Climate Change Induced Architectural Practice: Responsive Technological Integration for Sustainable Design Solutions

S.A. Olaniyan, O.O. Soyebo, J.O. Oyadokun

Abstract— Increasing urbanisation arising from continuous population and economic growths translate to additional infrastructure, facilities and buildings, to accommodate the emerging needs of the people. However, this is not without its attendant adverse climate change induced anthropogenic effects, largely due to increasing carbon emissions into the atmosphere. Thus, Architects who design such structures need to be weary of the impacts of their products on the environment, and evolve sustainable design solutions to combat any potential undesirable effects. Through literature review, with reference to specific pragmatic cases for illustrations, this paper therefore examines how climate change challenges have influenced architectural practice particularly, integration of emerging technologies, to evolve sustainable design solutions for a healthy environment.

Index Terms— Anthropogenic, Architecture, Building Simulation, Carbon Emission, Climate Change, Environment, Renewable Energy.

1 Introduction

ONE of the issues dominating the centre stage at the global level relates to the adverse Climate Change induced anthropogenic effects, largely due to increasing amount of carbon emissions into the atmosphere, for which the construction industry is significantly involved [1]. Environmental problems that used to be minimal and local in the middle of the previous century have now assumed a global dimension affecting every nation, and threatening all living creatures. Thus the search for solutions to climate change induced challenges and its attendant increase in atmospheric carbon dioxide, rising temperatures, and melting plant cover has accelerated [2]. This position is asserted by the Fifth Assessment Report of the International Panel for Climate Change [3] which states that the anthropogenic greenhouse gas emissions are now the highest in history. It further affirms human influence on the climate system largely due to population and economic growths. Thus, Urbanization and climate change are closely related as the urban built-up areas are expected to increase by 250% and cover about one million square kilometers by 2030 [4], [5]. Also, over the next 40 years, the world's urban population is projected to increase by more than three billion people [6]. Meanwhile, the addition of human population requires new infrastructures, facilities and buildings to accommodate their needs. Buildings for example, have an enormous and continuously increasing impact on the environment, using about 40% of natural resources extracted in industrialized countries, utilising nearly 70% of electricity, consuming 12% of potable water, and producing between 45% and 65% of the waste disposed in landfills [7]. Moreover, they are responsible for a large amount of harmful emissions, accounting for 30% of greenhouse gases (due to their operation), and an additional 18% caused indirectly by material exploitation and transportation [8], [9], [10]. Thus, Architects who design some of these facilities, buildings, etc. need to be weary of the impacts of their products on the environment and evolve sustainable designs that minimize the use of earth's resources, consume less energy, emit less carbon, produce less waste, and support the quality of human life to have a safe, healthy and comfortable living environment [7], [11].

Within architectural practice, sustainable design is a collective process whereby the built environment achieves unprecedented levels of ecological balance through new and retrofit construction, with the goal of long-term viability and humanization of architecture [11]. Focusing on the environmental context, sustainable design merges the natural, minimum resource conditioning solutions of the past (daylight, solar heat, and natural ventilation) with the innovative technologies of the present. The desired result is an integrated "intelligent" system that supports individual control with expert negotiation for resource consciousness [11]. Sustainable design of architecture and communities emerge as an approach to protect and improve the biological health of communities conceived as the ecology of building, site, and region. It is a necessary response to the increased severity of natural disaster [12]. The drive towards a sustainable built environment raises challenges for practitioners. These challenges stem from the need to reduce energy consumption, integrate clean energy supplies and mitigate environmental impacts, while meeting expectations for human wellbeing and economic growth [13]. Thus, the construction industry has a crucial role to play on carbon efficiency and its measurements throughout the construction life cycle. Building professionals particularly Architects, should be conscious of their design decisions from inception through ingenious use of appropriate materials and construction methods, integrated with evolving technology, with a

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view to creating sustainable environmentally responsive designs. From architectural point of view, this submission therefore highlights some of the steps adopted in addressing the climate change related challenges through responsive technological integration for sustainable design solutions. These steps are presented in a five-way sustainable approach of *Integration of Renewable Energy Sources, Application of Building Information Modelling, Introduction of Building Performance Simulation, Computational Design Integration,* and *Application of Computational Fluid Dynamics.*

2 Methodology

This submission adopts a literature review approach with case studies of specific practical architectural examples. Such examples are obtained from authors' previous works and additional materials from relevant secondary data source.

