiki (2003b) are some of the improvements in the design approaches towards achieving enhanced system performance in the country. Figs. 2 to 6 illustrate sketches used to obtain such improved equations and methods

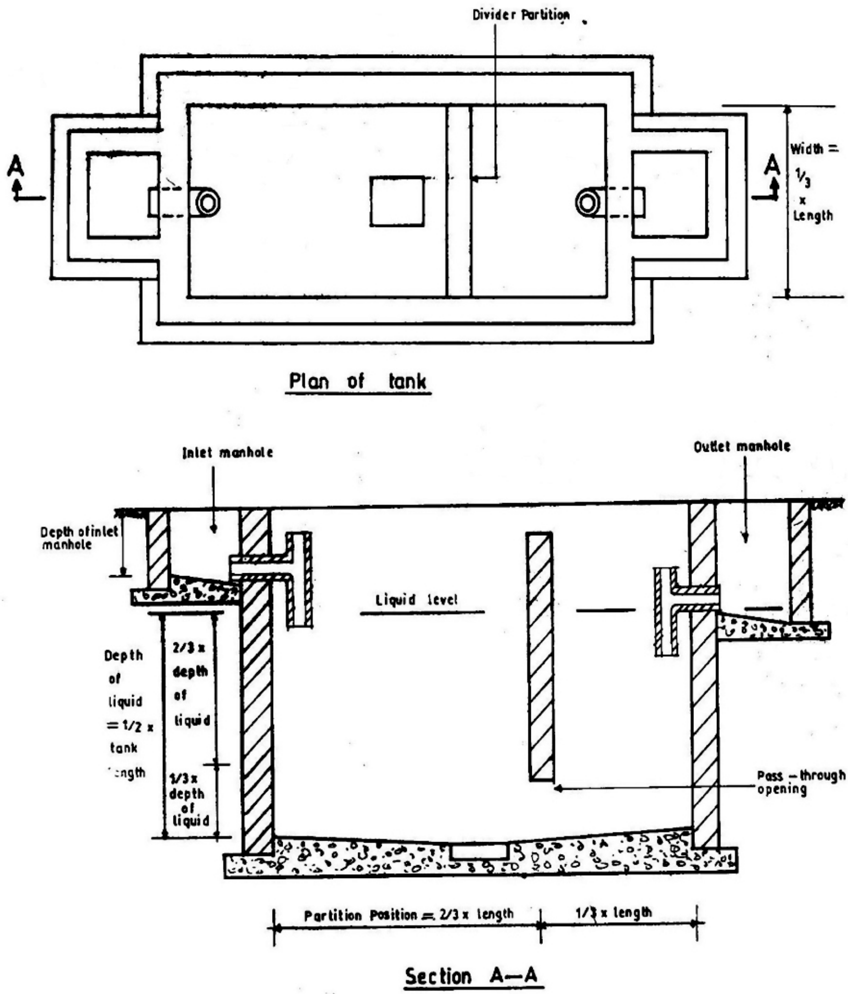


Fig. 2: Recommended Dimensions on Septic Tanks (Sodiki, 2003b)

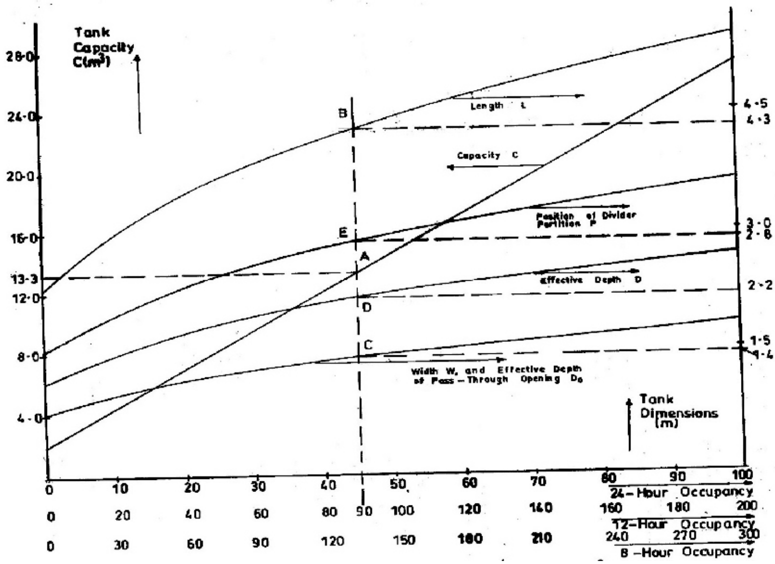


Fig. 3: Graphs for Sizing Septic Tanks (Sodiki 2003b)

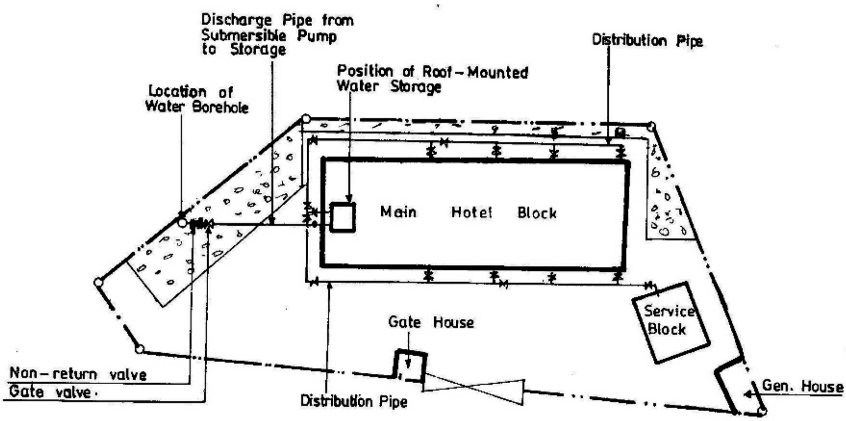


Fig. 4: Water Supply and Distribution Plan (Sodiki, 2003a)

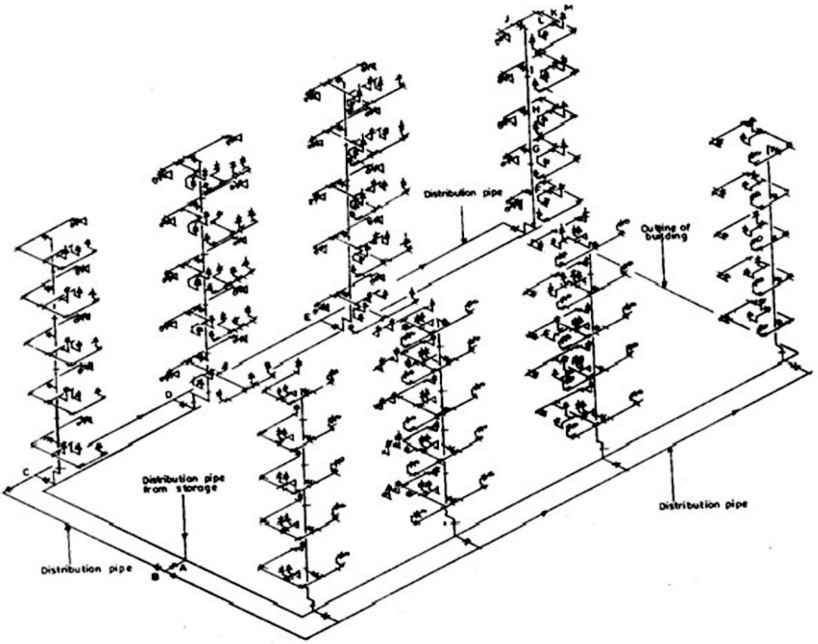


Fig. 5: Isometric Sketch of Water Distribution Network in a Hotel (Sodiki, 2003a)

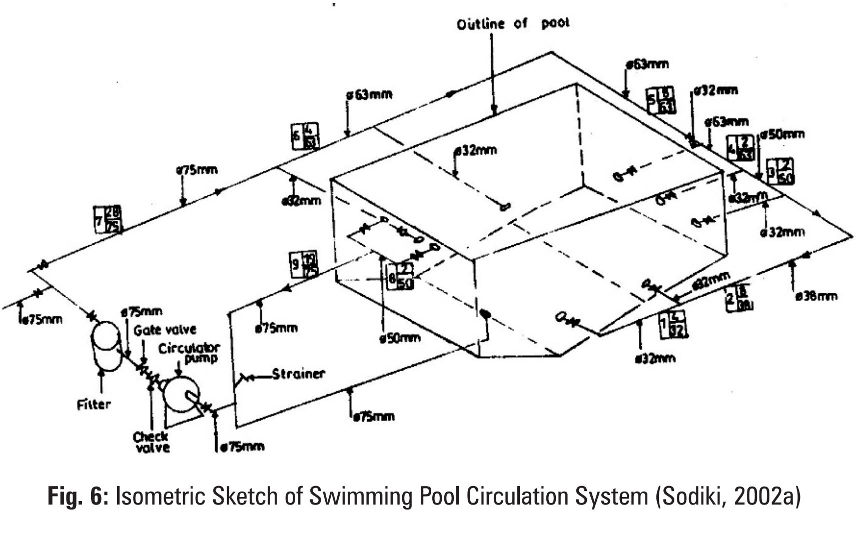


Fig. 6: Isometric Sketch of Swimming Pool Circulation System (Sodiki, 2002a)

iii. Studies on Energy Losses in Air Conditioning, Ventilation and Air Extraction Systems and Development of Design Aids for Selection of Fluid Machinery: Some of these are reported in Sodiki (2001b), Sodiki (2002a), Sodiki (2004b), Sodiki (2004c), Sodiki (2005a), Sodiki (2005c), Sodiki (2005d), Sodiki (2006), Sodiki (2014a), Sodiki (2014c), Sodiki (2014d), Sodiki (2015a), Sodiki (2015b), Sodiki (2015c), Sodiki (2016), Sodiki (2017a) and Sodiki (2017b). Figs. 7 to 15 illustrate some air duct systems which were analysed to obtain energy loss models. These resulted in design aids for duct systems and facilitated fan selection.

