A METHODOLOGY AND TOOLKIT FOR THE ASSESSMENT AND SELECTION OF LZC TECHNOLOGIES IN THE BUILDING DESIGN PROCESS

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ABSTRACT

The advent of environmentally driven building regulations, rising energy costs, and heightened client awareness of energy-related issues has increased the demand for the assessment of building integrated low-carbon (LZC) energy supply systems. However, it is seldom the case that any one software tool fulfils the needs for an appraisal of these types of systems. Therefore, there is a clear need for an effective methodology for the use of a range of software tools in LZC technology analysis. This paper describes a practitioner-driven project within which such a methodology and supporting software (termed a "toolkit") has been developed. The application of this toolkit to a real design problem is described and the results from the analysis are discussed. The paper also addresses the means by which the results from the analysis can be presented to clients and other stakeholders in the design process.

INTRODUCTION

The recent advent of environmentally driven building regulations across Europe and elsewhere e.g. [1], rising energy costs, and heightened client awareness of energy related issues has increased the demand for the integration of low and zero-carbon energy (LZC) technologies in buildings. Designers are increasingly being asked to assess the performance and energy yield of these technologies as part of the design process.

However, given that the requirement for LZC energy supplies have only recently been incorporated into European building legislation there is a lack of guidance for designers in terms of best practice in rigorous performance assessment. Additionally, while plenty of software packages are available to assess the performance of individual technologies, no single software tool currently fulfils the needs for a complete, integrated low carbon technology appraisal.

Therefore, there is a clear need for an effective multi-tool methodology for evaluating low or zero carbon (LZC) energy supply technologies and the integration of that methodology within a wider low carbon modelling and design process.

This paper describes the development and testing of such a methodology as part of a joint project between K J Tait Engineers and the University of Strathclyde.

LZC TECHNOLOGIES

Before elaborating the LZC design methodology, it is worth reviewing the common LZC technologies that are being integrated into buildings and the software that could be used to evaluate their performance. The technologies are:

- Conventional combined heat and power (CHP) is most commonly used LZC supply technology in the UK, and can greatly reduce carbon emissions when installed in appropriate situations [2]. Unlike building integrated renewables, the heat and power output of CHP technologies is controllable and predictable, however it is not a zero-emissions technology as a fossil fuel source is required.
- Biomass boilers or CHP systems are another technology that is increasing in popularity. Again, the heat/power output of these devices is controllable and can also be considered carbon neutral: the carbon released on combustion is balanced by the carbon absorbed by the fuel when it is growing.
- Ground Source Heat Pumps can potentially reduce emissions by 50% compared to alternative heat supply technologies [3], however they require space for the evaporator (e.g. boreholes or buried coils). Further, GSHP and are difficult to retrofit to existing buildings due to their incompatibility with radiator heating systems.
- Wind energy conversion has significant potential in Scotland, however its application in the built environment is fraught with technical difficulties: most of which stem from the unfavourable, turbulent air flow regime prevalent in many urban areas [4].
- Solar Photovoltaics (PV) have been sucessfully integrated into may building designs.

However the technology requires a significant capital investment and energy yields are small at northern latitudes [5,6].

- Solar Thermal systems are a relatively inexpensive and well-established renewable technology. A well designed system can contribute 40% to 50% of Domestic Hot Water [7]. The disadvantage with these technologies is that they require a back-up heat system during winter when demand is typically at its highest.
- Demand side reduction – this category of technologies incorporates a wide variety of measures that can be introduced into a building design with the aim of reducing energy consumption. These measures fulfill the dual role of reducing consumption and, when used in tandem with LZC energy supply technologies, allow those technologies to supply a greater proportion of the building's (reduced) energy demands. Examples of demand side measures include the use of natural ventilation and daylight-compensating lighting controls.

Clearly, the technology categories described have very different characteristics in terms of function, operation, energy yield (or saving) and controllability. However, the main reason for the installation of any of the technologies is to reduce the carbon emissions associated with heating and powering the building; this premise forms the basis of the methodology described later.

