BIM INTEROPERABLE ENERGY ANALYSIS IN SUSTAINABLE BUILDING DESIGN

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Brief Introduction of the topic

- The conceptual dimensions of sustainable building designs is that buildings are not just built to respond to housing deficits but that building construction respond to gap of sustainable development (Crosbie, Dawooud and Dawooud 2011). The associated sustainable development are that a constructed building zeroes global warming for a lesser greenhouse gas and zeros on non-renewable carbon sources for energy solutions, building materials components, water intake and preservation of biodiversity (Azhar and Brown 2009). Sustainable buildings reply to occupant's thermal comfort, quality of life, build ability and life cycle cost. Issues of building envelope energy, needs air quality, seismic and fire response strategies, acoustic balances are and must be demonstrable in sustainable building designs (Olivier 2018. Hsieh and Wu 2012). Sustainability in building designs are viewed in two perspective of global and systemic outlook (Olivier, 2018). Following the complexity of building construction and operations cost, it is important that sustainable designers evaluate, orientation in space and site layout, amount of envelope openings, HVAC systems, ventilations systems, structural component material, insulation reference and foundation filling materials (Olivier 2018 ,Perez-Lambard, Ortiz and Pout 2008).

- The various stakeholders required for actualizing a sustainably built building ranging from client, professionals, contractors and end users makes it a systemic effort (Olivier, 2018 and BCA, 2013). This systemic effort evaluates suburb and occupant orientation, energy management issues, size and areas of opening etc (IEA 2012, Evins 2013and Evins 2013). On a global note, sustainable building designs addresses issues of structural responses in terms of heavy (inertial)/light (insulation) materials and solar admittance level (Krygiel and Nies, 2008). It also offers ready solution to envelope optimization in terms of energy needs for lighting, cooling, heating, ventilation, hot water, other energy uses and must be addressed from renewable energy sources (Wong and Fan 2013). In the light of the accompanying remarks above, energy performance analysis are often conducted to validate the immediate mentioned performance indices. Accordingly this lecture proposes to show the use of building information model interoperable integrated energy analysis software at deliverable for building energy analysis, towards zero energy buildings (Hsieh and Wu, 2012).

Sustainable Building Designs

- \- Buildings designed for sustainability must be congruous with certain green conformal characterization such as thermal comfort, indoor air quality associated with ventilation and airtightness properties.
- \- Its system of design must necessarily reflect global consideration throughout seasons of the year by responding to cold winter and hot summer.
- \- Archiving this requires the appropriate determination of the buildings orientation in space wither for individual/multi-residential designs or public office buildings towards occupants thermal comfort.
- \- Buildings designed in sustainability Palance must validate amount of openings and facades, materials used for insulation and inertia by calculations for sustainability considerations.
- \- In winter season, a sustainably designed private building must show protection against cold and cold winds by orienting occupants rooms southwards and intermediary spaces northwards for the purpose of urban planning conformity.

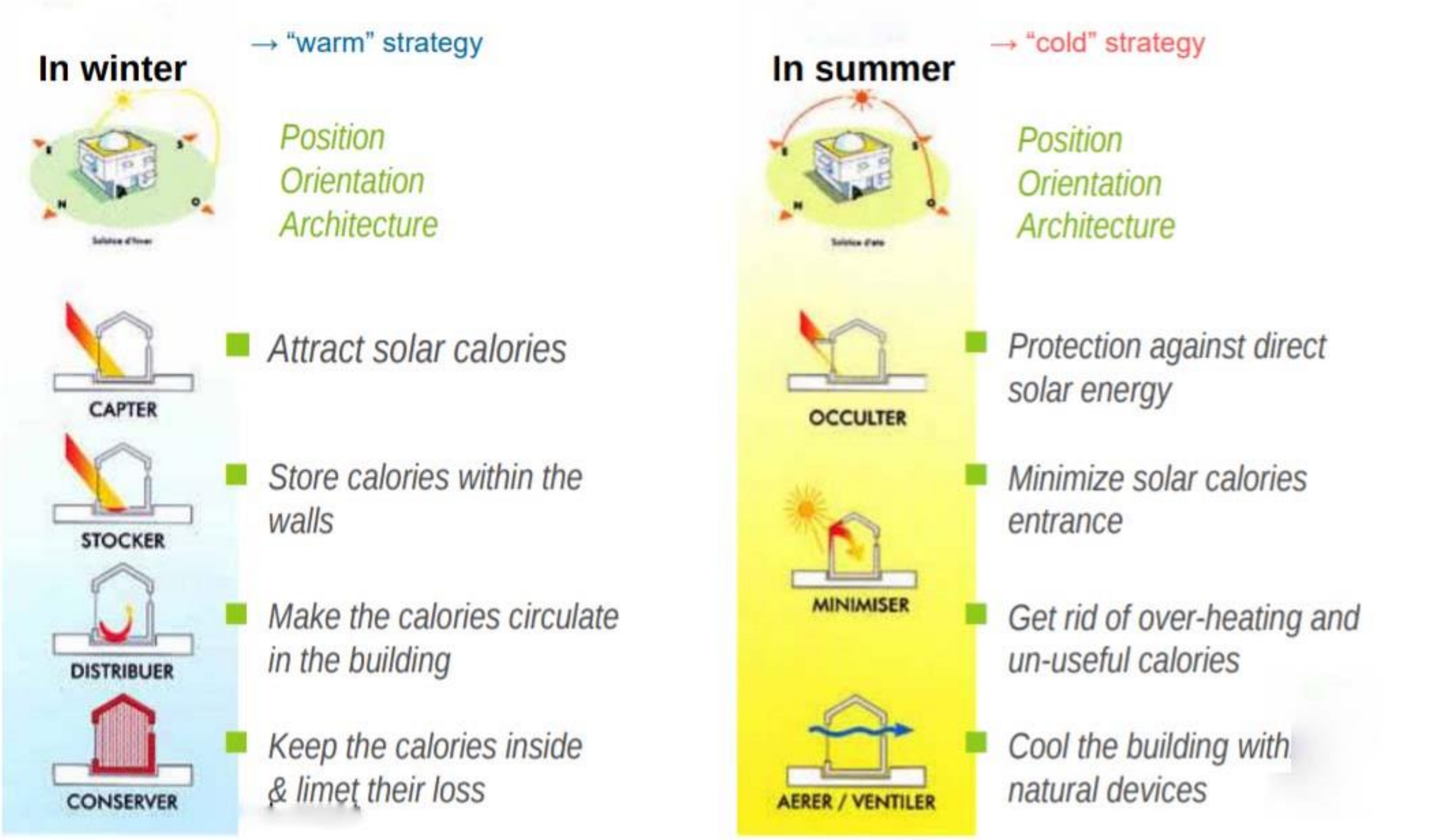
- It is appropriate that sustainably designed buildings respond to heat losses by insulation derivable form compact architectural design and determination of envelop to exterior surface maximum ratio.

- On the other hand, office and partly residential buildings are designed against winter cold by orienting them along east-west orientation and providing their intermediary spaces northwards while their heat loss by insulation is archieved by close-packed architecture for the purpose of responding to green-house effects.

