Reviewing the impact of buildings integration systems on energy consumption

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Abstract:
Based on the last update of the International Energy Agency (IEA) in October 2022, the building sector is responsible of approximately 34% of total global energy usage. The concept of building-integrated system design aims to find solutions for the exaggeration in energy consumption by controlling and reducing the unnecessary use. Thus, this research presents a comprehensive technical review of building integrated systems concerning building envelopes, structure and smart services and their role in minimizing building energy consumption.

Purpose:
The purpose of this paper is to clarify the capabilities of building-integrated system in optimizing energy efficiency. Thus, the paper explores several types of integrated facades, structure and mechanical systems, in order to find proper solutions for the excess of energy consumption within building sector. Understanding how a building's many systems interact with one another and with their surroundings is essential to achieve good architecture with a better quality of life. Thus, the research aims to explores current development in architectural practice that combines design and engineering fields to produce ethical and sustainable structures. The advantages of integrated practice should contribute to significant changes in the educational system and the professional function of architects.

Design/methodology/approach: The research started by a literature review of concepts and definitions of systems integration, Building management system (BMS), as well as, different types of data measurement used to achieve the integration. Then, the paper procced to an analytical review of five different examples around the world that have applied the concept of integration at different scale. These examples are arranged chronologically. A comparative analysis between these examples has been done according to the different way of interaction as discussed in the literature review.

Findings: The paper suggests that the implications of a building's energy performance guide the early design choices in the practice of integrated systems. A comprehensive approach of a multi-system integration in building design can achieve a positive environmental impact rather than just mimizing the harmful impact.

Research limitations/implications: This paper highlights major threats of energy consumption facing building sector. However, it lacks attention from architect, engineers, project managers and decision makers.

Practical implications: It suggests that building systems integrations strategies would help in minimizing energy consumption, while, adapting and achieving different

human comfort perception in indoor spaces. These strategies can help architect, structural engineer and clients to accept and develop more sustainable approaches in order to control building energy consumption.

Keywords: smart facades, smart structure, building integration systems, smart mechanical services, building energy consumption.

1. Introduction:

According to the IEA organization, last update in October 2022, building sector is responsible of approximately 34% of total global energy consumption (IEA. 2022) (See figure 1). It was mentioned that controlling indoor climate and environment of building can be responsible for 30 to 40% of global energy consumption (Wilby M. R., et al., 2013) (Omrany H., et al., 2016). This is a variable percentage that differ from one country to another depending on climate conditions, main energy resources, the economic and social situations, as well as, the concentration towards utilizing building energy codes (Krarti M. D. A., 2015) (Omrany H., et al., 2016).

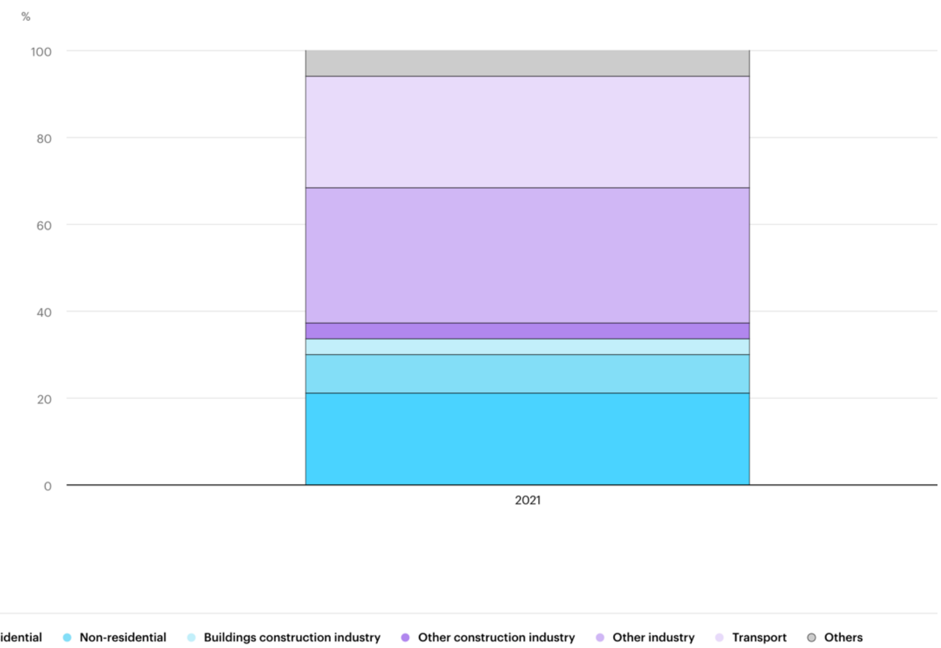

Figure 1: global energy energy consumption. Source: (IEA. 2022)

Several countries have paid attention to the importance of achieving energy efficiency within building sector. This was clearly reflected in the European, US, as well as, in china building regulation codes. According to the European Commission (2006), there were 3 out of 10 measures oriented to building energy management in the EU Action plan for Energy Efficiency (D&R International, 2012). The EU Energy Performance of Buildings Directive are recently requiring from new buildings to have nearly zero energy consumption. This requires to include building integration systems of passive and active design solutions. These solutions will help to achieve reduction in heating and cooling loads by improving indoor energy efficiency in building and by decreasing the usage of renewable energy (Stevanović S., 2013). In a similar way, the Comprehensive Building Energy Codes (BEC) of China has set some standards which address

integration systems within building envelope and air conditioning systems (HVAC) to regulate and control the energy use for lighting, heating and cooling withing residential and commercial buildings. For this reason, the Ministry of Housing and Urban-Rural Development in China has developed several targets for energy efficiency. These targets include: 50% reduction in energy consumption for new buildings, and 25%, 15%, 10% reduction in energy consumption for existing building by in big, moderate, and small cities, respectively (Nejat P. J. F., 2015). Moreover, US federal policy aims to reduce 70% of energy consumption in new buildings by using resources efficiently (Omrany H., et al., 2016). This paper presents a technical review of the integration between building systems including building envelope, structure and mechanical services in order and discusses their role in improving energy efficiency within building sector.
The scope of this research is to encourage architect, structural engineer and clients to accept and develop more sustainable approaches to achieve reduction in energy consumption within buildings.

2. Philosophy of integration

The synthesis of main systems in buildings is characterized by the integration and meshing among building envelope, structure, interior systems and mechanical services. Integration has passed through several stages of cultural and architectural values across 3 different ages of civilization, which are the preindustrial, industrial and postindustrial. Each of these eras is had it own prevailing philosophies that have defined the mutual missions of nature, science, art and culture. Historically, preindustrial philosophical thought beliefs distinguished by the intuition, superstition, and mystery (Bachman L. R., 2003). During the Renaissance period, many well known architects were engineers, master builders, artists and sculptors. This result with a synthesized art and technology in one building with an integrative practice (Vassigh S, et al., 2011). In the 17th century, the industrial thought began with the theories of Consciousness. In this era, the universe was seen as a large extension of the machine (Bachman L. R., 2003). Since this era, the demand for specialist professions increased due to the quick expansion of technological and scientific knowledge used in building design and construction. The industrialization of technology had a profound impact on society, resulting in a large gap between the fields of art and science. These resulting professional boundaries have characterized engineering and architecture as "applied sciences" and "design professions," respectively. This has divided the work between fragmented fieldx that are managed by construction managers, architects, structural, mechanical, and electrical engineers (Vassigh S, et al., 2011).To overcome the limitation of fragmented specialization during the latter half of 20^{th} century, the postindustrial concept has replaced the mechanistic certainty with a new perception of a deep interrelationships within the universe as a wide interdependent ecological network (Bachman L. R., 2003).

During the preindustrial architecture, concept of integration was not seen as an important issue as buildings were ritual places with no difference between science and art, nor, nature and technology. Several studies have investigated ancient buildings were designed to be in harmony with the universe. Whereas, the machine age has caused a separation between nature and technology. Thus, concept of integration arose during the postwar era in an attempt to heal this split between building systems and ecological architecture. Integration became a challenge during the post-industrial architecture aiming at creating more sustainable environment through responsive design approach. Ecological design provides distinguishable example of a mutual connection between the natural and built environment. Responsive design of the computing era aims to track the pattens of wind and sun in order to create the appropriate passive or active thermal solutions for building. It also works on integrating the needed systems within building components to create a balance between the indoor and outdoor environment (Bachman L. R., 2003).

