STOCK AGGREGATION

Methods for Evaluating the Environmental Performance of Building Stocks

Annex 31

Energy-Related Environmental Impact of Buildings

International Energy Agency

Energy Conservation in Buildings and Community Systems Programme

ANNEX 31

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INTRODUCTION

Stock Aggregation refers to the process of evaluating the performance of a building stock using environmental assessments of components of the stock. For example, total energy use by a stock of buildings can be estimated by adding up the energy estimates for all the individual buildings within the stock. Or for less effort, a subset of representative buildings can be analyzed, and the results then factored in proportion to the total number of such buildings in the stock.

Stock Aggregation methods can contribute to decision-making in two ways:

1. by assisting designers of individual buildings to understand how their design choices might affect – or be affected by - the overall stock performance, and
2. by providing planners and policy-makers at varying scales (local to national) with a richer, more powerful database on building costs, energy and resource use, and environmental effects.

Because Stock Aggregation begins with the analysis of individual buildings, it is referred to as a 'bottom up' approach. Any performance measurements that can be analyzed at the 'bottom' – for an individual building or specific technology - can be aggregated upwards and used to evaluate the performance of a building stock.

Stock Aggregation is frequently the best method available for analyzing stock performance because energy and resource flows are a function of dynamic relationships between a building's shell, and its constituent equipment, systems and operations. By first using the dynamic micro-models created for use at the building or end use level, and then aggregating upwards, one can observe, analyze and resolve energy use and environmental performance with greater accuracy.

The detailed and precise structure of a bottom-up database can facilitate the identification of sensitive variables that may be especially important to the overall performance. By changing such variables, it is possible to forecast the results of specific scenarios, and to prepare substantive arguments for particular building designs and policies. This type of planning exercise usually involves manipulating variables in order to achieve within the model a desired performance for the entire stock over a given time horizon. Scenario planning using a bottom-up model is sometimes referred to as 'normative futures analysis' or backcasting.

The scale of Stock Aggregation can vary, from a small housing stock within a single project, all the way to national building stocks for the residential, commercial, and institutional sectors. The base data and the results can be nested from neighbourhood to community to region to nation, while preserving the same data structure and detail. Partial stocks can be aggregated, consisting of sets of private or publicly owned buildings.

It is possible to aggregate and analyze the performance of a building stock in the present year, or at any time in the past, depending upon data availability. Profiles can be created for specific years, showing the breakdown of energy and resource use by each end-use (e.g. heating, cooling, lighting, equipment) and by each building type (e.g. office, school, apartment, retail). Trends can be established by comparing performance of the stock over a number of years. Benchmarks can be created by comparing individual buildings with other buildings or with the average performance results for related groups of buildings. One building stock can be compared with another.

Stock Aggregation can be used to estimate performance of building stocks in the future, if assumptions are made about the growth and turnover rates within a stock, and the adoption rates for new technologies. Forecasts for energy, water and land use, and for generation of solid and liquid wastes, can be compared with the current and planned capacity limits for the surrounding infrastructure. Environmental loadings originating with the stock can be compared with the ecological carrying capacity of the surrounding air sheds, watersheds, and land base.

How Stock Aggregation Methods Improve Building Performance

Stock Aggregation methods are of value to energy analysts, building scientists, statisticians and practically anyone involved with planning urban development and promoting environmentally friendly technologies.

Table 1 provides examples of user groups and typical queries suitable for Stock Aggregation methods.
In general, Stock Aggregation can be used to:

- Highlight areas where substantial potential exists for improvement in resource use and economic efficiency;
- Allow for quick "what-if?" analysis;
- Allow policy makers to optimize regulations and market incentives to achieve specific targets;
- Analyze how policies in one area, like energy security, or housing affordability, can affect other impacts from buildings, like air pollution, or energy demand; and
- Develop priorities for research and development.

Classes of Users and Responsibilities	Example Query
Policy Analysts • Local Agenda 21 • Regional Growth • National • European Union • International Energy Agency	*"What kinds of building technologies are needed in order to meet greenhouse gas emission targets?"*
Planners • Site Development • Infrastructure investment • Technology Promotion and Development	*"What is the potential for a district energy system?"*
Private Sector • Large Corporations • Specialty Businesses	*"What is the expected market size for window replacements?"*
Utilities • Electric / Gas • Water / Sanitary • Telecommunications	*"What is the expected peak demand for houses in the planned neighbourhood?"*

Table 1 *User Groups and Example Applications*

It is possible to communicate the results of Stock Aggregation using the same data presentation techniques used for describing the performance of individual buildings. The same performance criteria can describe one building or many, except in cases where impacts are definitely site specific. Stock performance can be presented using a number of common graphical methods:

i. Trend lines

Trend lines reveal historical patterns of energy and resource use, and permit rapid forecasting by simply extrapolating past performance.