3 Approaches to Responsive Technological Integration for Sustainable Design Solutions

The science of building and urban climatology can fully inform steps to address climate change challenges, so that the natural ecology of a region is returned to its original role in moderating the weather extremes, for sustainable design solutions [12]. From theoretical architectural practice, one major approach is adoption of Passive Design technique in which a well-insulated building is primarily designed to avoid heat gain through adequate shading and window orientation, thereby limiting any cooling load. The key to this approach is to take best advantage of the local climate. It involves working with natural resources efficiently, instead of relying predominantly on 'active' systems. Elements to be considered include window placement and glazing type, thermal insulation, thermal mass, and shading. The technique can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted". A passive house is a very economical low-energy house as it provides high quality internal environment while allowing significantly reduced energy consumption for heating and running at all times. The building does not require conventional heating or air conditioning and saves the economy of its natural resources as it reduces CO_2 emissions [14], [15].

However, integration of the evolving technologies has a significant impact in addressing the challenge more holistically. Technologies involving Renewable energy and computer applications particularly, computer simulations and other computational techniques have been widely and successfully applied to building design, optimization, construction, operation, and research. These techniques are credited to accelerate the design process and optimize building performance with relatively low cost. Before the wide availability of computer-aided simulation, building designers and engineers relied mainly on manual calculations and resorted to the "rule of thumb" methods and extrapolations in extending a design beyond conventional concepts [16], [17]. Thus, within this context, the following approaches involving responsive collaborative integration of technological innovations are presented in turn:

3.1 Integration of Renewable Energy Sources

Concerns about running out of resources, especially coal and oil, and about the environmental/atmospheric pollution they cause, have raised interest in exploring the use of clean, renewable energy sources [2]. Renewable energy refers to "energy that is produced by natural resources—such as sunlight, wind, rain, waves, tides, and geothermal heat— that are naturally and constantly replenished and can be harnessed for human benefits [18]. This is also extended to cover energy from replaceable matters such as wood or other plant materials [19]. Accordingly, all technologies that are able to convert natural resources (e.g., solar) to any kind of energy could help in the generation of renewable energy. It is commonly regarded as a 'Clean Technology' even though there might be one form of impacts or the other ranging from visual (in the case of wind rotors) to noise. At the global level, interest in renewable energy has surged due to impressive technical advances, environmental pressures as well as loss of faith in nuclear power among others [20], [21]. Of the two major relevant renewable energy sources are 'Solar Energy' and 'Wind Power'. Solar energy is derived from the sun through conversion of sunlight into direct electricity by installing free standing or roof mounted framed 'photovoltaic solar panels'. This may also entail using 'concentrated solar power' which uses lenses or mirrors to focus a large area of sunlight into a small beam for electric power production, applicable in heating swimming pools, water or air for residential and commercial use. For ease of integration within building fabrics, panels/modules may replace building components such as curtain walls, roof tiles, atria, structural glazing or vertical walls. On the other hand, 'Wind Power' is a technique through which airflows are utilized to run 'Wind Turbines' for power generation in areas where winds are stronger and constant (such as offshore and high altitude sites). Provisions can be made for medium sized installations directly in buildings [1].
It should be noted that apart from the renewable energy sources listed above, research works are still ongoing on other areas of interest which may be inclusive of (but not limited to) the possibility of exploiting Tidal Energy, Wave Energy, Ocean Salinity Gradients, High Altitude Atmospheric Jet Streams as well as Extra-Terrestrial Solar Flux [22]. For a practical illustration, Figure 1 illustrates integration of some Renewable Energy Sources (including Wind Turbines, photovoltaic panels and solar thermal collectors) into a three-dimensional Architectural Design Proposal for a particular Tropical site in Lagos, Nigeria.

