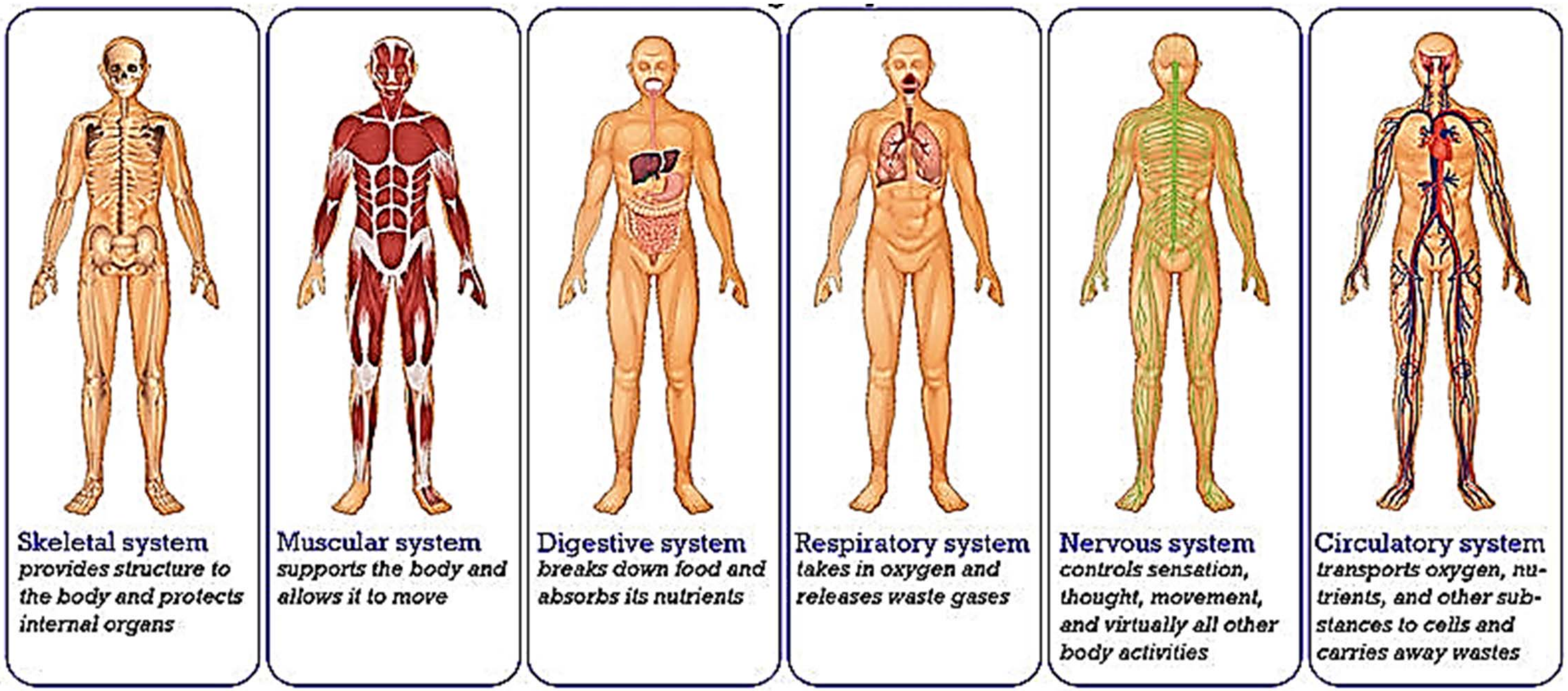
MODELING
DYNAMIC BUILDING THERMAL RESPONSE

Introduction

Energy is Continuously Flowing in Buildings & between Buildings & the Environment in response to dynamically changing climate & indoor conditions. Building Systems regulate energy flows to maintain indoor conditions within specified healthy & comfortable levels