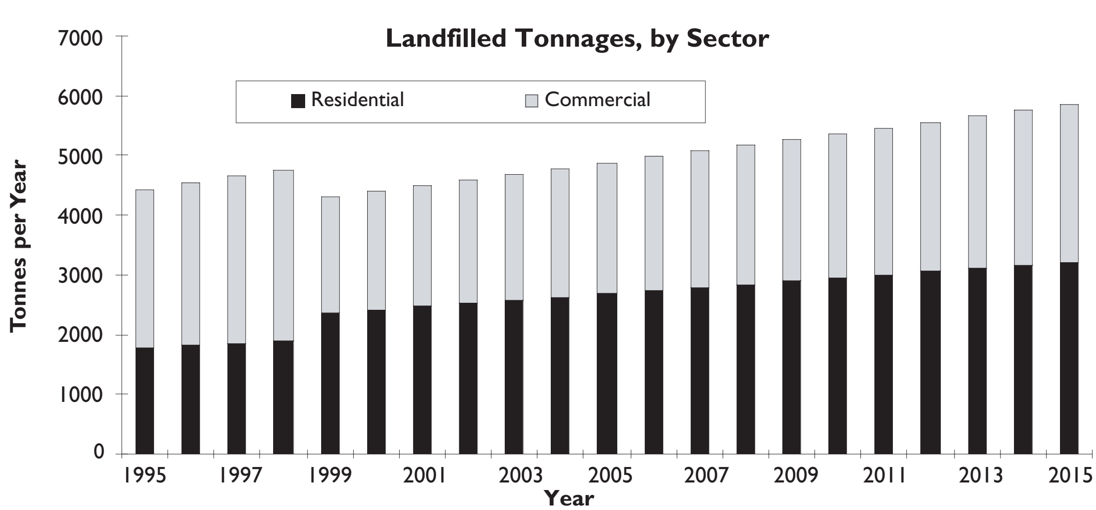

Figure 1 *Example Projection of Historical Trend line for a new Waste Management System (Smithers, Canada)*

ii. Profiles

Profiles breakdown the performance of the stock at a point in time. Profile charts can be designed to present a large amount of information quickly, in ways that allow readers to quickly identify the categories of greatest impact and concern.