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Fig. 1. Three-dimensional illustration of some potential Renewable Energy Sources into a residential Architectural Design Proposal for a site located in Lagos, Nigeria (source: Author's draft, May-2012)

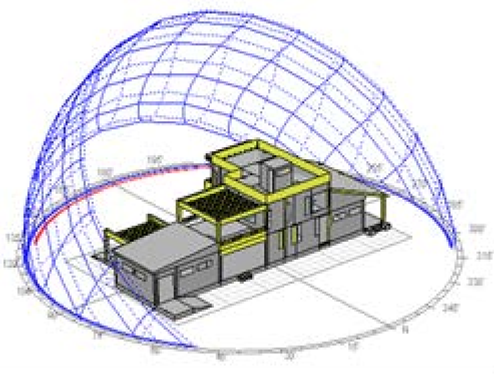
3.2 Application of Building Information Modelling

As interest in sustainable design increases and energy costs rise, Building Information Modelling (BIM) revolutionises construction to become a high-tech industry affecting how buildings are designed, built, and operated [23]. BIM is a technology based, rich integrated digital representation of physical and functional characteristics of a facility, consisting of multiple data sources, elements of which can be shared across all building stakeholders, and maintained across the life of a building (from inception to recycling). It offers significant benefits inclusive of cost reduction, compliance checking, better project management and particularly, entire carbon impact analysis, to name a few [23], [24], [25]. It is an innovative technology, suitable for collaborative delivery of information needed for improved sustainable building design and performance, through integrated project delivery and design optimization, using relevant BIM-based analysis tools such as TRACE700, eQUEST, Revit, etc. [1]. Energy analysis and modelling are just a few ways that BIM results in a more efficient building as it can help architects predict energy costs and understand how the design will impact energy use. It also provides architects with infinite creative freedom, increases the accuracy of drawings and streamlines the coordination of construction documents [23], [26].

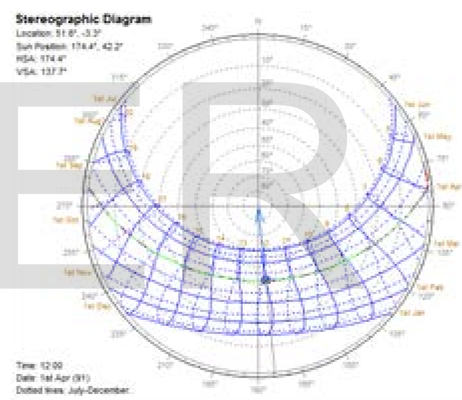
The cornerstone of BIM is the process of creation and joint use of three-dimensional model of the construction project by all the participants of the construction process. It should be noted that the possibilities of this technology are much wider than the creation of a 3D model for visualization and development of the project documentation alone: it allows carrying out complex accumulation and handling of all architectural designs, as well as other technological and economic issues on the project, during design, construction, and subsequent maintenance periods, in a common information space collection [27]. In general, BIM is considered as one of the responsive technological approaches utilised by Architects and other building stakeholders towards delivering sustainable design solutions.

3.3 Introduction of Building Performance Simulation

With the current emphasis on sustainability, including building energy and indoor environment, design requirements from the disciplines involved have become more important in the early design stages. As a consequence, building performance simulations (BPSs) are increasingly used to design buildings [28]. It involves assembling a virtual replica of a proposed building thereby estimating the energy use and operating cost by simulating its performance through the weather of an entire year, in the specified location as illustrated in figures 1a & 1b.