SOFTWARE REVIEW

A key element in the assessment of LZC process is obtaining data on the performance of a device in a realistic operational context. Modelling and simulation provides an appropriate means to do this. There are currently a broad range of software tools on the market to assist designers in assessing the performance of LZC technology options. These tools fall into four broad (and sometimes overlapping) categories:

- Single issue tools – tools which have been developed to assess the performance of a single technology. Examples include Radiance[1] (daylighting).
- Strategic design tools – tools which enable a designer to make a quick evaluation of the likely performance of a technology early in the design process where relatively little information is available. Examples include Merit (renewable energy)[2] and Energy10 (early stage building design)[3].
- Building simulation tools – enable the integrated performance of a building to be assessed, though typically with a high data input overhead and sometimes with a limited capabilities with regards to the modelling of LZC energy supply options [8]. Examples include IES[4], Energy Plus[5] and ESP-r[6].
- General engineering tools – which are developed to model a broad range of physical process, but which are not intended to model any specific technology, for example computational fluid dynamics (CFD).

A review of software tools capabilities indicated that a pragmatic approach to the assessment of LZC technologies in buildings would be to deploy a mix of tools throughout the design process: with strategic tools employed at the start of the design, when specific data is scarce; and detailed single-technology or building simulation tools employed later in the design process when more data is available for the evaluation. The software review also indicated different capabilities in many software tools so that again, a mix of tools would be required even at the same stage in the design process. For example, the strategic analysis tool HOMER[7] was suitable for the analysis of electrically-based LZC technologies, however for heat-based technologies the tool RetScreen[8] was employed.

ASSESSMENT METHODOLOGY

The ultimate goal of the project here is to develop an LZC assessment methodology to enabling the design team and clients to make informed choices with regards to which technologies or mix of technologies best meet their (disparate) requirements. As has been mentioned, the primary function of the assessment is to give an indication of the energy yield and carbon saving potential of building-integrated LZC technologies. Clearly however economic performance will also be of relevance; however, particularly when meeting legislative requirements regarding LZC supplies for new buildings [9], the carbon savings potential or energy yield of an LZC technology is very often the main factor in its selection.

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1 http://radsite.lbl.gov/radiance/

2 http://www.esru.strath.ac.uk/Programs/Merit.htm

3 http://www.esru.strath.ac.uk/Programs/ESP-r.htm

4 www.iesve.com

5 http://apps1.eere.energy.gov/buildings/energyplus/

6 http://www.esru.strath.ac.uk/Programs/ESP-r.htm

7 www.nrel.gov/homer/

8 www.retscreen.net/

The assessment methodology which emerged from the LZC technology review and review of software capabilities, coupled with a knowledge of the design process and varied client needs is shown in figure 4.

Specifically, the assessment process consists of two stages: a concept stage and detailed design stage. At the concept stage, the candidate LZC technologies are filtered in relation to performance using a basic assessment. A more detailed analysis was then carried out on the filtered technologies . It forms a logical process from which building integrated technologies are analysed from early design to pre-construction.

The methodology is also designed to be generic in that no specific software tools are defined. Instead the approach adopted is to specify the information required and how it is processed, individual software tools then "plug-in" to provide the data required for specific technologies.

The methodology also distinguishes between the generation of data for technical assessments and the processing of that data for decision making and presentation to clients. Given that a multi-tool, multi stage assessment is being made, a significant quantity of data is generated, this needs to be processed so that it can be presented to clients and other members of the design team in a concise and meaningful form; data processing is described later.

SOFTWARE COMPONENTS

As was stated earlier, no single tool is applicable to all stages of the design process. So, in order to provide the data necessary for the design process, the methodology needs to be populated with a range appropriate software tools. In this project both "off-the-shelf" and customised software is deployed. Together, the software and methodology forms an LZC design 'toolkit'. The following paragraphs describe the software employed within this particular project. However, the reader should be aware that alternative tools can be substituted as required.