3. Development of architecture systems:

Before the industrial revolution, buildings had the form of monolithic structures with controlled passive environments. Stared from 1830, when the industrial era began, the building design have changed to a glass-covered steel structure with intelligent mechanical systems. Since 1940, buildings have witnessed a technical evolution with rapid increase of mechanical, plumbing and electrical systems (Bachman L. R., 2003). Patrick Geddes (Scottish urban planner, biologist and ecologist) has called the period of machine age that started since the late 18th century as “the Paleotechnic era”. Geddes hoped to see the emergence of new era as he called it “the Neotechnic age”. He aimed that in this era buildings will be designed in respecting of the surrounding environment and wisely use of available resources for the effective health of place and well-being. The term “postindustrial” was first mentioned by David Riesman in 1958 and then the idea was developed by Daniel Bell in 1973. Bell presented his visional goals for this period as follow: changing from goods-production to a service economy; shifting from the practical knowledge of the industrial period to a theoretical knowledge as a basis for creative and sustainable design policy; the ability to plan and control the use of new technology (Lyle J. T., 1994). Since, the quality of all building systems including: building envelope, structure, interior spaces and the site have been equally affected by the development of building technology, thus, integration between them became an important need. The International Style and Postmodernism represent architectural design approaches that aim to orient the use of technology to the indispensable needs, while achieving a higher building efficiency. The Architectural anatomy and biological approaches follow the Neotechnic and postindustrial concept by using design knowledge to manage and operate cyclical flows in integrative building systems (Bachman L. R., 2003).

4. Building systems integration:

Biological and anatomical approach in building design help in recognizing the building as a living organism that operate as interrelated systems. The building anatomical section helps to explore how the different organ of the building (the structure, building envelope, electrical, mechanical (HVAC) and plumbing systems) can combine together to work efficiently just like a human body. Several anatomical researches make a representation between building systems and biological body system as follow: structure as the skeleton system; ventilation as respiratory system; building envelope as the epidermal of body, and electrical as nervous system, etc. The important characteristic of the architectural biological model is the interactive processes between systems which could be represented by the cycles of flow within building systems to achieve sustainable design. A biological buildings sections and plans will contain system dynamics of a building including: cycles flow of energy, material and information (Bachman L. R., 2003). Integrated systems design is considered a key to a sustainable design approach which attempt to respect the natural environment while expanding the formal ambitions of the architectural design. There are several rating systems methods that help architects and other building professionals to measure the efficiency degree of their sustainable design outcome. The practice of system integration can remediate the decision making in building design solution in order to match with building operation requirement and hence achieve higher efficiency. The synergy between different systems in buildings eliminates the inefficiencies of the design and construction process. Thus, in the integrated systems approach, architects have a multitaskers role as they should provide an overview of the mutual relationship between designers, engineers, and construction managers. Practicing the integrated system approach. The implications of a building's energy performance guide the early design choices in integrated practice (Vassigh S, et al., 2011).

5. Building performance and operational data

Energy use (such as data from smart metres) or operational data are two types of building data that can be used to characterize many elements of a building's performance (e.g., smart systems data, as well as occupancy operational data through BMS, IOT (internet of things)) (Salima F.D., et al., 2020) (see figure 2).

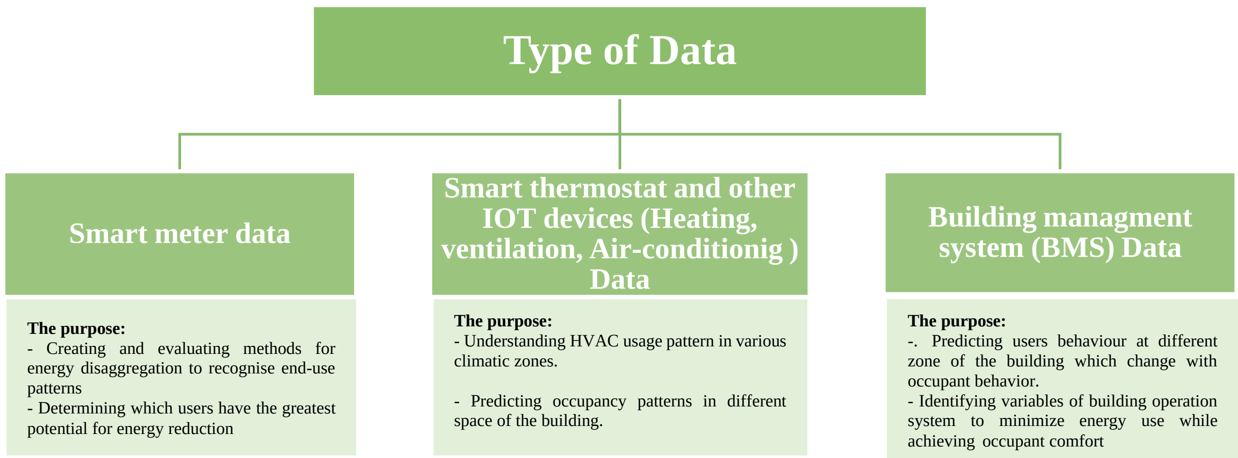

Figure 2: Examples of different data sources used to collect building operation and energy use data. Source: (Salima F.D., et al., 2020) adapted by the Autor.

Although, the building management systems (BMS) data is normally accessible for individual buildings, some researchers have succeeded to collecte BMS data from a number of buildings. They used these collected data to record indoor and outdoor temperature, zone temperature and to determine temperature set-point through interval of time. Whereas, smart thermostats and other IoT (Internet of things) devices offer significantly larger datasets from a huge number of buildings at the same time. Several programs such as: "Donate Your Data"; “Pecan Street Research Institute’s DataPort” are used in North America. These programs contain metadata such as building types, geographical location, and construction date. They also include measurements of the indoor and outdoor air temperatures, set-points, indoor RH, motion sensors, and HVAC equipment run times, all taken at 5-minute intervals. (Salima F.D., et al., 2020).

5.1. Operational data of the Indoor environment

The emergence of interior environment sensing technologies has made it possible to gather a variety of information about the indoor environment. These sensors can capture a variety of data on indoor settings, including temperature, humidity, light, CO_2, and air velocity. An unparalleled level of environmental situation awareness inside buildings can be achieved by combining these data from multiple environmental sensors (Salima F.D., et al., 2020).

5.2. Building management system as a smart solution

The use of building management system (BMS) data can provide an excess of data related to on occupant behaviour, operational trends, and occupancy. Hence, occupant and energy usage behavioural patterns that are typically ignored by conventional models can be captured by data-driven building and energy models. Since the computing era, detailed knowledge about building operation systems and performance is made possible by the ubiquitous use of sensing technologies in smartphones, household appliances, and high-speed wireless access, as well as by the Internet of Things' high availability (Salima F.D., et al., 2020).

5.3. Urban Energy Modeling (UBEM) and building thermal/energy performance

“Top-down” and “bottom-up” techniques are typically dominant in the literature on existing UBEM. Top-down models (based on data-driven) are not appropriate to assess important parameters for energy use reductions, such as determining the efficacy of applying an energy-saving strategy, because they lack end-user energy consumption breakdowns (Kavgic M.,et al, 2010) (Salima F.D., et al., 2020). Whereas, the bottom-up strategy (based on building performance simulation model) strives to classify buildings into archetypes by combining those that share comparable traits, such as principal usage, structural attributes, and construction geometry. It typically involves modelling for thermal and energy efficiency, lighting and daylighting, acoustics, and indoor air quality. These models are usually used as a way to find the most appropriate technologies and processes that can reduce carbon emissions or increase comfort at the lowest possible cost (Rivers N., et al., 2005) (Salima F.D., et al., 2020).

6. Modes of building systems integration for energy consumption

The production of hot water and space heating and cooling are thought to be responsible for almost half of all the energy used in buildings globally today. Several researches assumed that buildings with low-energy or zero-carbon heating and cooling systems could save 710 Mtoe of energy while lowering CO_2 emissions by up to 2 Gt by 2050 (Cabeza L. F., et. al., 2018). According to Cabeza L. F. (2018), The four basic technological methods for reducing a building's heating or cooling load can be considered as follows: improving the building envelope, BMS for enhancing the performance of heating and cooling systems, building structure integration, as well as, applying adaptive thermal comfort concepts to reduce the temperature difference between indoors and outside the building (Cabeza L. F., et. al., 2018).