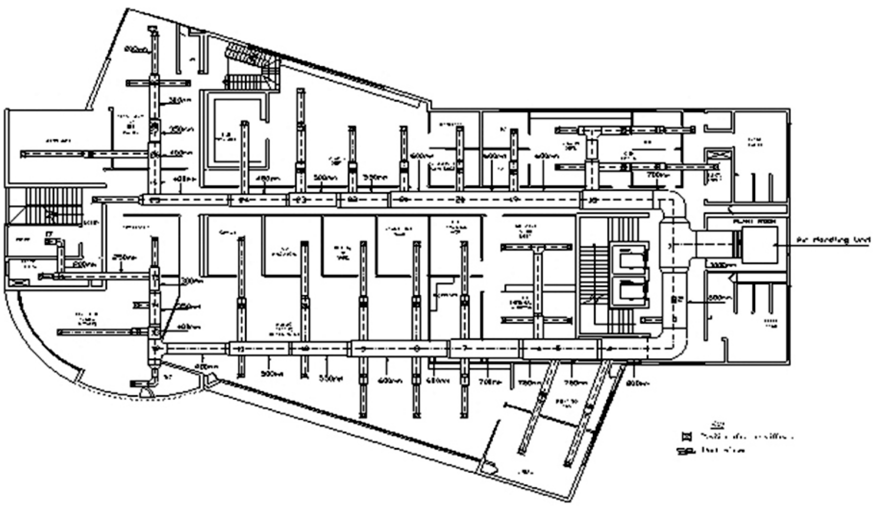


Fig. 7: Conditioned Air Distribution Duct Layout in a Floor of an Office Block (Sodiki, 2015c)

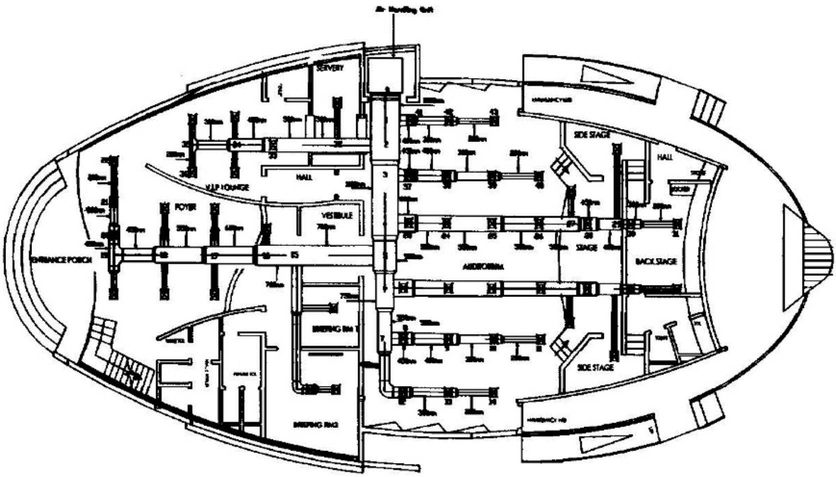


Fig. 8: Conditioned Air Distribution Duct Layout in an Auditorium (Sodiki, 2014d)

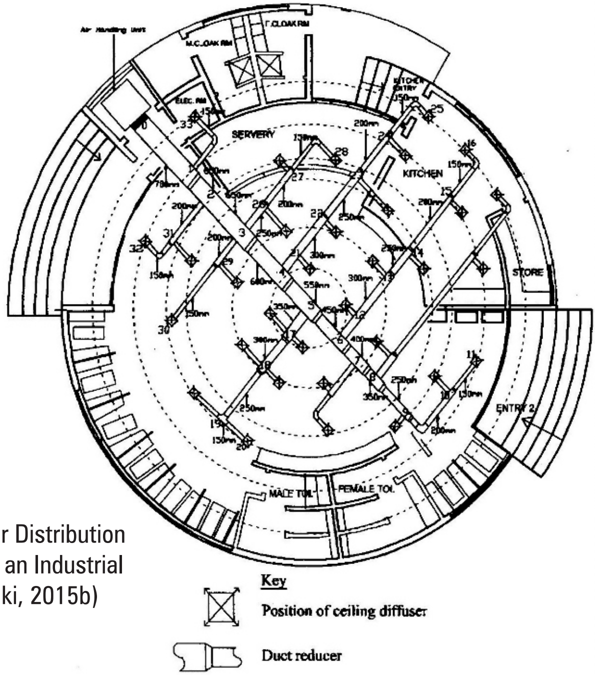


Fig. 9: Conditioned Air Distribution Duct Layout in an Industrial Cafetaria (Sodiki, 2015b)

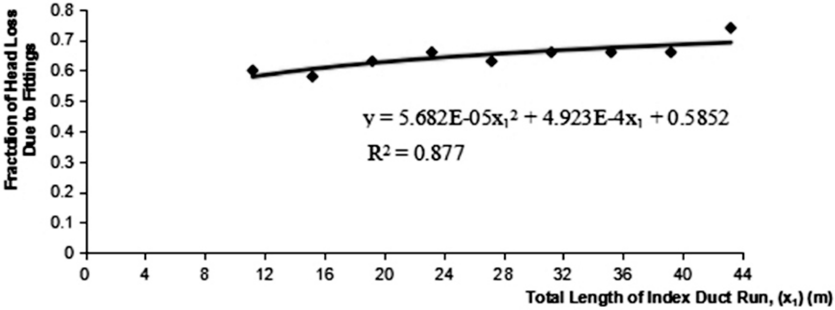


Fig. 10: Fraction of Head Loss Due to Fittings Versus Length of Index Run in an Air Conditioning Ductwork (Sodiki, 2014d)

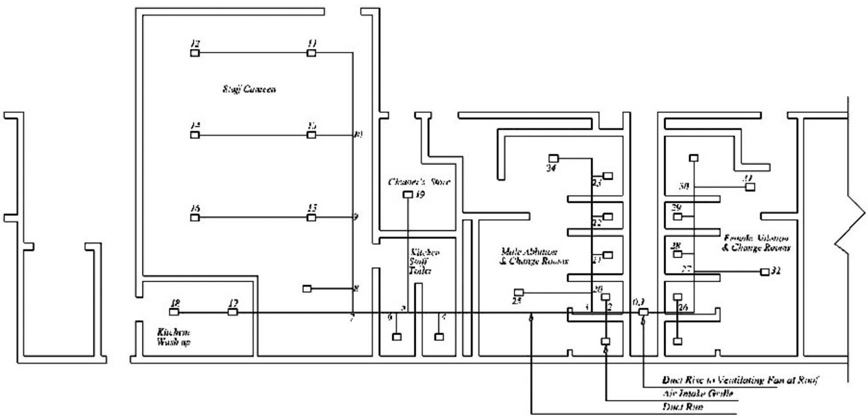


Fig. 11: Layout of an Extract Duct System (Sodiki, 2016)

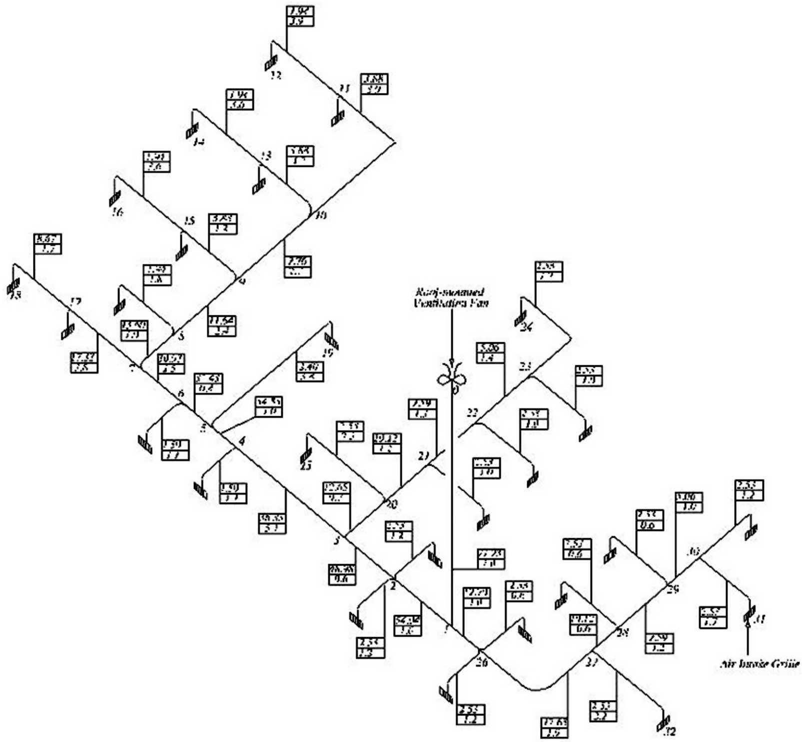


Fig. 12: Isometric Sketch of an Extract Duct System (Sodiki, 2016)