HUMAN BODY ANALOGY



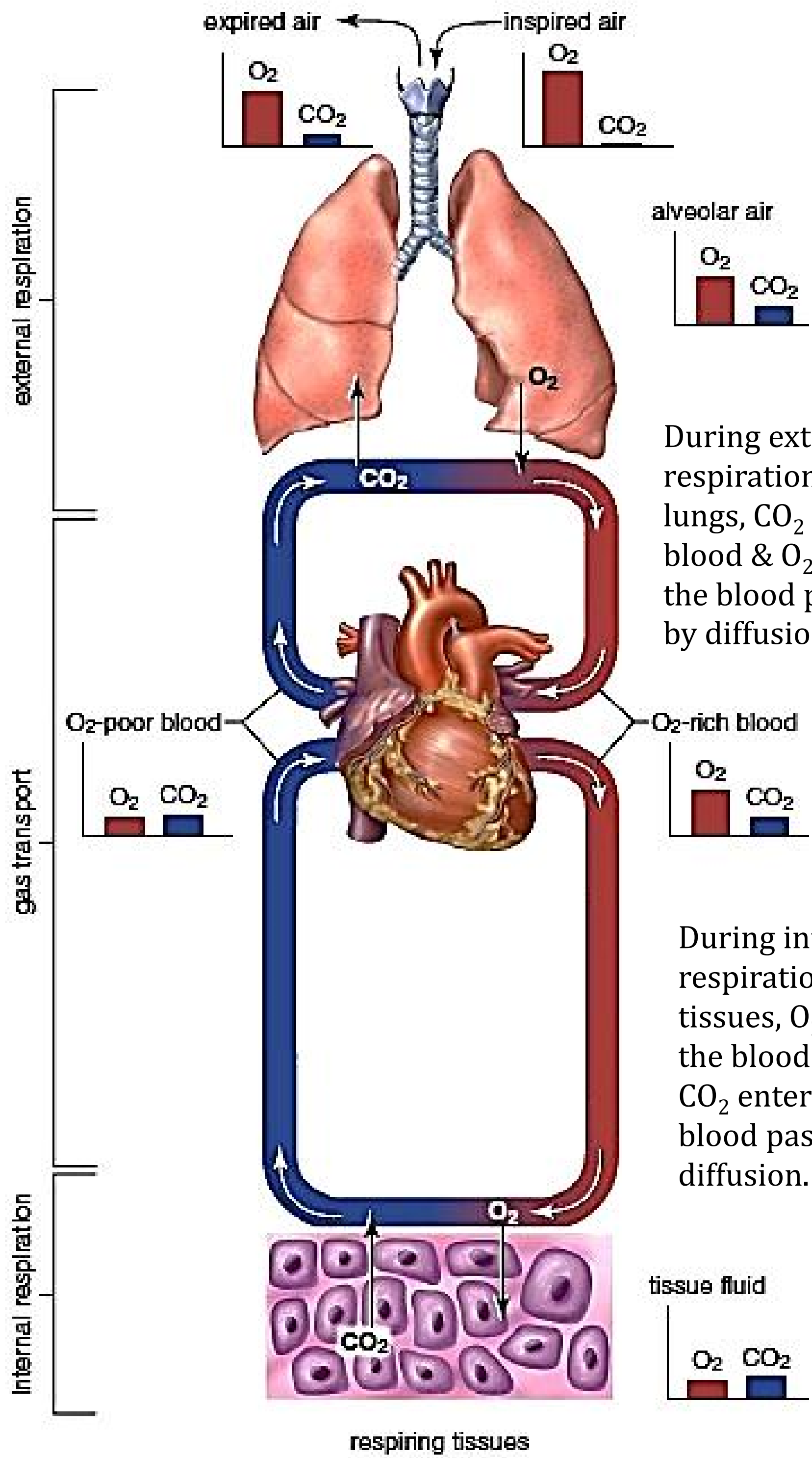
- Humans are homeotherms - They attempt to maintain their internal (core) temperature within an optimum range (about 37℃).
- Metabolic activities of the body result almost completely in heat that must be continuously dissipated & regulated to maintain normal body temperatures.

OXYGEN & LIFE

- In nature, free oxygen is produced by the light-driven splitting of water during oxygenic photosynthesis, which also fixes CO2 into sugar:

  carbon dioxide (CO2) + water + sunlight → glucose + dioxygen (O2)

- Green algae & cyanobacteria in marine environments provide about 70% of the free oxygen produced on Earth & the rest is produced by terrestrial plants.
- **Oxygen constitutes most of the mass of living organisms**, because water is their major constituent (for example, about two-thirds of human body mass). Many major classes of organic molecules in living organisms, such as proteins, nucleic acids, carbohydrates, & fats, contain oxygen, as do the major inorganic compounds that are constituents of animal shells, teeth, and bone
- Respiration is the process that gets oxygen from the air to the tissues of the body & removes carbon dioxide from the body.



During external respiration in the lungs, CO_2 leaves the blood & O_2 enters the blood passively by diffusion.

During internal respiration in the tissues, O_2 leaves the blood and CO_2 enters the blood passively by diffusion.