7. Exploring examples of buildings using integrated systems approach

Bachman L. R. (2003) categorized building systems as: envelope, services, structure, interior, and site. An analytical review of the different integration possibilities between building systems will be discussed through several example in order to understand their impact on energy consumption in buildings. There are countless combinations that could be created by integrating the five main building systems, as well as their individual subsystems. Bachman L. R. (2003), has outlined a primary list that could be used a start to help decision maker in their design (See table 1).

Table 1: Shows ten integration possibilities for pairing the five major systems with their subsystems. Source: Bachman L. R. (2003).

	Site	Structure	Envelope	Services
Interior	Indoor/out relationships	Exposed structure Integrated lighting	Daylighting	Exposed ducts Masking background Air-handling luminaries
Services	Cooling ponds Earth tube cooling	Duct routes Interstitial mechanical Plenums	Passive design Solar roofs Vented skin Double envelope	
Envelope	Earth shelter Natural habitat Noise barriers Storm water	Building shell Shading Light diffusing		
Structure	Underground Terraced			

7.1. Yale Center for British Art, New Haven, Connecticut, USA, (1969-74)

The Yale Center for British Art was designed by the architect Louis Kahn. It is located at the the northern shore of the USA (41.3°N 72.9°W). The sun angle is this region vary from 70 degree during the summer solstice and 25 degree in winter solstice (See figure 3) (Vassigh S, et. al., 2011).

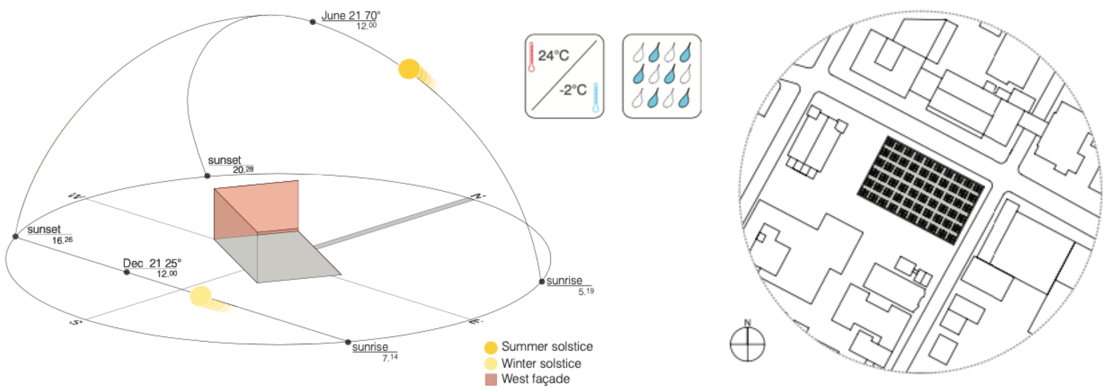

Figure 3: The Yale Center for British Art site condition. Source: Vassigh S, et. al., 2011

In this building, daylighting is achieved through a series of skylights which are covered in the interior space with translucent panels to protect the exhibit of artwork from the undesired UV rays. In order to minimize solar heat gain, external louvers are added to these skylights which are also used as light diffuser for better viewing of the artwork. The building façade is made out of glass panels and an exposed structural concrete frame. Urethane panels has been used for glass window insulation. An internal adjustable wooden louver has also been used to control natural light penetration (See figure 4) (Vassigh S, et. al., 2011).

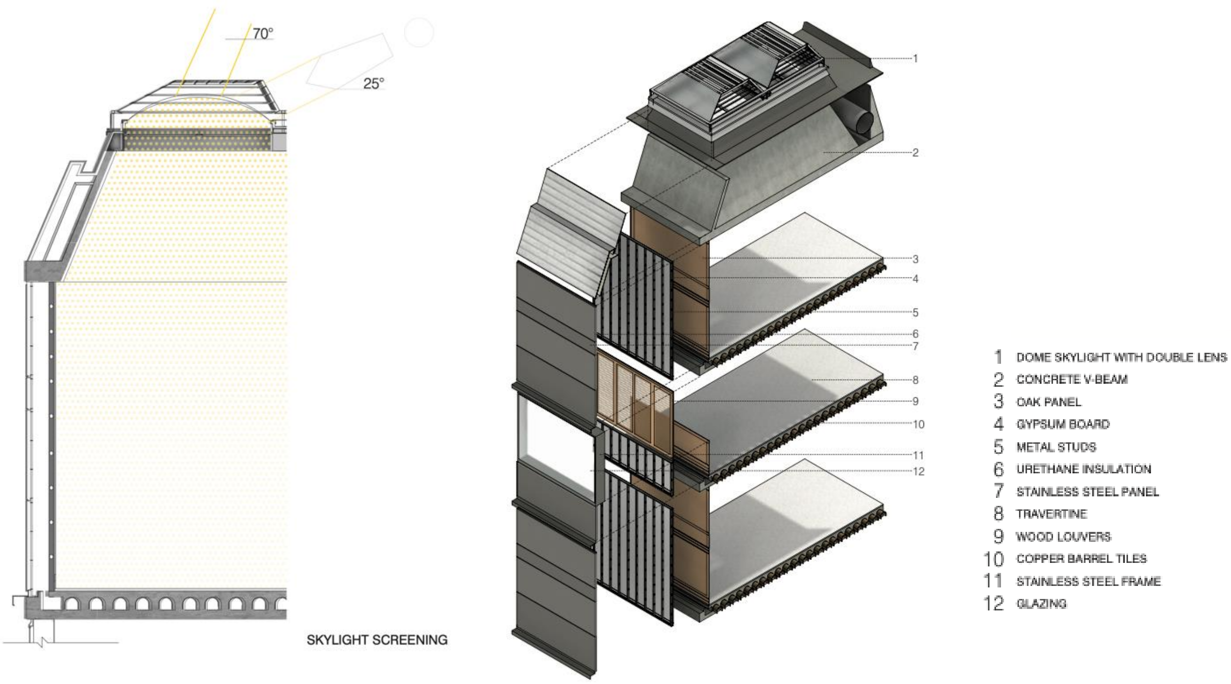

Figure 4: Different components of the Yale art Center Building envelope that allow integration between the site condition and interior systems. Source: Vassigh S, et. al., 2011

The architect has also designed the space needs for a forced-air mechanical system to be integrated within the building structure (Slabs and beams). The supply air ducts in typical floors are simply suspended from the concrete ceiling in the separated condition. Whereas, ducts have been integrated in the ceiling structure of the last floor as they were embedded in the v-shaped roof beam section. As for the return-air supply, a cast in hollow concrete floor slab has been designed with copper barrel tiles to house them (See figure 5) (Vassigh S, et. al., 2011).

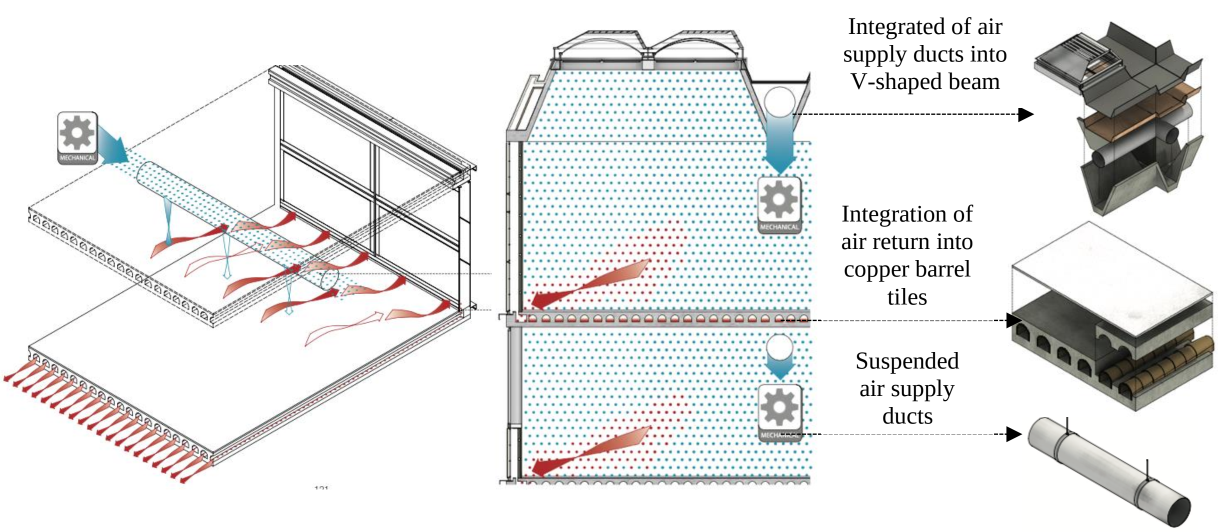

Figure 5: integration of forced-air mechanical system into the building structure. Source: Vassigh S, et. al., 2011

7.2. BRE Environmental Building, Watford, England (1994)

The BRE is an office building designed by Feilden Clegg Architects. It is located at the boundaries of Watford in southern England (51.7° N / 0.2° W). The sun angle is this region vary from 60 degree during the summer solstice and 15 degree in winter solstice (See figure 6) (Vassigh S, et. al., 2011).