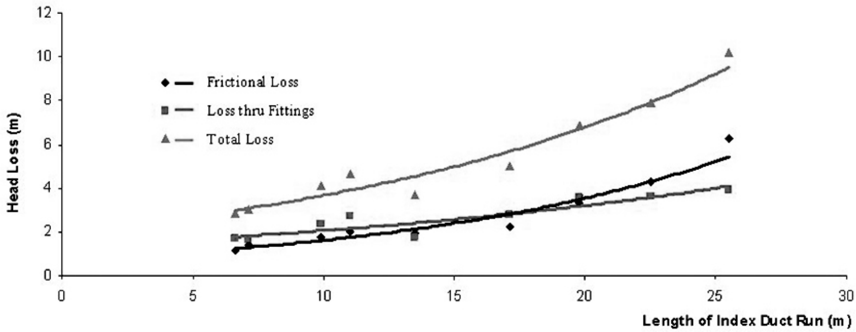


Fig. 13: Variation of Head Losses with Length of Index Run in a Extract Duct System (Sodiki, 2016)

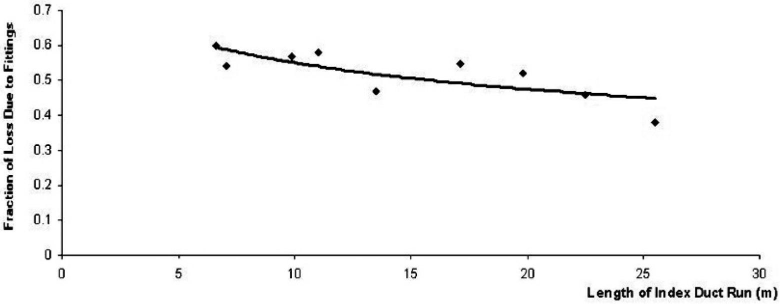


Fig. 14: Variation of Fraction of Loss due to Fittings with Length of Index Run in an Extract Duct System (Sodiki, 2016)

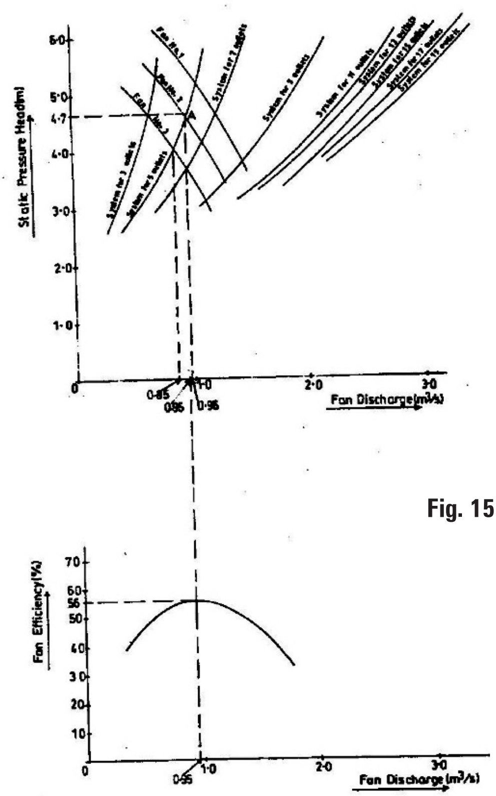


Fig. 15: Static Pressure Curves for Air Conditioning Fan Selection (Sodiki, 2005a)

iv. Novel Performance Assessment of Building Systems: Performance indices of complete installed building systems needed to be measured for corrective actions to be taken. These are reported in Sodiki (2004d), Sodiki (2005e) and Sodiki & Adigio (2015). Tables 4 and 5, and Fig. 16 illustrate such assessments for air conditioning, vertical transportation (lift) and water distribution systems, respectively.

Table 4: Air Conditioning Cooling Loads and Installed Capacities in a Building (Sodiki, 2004d)

SPACE SPECIFICATION	ESTIMATED COOLING LOAD (KW)	INSTALLED CAPACITY (KW)	REMARKS
(a)	48 800	2x55000Btu/h = 32kw	The installed 2 no are inadequate for the entire space. especially during meetings. 1 no of the same capacity should be installed
(b)	2 197	5.4	Adequate. Requires low tuning for enhanced comfort
(c)	2.647	5 4	Adequate Requires low tuning for enhanced comfort.
(d)	2.416	2x5.4	Only 1 no. 5 4 kw is adequate; Requires low tuning for enhanced comfort. 2nd one can remain as standby or be reassigned
(e)	3.175	5.4	Adequate. Requires low tuning for enhanced comfort
(f)	13.130	2x50000Btu/h = 2x14.5kw	Only 1 no. 14 5kw is adequate; 2nd one can remain as standby, and for use during conferences involving large crowds

Table 5: Measurement of Round-Trip Times of Installed Lifts (Sodiki, 2004d)

Elevator 1	Time leaving ground floor (pm)	2:30	2:33	2:35	2:37	2 40	2:45
	Interval (min.)	3	2	2	3	5	

∴ round-trip time = 1/5(3+2+2+3+5) = 3 min

Elevator 2	Time leaving ground floor (pm)	2 28	2 32	2 35	2 37	2 42	2:45	2 48
	Interval (min.)	4	3	2	5	3	3	

∴ round-trip time = 1/6(4+3+2+5+3+3) = 3 3 min
Average round-trip time for the two elevators = ½(3+3 3) min = 3.15 min

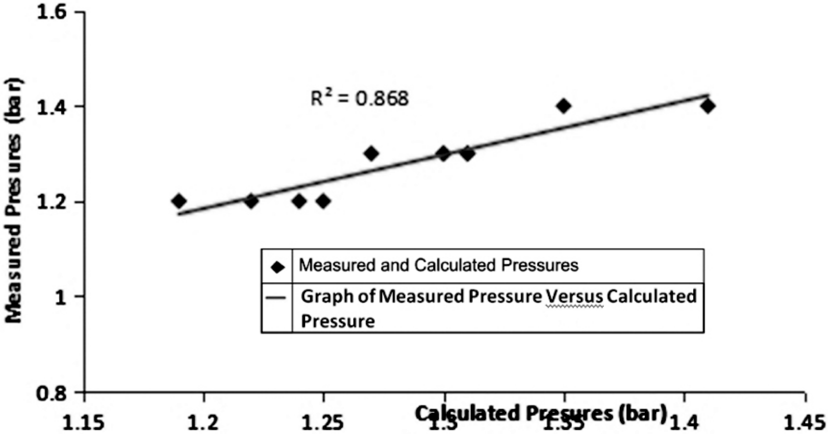


Fig. 16: Plot of Measured Pressures Versus Calculated Pressures for a Buildin Water Distribution System (Sodiki & Adigio, 2015)

v. Studies on Detection of Leaks and Other Operational Problems in Liquid Pipe Networks: These are reported in Okeke & Sodiki (2007), Okeke & Sodiki (2008), and Idoko et al (2021).

vi. Pipe Network Analyses and Development of Models for Determination of Head Losses in Water Distribution Systems: Contributions in this aspect include those reported in Sodiki & Orupabo (2011), Sodiki & Orupabo (2013), Sodiki (2013a), Sodiki (2013b), Sodiki (2013c), Sodiki (2014a), Sodiki & Adigio (2014a), Sodiki & Adigio (2014b), Sodiki & Adigio (2014c), Sodiki & Adigio (2014d), Sodiki & Adigio (2017a), Sodiki & Adigio (2017b), Ifiemi et al (2019) and Sodiki & Ifiemi (2021). Figs. 17 to 22 and Tables 6 to 9 provide some insight to these contributions.

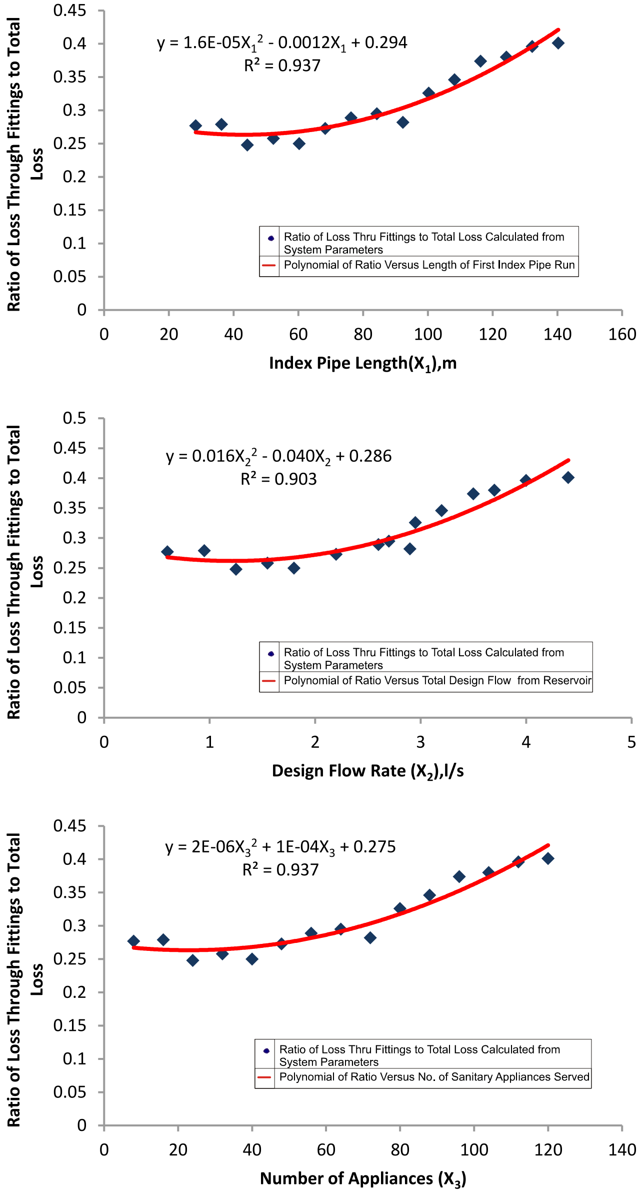


Fig. 17: Variation of Ratio of Loss through Fittings to Total Head Loss with Pipework Complexity (for Distribution within Building) (Sodiki & Adigio, 2017a)