- At summer time, designs are in favour of protecting occupants rooms from sun's heat using shading devices, facades and blinds. Heavy heat loss is archieved by open out designs for natural ventilation form wind gain.

- Archieving these balance between cold winter and hot summer squarely lies as the dilemma of sustainable designs. Olievier (2018) had shown envelope response strategies by bioclimatic designs approaches for sustainable building designs. (see figure 1 – Envelope bioclimatic design, Olievier 2018).

Envelop Bioclimatic Design



Olievier (2018)

- Construction materials for building insulation and their inertias in sustainable building designs have to respond to insulation by protection against cold and warm temperature conditions, able to limit and suppress heat movement/dynamics within the envelope.

- Such materials also respond to thermal inertia of flattening out heat flow fluctuations by warmth/cold heat accumulation and providing for variable speed of heat modulation.

- Sustainable designs towards building insulation and inertia by construction materials have been shown by Olievier (2018) in the accompanying figure 2 for construction materials for building insulation and inertia.

- Designs specifically for sustainable designed walls in terms of thermal conductivity λ(W/m.k) and thermal resistance R(m^2.K/W) have been computed in Olievier (2018), Chow and Yu (2000), Crosbie et.al. (2011), Schlueter and Thesseling (2009) in table 1 below.

Table 1

S/N	Thermal Conductivity λ(W/m.k)	Thermal Resistance R(m².K/W
	Watts	
1.	Low T.C. (good insulation) Fiberglass, straw λ(0.3 to 0.06)	1. High R (good insulation) (i) 20cm concrete R = (0.2m². K/W) (ii) 20cm concrete +20cm Insulation R = (5.2m².K/W)
2.	High T.C (Poor Insulation) (i) Concrete, earth = λ (0.7 to 1.1) (ii) Wood λ(0.13 to 0.2) Windows Thermal Transmission Coefficient $V=\frac{1}{R}$ (W/m².°C)	
3.	Low U (insulated glazing) (i) Simple glazing U_g = 6 W/m².°C (ii) Triple glazing U_g = 0.5 W/m².°C (iii) 20cm fiber glass U = 0.2 W/m².°C	

Fig 2

- Load bearing materials
  - Inertia :
    - Concrete and concrete blocs
    - Earth, adobe, straw ...
    - Burnt blocks
  - Insulating material :
    - autoclaved aerated concrete
    - ~ perforated burnt bricks
    - ~ wood
- Filling Materials
  - Inertia :
    - Burnt blocks
    - concrete blocs, earth
    - Hemp-, wood-, flax- lime blocks
  - Insulating material :
    - Mineral wool
    - Vegetal wool (wood, hemp, ...)
    - Polystyrene ...
    - straw

- Sustainability designs regarding insulations in walls are geared towards energy losses which is obtained by determining the heated volume and calculating the loss through walls, roofs, floors and windows by heat energy transfer function as:

  Transfer of Energy = $\frac{1}{R}.A.\Delta t$

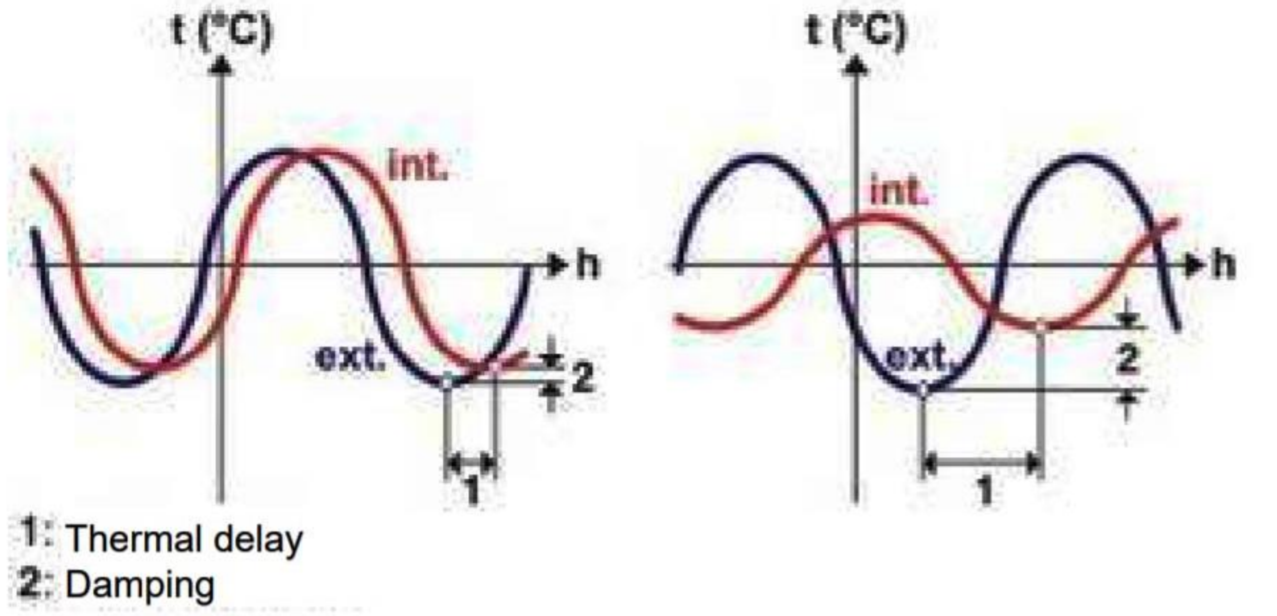
- Heat flow dynamic behaviours by designs should respond from time-shift (phaselag) and flattening (damping) out of quick transfer of accumulated cold or heat from building's outdoor to the envelope temp response and deposition of their excess in the wall membranes.
- This process is governed by Fourier's Law as:

$$\rho c \frac{\delta T}{\delta t} = \lambda \frac{\delta^2 T}{\delta x^2}$$

- Approach to model such heat fluctuations requires data for day and night modeling to obtain thermal delay and damping in building walls for low or high inertia. See fig. 4.

Fig 3:

Low inertia ***High inertia***



Olievier (2018)

- Materials requirements and specification for sustainable designed building of thermal mass (inertia) are found in the works of Olievier (2018) and Verbeke and Audenaert (2017).

Inertia : material specification

- Thermal capacity (or specific heat) C : W/m. °C
  - Capacity to store heat
  - Copper : 380 concrete : 1.75 insulating material wool : 0.04
- Thermal diffusivity = $(\lambda / \rho.\ C)$ m^2/s
  - Speed in transmitting heat → thermal delay
  - Concrete : 5 to 8 10^{-7} PSE : 4 to 8 10^{-7} wood: 2 10^{-7}
- Thermal effusivity = $(\lambda.\rho.C)^{1/2}$ en $W.h^{1/2}/m^2.°C$
  - Speed to absorb/ give back heat
  - steel 14 000 ; concrete: 2000 ; wood: 350 ; PSE : 40

- Design mix optimization related by insulation, thermal mass and occupant’s comfort in cold and warm region habitation is such that designs must attempt to keep away the cold by adequate insulation and delaying heat peak by thermal delay and lowering it by damping.