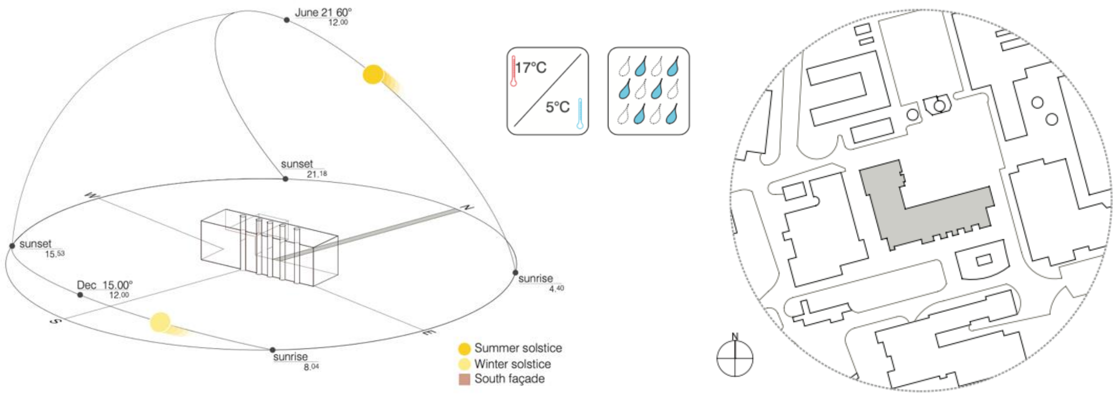

Figure 6: The BRE Environmental Building site condition. Source: Vassigh S, et. al., 2011

Cross ventilation and daylighting are made possible by the building's tiny cross section and high ceilings. The building envelope is cladded with facing bricks and recycled timber. It has a lot of glazing on the north and south façades. Approximately 90% of the site-cast concrete used in the structure is made of recycled aggregate. The building employs a large variety of energy-saving techniques to lower its energy usage and lessen its negative environmental impact. These methods include: the use of thermal mass, resource-efficient building materials, borehole cooling, cooling stacks, natural ventilation, photovoltaic panels, as well as roof insulation. The study of the building's sun path diagram helped to identify appropriate design solutions to enhance building energy performance. The building's north facade makes great use of windows to let in diffused light. Clerestory windows on the third floor let light and cross-ventilation in form the north side. During the summer, the south elevation receives light at an angle of 60 degree. Thus, movable horizontal shading louvres were designed to minimize solar heat gain, while allowing some light to enter the building (See figure 7) (Vassigh S, et. al., 2011).

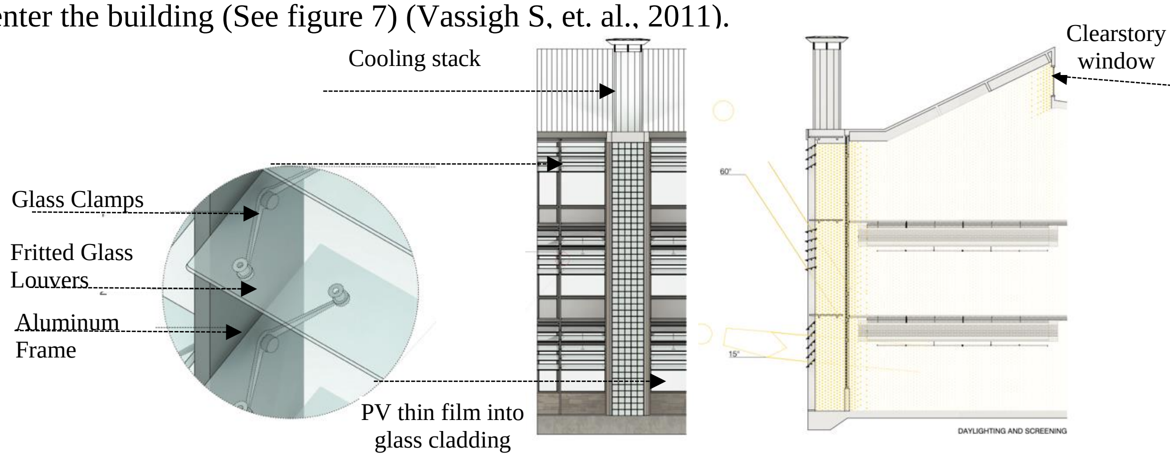

Figure 7: Different components of the BRE Environmental Building envelope (South façade) that allow integration between the site condition and interior systems. Source: Vassigh S, et. al., 2011

The glass louvers are automatically rotated and adjusted by the BMS in accordance with the location of the sun. The motorized louvres are also used to reduce the use of artificial lighting. It is angled so that when exposed to diffused sunshine, light reflects off of their upper surfaces and onto the ceilings of the office spaces. Photovoltaic (PV) arrays that use thin film silicon cells has been integrated into the south glass façade. which are built into glass cladding. The power generated by these PV cells is directed into the building's main supply panel. It supplies up to 1.5KW of the building's electricity needs (See figure 7) (Vassigh S, et. al., 2011).

An integrated floor system has been designed in this building to provide active cooling and heating in order to maintain the indoor temperature at the comfortable level. The Borehole cooling system is used if the indoor temperature exceeds 28° C to provide natural ventilation and avoid the use of air-conditioning system. Whereas, Low-pressure hot water system is used to provide heating in the building in the winter when temperature drop below 18° C (see figure8). This hot water is heated by gas boiler which is operated and controlled by the BMS. During summer night, windows automatically open to let out extra heat that has accumulated over the day. Whereas, windows are kept closed during winter night to avoid inside frost (see figure 10) (Vassigh S, et. al., 2011).

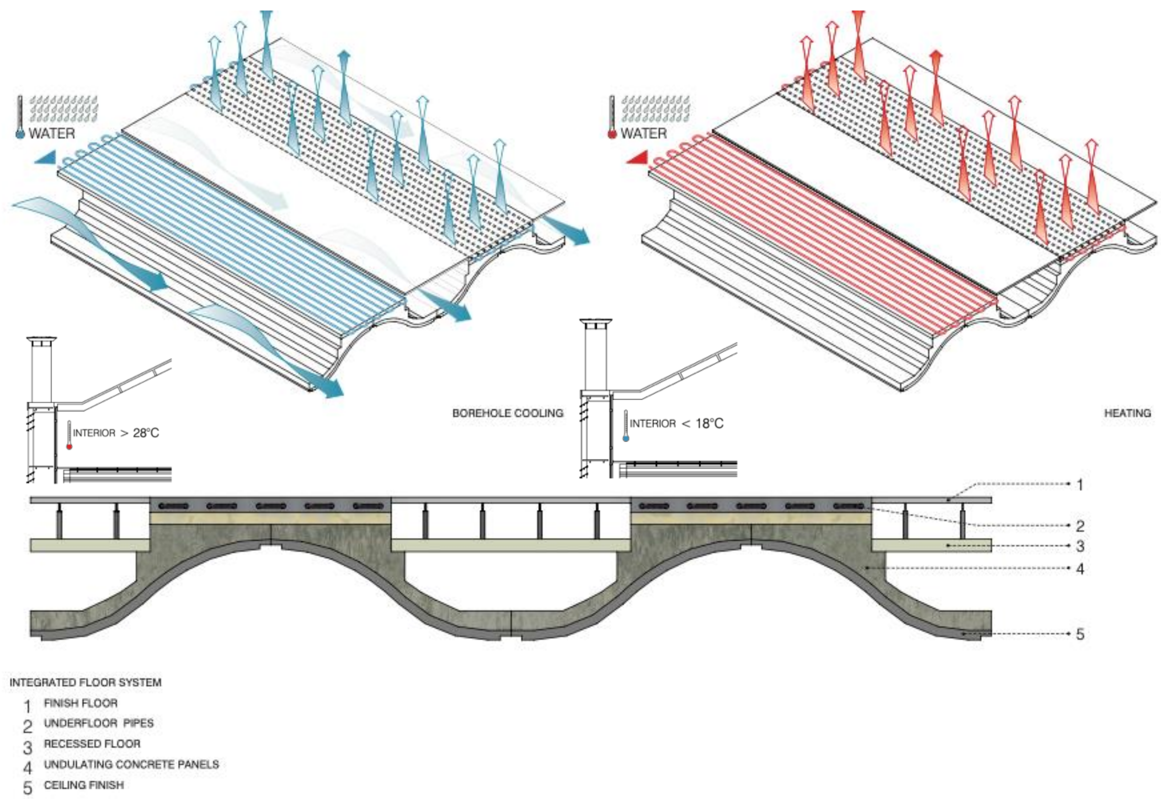

Figure 8: Integrated floor system at the BRE Environmental Building. Source: Vassigh S, et. al., 2011

Cooling stacks has also been designed in the southern building façade to maintain an indoor pleasant temperature by improve airflow through this small building. They are integrated with the hollow concrete floor slabs and are an essential component of the ventilation and cooling plan. Fresh air is pulled into the structure from the north side on warm, windy days through paths in the hollow concrete slabs. Exhaust air rises via the chimney-like vertical shafts, improving airflow throughout the structure (see figure 9) (Vassigh S, et. al., 2011).