Focusing on the concept stage, the tools RETScreen and HOMER are used to filter candidate LZC technologies; these two pieces of software are specifically developed for evaluating technologies at an early stage. RETScreen also includes extensive financial analysis facilities, providing estimates on payback time. HOMER uses optimisation and sensitivity analysis to evaluate the economic and technical feasibility of electricity generating technologies. Together, the programs are used to analyse the basic technical, environmental and financial performance of candidate LZC technologies with a view to selecting the most promising performers for further analysis.

As the design process progresses a more detailed analysis is undertaken using more sophisticated modelling tools. Within this project IES VE, an integrated building simulation tool and the Fluent CFD package are deployed. Solar analysis data from IES VE is used to provide solar resource data, which is in turn used in the assessment of solar component performance. Fluent is used to provide data in the assessment of building integrated wind turbine installations, and is used, along with building simulation, in the assessment of natural ventilation schemes: here carbon savings are quantified by comparing performance with a mechanically-ventilated or air conditioned equivalent building.

The detailed modelling tools are augmented with detailed mathematical models of photovoltaic panels, solar thermal collectors and wind turbine devices. These models were developed specifically for this project and use boundary condition data from the building simulation or CFD tool to predict annual energy yields.

Finally, an excel-based data processing 'back-end' has been developed. This functions to collect raw performance data from all of the different software applications used within the methodology. The data is then processed and presented in graphical form, which can be tailored to the needs of the intended audience. The collected graphs form an integrated performance view [10] of the LZC technologies being analysed, that encompasses technical environmental and financial performance. The tool can also auto-generate template client reports, populating the document with the results of the analysis.

In operation, basic input data is inserted into the software for conducting a concept stage analysis: this includes location, appropriate climate data and basic device characteristics such as capacity and conversion efficiencies. The basic outputs from the concept analysis are energy yield (kWh), simple payback period (yrs) and Carbon Dioxide reduction (kgCO_2). Comparison graphs are produced scrutinising the outputs according to user-defined filtering criteria, which are dependent on the project requirements. The better performing technologies are given priority at detailed design stage.

The results from the concept analysis can be used to form the basis of an interim report; again, a template for this is generated by the 'back-end' software. As well as the energy yields the report includes the assessment criteria and technology selection for the detailed design stage.

During the detailed analysis, results from building simulation packages are extracted to form inputs for the customised LZC device models and data processing software. The data extracted depends upon the technology being analysed. For example external surface solar radiation data can be passed to and processed by both the PV and solar thermal device models in their calculation of energy yield.

CFD is also used in an external flow analysis on the building. This yields useful data on the 3-D velocity fields the building and wind-induced pressures on external surfaces at different wind directions. This data is further processed by the "back-end" to yield wind resource maps and pressure coefficient sets for use in micro-wind-turbine analysis and natural ventilation studies respectively.

The results obtained from the detailed analyses form the basis of the final client report (figure 4). The client report consists of a full energy assessment that combines the energy consumption details of the building (obtained from a building simulation analysis) and energy yield data for each renewable technology assessed. This report features three appraisal categories for each technology, economic feasibility, environmental emissions reduction and technical performance.

CASE STUDY

The toolkit has been applied to a prospective building design located in North Eastern Scotland. This region has a cold, sunny climate with high average wind velocities.

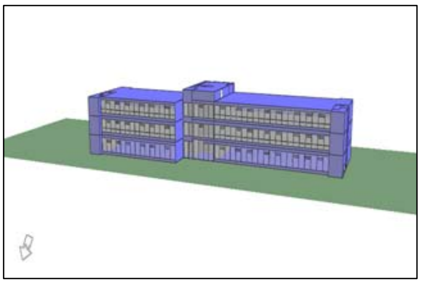


Figure 1 – IES VE generated image of Building

The building is a three-storey office block and is part of a suburban office development. Each floor has two open plan offices and a central block, which comprises circulation areas, (including reception) and toilets. The building is orientated North-South with large double glazed areas on the long North and South facades. Solar shading devices have been installed, on the south facade reducing internal heat gains from solar radiation.