- Occupants comfort in validly sustainable designs of building is accounted for by the buildings humidity and temperature levels.

- Designs must pre-empt and predict humidity originating from occupants cooking, bathroom, capillarity and outside air. Also temperature originating sources of occupants, cooking devices, solar admittance through windows and heaters.

- Indoor air quality is important for occupant’s comfort besides thermal comfort. Sources of bad indoor air quality can originate from occupant’s pollution and human activities derivable from water vapour, CO_2, smoke and cleansen agent.

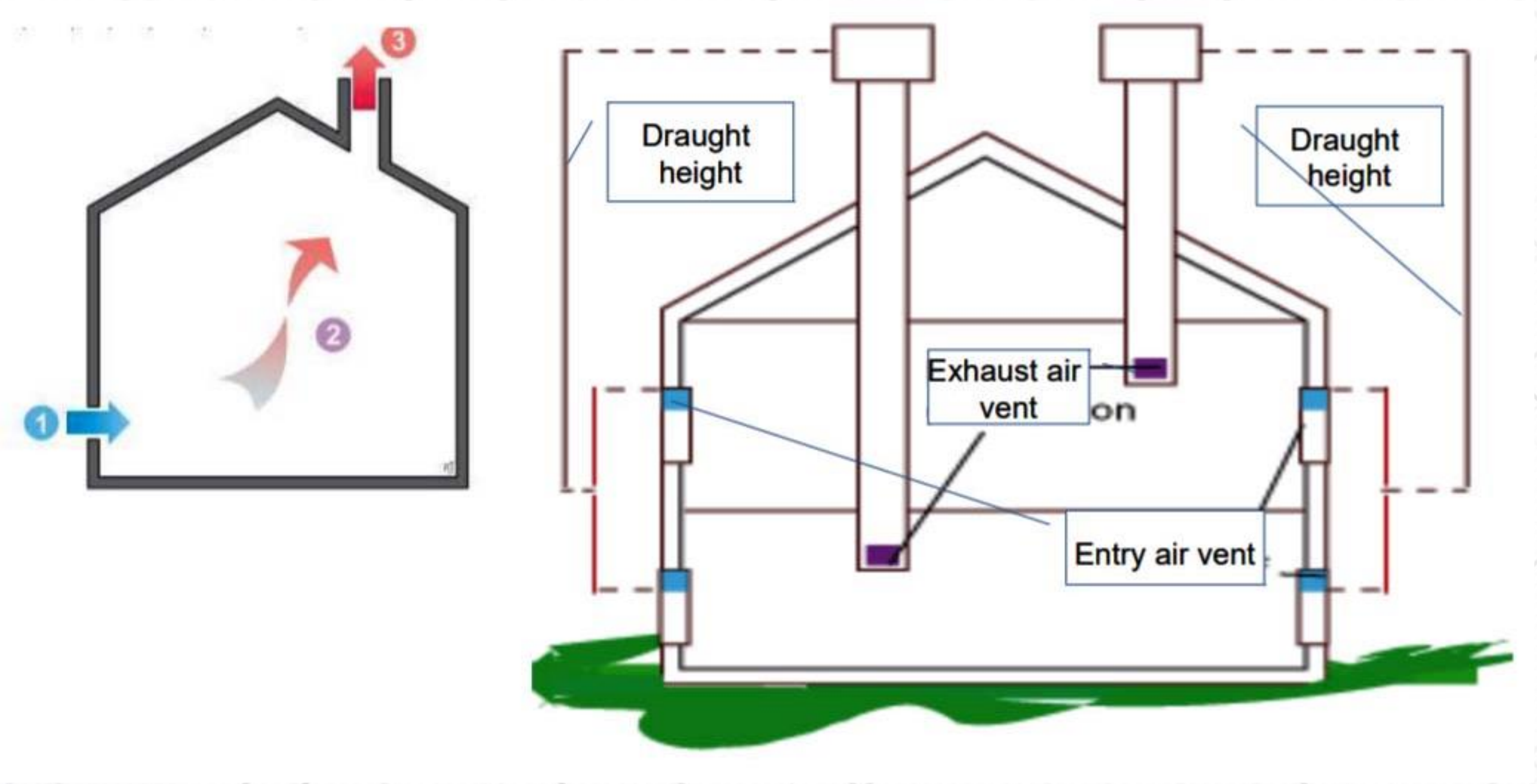
- Environmentally building and furniture materials constitutes large portions of outdoor air pollution, that may ultimately find their way into the building by infiltration.

- Design approaches to indoor air quality and occupants comfort are linked to air renewal theories in architecture by ventilation/aeration.

- This can be mechanically provided for by, heat recuperation exchanges and humidity control. Naturally it can be approached by window openings, incinerators and vertical arducts

Ventilation

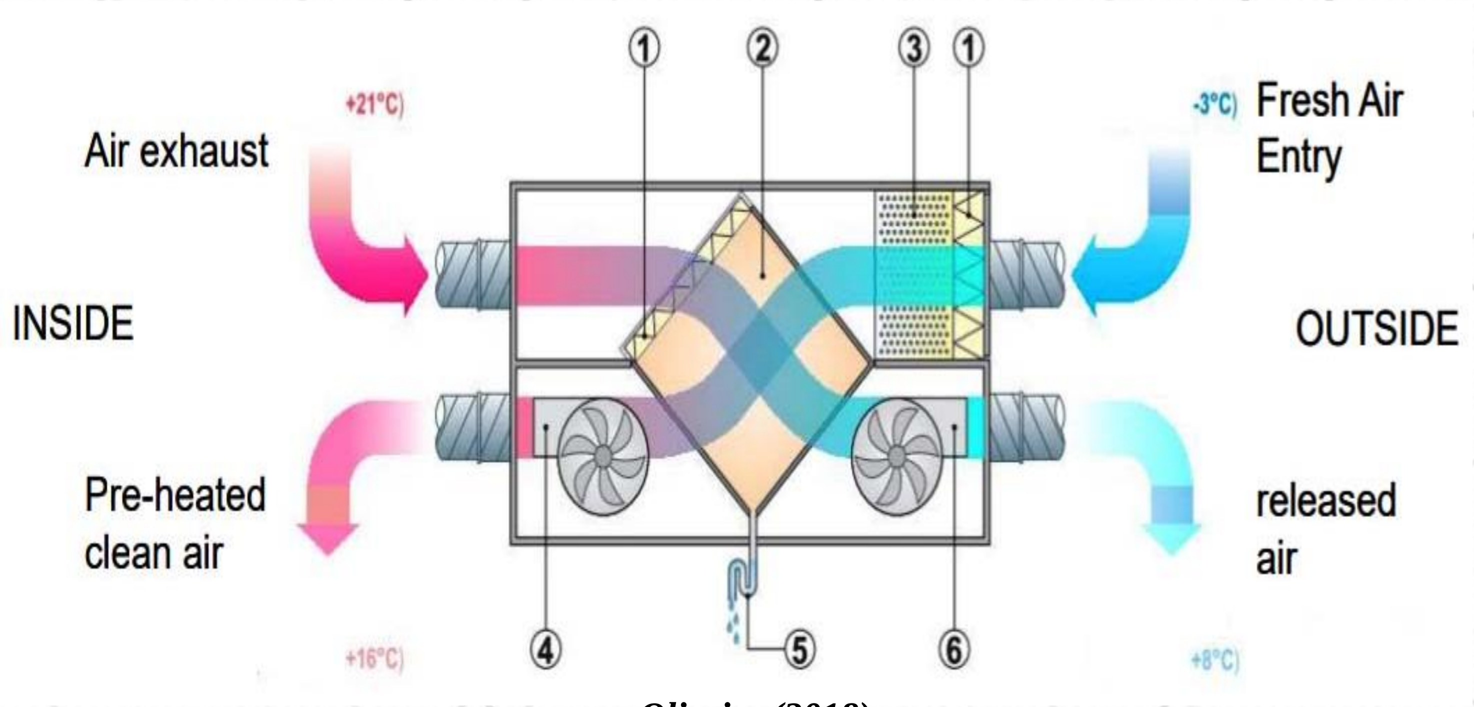
natural ventilation



Olievier (2018)