Table 6: Validation of Regression Model Equations for Water Distribution within Buildings (Sodiki & Adigio, 2017a)

S/No.	Case Study	Regression Model Equation	Independent Variable x		Dependent Variable y: Ratio of Fitting Loss to Total Loss (i.e. Fraction of Loss due to Fittings)			Remarks*
			Definition	Value	Calculated from Regression Equation	Calculated by Usual Procedure	% Deviation of Usual Procedure from Regression Model	
1	448 – Bed Student Hostel	$y = 0.294 - 0.0012x_1 + 1.6 \times 10^{-5}x_1^2$	Length of Index Pipe Run, x_1	135.5m	0.425	0.423	0.5	Equation is Validated
		$y = 0.286 - 0.04x_2 + 0.016x_2^2$	Reservoir Discharge x_2	4.4l/s	0.420	0.423	0.7	"
		$y = 0.275 + 1 \times 10^{-4}x_3 + 2 \times 10^{-6}\ x_3^2$	Number of Sanitary Appliances x_3	270	0.448	0.423	5.6	"
2	36 – Room Hotel Building	$y = 0.294 - 0.0012x_1 + 1.6 \times 10^{-5}x_1^2$	Length of Index Pipe Run x_1	86.3m	0.310	0.360	16.0	"
		$y = 0.286 - 0.04x_2 + 0.016x_2^2$	Reservoir Discharge x_2	3.7l/s	0.357	0.360	0.8	"
		$y = 0.275 + 1 \times 10^{-4}x_3 + 2 \times 10^{-6}\ x_3^2$	Number of Sanitary Appliances x_3	108	0.309	0.360	16.5	"
3	250 – Occupancy Office Building	$y = 0.294 - 0.0012x_1 + 1.6 \times 10^{-5}x_1^2$	Length of Index Pipe Run x_1	99m	0.332	0.320	13.5	"
		$y = 0.286 - 0.04x_2 + 0.016x_2^2$	Reservoir Discharge x_2	2.8l/s	0.299	0.320	7.0	"
		$y = 0.275 + 1 \times 10^{-4}x_3 + 2 \times 10^{-6}\ x_3^2$	Number of Sanitary Appliances x_3	95	0.303	0.320	5.6	"

* Deviations less than 20% from the regression equation are considered acceptable for approximation purposes and, hence, validate the relevant regression equation.

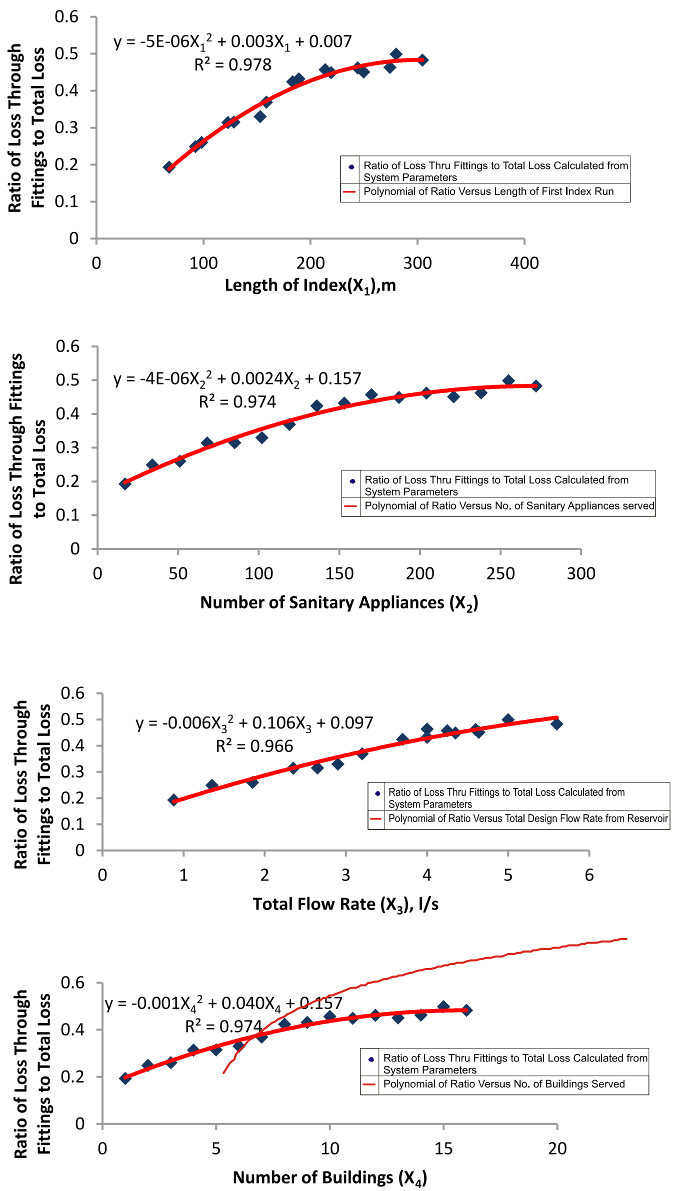


Fig. 18: Variation of Ratio of Loss through Fittings to Total Head Loss with Pipework Complexity (for Distribution to Groups of Buildings) (Sodiki & Adigio, 2017b)

Table 7: Validation of Regression Model Equations for Distribution to Groups of Buildings (Sodiki & Adigio, 2017b)

S/No.	Case Study	Regression Model Equation	Independent Variable x		Dependent Variable y: Ratio of Fitting Loss to Total Loss (i.e. Fraction of Loss due to Fittings)			Remarks*
			Definition	Value	Calculated from Regression Equation	Calculated by Usual Procedure	% Deviation of Usual Procedure from Regression Model	
1.	12 – Unit Residential Housing Estate	$y = 0.007 + 0.003x_1 - 5 \times 10^{-6}\ x_1^2$	Length of Index Pipe Run x_1	181.0m	0.386	0.415	7.5	Equation is Validated
		$y = 0.157 + 0.0024x_2 - 4 \times 10^{-6}\ x_2^2$	Number of Sanitary Appliances x_2	224	0.496	0.415	16.0	"
		$y = 0.097 + 0.106x_3 - 0.006x_3^2$	Reservoir Discharge x_3	3.6l/s	0.401	0.415	3.5	"
		$y = 0.157 + 0.04x_4 - 0.001x_4^2$	Number of Buildings x_4	12	0.493	0.415	15.8	"
2.	3 Blocks of Terrace Building Each Having 4 Family Units	$y = 0.007 + 0.003x_1 - 5 \times 10^{-6}\ x_1^2$	Length of Index Pipe Run x_1	171.5m	0.374	0.430	15.0	"
		$y = 0.157 + 0.0024x_2 - 4 \times 10^{-6}\ x_2^2$	Number of Sanitary Appliances x_2	230	0.497	0.430	13.5	"
		$y = 0.097 + 0.106x_3 - 0.006x_3^2$	Reservoir Discharge x_3	5.2l/s	0.486	0.430	11.5	"
		$y = 0.157 + 0.04x_4 - 0.001x_4^2$	Number of Buildings x_4	12	0.493	0.430	12.8	"
3.	8 Units Each of Two Prototype Buildings	$y = 0.007 + 0.003x_1 - 5 \times 10^{-6}\ x_1^2$	Length of Index Pipe Run x_1	219.5m	0.425	0.486	14.4	"
		$y = 0.157 + 0.0024x_2 - 4 \times 10^{-6}\ x_2^2$	Number of Sanitary Appliances x_2	396	0.480	0.486	0.4	"
		$y = 0.097 + 0.106x_3 - 0.006x_3^2$	Reservoir Discharge x_3	8.7l/s	0.565	0.486	14.7	"
		$y = 0.157 + 0.04x_4 - 0.001x_4^2$	Number of Buildings x_4	16	0.541	0.486	11.1	"

* Deviation less than 20% from the regression equation are considered acceptable for approximation purposes and, hence, validate the relevant regression equation.