The building is a generally lightweight construction with U-values for all construction elements conform to current UK building regulations.

The office areas are heated and cooled using fancoil units and central heating radiators are installed for circulation and toilet areas.

The building has been modelled on IES VE using 42 distinct thermal zones. These are augmented with fabric and services data. The model is used to both to obtain annual energy consumption figures and provide data for the LZC technology analysis (results from which are shown in as in table 1).

Concept Stage Analysis

In this case study three renewable schemes (proposed by the client) will be assessed for possible integration into the case study building these are: solar thermal, solar PV and a micro wind turbine.

For this stage of the analysis, basic input data was used including monthly averaged weather data device rated power and capital cost. The analysis also required building consumption data (heating and electricity consumption); this was obtained using as a simplified building energy model (SBEM)[9].

- Solar Thermal **-** a 14.2 kW system has been proposed, taking up 25m² of the flat roof area.
- Solar PV **-** a 10 kW system has been proposed with an approximate roof area of 35 m².
- Wind Turbine - a 6 kW device is proposed, to be sited on the roof of the building.

The technologies were appraised based on Simple Payback Period (years), CO_2 emissions displaced ($kgCO_2$/yr) and Energy Yield (kWh/yr).

Technology	**Simple Payback Period (yrs)**	**CO_2 Reduction ($kgCO_2$/yr)**	**Energy Yield (kWh/yr)**
Solar Photovoltaic	64.7	2731	4808
Solar Thermal	61.7	2347	12100
Micro Wind Turbine	14	4503	7929

Table 1 – Performance Parameters for Concept Design Analysis

In this case, the best performing technology overall is the 6kW Micro Wind Turbine. The highest energy yield and CO_2 reduction is the PV system, however the payback indicates that this option is uneconomical; this finding is consistent with may other studies e.g. [5,6]. Solar Thermal also proves to be an uneconomical option, even though in comparison to Solar PV, it's an inexpensive technology.

These results provide a relatively quick analysis using basic information. In a real design situation only the more promising technology or technologies (i.e. Micro Wind Turbine) would be

9 www.ncm.bre.co.uk/

carried forward for a detailed design analysis. However, in this case study all three renewable technologies are carried through to the detailed design stage for the purposes of comparison.

Detailed Analysis

In this case study the detailed design stage uses Fluent and IES VE to assist in producing a more detailed analysis of the candidate technologies. IES VE is used to generate building specific external surface solar and temperature data, while Fluent is used to generate data for the optimum placement and analysis of the wind turbine.

In the analysis of the PV and solar thermal installations the incident solar radiation and temperature for the surfaces on which the technologies would be mounted is calculated for each hour of the year. This data along with manufacturer's technical data is used with the appropriate technical model to calculate the yearly energy yield.

Wind energy yield is evaluated using data from a Computational Fluid Dynamics (CFD) analysis. The velocity field around the building is calculated for 45^o wind direction increments (8 simulations). An average velocity coefficient (equation 1) can then be calculated for potential micro-turbine sites on the building roof (figure 2). This average coefficient is calculated using the incident wind velocity at the height of the micro-turbine hub and the individual velocity coefficients from each CFD analysis, weighted according to the wind rose for the site:

$$c_{vx\ ave} = \sum_{i=1}^{i=8} c_{v\ xi} \times w_i \qquad (1)$$

Where $c_{v\ xi}$ is the velocity coefficient at location x and wind direction i (0^o,45^o …. 315^o) and w_i is the fraction of time the wind blows from direction i over the course of the year. The local velocity coefficient is calculated using as follows:

$$c_{vx\ i} = \frac{v_{xi}}{v_{\infty}} \qquad (2)$$

Where v_∞ is the free stream wind velocity at the turbine hub height.

The average velocity coefficient data can then be used to generate a map that can be used to identify the optimum location for a turbine. (figure 2). In this case the turbine is best located in the south west corner of the building 2.4m above roof level. Where average wind speeds are 110% of the free stream velocity.