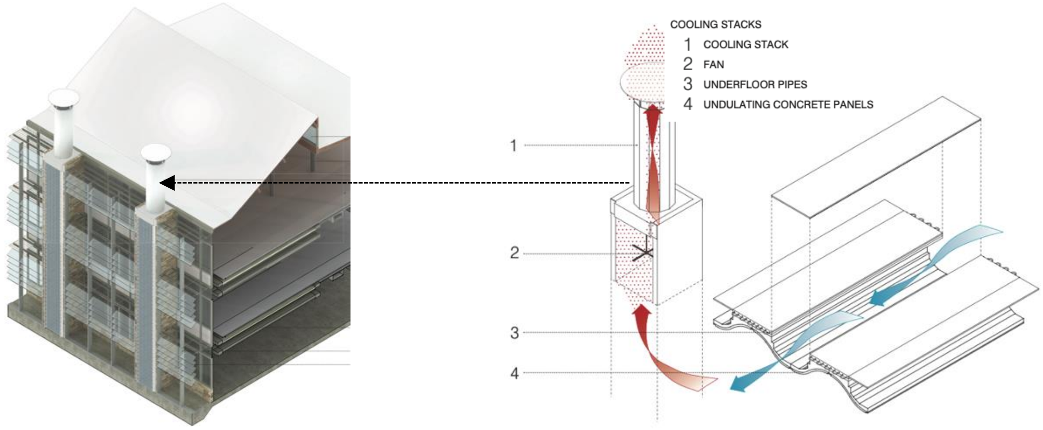

Figure 9: Integrated façade system (cooling stacks) with the floor building structure at the BRE Environmental Building to enhance cooling performance. Source: Vassigh S, et. al., 2011

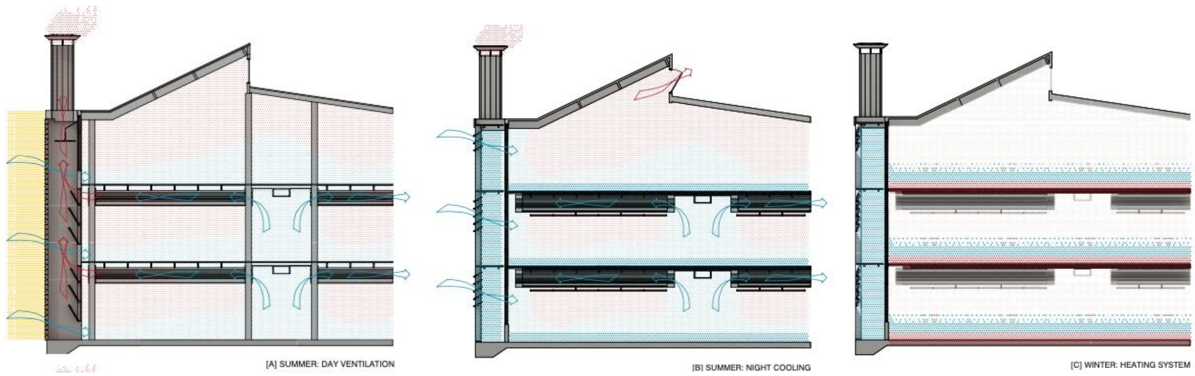

Figure 10: Cross section at the BRE Environmental Building showing cooling and heating system suring summer and winter. Source: Vassigh S, et. al., 2011

7.3. Singapore National Library, Singapore, (2004)

The Singapore National library was designed by the architect T.R. Hamzah & Ken Yeang. It is located in the downtown district of Singapore, (1.2°N 103.5°E). The sun angle during summer and winter is this region which are 67 degree and 65 degree, respectively (See figure 11) (Vassigh S, et. al., 2011).

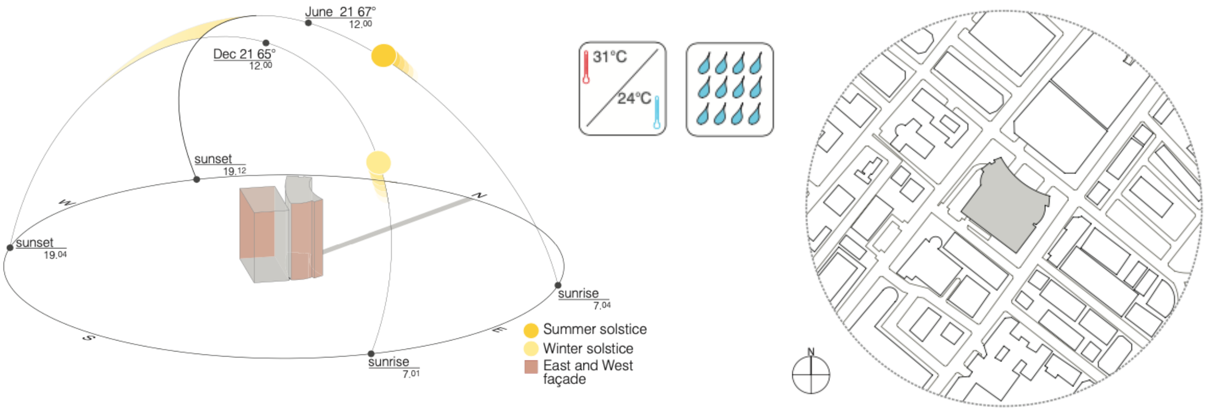

Figure 11: The Singapore National Library site condition. Source: Vassigh S, et. al., 2011

Several strategies have been applied by the Singapore National Library building to enhance its performance by lower energy usage and the building's environmental impact. First, the architect used the building simulation during the early design stage approach to predict, assess, and adjust the building's performance. The simulation included the study of thermal, daylighting, and wind parameters in relation to the building configuration and orientation, the use of sun shading mechanisms, natural ventilation, green terraces, and façade treatment. The results of this simulation helped to select an appropriate design to adapt the building performance with the climate condition. As a result, the architect succeeded to reduce around 31% of the building's electric energy consumption compared to the country’s average usage. Landscape (garden terrace) elements as also been integrated within the design in order to reduce energy demand by lowering the ambient temperature. Second, gardens and landscape areas helped in controlling the indoor environment to kept it cool as much as possible. Third, recycled and reused materials, wall textiles and wooden fittings with lower embodied energy material and careful selection of sustainable local lumber have all been used in order to reduce the building's negative environmental effects. The building has achieved several awards for sustainability, including the ASEAN Energy Efficiency Award and the green mark platinum award in the building (Vassigh S, et. al., 2011).

West and east facades are subjected to a large amount of solar radiation during summer. Hence, a low-E glass curtain wall with metal blades solar screening has been used in the east facade to control and diffuse sunlight onto the indoor spaces (see figure 12). These metal blades also block direct sunrays in the southern and western façades (Vassigh S, et. al., 2011).