Ventilation

Global balanced ventilation: heat exchanger

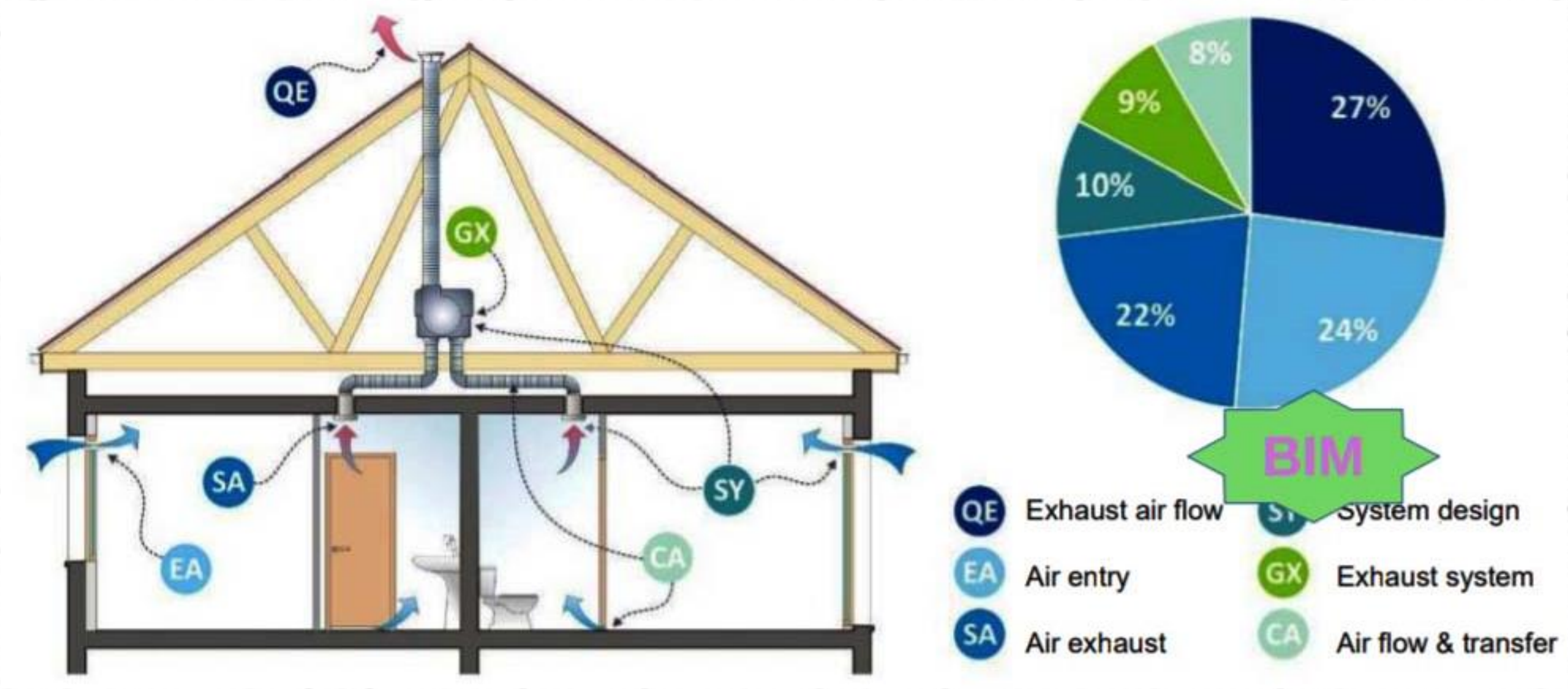


Olievier (2018)

There are many problems associated ventilating systems regarding air in flores and transfers having to do with the system design taking the appropriate mix between exhaust air flow (air entry) and air exhaust at exhaust system point.

Ventilation

Main problems with ventilation system



Olievier (2018)

- Reference made to quality of ventilation form such exhaust system requires appropriate audit of the whole system design, deployment of the whole system and measurement of the exhaust air flow.

- Ventilation frameworks and residential buildings according to European Standards are squarely discussed in the following documents.

- EN14134, 2004 revised 2019 for performance testing and installation of ventilation systems

- EN16211, 2015 for measurement of air flows in-situ methods.

- En 15299, 2019 for services.