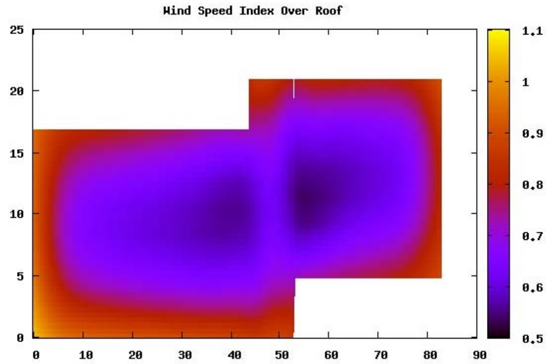


Figure 2 – average velocity coefficient map for roof of case study building (at turbine hub height)

The direction-dependent velocity coefficients derived from the CFD analysis can also be used in conjunction with climate data and turbine data to calculate the annual energy yield from a turbine:

$$E_x = \int 0.5 c_p(t) \rho A [c_{v\,xi} v_\infty(t)]^3 \eta \, dt \quad (3)$$

In equation 3, η is the overall turbine efficiency. The power coefficient (c_P) is obtained from turbine manufacturers data and varies with velocity, A is the swept area (m^2) of the turbine blades.

For this case study, the following quantities are of interest for each technology:

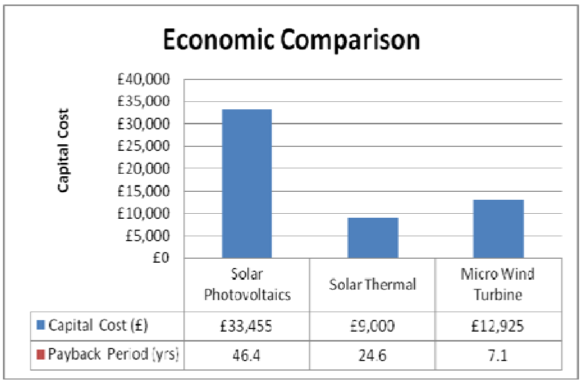
The *energy yield* is calculated by using the customised renewable technology models and the boundary condition data from the CFD and building simulation tools.

The *renewable fraction* is the percentage contribution of renewable energy to the whole building energy consumption (calculated using a building energy simulation) from each technology.

The *payback period* is calculated including capital cost and maintenance costs. Grant Funding, Renewable Obligation Certificates (ROC's), Enhanced Capital Allowances (ECA), and Climate Change Levy (CCL) benefits are also taken into account. A 2% annual inflation rate in energy costs is also taken into account.

Renewable Technologies	Area (m2)	Rated Power (kW)	Energy Yield (kWh)	Renewable Fraction (%)	Carbon Emissions Reduction (kgCO$_2$)	(%)	Capital Cost (£)	Payback Period (yrs)
Solar Photovoltaic	36	5	4010	1.10%	2278	1.61%	33455	46.4
Solar Thermal	25	14	14569	3.99%	2826	2.00%	35000	33.5
Micro Wind Turbine	24	6	15517	4.25%	8813.4	6.25%	12925	7.1

Table 2 - Energy Yield for Detailed Design Stage



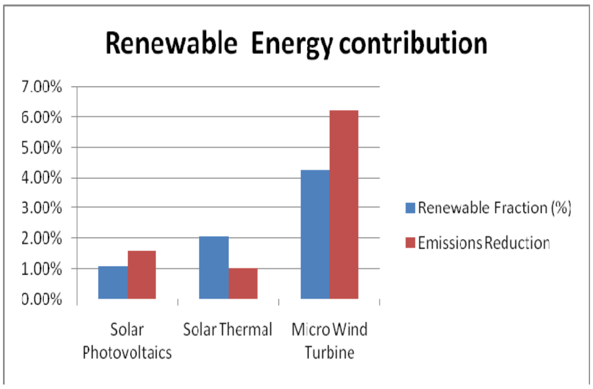


Figure 3 – Performance analysis

The data from the detailed appraisal builds upon the information obtained in the concept-stage analysis including: are more detailed estimate of device energy yield and CO_2 reductions; the contribution of the device to the total energy demand of the building and the financial characteristics of the device.