Respiration :

- Air enters the nose, where it is warmed and humidified before entering the lungs. When the air reaches the alveoli, small air sacs in the lungs, the oxygen diffuses into the blood in the capillaries around the alveoli while carbon dioxide (the product of metabolism) leaves the blood & enters the air. During exhalation the carbon dioxide is released into the atmosphere.

Blood Circulation & Metabolism

- The oxygenated blood leaves the lungs and is pumped throughout the body by the heart. When the blood enters the capillaries in the tissues, oxygen diffuses out of the blood and into the tissue. Cells use this oxygen in metabolic reactions. Metabolic reactions produce carbon dioxide. The carbon dioxide enters the blood as it leaves the tissues to be returned to the lungs and eventually the atmosphere.

COLUMN REFRIGERATION APPLICATIONS

Andy Pearson

HVAC of the Human Body

BY ANDY PEARSON, PH.D., C.ENG., FELLOW ASHRAE

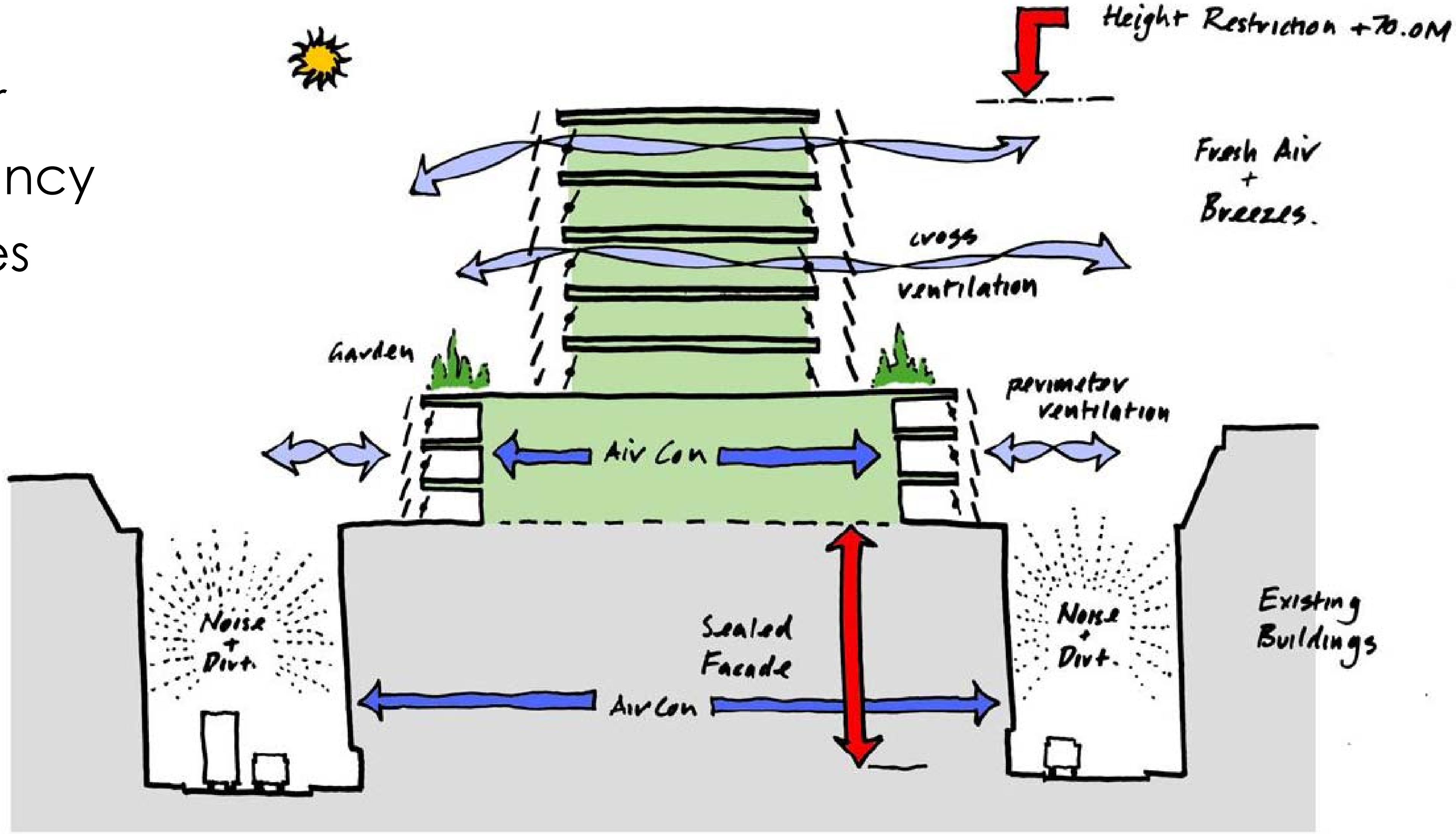
Horses sweat, gentlemen perspire, and ladies glow. Whatever it's called, we all recognize the benefit of evaporative cooling when it comes to keeping our cool. There is an instinctive understanding of the effect of relative humidity on the performance of our corporeal cooling; too high and the benefit is reduced due to lack of evaporation, whereas too low humidity causes other discomforts.