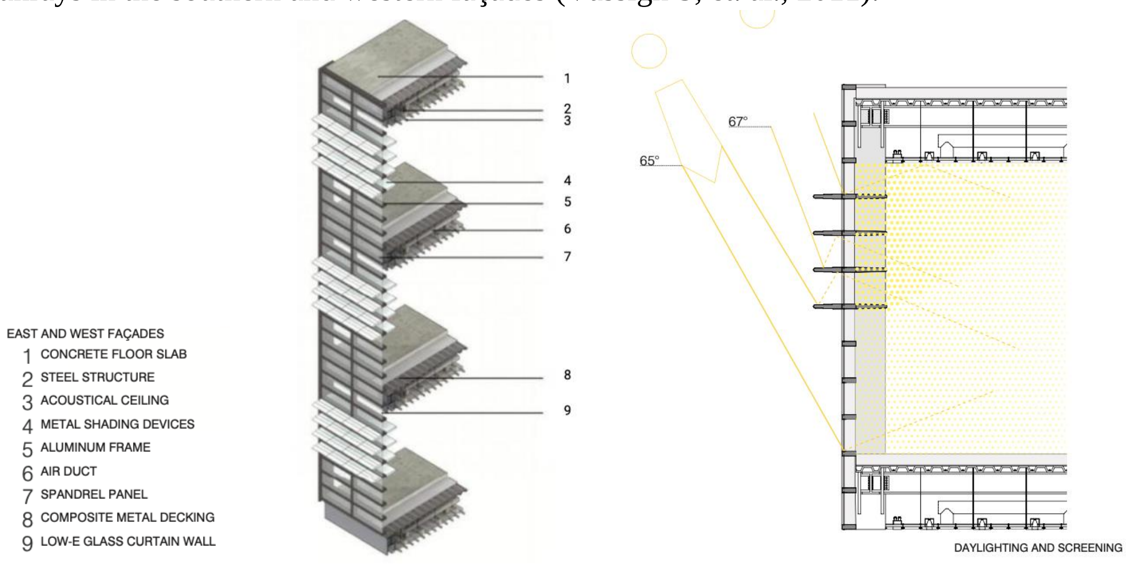

Figure 12: The Singapore National Library integrated systems in south and east facades. Source: Vassigh S, et. al., 2011

The indoor temperature of the Singapore National Library is managed via a zonal climate control system. The "full mechanical mode" is used for the theatre, study rooms, and library collections as they artificial lighting and are completely air-conditioned. Whereas, The "mixed mode" is used for transitional areas. To attain a comfortable temperature, they combine mechanical and natural ventilation systems. Natural ventilation is achieved through internal atrium which is oriented to take advantage of the prevailing breezes. The atrium roof's glass louvres open and close control and circulate the fresh air through it (see figure 13).

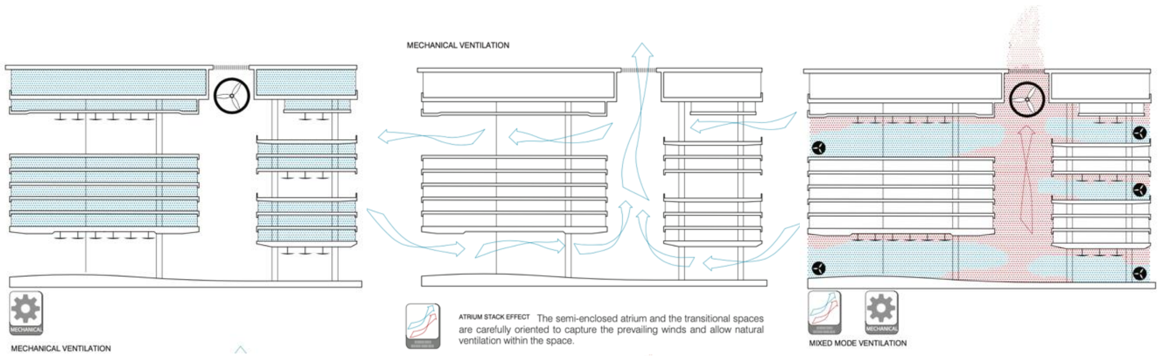

Figure 13: Modes of ventilation at the Singapore National Library. Source: Vassigh S, et. al., 2011

7.4. San Francisco Federal Building, San Francisco, California, USA (2007)

The San Francisco Federal Building is designed by Tom Mayne and Morphosis Architects. It is located at San Francisco northern edge (32.8° N / 122.2° W). The sun angle is this region vary from 70 degree during the summer solstice and 30 degree in winter solstice (See figure 14) (Vassigh S, et. al., 2011).

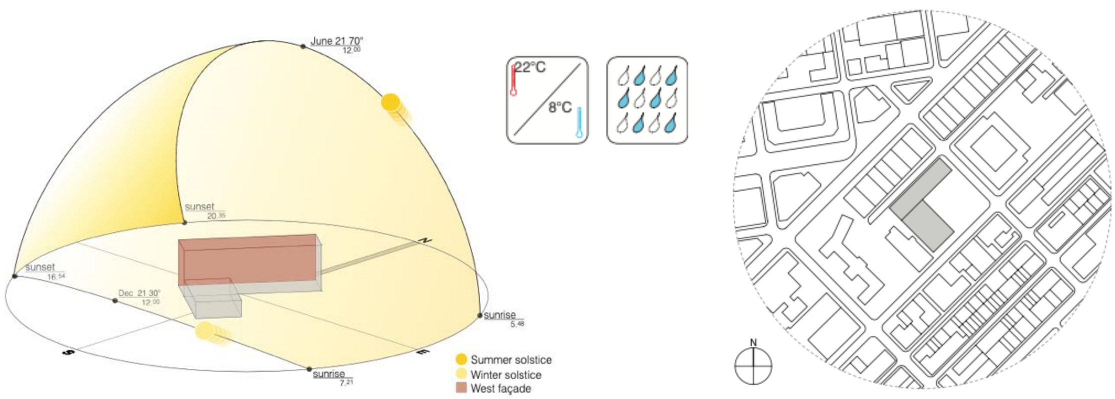

Figure 14: The San Francisco Federal Building site condition. Source: Vassigh S, et. al., 2011

Building design orientation, form, envelope and interior layout have helped in reducing energy consumption and thus, minimizing the harmful impact on the environment. solid narrow walls have been designed for the southwest and northeast faced to minimize heat gain. Whereas, vertical translucent glass panels have been installed in the northwest façade in order to control and diffuse the sunlight penetration into the indoor spaces. The glass curtain wall has a movable vent that allow fresh air to penetrate into the indoor spaces. (see figure 15). As for the southeast façade, horizontal solar shades are added in front of the curtain wall glass window. This shades panels control solar radiation while allowing appropriate daylight to penetrate into the indoor spaces (see figure 16). The building management system (BMS) is used to control lighting and ventilation needed in the building which differ throughout the day and the months**.** Sensors was added to monitor the amount of daylighting. Hence, artificial lighting is automatically controlled to dim or brighter to achieve the desired level of space lighting. As for natural ventilation, a computerized system was added to the northwest façade which allow an automated adjustment of the windows in order to control the amount of needed fresh air (Vassigh S, et. al., 2011).

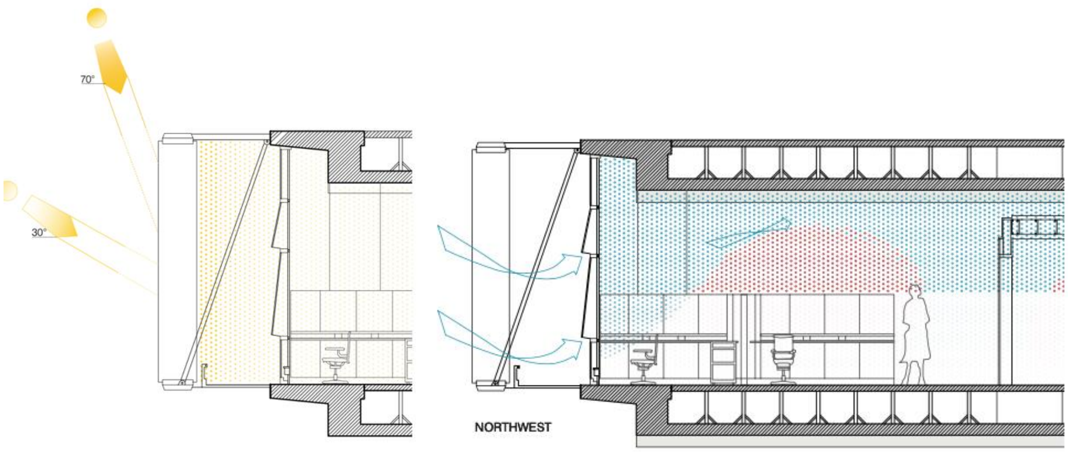

Figure 15: The San Francisco Federal Building integrated systems in northwest façade for natural light and ventilation. Source: Vassigh S, et. al., 2011