(a)

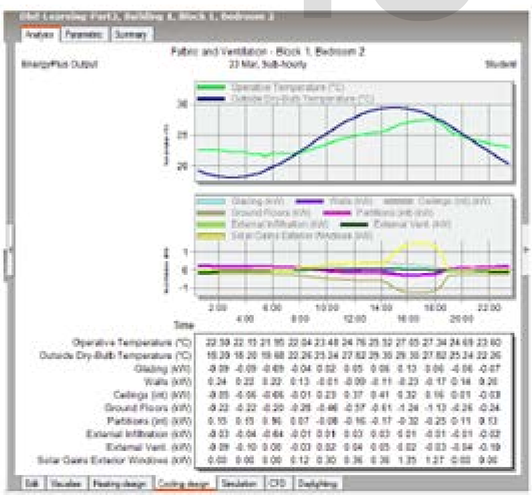


(b)

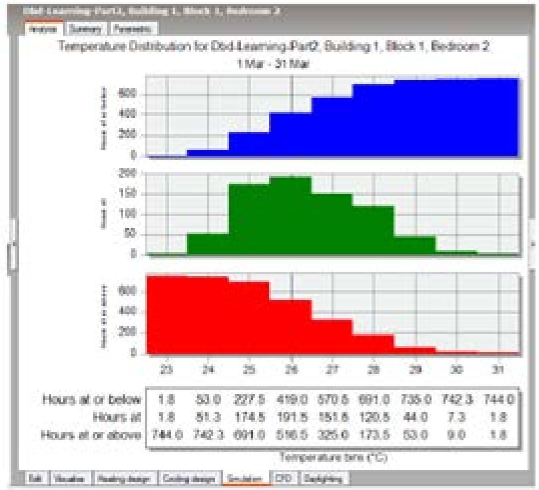
Figures 1(a) & (b): illustrating Annual Sun-path and Annual Stereographic Diagram of a typical location respectively, using Ecotect interface (source: [29])

The technology allows building practitioners to routinely model the interacting heat, air, moisture, light, sound, electricity, pollutant and control signal flows, and thereby nurture performance improvement by design. Software packages for building energy performance simulation carry out numerous and complex calculations (through some relevant equations) that, when combined, describe how buildings use energy. It provides valuable information that helps designers make better decisions about the characteristics of building envelope components, glazing, lighting, and HVAC systems. The approach can be used to ensure requisite levels of comfort and indoor air quality; to devise energy efficiency and demand management solutions; to embed new and renewable energy technologies; to lessen environmental impact; to ensure conformance with legislative requirements, and; to formulate energy action plans at any scale [13], [30]. It is a collaborative way to quantitatively predict the future performance of a building in respect of carbon emissions. This allows architects, engineers and other building professionals to compare alternative design solutions and select the best with regard to annual carbon di-oxide emissions and life cycle payback. This is achievable through its Load Design mechanism which determines cooling/heating energy need, volumetric air flow requirements, equipment capacities, supply temperatures, etc. and, Energy-Analysis tool which predicts annual/monthly energy consumption and cost. Several appropriate software inclusive of Ecotect, Anthermc, DesignBuilder, eQUEST, TRACE 700, IES, TAS, etc. [31] can be used for these simulation purposes. In doing this, relevant information in respect of the anticipated location, building materials/components (i.e. walls, windows, u-values, shading coefficients, etc.), operational pattern, interior load values (Lighting, Plug Loads, Occupant numbers and Activity Level), among others, must be adequately provided [24], [32], [33].

Fig. 2 (a & b) represent typical results of such analyses as obtained from DesignBuilder energy tool [31]. In this case, the results represented in forms of graphs, Charts and Tables are interpreted for necessary actions. This involves repeated cycles of critical evaluations of building components' behavioural patterns with a view to replacing any (if necessary), for overall anticipated improved building performances. It is often the case that a few building simulations run in the early phases of a project can lead to design solutions that, though appear simple, significantly improve building energy performance [34].



(a)



(b)

Fig. 2 (a & b). Typical results of a simulation as captured on DesignBuilder Interface (source: [29])

As a response to the climate change related challenges, and an attempt at achieving sustainable design solutions, designers often use these thermal simulation programs to analyse thermal and energy behaviours of a building towards achieving specific targets especially, reduction of energy consumption and environmental impacts, as well as improving indoor thermal environment [32].