Many other HVAC subsystems in our bodies are closely analogous to HVAC plants in buildings, but are less evident. Most are related to blood flow. Blood is remarkably multifunctional because it provides heating and cooling like a hydronic system, it carries fuel and oxidants to the localized combustion chambers, and it removes the waste products of combustion. The fuel is a form of hydrocarbon

Blood provides other functions, too. It is used to control the rate of extract ventilation provided by the lungs in an unusual way. The concentration of exhaust gas (CO_2) in the blood is regulated by monitoring the blood pH, and the rate of ventilation is modulated to maintain a steady pH level of 7.4, ±0.05: if the pH falls it is presumed the CO_2 level is high, so the ventilation rate increases, and

DRIVING FORCES

1. Weather
2. Occupancy
3. Processes



{source: ARUP)

BUILDING MODELING & SIMULATION

- Building Models are virtual mockups that represent the building systems & the physical processes that take place in a building.
- Modeling involves a certain degree of abstraction. The art of modeling turns on selecting the level of detail according to the need at hand.
- Simulation is dynamic virtual experimentation with the model to investigate & understand/interpret its response to changing conditions inside & outside the building.
- Abstraction & Interpretation are therefore two critical aspects of dynamic simulation modeling.

[Ljubomir Jankovic 2012, Designing Zero Carbon Buildings Using Dynamic Simulation Models]

BUILDING MODELING & SIMULATION

- Building simulations models are built from first principles equations of heat, air, moisture, & momentum conservation.
- They run on time scales of one hour or less, to replicate the dynamic performance of a building that is close to the performance of its real world equivalent.
- Until simulation models are validated with real life experiments, building simulations cannot give absolute answers about the performance of a building.
- A main value of simulation is as a comparative analysis tool to support decision making for trade-offs between various design options.

[Ljubomir Jankovic 2012, Designing Zero Carbon Buildings Using Dynamic Simulation Models]

THE ROLE OF MODELING

- A model is a mathematical simplification of a real system that represents only those factors/variables that are seen to be significant to the problem at hand.
- In general, modeling is not an alternative to observation & measurement, but a tool for understanding observations & helping explain & predict physical phenomena.
- The model can be exercised to learn many aspects of how the building responds to different disturbances or stimuli
- By looking at the changes in the building loads versus any change in the driving forces, one can determine any changes needed in the building design & what features have a big influence on the building loads.
- There are two types of models:
  1. **Empirical models**: build correlations between variables from data collected.
  2. **Mechanistic models:** make use of fundamental physical laws (e.g. energy balance, mass balance, momentum balance) to describe processes.

"Everything should be made as simple as possible, but not simpler" Albert Einstein