- EN16798-17, 2017 for energy performance of buildings

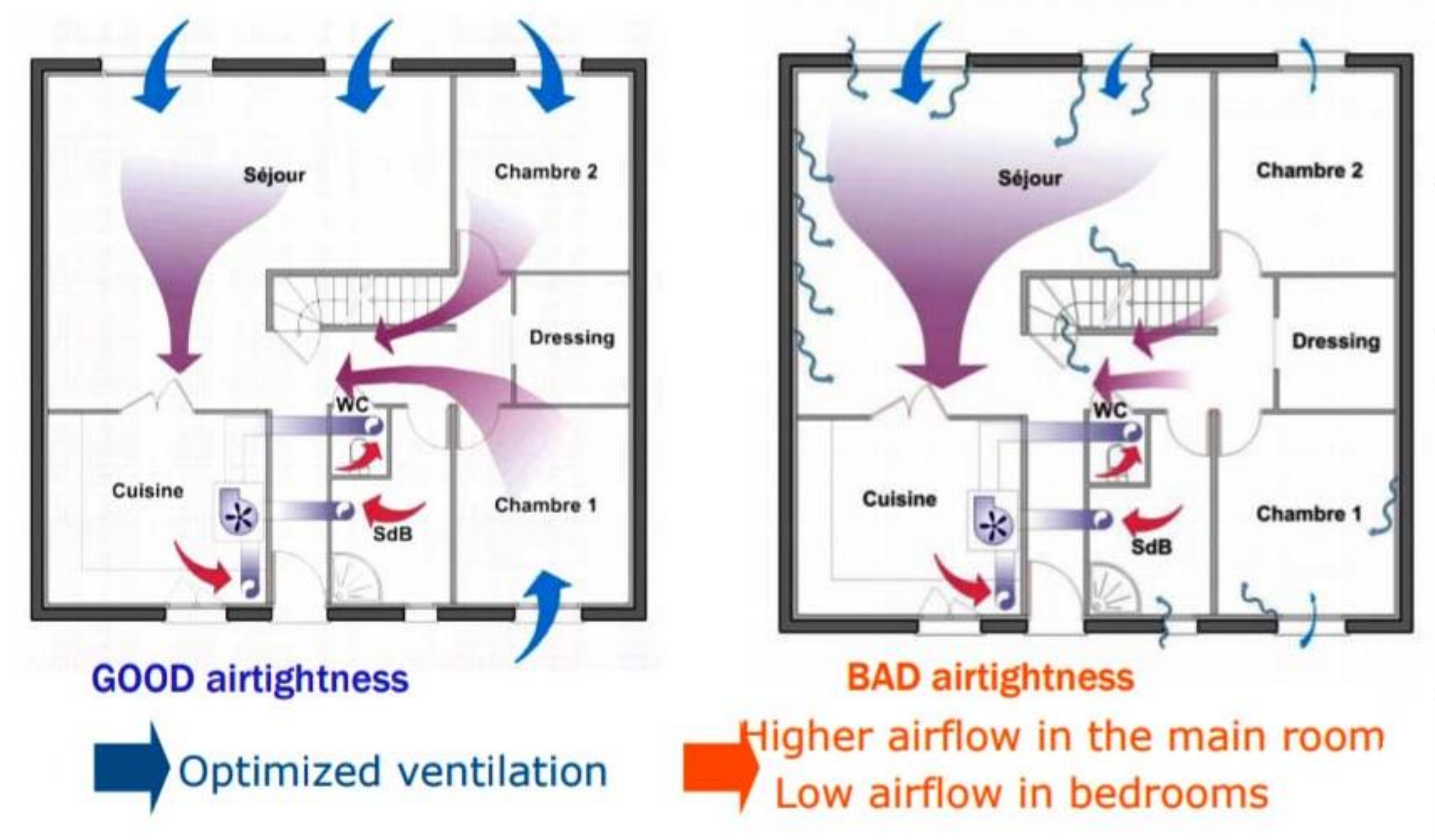
- Air tightness is another requirement for consideration in sustainable building designs. It is aimed at limiting all un-controlled air flows around and through the heated building space.

- Three ways of doing this are by:

1. Obtaining the limit of the heated building space
2. Analyzing all the various components longitudinally and transversely across the limit.
3. Resolve all main points to retain airtight envelope.

- Achieving efficient ventilation in architectural designs is obtained by good airtightness through optimizing ventilation. On the other hand, bad airtightness is evident in discriminatory airflows with higher airflows for main rooms and lower air flows bedrooms.

More efficient ventilation



Olievier (2018)

- Low airtightness is sustainable designs gives with reduced energy recovery in a balanced heat exchange.

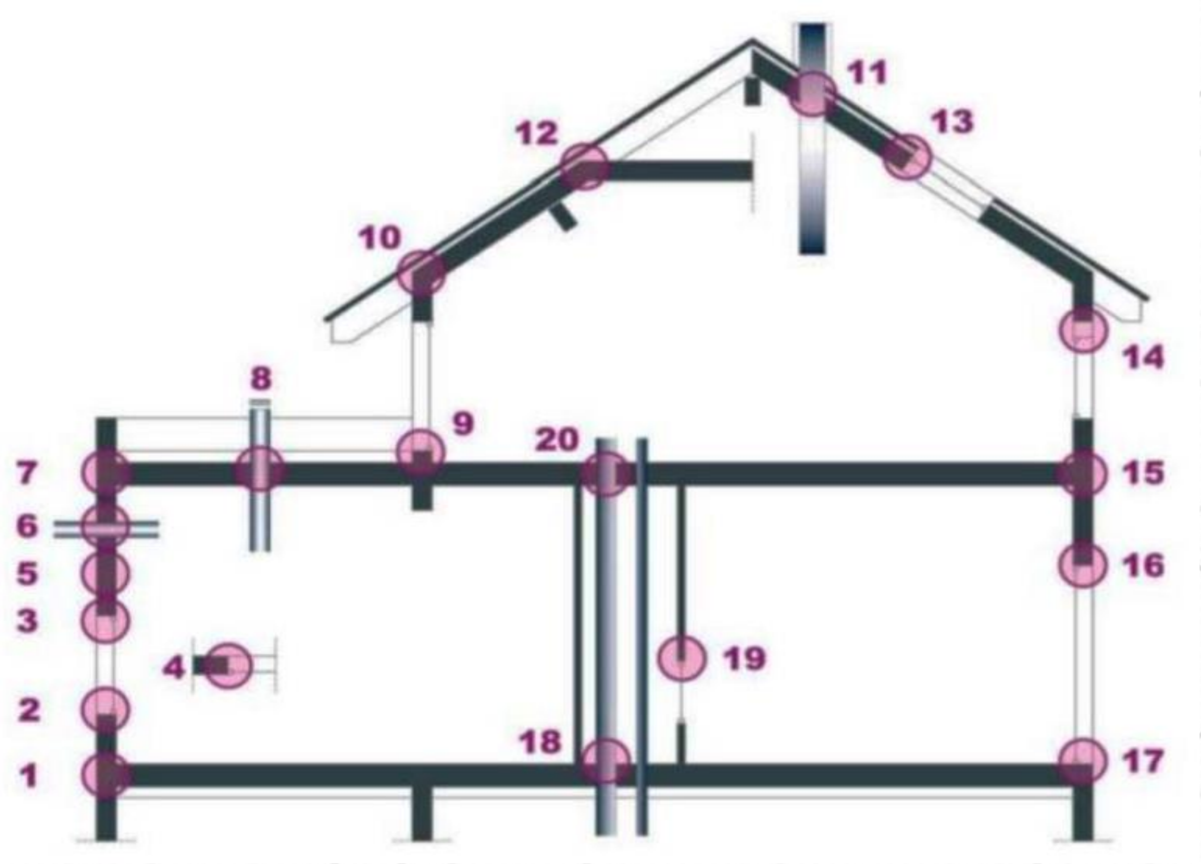
- Occupants thermal comfort consideration under air tightness can be linked to cold air infiltration through cracks causing cold draught, temperature differentials and cold wall sensation. Also, acoustic comfort to exterior sound infiltration from cold air infiltration through cracks.

- Air tightness provides better building conservation by ensuring that interior loaded with humidity finds its way outside the crossing insulating materials thereby getting colder.

- At this rate, consideration sets in giving rise to moist insulating wall materials, thermal property, loss, steel corrosion, black stains, and mould formation.

- Singular points airtightness sources for remediation at design and documentation times are concrete/block wall by surface rendering, wooden and insulating materials by airtightness membranes, joineries (doors and windows) by adaptable and non-shrinkable sealants and pipe sheathing for electricity. Airvents, water etc by adapted treatment.

Check all singular points



Olievier (2018)

- Airtighness are experimentally measured by blower door residential and multi-residential homes with 2 or 3 ventilators envelope space between 4000 to 6000m^3 or 1 ventilator for less than 2000m^3 and where houses with envelope space for 18000 – 75000m^3 with higher ventilators.