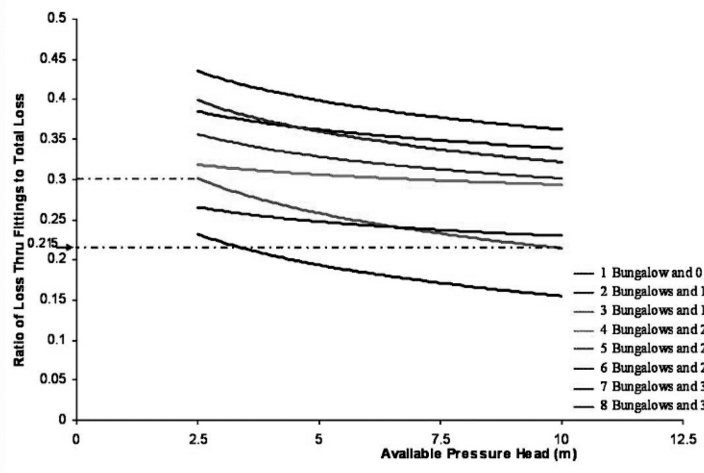


Fig. 19: Variation of Fitting Loss Fraction with Available Head for Distribution to Groups of Buildings (Layout Variation = 0.300 – 0.215 = 0.085) (Sodiki, 2013c)

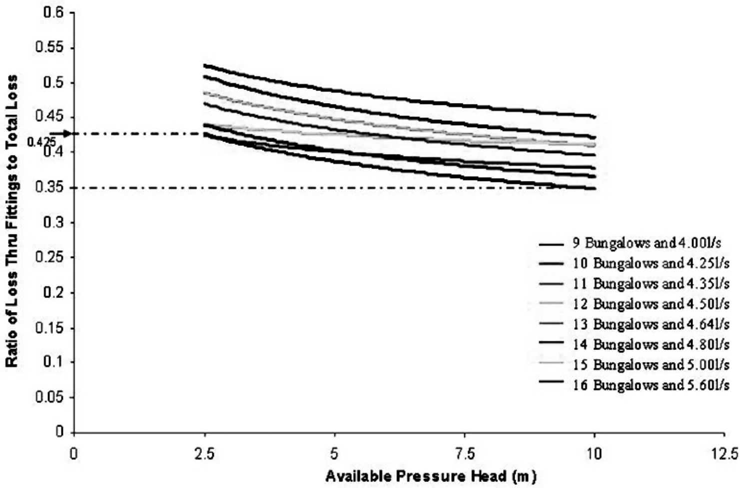


Fig. 20: Variation of Fitting Loss Fraction with Available Head for Distribution to Groups of Buildings (Largest Variation of Fraction = 0.425 – 0.350 = 0.075) (Sodiki, 2013c)

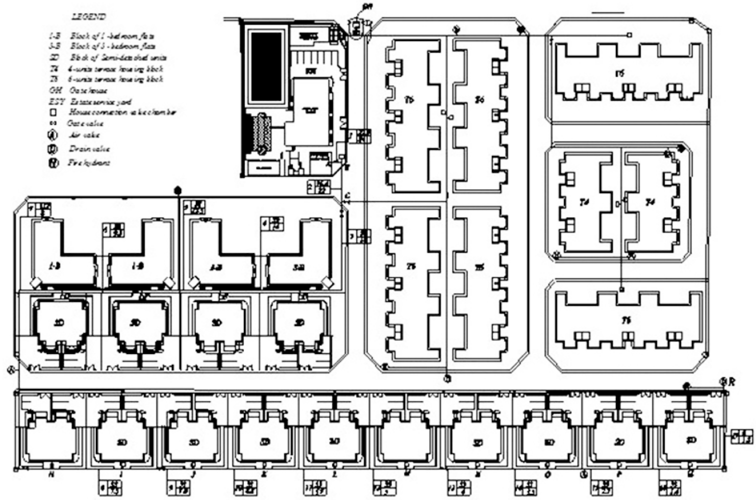
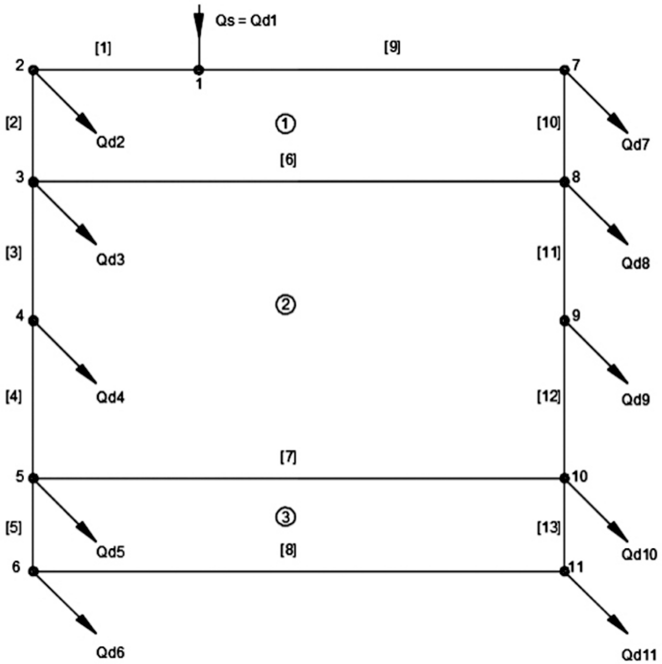


Fig. 21: Water Distribution Network to a Group of Buildings (Sodiki & Adigio 2014b)



LEGEND	
[ ]	Pipe Section
1,2,3,…,11	Nodes

Fig. 22: Schematic Diagram of a Water Distribution Network for Newton-Raphson Multivariate Analysis (Ifiemi et al, 2019)

Table 8: Two out of 255 Network Solutions using the Newton-Raphson Method on the Distribution System (Sodiki & Ifiemi 2021)

Result Set 1:

For Pipe 1, Diameter = 0.034544 m, Flow-rate = 0.00199528 m ^ 3/s, Headloss = 4.86788 m, and Velocity = 2.12897 m/s (Turbulent Flow)

For Pipe 2, Diameter = 0.0261366 m, Flow-rate = 0.000340281 m ^ 3/s, Headloss = 0.682979 m, and Velocity = 0.634233 m/s (Turbulent Flow)

For Pipe 3, Diameter = 0.0120142 m, Flow-rate = 0.000154994 m ^ 3/s, Headloss = 6.95355 m, and Velocity = 1.36721 m/s (Turbulent Flow)

For Pipe 4, Diameter = 0.034544 m, Flow-rate = -0.00150001 m ^ 3/s, Headloss = -2.48859 m, and Velocity = 1.60051 m/s (Turbulent Flow)

For Pipe 5, Diameter = 0.0261366 m, Flow-rate = -0.000915378 m ^ 3/s, Headloss = -3.925 m, and Velocity = 1.70613 m/s (Turbulent Flow)

For Pipe 6, Diameter = 0.040386 m, Flow-rate = -0.00146971 m ^ 3/s, Headloss = -3.05756 m, and Velocity = 1.14731 m/s (Turbulent Flow)

For Pipe 7, Diameter = 0.040386 m, Flow-rate = -0.00223963 m ^ 3/s, Headloss = -6.4859 m, and Velocity = 1.74833 m/s (Turbulent Flow)

For Pipe 8, Diameter = 0.0519938 m, Flow-rate = -0.00257038 m ^ 3/s, Headloss = -2.47058 m, and Velocity = 1.21061 m/s (Turbulent Flow)

For Pipe 9, Diameter = 0.101549 m, Flow-rate = 0.0145547 m ^ 3/s, Headloss = 1.26181 m, and Velocity = 1.79705 m/s (Turbulent Flow)

For Pipe 10, Diameter = 0.0894334 m, Flow-rate = 0.0128997 m ^ 3/s, Headloss = 1.23149 m, and Velocity = 2.05348 m/s (Turbulent Flow)

For Pipe 11, Diameter = 0.0894334 m, Flow-rate = 0.00977501 m ^ 3/s, Headloss = 0.746284 m, and Velocity = 1.55606 m/s (Turbulent Flow)

For Pipe 12, Diameter = 0.101549 m, Flow-rate = 0.00812001 m ^ 3/s, Headloss = 0.290342 m, and Velocity = 1.00257 m/s (Turbulent Flow)

For Pipe 13, Diameter = 0.101549 m, Flow-rate = 0.00422538 m ^ 3/s, Headloss = 0.0903151 m, and Velocity = 0.521702 m/s (Turbulent Flow)

Result Set 2:

For Pipe 1, Diameter = 0.0204216 m, Flow-rate = 0.000636592 m ^ 3/s, Headloss = 7.87032 m, and Velocity = 1.94353 m/s (Turbulent Flow)

For Pipe 2, Diameter = 0.0261366 m, Flow-rate = -0.00101841 m ^ 3/s, Headloss = -4.74693 m, and Velocity = 1.89816 m/s (Turbulent Flow)

For Pipe 3, Diameter = 0.0261366 m, Flow-rate = 0.000304486 m ^ 3/s, Headloss = 0.562191 m, and Velocity = 0.567518 m/s (Turbulent Flow)

For Pipe 4, Diameter = 0.040386 m, Flow-rate = -0.00135051 m ^ 3/s, Headloss = -0.976853 m, and Velocity = 1.05426 m/s (Turbulent Flow)

Table 8 Cont'd

For Pipe 5, Diameter = 0.040386 m, Flow-rate = -0.000793744 m^3/s, Headloss = -0.381219 m, and Velocity = 0.619625 m/s (Turbulent Flow)

For Pipe 6, Diameter = 0.062103 m, Flow-rate = -0.00297789 m^3/s, Headloss = -1.37166 m, and Velocity = 0.983092 m/s (Turbulent Flow)

For Pipe 7, Diameter = 0.062103 m, Flow-rate = -0.00221177 m^3/s, Headloss = -0.807535 m, and Velocity = 0.730172 m/s (Turbulent Flow)

For Pipe 8, Diameter = 0.0772668 m, Flow-rate = -0.00244874 m^3/s, Headloss = -0.340576 m, and Velocity = 0.522237 m/s (Turbulent Flow)