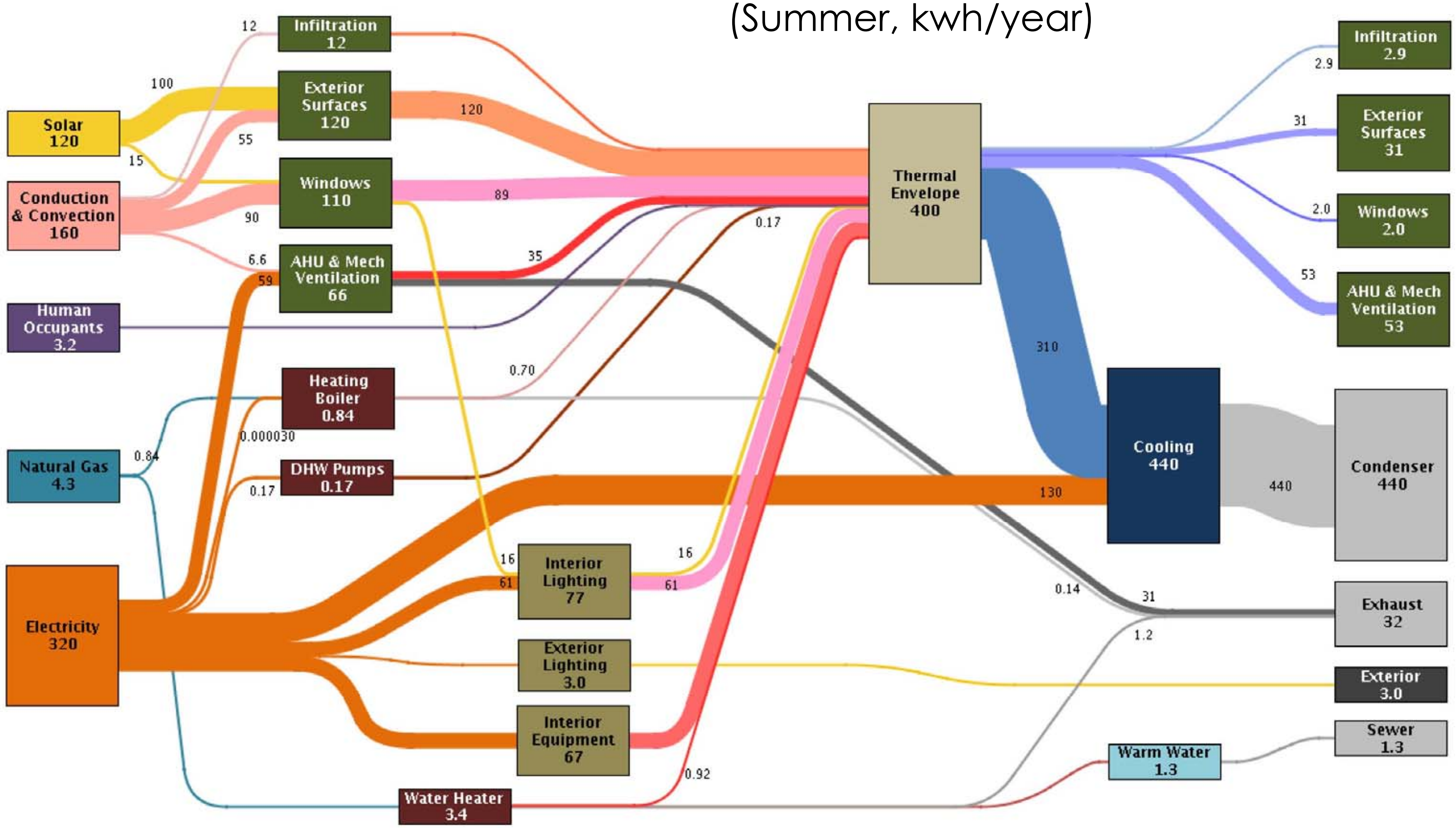
THE ROLE OF MODELING

- It is good practice to construct a simulation model of an experiment before building the actual experiment. The reasons are two-fold:
  1. The model, even a simple one, can help identify and quantify the factors that are expected to have greater impact on the experiment's measurements, and fine-tune the experiment to maximize the value of the results
  2. The model can then be improved and calibrated with the experiment and be used to more accurately predict results in future experiments or to extrapolate results. The model can also be scaled to more real applications