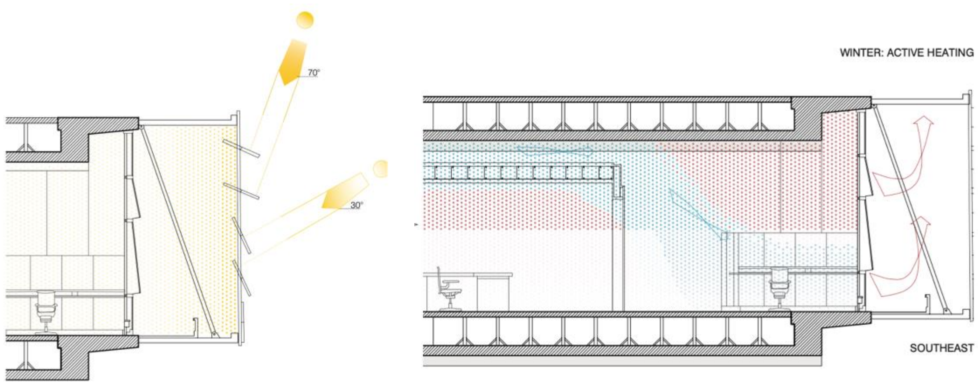

Figure 16: The San Francisco Federal Building integrated systems in southeast façade for natural light and active heating. Source: Vassigh S, et. al., 2011

Air is vented out of the building through the southeast wall as it moves from one side to the other over the internal space. Undulating concrete ceilings make it easier for outside air to circulate throughout the small floor. Additionally, the wavy concrete ceilings function as a thermal mass to keep the building cool in the summer. The higher windows open automatically to discharge heat build-up and let air cool the building's concrete interior, taking advantage of San Francisco's mild evenings. The undulating concrete ceilings' thermal mass stores cooling energy at night and releases it to cool the moving air throughout the day (see figure 17) (Vassigh S, et. al., 2011).

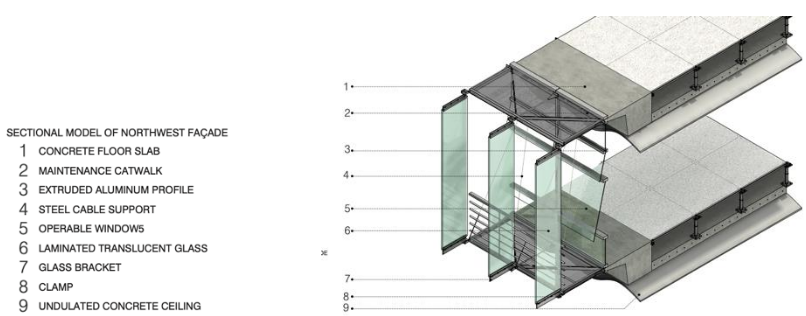

Figure 17: The integration of ceiling structure with northwest façade. Source: Vassigh S, et. al., 2011

7.5 Freiburg's New City Hall, Freiburg, Germany (2015 - 2019)

The City Administration Centre in Freiburg, Germany (48°N / 7°49E). The building has received the 1st world's public building that succeed to achieve zero-energy consumption. This indicates that the building generates more energy each year than it uses. The city grid receives the extra energy produced by the building. For heating, cooling, ventilation, and hot water delivery, the town hall's primary energy consumption is as low as 55 kilowatt hours per sq. meter per year, which is only 40% of the primary energy demand of comparable modern commercial buildings. The building was built and operated during a long term research project by ingenhoven associates architects and sponsored by the German Federal Ministry for Economic Affairs and Energy (BMWi) and the Project Management Jülich PTJ. Further developing methods for integral planning and success control is the goal of the research project. During operation, the dynamic load profiles of supply and demand have been optimised. The plus energy target has virtually been met, according to Fraunhofer ISE's first full operational year. In order to evaluate the concept's robustness and long-term performance, the building operation will continue to be rigorously tracked after the first year of operation. The project has a second phase has scheduled to be completed by 2024 (Fraunhofer Institute for Solar Energy Systems ISE, 2022).

The city hall's exterior is covered entirely by vertically projecting modules with photovoltaic cells. Photovoltaic panels on the roof and in the facade produce electricity and high-quality thermal insulation (see figure 18). The PV cells of the smart façade track the sun direction and move automatically the vertical panels to reduce glare and heat gain in the indoor spaces (see figure 19). Additionally, suction and injection wells, thermal solar panels, and heat pumps are used in conjunction with each other to produce the energy needed for the building. Hybrid collectors (PVT), which are supported by a gas condensing boiler, are used to treat hot drinking water. Two ground-water coupled heat pumps are used for the heating, and a ground-water heat exchanger is used for cooling. Pipes used for cooling and heating systems have been integrated within the ceiling structure (see figure 20). Surface-based systems are energy-efficient for heating and cooling. The ventilation concept is formed by heat recovery ventilation systems (Fraunhofer Institute for Solar Energy Systems ISE, 2022).

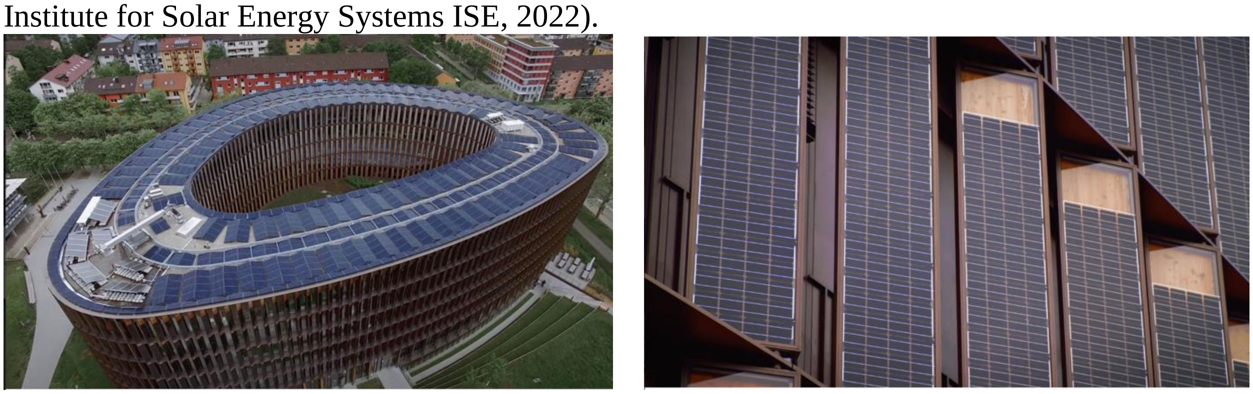

Figure 18: The integration PV panels in all building envelope (façades and roof). Source: (Fraunhofer ISE, 2022)

The energy-saving approach also includes exterior solar screens, triple glazing, and mechanical background ventilation with heat recovery. To maximise the intake of daylight, a skylight in the internal court floor, as well as, glass facade pieces up to a story height are used. Green courtyard has also been used to minimize heat island effect (see figure 19). The front of the circular day nursery building has wide apertures with balcony doors, vertical timber cladding in narrow strips, and an access balcony on the second floor (see figure 20). A simulation-based energy management is used to measure and optimize the plus energy during the operation phase (see figure 20) (Freiburg Town Hall, 2022).

Figure 19: use of skylight and green roof in the internal court.
Source: https://archello.com/story/50247/attachments/photos-videos/18