3.4 Computational Design Integration

Computational design is a design approach that operates mostly through the facilities of mathematical thinking due to the calculation skills of computers. It requires a mode of thinking, based on well-defined steps, algorithms and parameters, which necessitates a design strategy to be developed at the initial phase of design process [35], [36]. It is the discipline of applying computational approaches to design problems, whether related to presentation, analysis or aesthetic expression [37]. In some other contextual framework, it is referred to as 'Parametric Design', which implies a mode of thinking based on well defined steps, algorithms or use of parameters to define a form through either relational, variational or constraint based design technique, involving dozens of possible scripting or programming languages used to conceive and code the project work [38]. It involves setting up a parametric model through an understanding of associative geometry in which the constituting elements are referenced to each other using a number of clearly defined variables and constraints. Thus, the completed model can be changed, modified and regenerated, while conforming to the pre-set conditions. As such, a parametric model can be updated by changing the values of the parameters while keeping the relations [35].

Goals of the research within this context include among others: automatic generation of a range of design alternatives; sparkling creativities and innovations; creation of automated tools to solve tedious or time-consuming engineering tasks, and; academic curiosity in exploring the potential creative abilities of computational systems. In its advanced stage, it is also being employed in the analysis of the building energy consumption and estimation of potential carbon emission likely to arise from the use of the structure. The parameters such as sun altitude angles, climatic data, structural limits or acoustic pre-requisites are also essential aspects of design that can be computed in association to each other [39]. In a way, this is sometimes brought about through division, assemblage, machining or modelling of surfaces by software that are entirely surface-oriented with its underlying mathematics [40]. In doing this, application of relevant software in form of specifically related design programming language, which may be inclusive of *Processing, Generatorx,* among others, is employed. For the purpose of this submission, *Processing* is employed as a required spring board to make a launch in this regard. *Processing* is an open source programming language and environment for people who want to create images, animations, and interactions as it provides a contextual framework for exploring the emerging conceptual space enabled by electronic media [41]. It is an environment for learning the fundamentals of computer programming within the context of the electronic arts as well as serves as an electronic sketchbook for developing ideas. As a typical illustration, the programming codes below is run on *Processing* computational Software to generate fig. 3.

```
import processing.opengl.*;
import anar.*;

/**
 * @author lluj
 *
 */
Group importGroup;
//Group importGroup2;
Group importGroup3;
Group newbuilding = new Group();
Group newbuilding2 = new Group();
//Group newbuilding;

Sun sun;
//Group parametric;
Group Shade;
Group Shade1;
Group Shade2;
Group Shade3;

String file = "building.obj";
String file2 = "t2.obj";
String file3 = "sketchup_topo_tower5.obj";
int counting;

void setup() {
  size(800,400,OPENGL);