"Essentially, all models are wrong, but some are useful." George E.P. Box

BUILDING ENERGY FLOWS

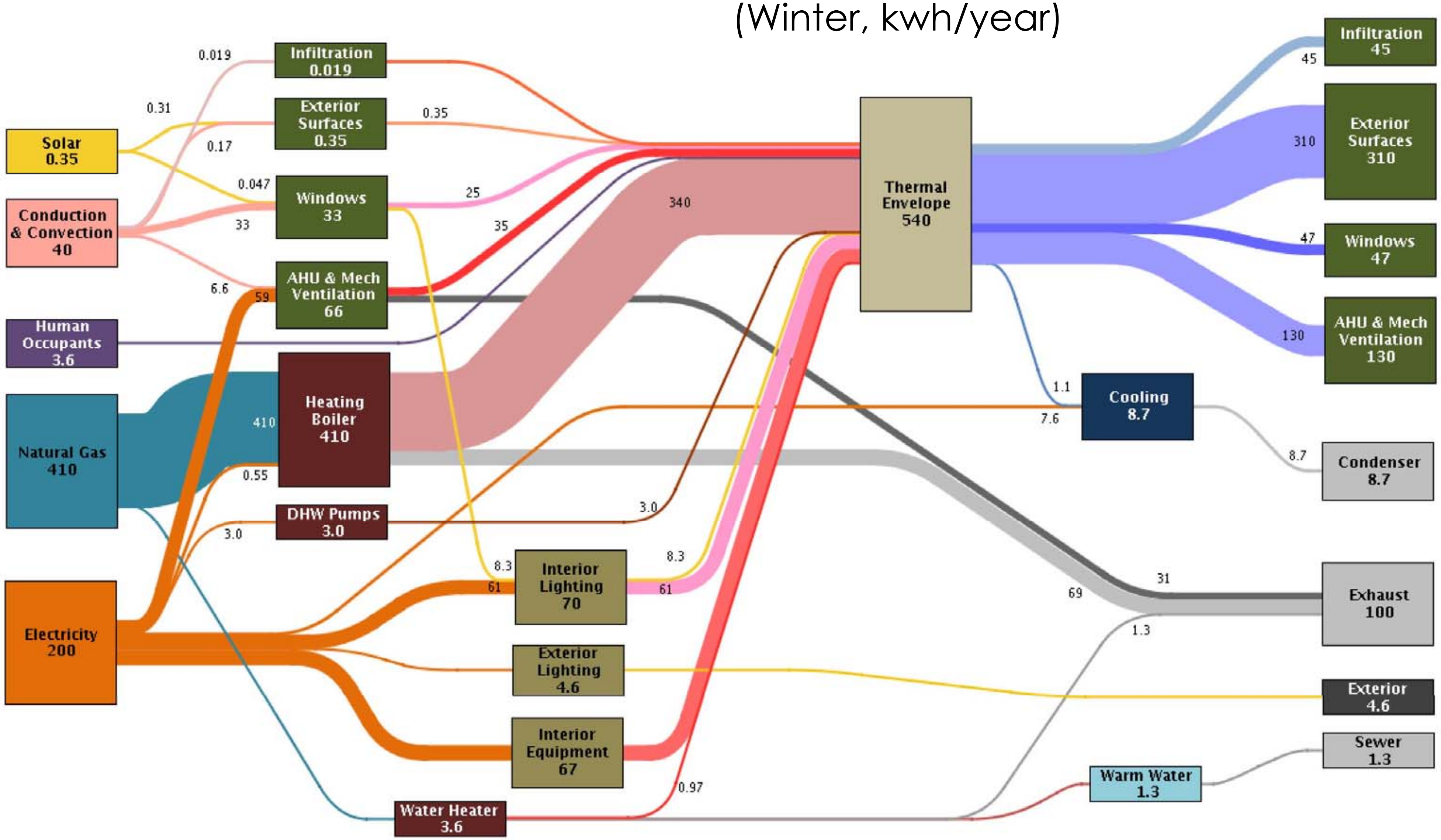
(Summer, kwh/year)



http://www.sankey-diagrams.com/tag/building/

BUILDING ENERGY FLOWS

(Winter, kwh/year)