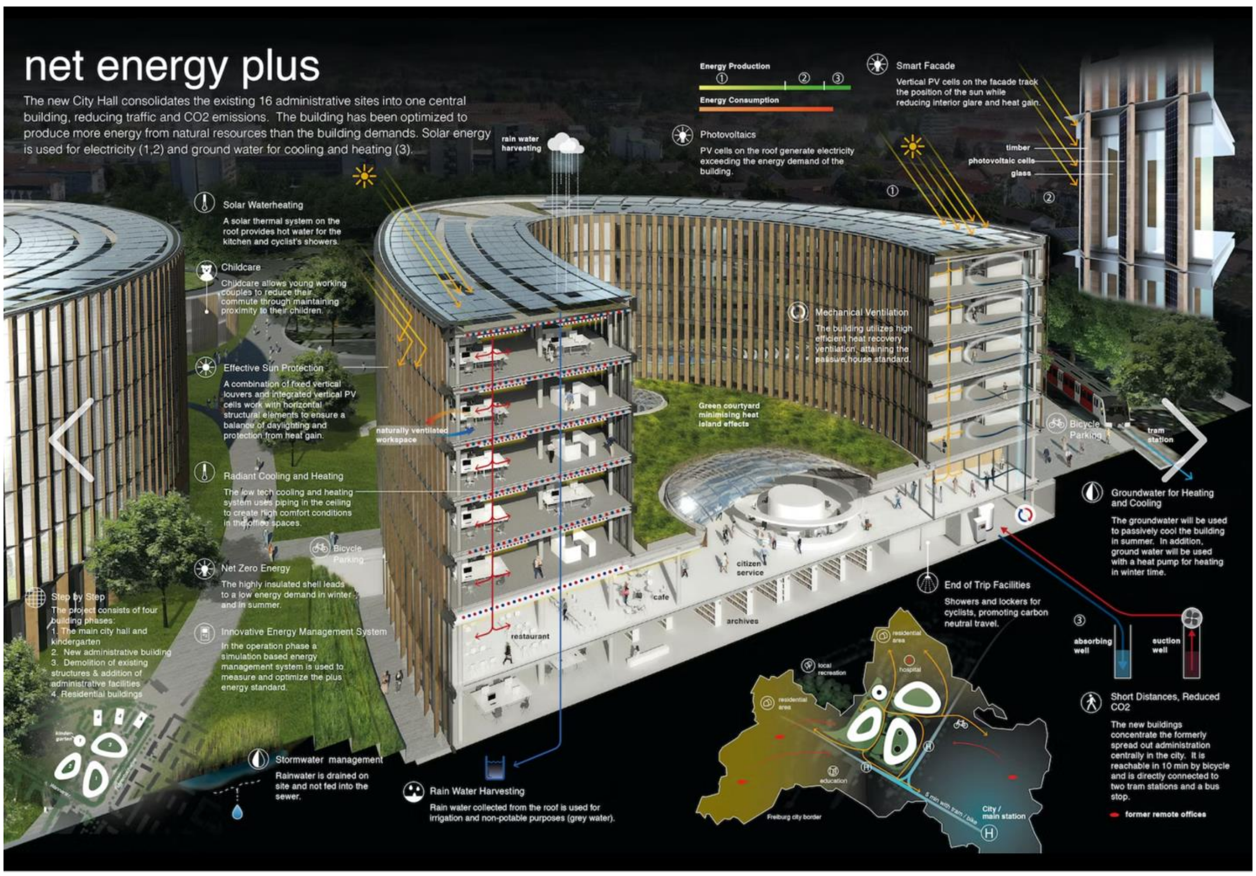

Figure 20: Building Systems integration of the Freiburg's New City Hall to achieve net energy plus.
Source: https://architizer.com/projects/freiburg-town-hall/

8. Summarizing the sorts of integration within building system for the studied examples

The following table represents a comparative analysis that highlights the ways of integration between building systems in the five examples that have been discussed (see table 2). The comparison is made based on the integration possibilities for pairing the major systems with their subsystems (Bachman L. R., 2003).

Table 2: integration between major building systems and their subsystems for five different Examples. Source: the author

Building systems	Case studies	Building systems			
		Site	**Structure**	**envelope**	**services**
Interior (performance)	**Yale Center for British Art, 1974**	-Building orientation allow better natural lighting		-Daylight achieved through skylight - internal adjustable wooden louver to control natural light penetration	-The supply air ducts in typical floors are simply suspended from the concrete ceiling slab.
	BRE Environmental office Building, 1994	-Building orientation allow better natural lighting		-The glass louvers are automatically rotated and adjusted by **the BMS** to achieve better daylighting - Clerestory windows facing north for natural lighting	
	Singapore National Library, 2004	-Computerized simulation of the Building during the design stage, has produced a respectful design with its surroundings site. -Landscape (garden terrace) reduce energy demand by lowering the ambient temperature.		-low-E glass curtain wall with metal blades solar screening (on east façade) to control and diffuse sunlight into the indoor spaces and block direct sunrays in the southern and western façades	
	San Francisco Federal Building, 2007	-Building orientation allow better natural lighting		-vertical translucent glass panels in the northwest façade to control and diffuse the sunlight	-Sensors was added to monitor the amount of daylighting.
	Freiburg's New City Hall, 2019	- Ground water is used for passively cooling the building in summer - site is accessible within short distance by pike, walk or public transportation which reduce CO_2 emission of the building.		-Vertical louvers for balanced natural lighting -Highly insulated shell lower the energy demand in summer and winter - skylight in the courtyard for natural lighting.	
Service	**Yale Center for British Art, 1974**		- forced-air mechanical system imbedded within the building structure (Slabs and beams). -cast in hollow concrete floor slab has been designed with copper barrel tiles to house the return supply	- External louvers added to skylight to minimize heat gain - Urethane panels for glass window insulation	
	BRE Environmental office Building, 1994		- integrated floor system Low-pressure hot water system for heating & borehole cooling system - The hot water is heated by gas boiler which is operated and controlled by **the BMS**	- cooling stacks for natural ventilation -Clerestory windows facing north for cross ventilation - Photovoltaic (PV) arrays that use thin film silicon cells installed in the south façade.	-integration of BMS
	Singapore National Library, 2004		- Artificial lighting and airducts are integrated with the ceiling steel structure of some spaces.	-Natural ventilation through internal atrium which adjustable louvers to control air flow.	
	San Francisco Federal Building, 2007		- the wavy concrete ceilings function as a thermal mass to keep the building cool in the summer	-The glass curtain wall has a comprised movable vent to control the amount of needed fresh air to penetrate into the indoor spaces.	- artificial lighting is automatically controlled by BMS to dim or brighter to achieve the desired level of space lighting
	Freiburg's New City Hall, 2019	-Storm water management - heat pumps is used with ground water for heating the building in winter. - Extra energy produced by the building went to the city grid	-Heating and cooling Pipes imbedded in the ceiling structure . - high efficient heat recovery ventilation system.	-Vertical louvers and integrated PV cells for balanced natural lighting - hot water for kitchen and showers is provided from solar thermal system on the roof	
Envelope	**Yale Center for British Art, 1974**		- External louvers added to skylight and internal v-shaped beams used as a light diffuser for better viewing of artwork		
	BRE Environmental office Building, 1994				-integration of BMS
	Singapore National Library, 2004	-Landscape (garden terrace) provide natural habitat and noise barrier			
	San Francisco Federal Building, 2007				
	Freiburg's New City Hall, 2019	-Rain water harvesting used in irrigation - Installation of timber facades of locally sourced larch wood. -Green courtyard minimize heat island effect.			-(BMS) of Smart façade reduce heat gain in the indoor spaces.

The table indicates that building energy efficiency could be achieved through: smart ventilation/heating systems; high quality insulation; energy efficiency lighting, using renewable energy and thermal energy storage, as well as, site and building management systems.

9. Conclusion and recommendation

The danger of accidental duplications and incorrect interpretations of the intentions of the involved parties could be minimized by the integration of the building systems. The implications of a building's energy performance guide the early design choices in the practice of integrated systems. The construction, performance, and system efficiency of buildings are most affected by the initial choices made. This will not only avoid expensive redesigns of design choices, but it will also enable synergistic collaborations that reexamine outdated methods. The concept of building systems integration has been applied to several building since 1970s to achieve reduction in energy consumption, as well as, enhancing the building performance. However, the concept of net energy plus couldn't be achieved before the development of computational programs together with the internet of things (IOT). The Building Information Modeling (BIM) help to create a simulation for the building in an artificial intelligence world that can make a clear link between integrated practice, high-quality design, and sustainability to select the more appropriate design solutions according to the site context. The majority of high-performance and sustainable structures are the result of tight cooperation between architects, engineers, construction managers, and building owners who make decisions together from the beginning to the end of the development, design, and construction process. 2019, represents a great revolution in the world of biophilic design, since that the City Administration Centre in Freiburg has been considered as living organism that can contribute positively to the environment (energy production exceeds the energy consumption). Hence, in order to achieve smart cities that provides better quality of life, some specific guidelines have been recommended as follow:

- In architectural education, students should learn to apply technological principles into the design concept as well as to discover the critical role that integration plays in spurring creativity and innovation.
- In the world of practice, architects should understand gaining great performance and efficiency need does not mean sacrificing design and architectural expression. High performing, highly sustainable buildings can still have significant architectural value.
- Developing an integrating high-performing structure within layered systems rather than monolithic on, can exemplify the immeasurable value of aesthetics and architectural traditions.
- Using architectural design languages that take into account the climate, site, orientation, custom, use, and history can improve building performance, efficiency, and environmental sustainability.

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