- The primary procedure is to locate the leakage points and measure associated air leakage with a trial pressure of 50% and estimate the heated volume of the building per hour.

- At 50%, with 6 to 8 volume/hour represent bad airtighness. At 2 to 3 volume/ per hour represent good airtighness. At less than 0.6 volume/hour represent passive Haus label airtighness.

- In such experimental situation the European through the ENISO 9972 document of 2015 gave guidelines for valid results concerning measurements for air permeability of buildings in the field and air flow rate across indoor-outdoor static pressure differentials.
- In general towards sustainable building designs, airtighness presents us with key building quality indicator in terms of construction durability, occupants comfort and impact of IAQ and health.
- It is the responsibility of the owner to give designers project specification, on-site following and building maintenance template for sustainability sake.

Energy Performance Analysis

- Building energy performance analysis is related to the various appraisals and evaluation conducted on solar, ventilation, thermal mass (inertia), space orientation and optimization HVAC equipment to understand the environmental performance of buildings.

- The need for such energy analysis is to gauge the energy cost consumption pattern whether they have regular or irregular profile and providing remediation measures for improvement opportunities (Hogeling and Derjaneez 2018).

- Such energy management strategies is usually desirable at preliminary design stage in sustainable construction with the aim of detecting inefficient energy route in the designs.

- Pre and post occupancy assessments are required for the purpose of cost optimization, statutory compliance to energy guidelines, government updates of annual budgeting provisions, and appraisal of comparative designs for energy systems, subsystems and components (li, Kubicki, Guerriero and Rezgui 2019).

- The validation of building energy performance is made to ascertain what the energy status is and what it ought to be at post occupancy (Asdrubali et al. 2020).

- The guideline for such energy performance can be referenced to those provided for by the European Union which must appraise the thermal profiles of the building in terms of occupants comfort and airtightness, HVAC installations, built-in light installations, building orientation in space with psychometric properties, indoor climate conditions, natural ventilation and solar screens.

- However, weighted factors such analysis are traceable to occupants activities, sustainability of the design and climatic factors (Gonzalez et. al. 2019).

- An excellent energy analysis requires hands on data for building space out lay and orientation in space, psychometric weather data, HVAC ratings and types, energy loads across envelope, utility rates, construction materials etc.

- At conceptualization, these metrics provides primary determinant feedback with respect to different consumption pattern and configuration around yearly energy performance.

- With sustainability in view, there is need for integrated approach to building energy performance analysis which is usually performed at architectural designs and preconstruction styles towards design optimization (Elagiry et. al. 2020).

- Trending research in construction building information science and engineer supports the adoption of BIM to addressing complex issues related to integration of building energy performance analysis to building sustainability designs.

- BIM under the integrated approach serves intra and inter disciplinary data well to providing energy analysis in designs by fetching sketches of building energy performance at stages of the designs process (Elagiry et. al. 2019).

- BIM impact in sustainable building design energy performance and analysis represents the following features:

Feature	Optimized potential
Sustainable construction materials	Aimed at lowering energy draining materials and utilization of potential recycled materials.
Building inertial	Aimed at optimizing the thermal properties enveloped and analyzing the building form
Orientation in space	Aimed at selecting the best building position to offer minimal energy cost.
Energy modelling	Aimed at optimizing designs to reduce energy consumption and offer renewable options.
Water harvesting	Aimed at providing water demand reduction in building.
Day lighting analysis	Aimed at providing insights to energy conservation capability

- Besides BIM application in the design processes of conceptualization, design and analysis, providing construction stage information and design and construction integration, its support through these processes are beneficially evident in the functionality attributes of building energy performance regarding structural integrity, temperature modulation, airtightness, space circulation, acoustic comfort, energy distribution and consumption pattern, water supply and disposal system are well validated.

- BIM integration in sustainable energy performance assessment is favoured by collaboration amongst design team specialists which requires the deployment of interoperable tools as requisites for design work station when integrated (Ullah et. al. 2019).

Interoperable Analysis with BIM

- Literature evidences showed that energy consumption on a global scale has been attributed to building occupant use at 40% rate.

- Attempts at minimizing such consumption rate has seen the deployment of virtual reality and digital wares into interoperability between integrated building analysis software with BIM for the purpose of development cost savings and improving building designs process.

- Integration requires automated workflow between any of the building energy models of Autodesk Ecotect, Autodesk Green Building Studio and Integrated Environmental Solutions (IES) Virtual Environment (VE) and BIM Compilation tool (Revit) (Osello et. al. 2011).

- The integrated process requires a representation of plan of sharing information without data loss, by simulating interoperability between architecture software (Revit) and Building performance software (Spiridigliozzi et. al. 2019).

- The sequence of data exchange between Revit architecture and integrated Environment Solution Virtual Environment (IESVE) is enabled by interoperable linkage with Autodesk Ecotect and the outcomes are usually tested by IFC, gbXML and FBX (Farzaneh et. al. 2019).