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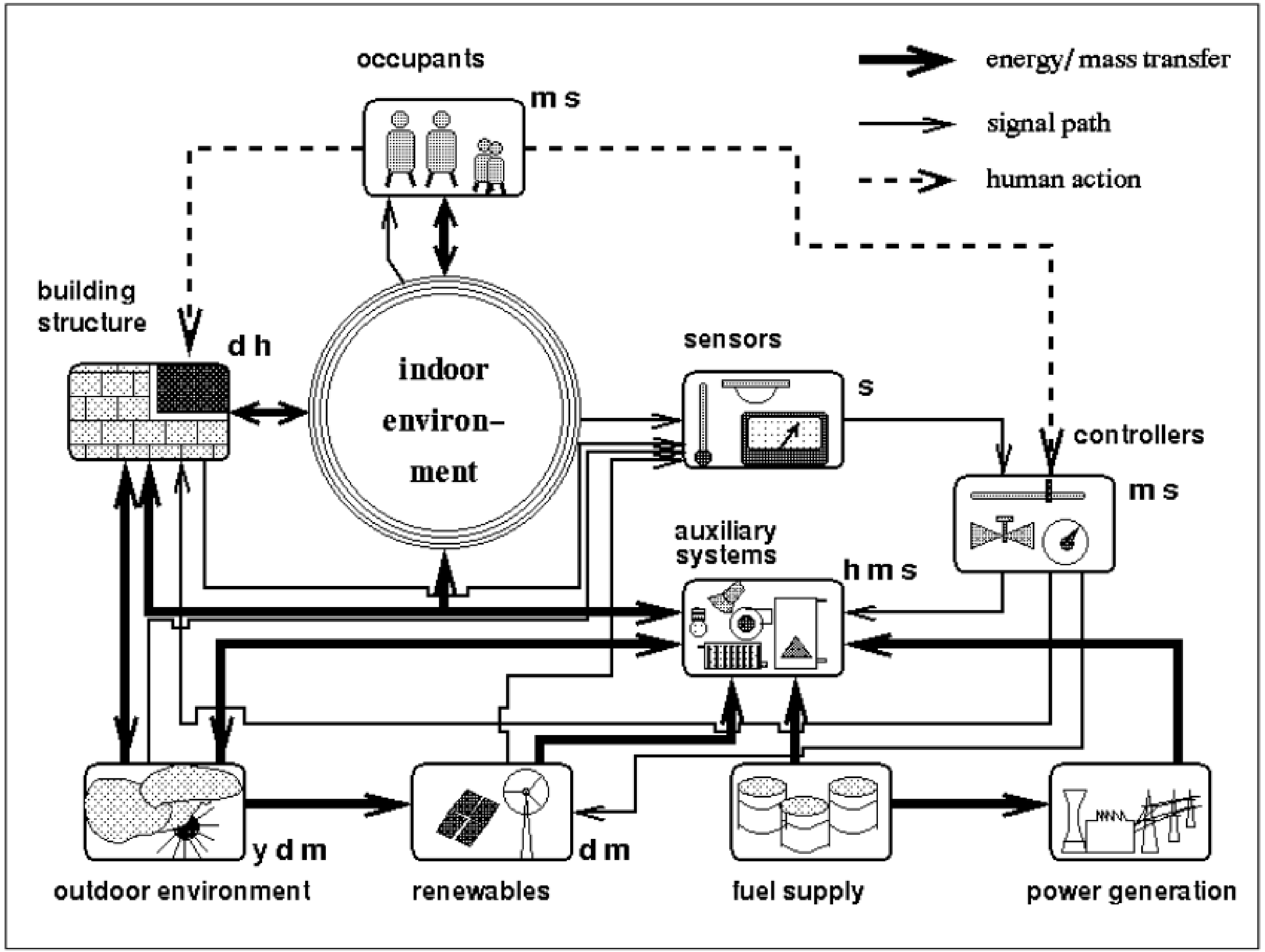
BUILDING ENERGY SYSTEMS INTEGRATION



INTEGRATED SIMULATION FOR (SUSTAINABLE) BUILDING DESIGN: STATE-OFTHE-ART ILLUSTRATION J L M Hensen and J A Clarke

BUILDING ENERGY/THERMAL MODELING

- Given a full description of the building & its dynamic boundary conditions: weather data, & indoor occupancy & process loads,
- Energy modeling software simulate the dynamic, hourly or sub-hourly, flows of energy in a building, affected by HVAC systems, in response to the ambient weather conditions & the internal gains.
- In doing so, it calculates time series data from heat, air, and moisture balances in building materials and spaces to predict the building indoor climate conditions.
- Powerful tool to simulate virtual experiments prior to full scale testing in a laboratory or a real building in order to determine the impact of different factors under a range of boundary conditions

FROM THE ARCHITECTURAL MODEL TO THE THERMAL MODEL (*TRNSYS 18 MANUAL*)

Thermal models are quite different to architectural 3D-models which include lots of information not important for energy modeling. Thus, the energy model becomes a derived version with a focus on heat transfer aspects.