For Pipe 9, Diameter = 0.101549 m, Flow-rate = 0.0159134 m^3/s, Headloss = 1.48289 m, and Velocity = 1.96481 m/s (Turbulent Flow)

For Pipe 10, Diameter = 0.127406 m, Flow-rate = 0.0142584 m^3/s, Headloss = 0.268834 m, and Velocity = 1.1184 m/s (Turbulent Flow)

For Pipe 11, Diameter = 0.153187 m, Flow-rate = 0.00962551 m^3/s, Headloss = 0.0548416 m, and Velocity = 0.522261 m/s (Turbulent Flow)

For Pipe 12, Diameter = 0.127406 m, Flow-rate = 0.00797051 m^3/s, Headloss = 0.0946257 m, and Velocity = 0.625193 m/s (Turbulent Flow)

For Pipe 13, Diameter = 0.101549 m, Flow-rate = 0.00410374 m^3/s, Headloss = 0.0857399 m, and Velocity = 0.506684 m/s (Turbulent Flow

Table 9: Optimal Network Solution with assumed flow direction (Sodiki & Ifiemi et al, 2019)

	Diameter (D) (m)	Nominal size (inch)	Flow rate (Q) (m^3/s)	node direction	Flow type
1	0.062103		0.0067375	1-2	turbulent
2	0.0519938	2	0.0050825	2-3	turbulent
3	0.0519938	2	0.00468377	3-4	turbulent
4	0.0519938	2	0.00302877	4-5	turbulent
5	0.0519938	2	0.00148161	5-6	turbulent
6	0.040386	1 ½	0.00125627	3 8	turbulent
7	0.0152908	½	-0.000107847	5-10	turbulent
8	0.0204216	¾	-0.000173387	6-11	turbulent
9	0.0772668	3	0.0098125	1-7	turbulent
10	0.0772668	3	0.0081575	7-8	turbulent
11	0.062103	2 ½	0.00524623	8-9	turbulent
12	0.0519938	2	0.00359123	9-10	turbulent
13	0.040386	1 ½	0.00182839	10 11	turbulent

vii. Energy Audits: These were done in various building types (factories, residencies, offices, hotels, hospitals, schools, etc.) for energy economics studies. Examples are reported in Green et al (2019) and Salihu et al (2021). Figs. 23 and 24 illustrate an energy audit outcome.

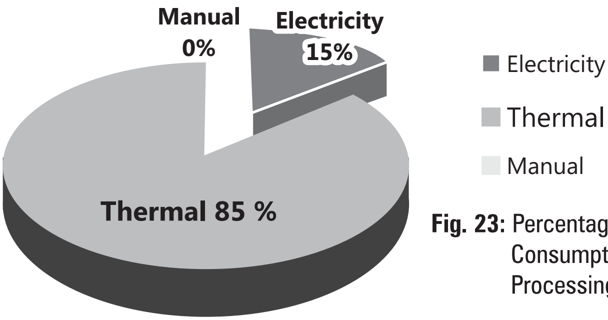


Fig. 23: Percentages of Total Energy Consumption in Wheat Flour Processing (Green et al, 2019)

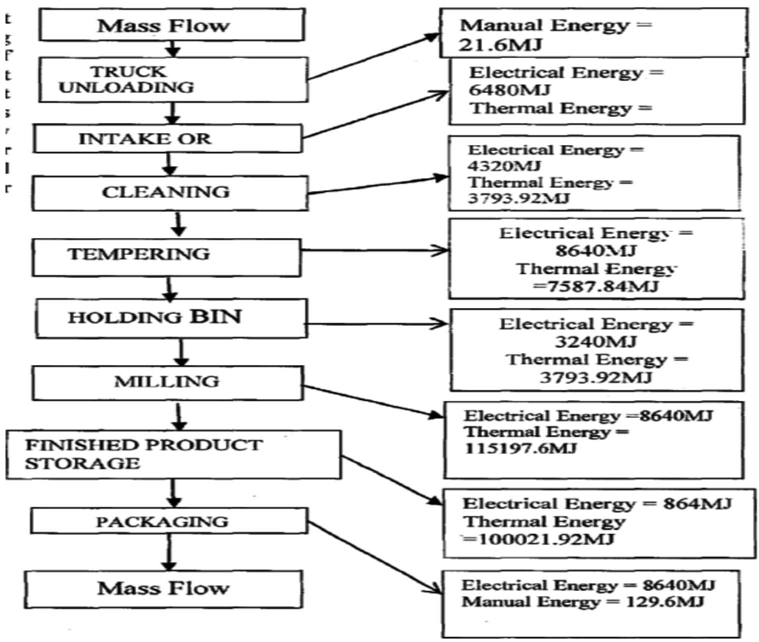


Fig. 24: Energy Balance Diagram of Wheat Flour Production (Green et al, 2019)

viii. Studies on Renewable Energy Systems: Examples are reported in Sodiki (2014b) and Gbarabe & Sodiki (2021). Using such data as provided in Figs. 25 to 27, results such as Figs. 28 and 29, and Table 10 were obtained, for a case of solar energy utilization for rural water supply.

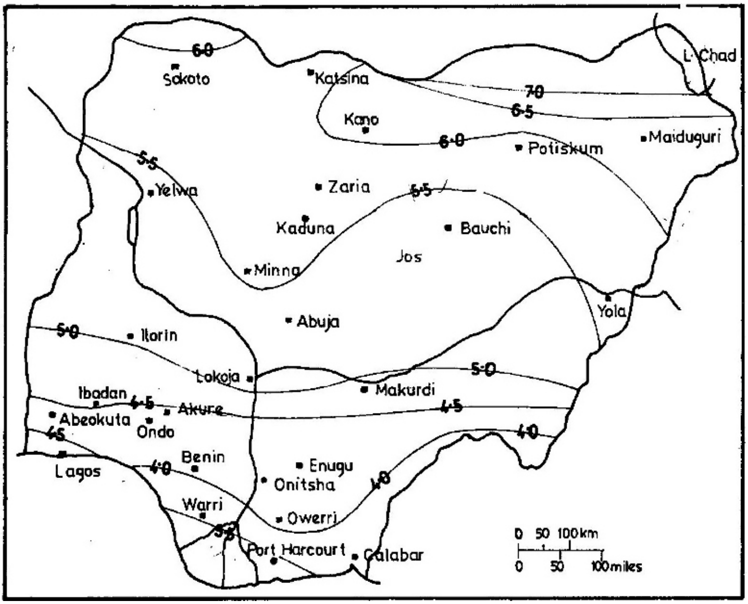


Fig. 25: Annual Average of Global Solar Radiation in Nigeria [kwh/m2/day] (Ojosu, 1988)

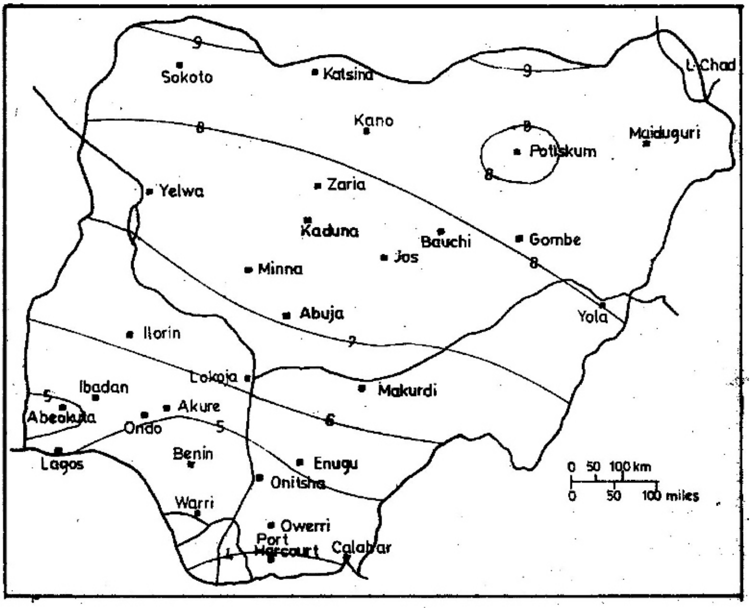


Fig. 26: Annual Average of Daily Sunshine in Nigeria (Ojosu, 1988)

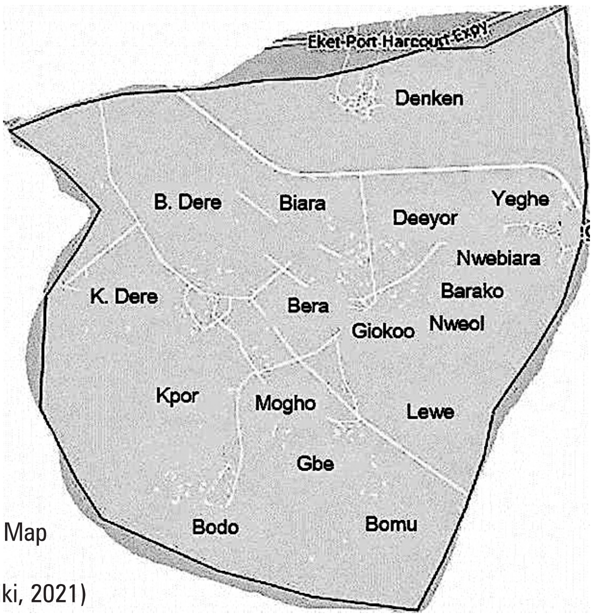


Fig. 27: Google Satelite Map of Gokana (Gbarabe & Sodiki, 2021)