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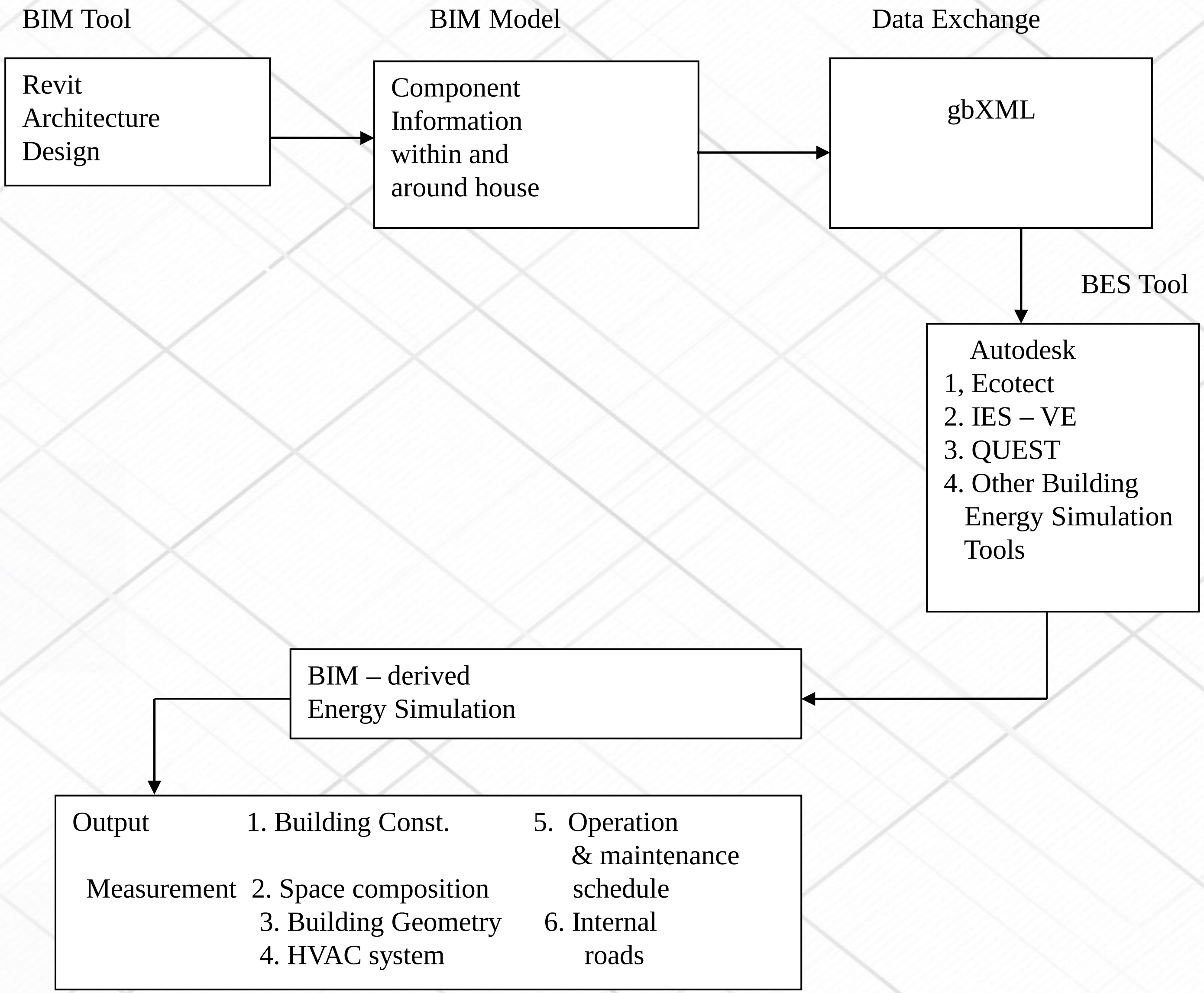
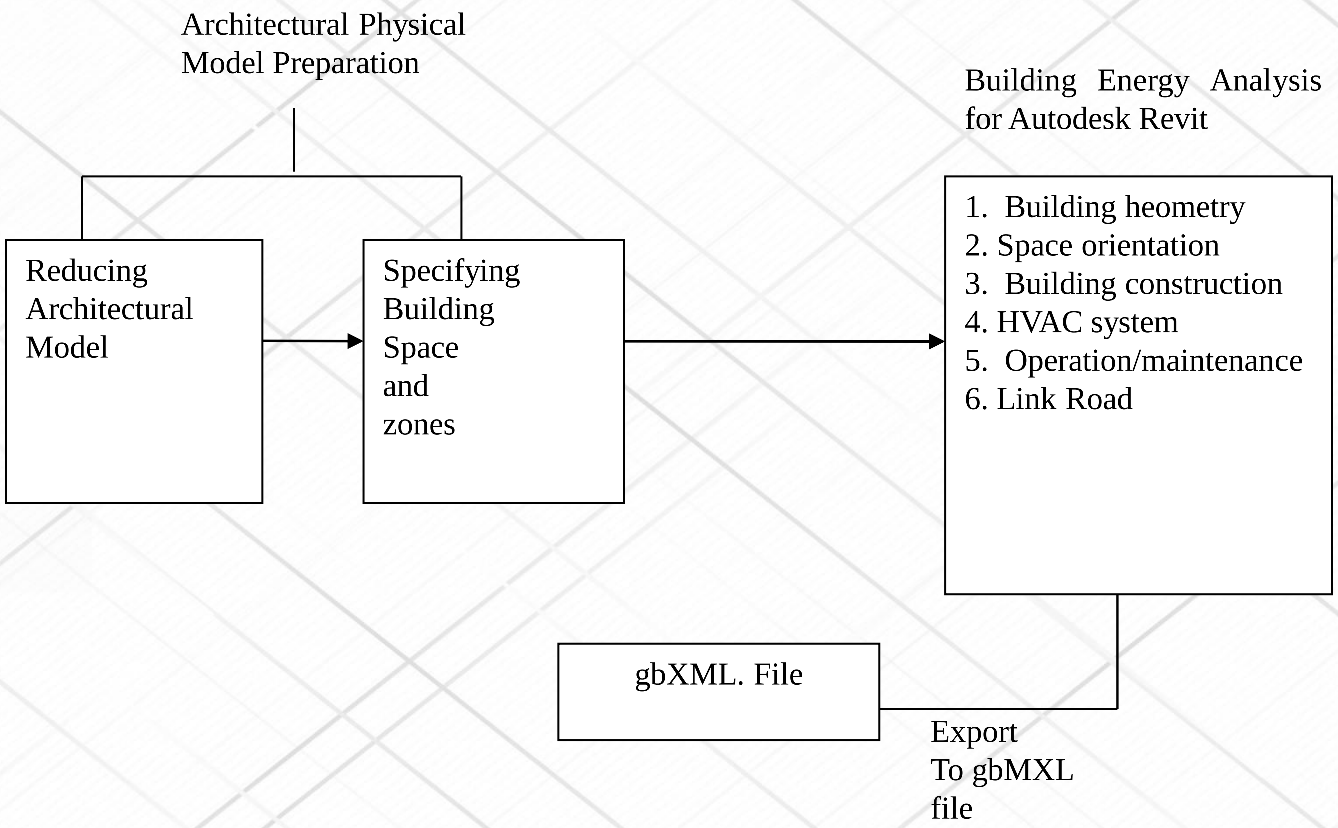
- The process of interoperability originates from preparing a physical architectural in Autodesk Revit, defining building components information and converting the building information form BIM model to gbXML environment (Hijazi et. al. 2015).

- The requisite component information are centered around building spaces and allotment information.

- The workflows pattern of interoperability is shown in the occupancy framework.


BIM Tool
BIM Model
Data Exchange
Revit Architecture Design
Component Information within and around house
gbXML
BES Tool
Autodesk
1, Ecotect
2. IES – VE
3. QUEST
4. Other Building Energy Simulation Tools
BIM – derived Energy Simulation
Output Measurement
1. Building Const.
2. Space composition
3. Building Geometry
4. HVAC system
5. Operation & maintenance schedule
6. Internal roads

- Interphasing process of exporting BIM – based information to gbXML follows the accompanying workflow below.



The basic information for building components in terms of space and zone as extracted from Revit is given as example in Chen et.al. 2018

Space Component	Zone Component
Living room	1
Toilet 1	2
Toilet 2	3
Bedroom 1,2,3	4
Corridor	5
Toilet 3	6
Bedroom 4	7

Requisite information deployed to Auto-desk Revit Chen et.al. 2018

Category	Analytic Construction	Value
Exterior Walls	Standard Wall Construction	0.3495
Roofs	Stopping roof including loft	0.1589
Floors	Wilton Carpet on Concrete	1.2908
Interior Walls	Light Plaster, brick light plaster	1.6896
Doors	Wooden	2.1944
Exterior Windows	Low-F double glazing	1.6743

Output from Autodesk Revit

- BIM Model conversion into gbXML follows two (2) step approach by firstly using the Energy Analysis function in Revit environment to generate energy simulation model in gbXML format and upload to Autodesk Green Building Studio (GBS). This step derivably gives information on energy analysis.