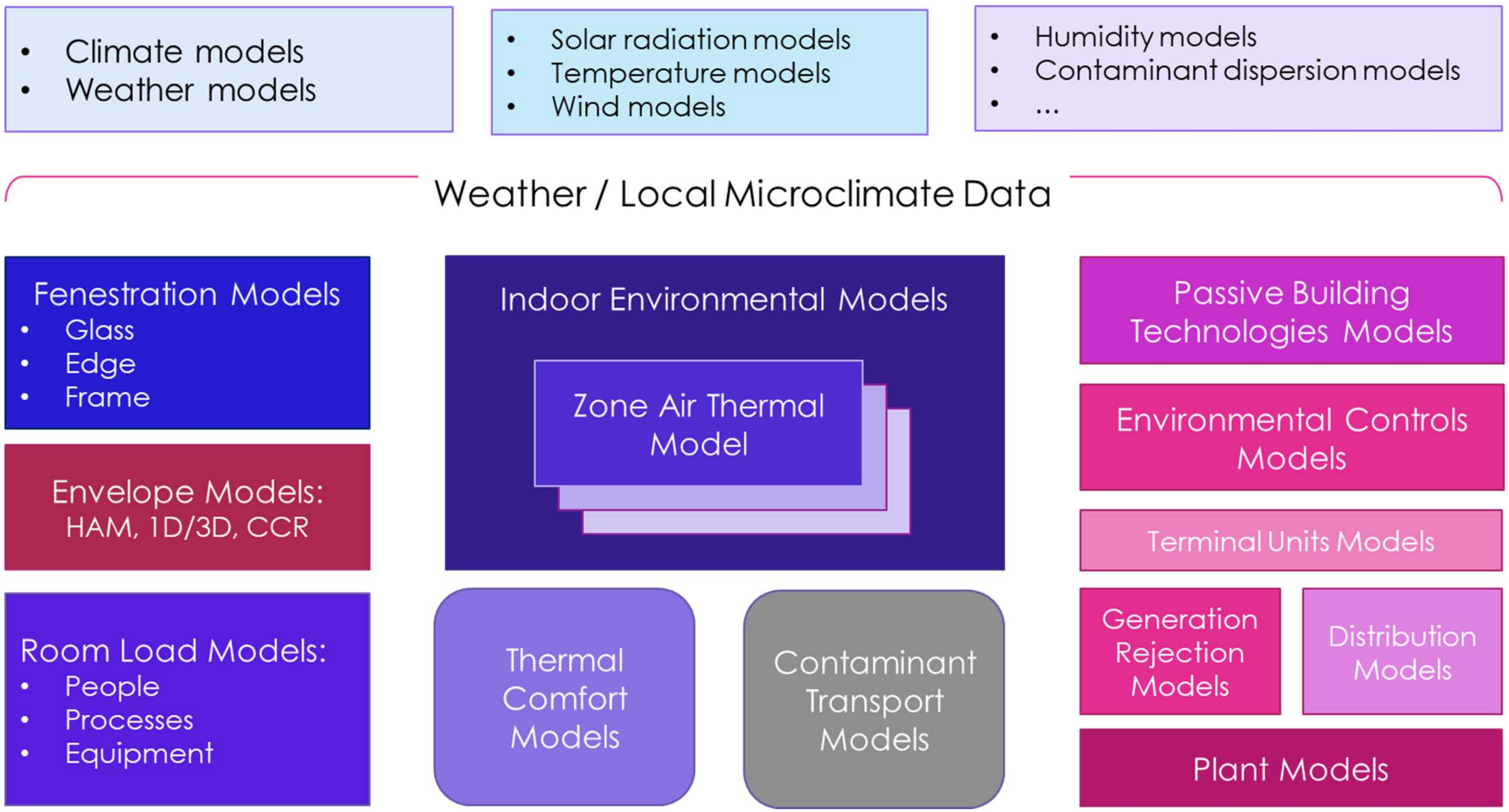
- Keep it as simple as possible. The user effort, complexity and computation time increases significantly with the number of zones and not necessarily accuracy.
- A thermal model doesn't have to look like an architectural model, but has to model the thermal behavior. For most cases the geometry can be simplified. E.g. for zone with ten windows 1m x 2m in the south façade it is not necessary to draw ten windows instead draw one with the same total size.
- The zoning depends on the expected results of the simulations. Similar areas with respect to solar gains, construction, utilization and conditioning show the same thermal behavior and can often be combined into one zone for energy simulations. For detailed analysis of comfort and detailed temperatures it is recommended to simulate "special areas" as separate zones.

MODELLING THERMAL STRATIFICATION (E.G. ATRIA)

E.g. TRNSYS:

- Thermal stratification is normally modelled with a stack of several zones.
- To model this example as an atrium, assign the horizontal construction separating stacked zones as '*VirtualSurface*'.
- When it gets imported into the TRNSYS TRNBUILD, the *VirtualSurface* will automatically be deleted and reflect an accurate radiative model.

Dynamic Building Modeling & Simulation



- Virtual mock-ups
- Virtual experimentation
- Quantify
- Abstractions of reality
- Simplifications
- Assumptions
- Uncertainties
- Fine-tune
- First principles
- Empirical/Laboratory
- Investigate
- Understand
- Explain
- Interpret
- Dynamic responses
- Changing conditions
- Comparative analyses
- Trade-off analyses

In general, modeling is not an alternative to observation & measurement, but a tool for understanding observations & helping explain physical phenomena.