  Anar.init(this);

  //Anar.globalScale(Anar.METERS);
  Anar.drawAxis();
  OBJLoader.debug = true;

  Pts.globalRender = new RenderPtsAll();

  OBJLoader.mergeIdenticalPoints = true;

  importGroup = new OBJLoader(sketchPath(file)).main;
  //importGroup2 = new OBJLoader(sketchPath(file2)).main;
  importGroup3 = new OBJLoader(sketchPath(file3)).main;

  //importGroup.translate(0,0,-1000) ;
  //importGroup3.translate(0,0,-1000) ;

  //Param s = new Param(.1f,.1f,2).addToSlidersMain();
  //Param t = new Param(0,0f,2).addToSlidersMain();

  //importGroup.obj(0).face(143).pt(2).translateZ(t);
import processing.opengl.*;
import anar.*;

/**
 * @author lluj
 *
 */
Group importGroup;
//Group importGroup2;
Group importGroup3;
Group newbuilding = new Group();
Group newbuilding2 = new Group();
//Group newbuilding;

Sun sun;
//Group parametric;
Group Shade;
Group Shade1;
Group Shade2;
Group Shade3;

String file = "building.obj";
String file2 = "t2.obj";
String file3 = "sketchup_topo_tower5.obj";
int counting;

void setup() {
  size(800,400,OPENGL);
  Anar.init(this);
```

```
  //Anar.globalScale(Anar.METERS);
  Anar.drawAxis();
  OBJLoader.debug = true;

  Pts.globalRender = new RenderPtsAll();

  OBJLoader.mergeIdenticalPoints = true;

  importGroup = new OBJLoader(sketchPath(file)).main;
  //importGroup2 = new OBJLoader(sketchPath(file2)).main;
  importGroup3 = new OBJLoader(sketchPath(file3)).main;

  //importGroup.translate(0,0,-1000) ;
  //importGroup3.translate(0,0,-1000) ;

  //Param s = new Param(.1f,.1f,2).addToSlidersMain();
  //Param t = new Param(0,0f,2).addToSlidersMain();

  //importGroup.obj(0).face(143).pt(2).translateZ(t);
// for (int i=160; i<178; i++)
   //importGroup.obj(0).face(i).pt(2).translateZ(t);

  //importGroup.scale(s);

  //Anar.camTarget(importGroup);
  initForm();
}

void initForm() {

  ////////////////////////////////////
  //BOX
  ////////////////////////////////////
  Obj box = new Box(50,75,80);

  //box.tag("box");
  //box.rotateZ(0);
  //box.rotateX(0);
  box.translate(100,0,0);
 Param s = new Param(1,1,10).addToSlidersMain();
 Param s2 = new Param(1,1,1);

 box.scale(s2,s2,s);
  newbuilding.add(box);

  ////////////////////////////////////
  //SWISSCROSS3D
  ////////////////////////////////////
  Obj swissCross3D = new SwissCross3D(30,80);
  //swissCross3D.tag("swissCross3D");
  //swissCross3D.fill(255,0,0,200);
  //swissCross3D.translate(-100,0,0);
  //group.add(swissCross3D);
  newbuilding2.add(swissCross3D);


  // init sun
  Sliders dateTime = Sun.getDateTime(6,6,14,30,53.22,-1.28,-1.5);
  Param distSunParam = new Param(300,100,1000);
  sun = new Sun(dateTime,distSunParam);
  sun.render = new RenderPtShapeOriented(new Circle(20), new AColor(0,0,0,70), new AColor(255,100,0),Anar.scene);
  Anar.sliders(sun);

  //initiate shadow and projection;
  Shade = newbuilding.project(sun,Pt.ORIGIN, Pt.xAxis, Pt.yAxis);
  //Shade1 = importGroup3.project(sun,Pt.ORIGIN, Pt.xAxis, Pt.yAxis);
  Shade2 = importGroup.project(sun,Pt.ORIGIN, Pt.xAxis, Pt.yAxis);
  Shade3 = newbuilding2.project(sun,Pt.ORIGIN, Pt.xAxis, Pt.yAxis);

   //Specify Color;
  //myObj.fill(255,0,0,80);
  Shade.fill(198, 34,67);
  //Shade1.fill(0);
  Shade2.fill(0,0,0,25);
  Shade3.fill(12, 65, 137);
}

void draw() {
  background(38,126,125);
  importGroup.draw();
  importGroup3.draw();
  newbuilding.draw();
  newbuilding2.draw();
  sun.draw();
  Shade.draw();
  //Shade1.draw();
  Shade2.draw();
  Shade3.draw();
  counting++;
  //                    Anar.showInfo(importGroup.obj(0));
}
void keyPressed() {
  if (key == ' ') {
    save("arts_tower"+counting+".jpg");
  }
}
```