While the outcome is generally similar to that obtained in the concept analysis, the power output estimate from the wind turbine is almost double that obtained with the less detailed model. There are two reasons for this. First, the concept analysis used monthly averaged free stream wind speeds – this approach tends to underestimate energy yields as the influence of higher wind speeds cannot be accounted for with an average wind speed value. The detailed analysis uses hourly values, which while still averaging out some wind gusts does give a more accurate estimate of likely power output. Second, the detailed model accounts for the acceleration of flow as the air passes over the building, the acceleration factor in this case is approximately 110% of the free stream velocity; again this increases the likely energy yield from the turbine.

The results also show that each technology can provide only a small fraction of the total energy consumption of the building (for example solar PV can provide only around 1% of the total electrical demand; this indicates that demands reduction must be prioritised in the design process if renewables are to make a substantial contribution to the building's energy supply.

Finally, it should be noted that for brevity this analysis assumed minimal disruption to the performance of each technology such as clear flow path for the wind turbine (i.e. the impact of surrounding buildings) and no shading affecting solar panels. A more detail analysis incorporating these effects would result in reduced energy yield.

CONCLUSION

This paper has introduced a methodology based on the use of multiple software tools (a "toolkit") to assesses low or zero carbon (LZC) energy supply technologies at different stages in the building design process: concept design and detailed design. For concept design, strategic energy analysis software tools are used to assess a range of candidate technologies enabling underperforming schemes to be discounted at an early design stage. At the detailed design stage a comprehensive analysis is undertaken using advanced simulation software to provide a more detailed appraisal of energy, environmental and economic performance. The resulting data is presented in a client-friendly format so that the results are easily accessible and understandable to the non-technical stakeholder.

A design case study was used to demonstrate the use of the toolkit, analysing three different renewable technologies.

This toolkit described is designed to be expandable and flexible, allowing many different LZC technologies (not just renewables) to be considered at all design stages. Technologies that will be incorporated into an expanded methodology include Ground Source Heat Pumps, Combined Heat and Power and Biomass Heating. While these technologies differ widely, the analysis methodology into which each technology type can be integrated (shown in figure 4) is the same.

REFERENCES

1 EU (2002). 'On the Energy Performance of Buildings', Directive 2002/91/EC of the European Parliament.

2 Energy Efficiency Office (1990) Good Practice Guide 3, Introduction to Small-Scale Combined Heat and Power,

3 Energy Saving Trust (2004) Good Practice Guide Domestic Ground Source Heat Pumps: Design and installation of closed loop systems CE82. E&OE

4 Grant,A.D. and Kelly,N. J (2004) A ducted wind turbine model for building simulation. Build. Services Eng.Res. Technol., 25(4), 339–350.

5 Bakos, GC., Soursos, M (2002), Technical feasibility and economic viability of a grid-connected PV installation for low cost electricity production. Energy and Buildings (34), p753-758, Greece

6 Bakos, GC., Soursos, M., Tsagas, NF (2003) Technoeconomic assessment of a building – integrated PV system for electrical energy saving in residential sector. Energy and Buildings (35), p757-762.

7 Solar Trade Associateion (STA) (2006) Solar Energy, Active Solar Heating in the UK,

8 Crawley, Drury.B; Hand, Jon.W; Kummert, Michael; Griffith, Brent (2005) Contrasting the capabilities of building energy performance simulation programs.

9 SBSA, Technical Handbook (2007) Section 6, Non Domestic Building Standards. Scottish Building Standards Authority

10 Clarke J A, Hand J W and Janak M (1998) 'Results from the integrated performance appraisal of case study buildings within the Daylight-Europe project', Proc. CIBSE National Lighting Conf., Lancaster University, 5-8 April.