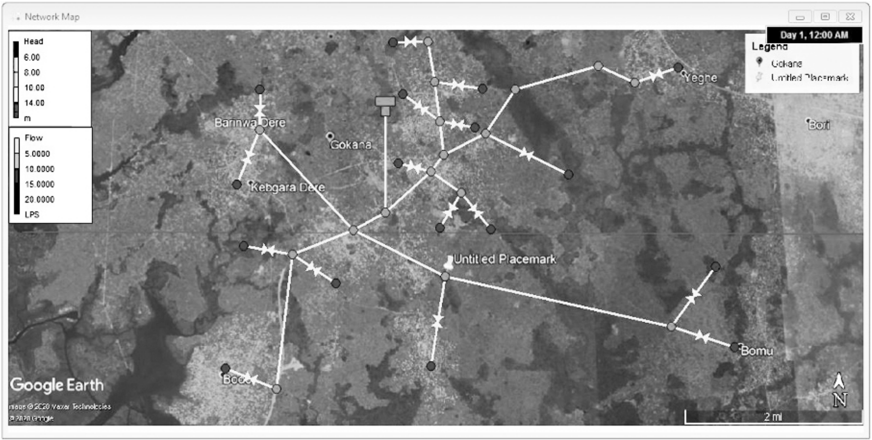


Fig. 28: EPANET Simulation of Pressure and Flow in Distribution System (Gbarabe & Sodiki, 2021)

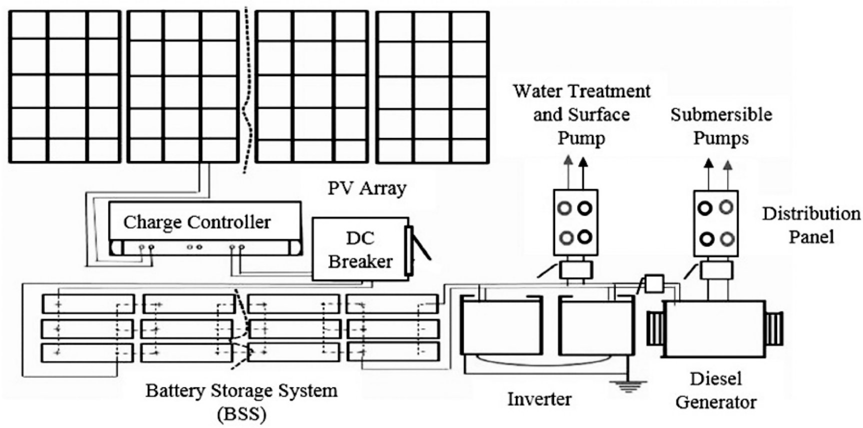


Fig. 29: Schematic Diagram of Hybrid Energy System (Gbarabe & Sodiki, 2021)

Table 10: Summary Bill of Engineering Measurements and Evaluations of the Reengineered Rural Water Scheme (Gbarabe & Sodiki, 2021)

S/N	Description	Qty	Rate(N)	Cost(N)
1	Preliminaries/ Community Engagement and Mobilization		Provisional Sum	1, 000,000
2	Pipe Work/Rehabilitation of Existing Pipe Network		Lump Sum	2,000, 000
3	Provision/Installation of 21900m3 Raw Water Tank	1	Lump Sum	15, 000,000
4	Rehabilitation of Existing Overhead Treated Water Tank	1	Lump Sum	200,000
5	Provision/Installation of 15kW Water Treatment Plant	1	Lump Sum	27,700,000
6	Provision/Installation of Additional 40hp Submersible pumps	10	790,440	790, 440
7	Provision / Installation of 8kW / Surface Pump	1	458500	458, 500
8	Provision/Installation of 770kW diesel generator	1	52,500,000	52, 500, 000
9	1956 x 995 x 40mm Solar Panels	243	45000	10,935, 000
10	100A Charge controller	1	66,420	66, 420
11	50kVA Inverter	2	900,000	1, 800,000
12	48V, 250Ah Battery	63	245,590	15, 472, 170
13	DC Breaker	1	9000	9,000
14	AC Breaker	3	4500	13, 500
15	Distribution Panel	2	92,000	184,000
16	Cable and Accessories		Lump Sum	2,000,000
17	Solar Installation Labour		Provisional Sum	200,000
18	Miscellaneous		Provisional Sum	1,000,000
	Total			**131, 329, 030**

ix. Performance Evaluation of Thermo-Fluid Industrial Equipment (Turbines, Boilers, Heat Exchangers, etc.): These were executed by the inaugural lecturer with his postgraduate students and colleagues as reported in Igoma et al (2016); Isah et al (2019), Gbonee et al (2019); Bala et al (2021), Jumbo et al (2021) and Davids et al (2021). Tables 11 to 13 and Fig. 30 provide some insight to the evaluation exercise carried out on gas turbine plants; while Table 14 provides same for industrial boilers.

Table 11: Turbine Design Parameters (Igoma et al, 2016)

S/N	Parameters	Units	Design Data
1	Power Output	MW	25.0
2	Thermal Efficiency	%	26.6
3	Heat Rate	Kcal/W·h	2.833
4	Specific Fuel Consumption	Kg/KW·h	0.308
5	Ambient Temperature	°C	25.0 - 45.0
6	Specific Heat at Constant Pressure of gas	KJ/KgK	1.155
7	Specific Heat at Constant Pressure of Air	KJ/KgK	1.005
8	Isentropic Constants for air	None	1.40
9	Isentropic Constants for gas	None	1.33
10	Mass Flow Rate of air	Kg/s	122.9

Table 12: First Set of Calculated Turbine Working Parameters (Igoma et al, 2016)

S/N	T_1°C Ambient Temperature	T_2°C Compressor Exit Temperature	T_3°C Turbine Inlet Temperature	T_4°C Exhaust Temperature	$\dot{m}_f$ (kg/s) Fuel Supply	$\dot{W}_c$ (KW) Compressor Work	$\dot{W}_T$ (KW) Turbine Work	$\dot{Q}_{add}$ (KW) Heat Supplied	$\dot{W}_{net}$ (KW) Net Work	AFR Air Fuel Ratio	η_{th}(%) Thermal Efficiency	SFC (kg/KWh) Specific Fuel Consumption	HR (KCal/W·h) Heat Rate	(MW) Power Output
1	25	240	1017	378	2.60	26,556	1670	98,002	24,886	0.485	25.39	0.298	3.94	11.14
2	26	242	1025	382	2.62	26,679	1693	98,774	24,986	0.481	25.30	0.300	3.95	11.14
3	27	244	1032	384	2.64	26,803	1719	99,420	25,084	0.478	25.23	0.300	3.96	11.13
4	28	246	1041	385	2.66	26,926	2015	100,319	24,911	0.474	24.83	0.305	4.03	11.13
5	29	247	1045	387	2.67	26,926	2029	100,706	24,897	0.472	24.72	0.306	4.05	11.13
6	30	248	1049	390	2.68	26,926	2040	101,093	24,886	0.470	24.62	0.308	4.06	11.13
7	31	250	1054	392	2.69	27,050	2054	101,479	24,996	0.470	24.60	0.308	4.06	11.12
8	32	254	1092	394	2.80	27,420	2257	105,863	25,163	0.449	23.77	0.319	4.20	11.11
9	33	257	1101	388	2.82	27,667	2322	106,638	25,345	0.445	23.77	0.319	4.20	11.10
10	34	258	1127	400	2.90	27,667	2435	109,867	25,232	0.432	22.97	0.330	4.35	11.09
11	35	260	1135	389	2.92	28,451	2516	110,643	25,935	0.430	23.44	0.322	4.27	11.08
12	36	262	1156	388	2.98	28,591	2643	113,099	25,948	0.420	22.94	0.330	4.36	11.07
13	37	265	1165	379	3.00	28,849	2724	113,877	26125	0.418	22.94	0.330	4.36	11.04

Table 13: Second Set of Calculated Turbine Working Parameters (Igoma et al, 2016)

S/N	Ambient Temperature (°C)	Percentage of Power Output (%)	Power Differential (%)	Percentage of Thermal Efficiency (η_{th}) (%)	Percentage of Specific Fuel Consumption (*SFC*) (%)	Percentage of Heat Rate(*HR*) (%)
1	25	44.56	55.44	95.45	96.75	139.08
2	26	44.56	55.44	95.11	97.40	111.90
3	27	44.52	55.48	94.85	97.40	139.78
4	28	44.52	55.48	93.35	99.03	142.25
5	29	44.52	55.48	92.93	99.35	142.96
6	30	44.52	55.48	92.56	100.00	142.31
7	31	44.48	55.52	92.48	100.00	142.31
8	32	44.44	55.56	89.36	103.57	148.25
9	33	44.40	55.60	89.36	103.57	148.25
10	34	44.36	55.64	86.35	107.14	153.55
11	35	44.32	55.68	88.12	104.54	150.72
12	36	44.28	55.72	86.24	107.44	153.90
13	37	44.16	55.84	86.24	107.44	153.90