- This is followed by exporting the gbXML file from GBS chord service into a BES software tool to enable extraction of correct non-geometric information like occupancy, lighting, weather cooling and heating design day, types and rating of HVAC system and external air information.

- The two steps when combined.

- The process of creating gbXML, file Revit model is shown on the porsani et. Al. 2021 framework.

Net Zero Energy Building

- The essence of profiling building designs for sustainability is to promote near zero energy utilizing building which translate to mean zero energy consumption.

- This concept is hinged on deriving the total amount of energy utilized by building on yearly basis to be obtained in-situ from the amount of renewable energy created on site.

- Obtaining the required energy for a nZEB follows calculations for domestic hot water, cooling and heating loads, ventilation and lighting.

- Recent advances towards nZEB have shown technological advancement in the use of distributed energy systems to augment electricity and thermal energy needs of buildings.

- The need for a carbon neutral society has given rise to use of renewable energy sources to power buildings sand thus making them green conformal with attendant benefit of reducing energy demand pressure and reduction of GHG effect.

- Abandonment of fossil fuels for building energy needs have seen the upshot of integrated energy systems designed in buildings with renewable sources.

- Such advances have birthed technologies such as photovoltaic/thermal (PV/T) energy sources that produces building’s electricity need when constructively coupled on roofs and facades to harvest direct sun’s energy and converted to electricity.

- In spite of PV/T potentials for green/renewable benefits it has not addressed energy optimization problems in building envelopes.

- Responding to PV/T energy shortfalls saw the integration of photovoltaic arrays into building envelope to which is the BIPV/T - Building integrated photovoltaic system owing to its acceptability with envelope physics.

- Air source heat pumps (ASHP) are derived from BIPV/T which is a system of energy source obtained from Photovoltaic array modules fluid circulation which heat up on exposure to sunlight and are directly converted for space/domestic hot water heating.

- Another modification to ASHP is the ground source heat pump (GSHP) with cheaper installation cost.

- Interoperability of ASHP to BIPV/T has shown to be cost effective in terms of energy delivery even better to GSHP linkage which requires treatment of outdoor air.
-
- Thermal energy storage (TES) and seasonal solar thermal energy storage (SSTES) are also sources of renewable energy delivery.

- Building construction towards nZEB has been documented in France with RT2012 regulation wherein the "Bbio" index is used to account for the impact of bio-climatic designs on building energy performance is estimated from:

  'Bbio = $ZE_{heat} + ZE_{cooling} + 5E_{lighting}$

  Criterion: Bbio < $bbio_{max}$ (RT 2012)

- Since 2013, all new development must show compliance to criterion estimate above.

- Following the underlying conditions, nZEB must show energy efficiency rate of 40 to 60 $KWh/yr/m^2$ for building of not less than 42^o south and 72^o North latitudes

- Airtightness criterion for nZEB must show building test result at Q_{4pa} Surf = 0.63/hr/m^2 for personal houses and

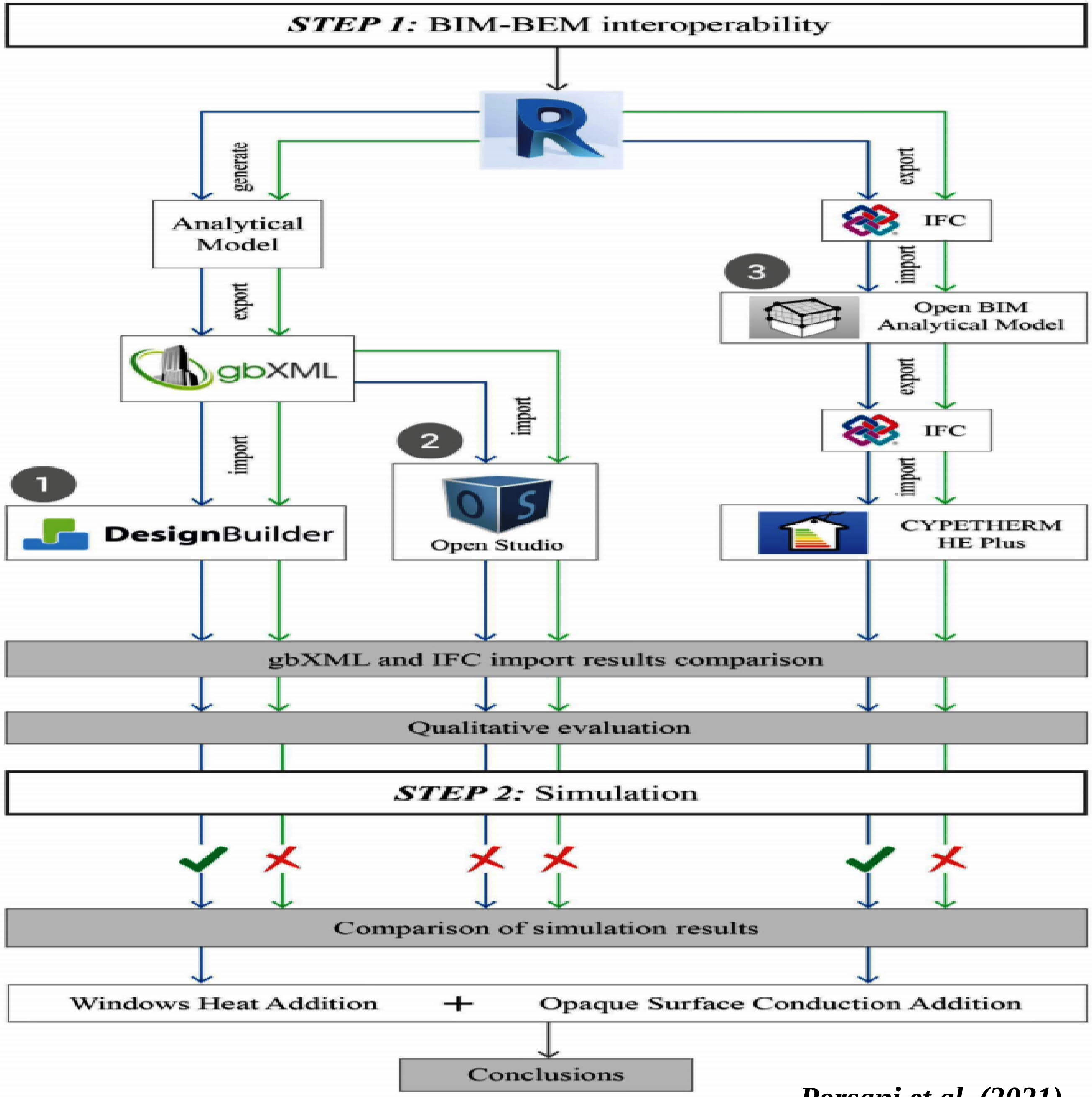
- Q_{4pa} Surf = 1m^3/hr/m^2 for apartment houses.

- Attain these RT2012 minimum with varying conditions in other European countries according to Olivier 2018 suggests that all building thermal bridge must be treated.

- Buildings must depend on green/renewable energy sources to meet their energy needs.

- Window areas in buildings must be demostratably be occupying in designs a minimum of 1/6 of total wall area.

- The European countries regulations are shown below.



Porsani et al. (2021)