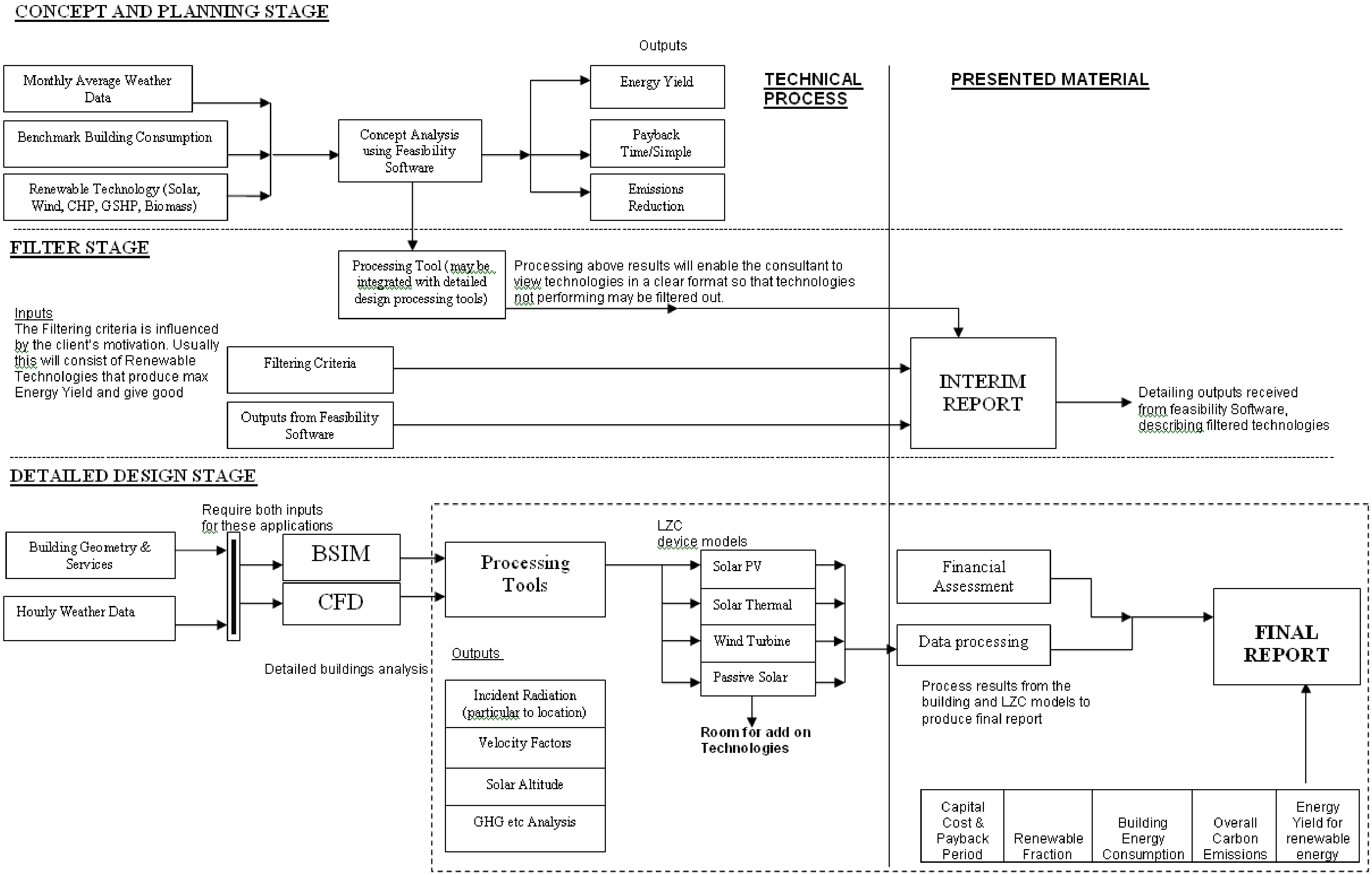


Figure 4 Diagram of LZC assessment toolkit.