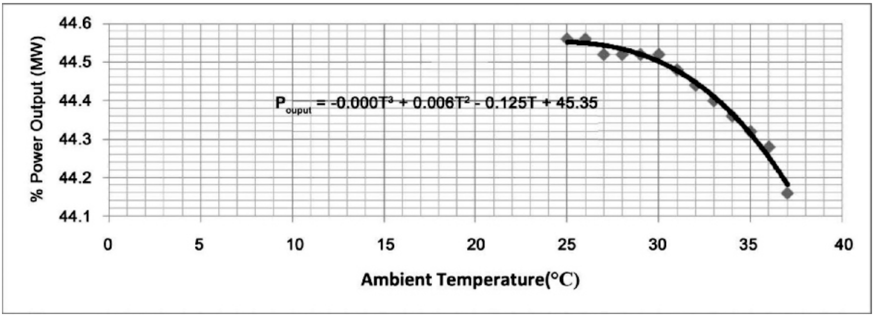


Fig. 30a: Effect of Ambient Temperature on Power Output

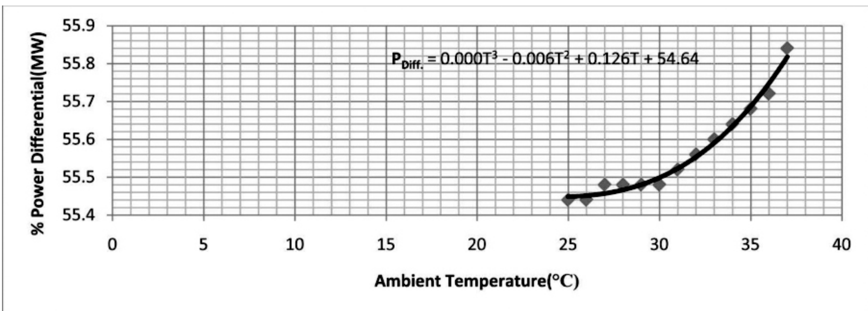


Fig. 30b: Effect of Ambient Temperature on Power Differential

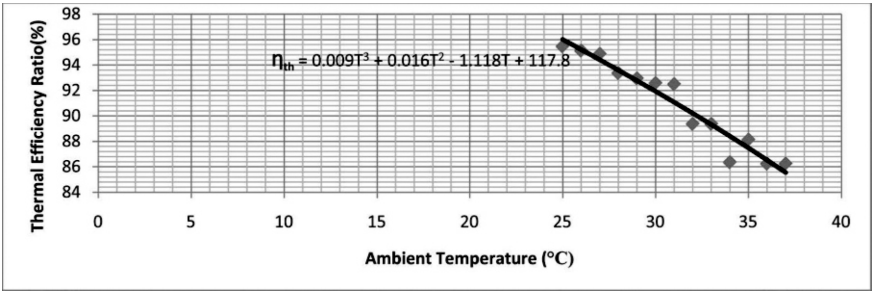


Fig. 30c: Effect of Ambient Temperature on Thermal Efficiency Ratio

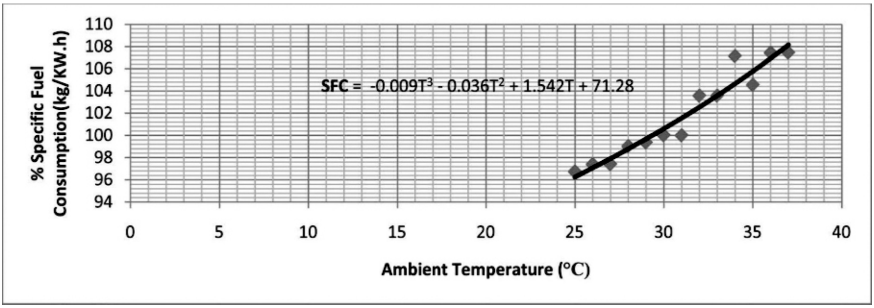


Fig. 30d: Effect of Ambient Temperature on Specific fuel Consumption

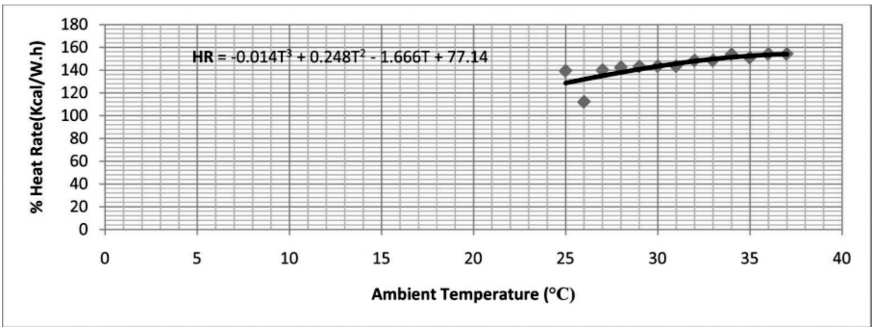


Fig. 30e: Effect of Ambient Temperature on Heat Rate

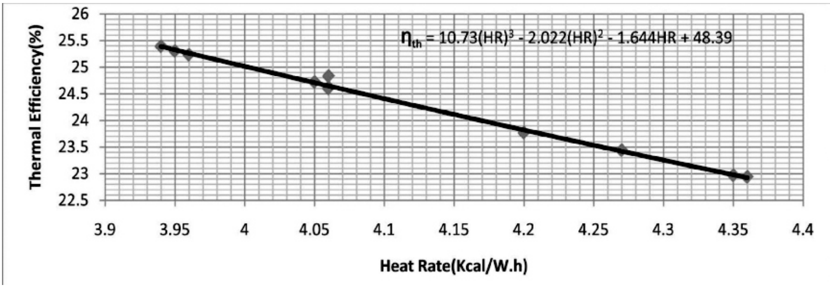


Fig. 30f: Effect of Ambient Temperature on Thermal Efficiency

Fig. 30: The Effect of Ambient Temperature on Gas Turbine Performance

Table 14: Comparative Values of Performance Indices of Two Boilers in a Fertilizer Plant (Isah et al, 2019)

S/NO	PARAMETERS	UNITS	CALCULATED VALUES STAGE 1	CALCULATED VALUES STAGE 2	DESIGN VALUES	DEVIATIONS FROM DESIGN VALUES STAGE 1	DEVIATIONS FROM DESIGN VALUES STAGE 2	% DEVIATION OF STAGE 1 FROM STAGE 2
1	Heat duty (Q_a)	kW	16843	31729	52500	67.92	39.56	46.92
2	Overall heat transfer coeff. (U_0)	W/m^2K	202.9	480.97	550.24	63.13	12.59	57.81
3	Capacity ratio (R)	-------	1.31	1.13	1.08	17.56	4.42	13.74
4	Effectiveness (P)	——	0.18	0.34	1.5	88	77.33	47.06
5	Temp. range of hot fluid (ΔT_h)	K	15.29	25	88	82.63	71.59	38.84
6	Temp. range of cold fluid (ΔT_c)	K	11.69	22	66	82.29	66.67	46.86
7	Temp. eff. Of hot fluid (ε_h)	%	23.43	38.35	95.3	75.41	59.76	38.90
8	Temp. eff. Of cold fluid (ε_c)	%	17.92	33.88	97.3	81.58	65.18	47.11
9	Pressure drop shell-side(ΔP_S)	kpa	7.053	6.37	2.35	66.68	63.11	9.68
10	Pressure drop tube-side(ΔP_t)	kpa	254.61	240.39	170	33.23	29.28	5.59
11	$LMTD_C$	K	51.59	41	35.65	30.90	13.05	20.53
12	FOULING FACTOR	m^2K/W	0.0048	0.002	0.0005	89.58	75	58.33

Vice Chancllor Sir,

There are several other areas in which the inaugural lecturer has contributed to theory and practice of Thermo-Fluids and Building Services Engineering, as evidenced in over one hundred number of scholarly publications to date. Further research works are ongoing, in conjunction with his postgraduate students and colleagues.

6.0 CONCLUSION AND RECOMMENDATIONS

Vice Chancellor Sir, in a few pages, the main subject areas of Thermo-Fluids Engineering; namely Engineering Thermodynamics, Heat Transfer, Fluid Mechanics, Mass Transfer and Combustion Engineering have been introduced. The relationship between Thermo-Fluids and Building Services Engineering has been drawn. Also the roles and possible career directions of the engineer have been listed.

Furthermore, the inaugural lecturer's contributions to theory and practice of Thermo-Fluids and Building Services Engineering have been illustrated.

Vice Chancellor Sir, as a Professor of Thermo-Fluids and Building Services Engineering, I make the following recommendations for improving the training and entrepreneurship foundation of the engineer, as well as for the proper management of thermo-fluid and building services installations by relevant authorities:

i. Building Services Engineering consultancy practice is one enterprise which is not too financially demanding to set up, requiring mainly books (including codes of practice) and design and draughting software. Therefore, to engender an entrepreneurship foundation for our graduates, the Mechanical and Electrical Engineering university curricula should include and emphasize such courses as Acoustics, Fire, Vertical Transportation (Lifts) and Drainage; Building Heat

Transfer and Air Conditioning; Energy Conversion Technologies; Building Management and Control Systems; and Lighting Design

ii. In order to improve the reliability and availability of plant and machinery in Nigeria, industries should partner with the academia to set up and execute performance evaluation programmes for these assets.

iii. As building services constitute the dynamic elements in static structures, they are more prone to requiring maintenance attention than the latter. Therefore, these services should be assessed periodically, especially requiring government and other authorities to set up departments with such responsibilities for public buildings and similar facilities.

iv. For the same reason as in iii above, government approvals of designs for construction and installation of building services and similar facilities should follow strict quality control procedures.

v. Lending a voice to the issue of funding, governments at various levels are called upon to better equip the laboratories and workshops in our academic institutions, in order to improve the quality of the products – the graduates.

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