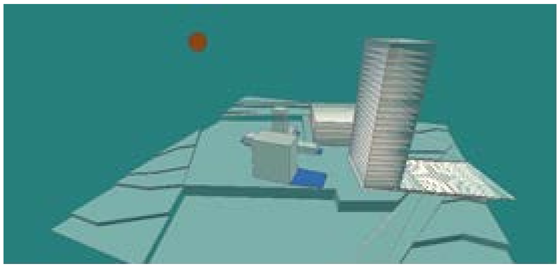
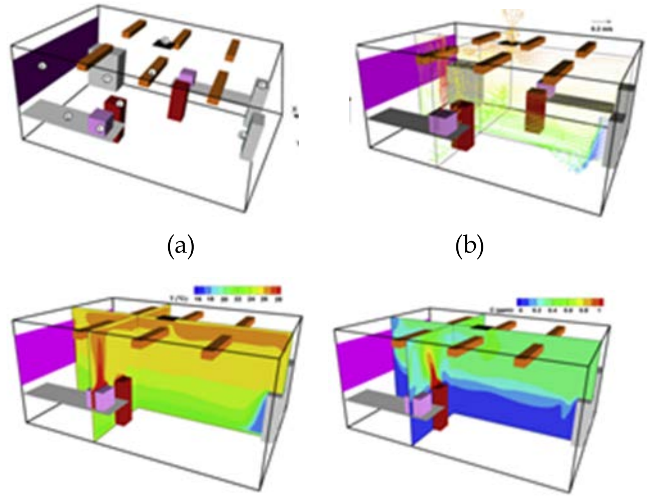


Fig. 3. Illustration of the result (as generated) of the *Processing* Program Code defined above (source: Author's work, 2011)

Apart from the general image generated from the codes above, many of the software in this category have the capability to give required thermal analyses (both cooling and heating loading) of the building when in use and particularly, the expected carbon emissions. However, this is a subject for extensive exploration at a higher level.

3.5 Application of Computational Fluid Dynamics

Computational fluid dynamics (CFD) has become an integral part of engineering development of complex air distribution and ventilation systems in buildings. It is essentially numerical solution of the governing equation of fluid flow, popular in the building ventilation and architectural design. It is used to provide visual and quantitative results for decision making in predicting indoor and outdoor airflow, pressure, temperature, humidity, and chemical species distribution [16], [42]. CFD technique is used to predict the air flow and temperature contours induced by the Heating, Ventilation and Air-conditioning (HVAC) systems installed in buildings with different configurations. It is suitable for a big air-conditioned space such as a gymnasium, an atrium, a factory, or a shopping mall. Results can be used to assess the air distribution system performance so that proper diffuser spacing, location of exhaust, flow rate and intake air temperature can be achieved. A better estimation of heat transfer coefficient can be made for accurate calculation of cooling load. The applications of CFD in building design include site planning, natural ventilation studies, HVAC system designs or pollution dispersion and control [43]. At present, application of CFD technology in the HVAC field is mainly concentrated in several aspects of air distribution design, air conditioning equipment performance improvement, and to an extent, building environmental analysis and design [44]. Fig. 4 (a – d) illustrate prediction of three-dimensional distribution of air flow pattern, temperature, and moisture content in an air-conditioned space using a CFD model. This is very useful for large spaces such as a gymnasium or an atrium where temperature and moisture gradients are found.



(a) (b) (c) (d)

Fig. 4. (a) Sketch of an office with displacement ventilation (1-computer, 2-occupant simulators, 3-tables, 4-lamps, 5-air supply diffuser, 6-air exhaust, 7-furniture, and 8-window); (b) Air velocity distributions; (c) Air temperature distributions; and (d) Contaminant concentration distributions. (Source: [45])

From the predicted results of the air flow, temperature and moisture content as illustrated in Fig. 4, it is possible to verify whether the air-conditioning design for the enclosures can provide a satisfactory environment. Thus, a balance can easily be achieved, thereby reducing unnecessary waste of energy which might otherwise translate to more carbon emissions.

5 Conclusion

Since buildings have an enormous and continuously increasing impact on the environment, thereby responsible for a large amount of harmful emissions (accounting for 30% of greenhouse gases, due to their operation, and an additional 18% indirectly associated with material exploitation and transportation [7], [8], [9], [10], it is very necessary for the building professionals particularly, Architects, to pay a very special attention towards mitigating potential impacts of their designs and structures on the environment. Thus, this submission has highlighted how the concerns for the protection of the environment has shaped the practice of architecture, particularly, collaborative integration of the emerging technologies, for reduced carbon emissions and overall general wellbeing of the environment.

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