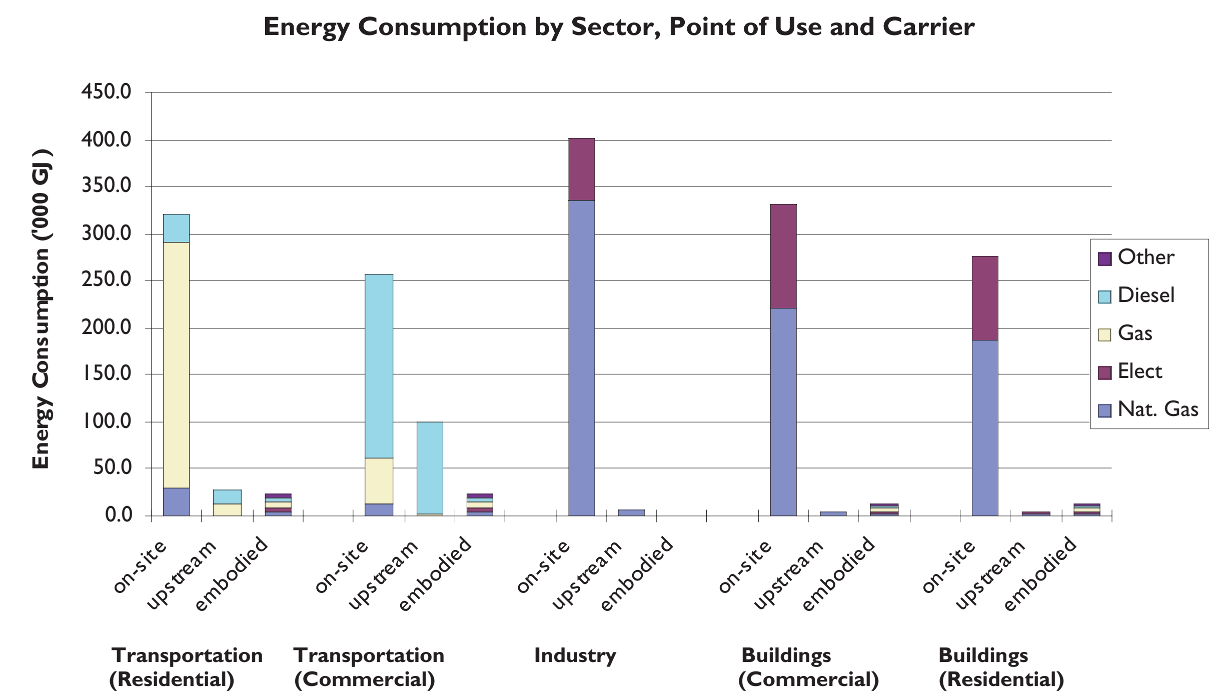

Figure 2 *Example presentation of an energy use Profile Forecast*

Forecasts of different scenarios can be graphically illustrated using charts and tables. Usually forecasts entail specific assumptions for how each part of the stock might change, in increments of one to five years. For example the growth in the stock may be assumed for 5, 10 and 15-year horizons. The stock is then remodelled for each of these horizons, and the intervening years are estimated from interpolation. As shown in Figure 3, forecasting typically begins with a default or baseline forecast, based on a 'business-as-usual' scenario. Alternative scenarios are then created by packaging portfolios of new technologies with assumed rates of change in the cost of materials, the behaviour of occupants and the composition of the building stock.

Sometimes each scenario is examined from a variety of "futures". For example, forecasts for two scenarios – Default and Conserver - are shown in Figure 3. Each scenario is forecast twice, to reflect two possible futures: one with a 2% annual growth in population, and another at 3.5%.

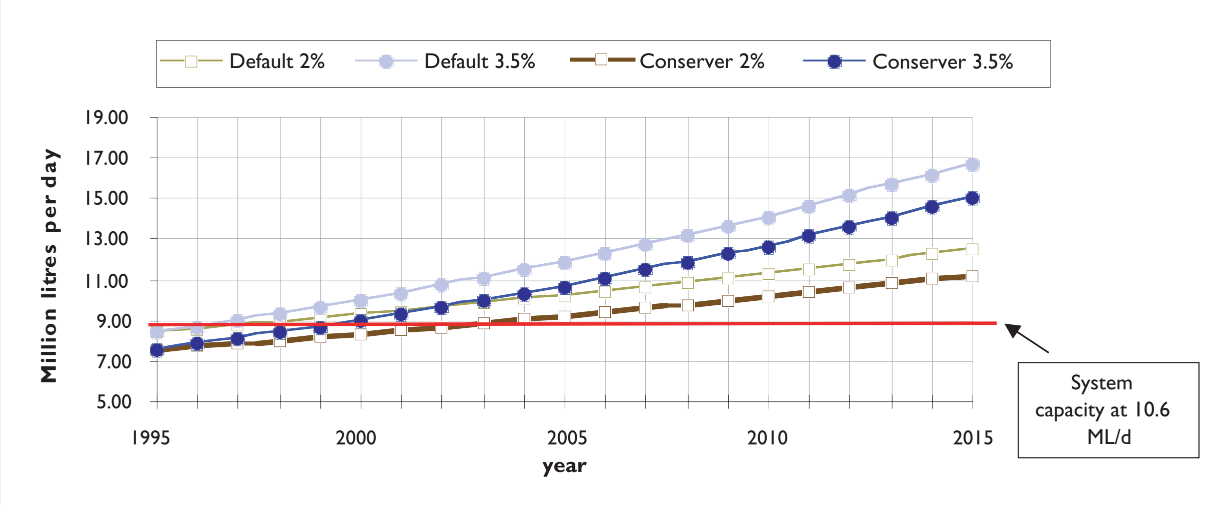

Figure 3 *Example presentation of Forecasts for water demand (Smithers, Canada)*

It is often useful to include with the forecast charts a number of specific thresholds, targets or capacity constraints that may be of interest to decision-makers. Different scenarios can be compared using performance indicators.

Applying Stock Aggregation Methods at Different Scales

The appropriate spatial scale for Stock Aggregation will depend upon the areas of influence and control for the decision-makers involved, and the type of questions they want answered. As shown in Figure 4, the planning horizon tends to lengthen as the spatial area increases

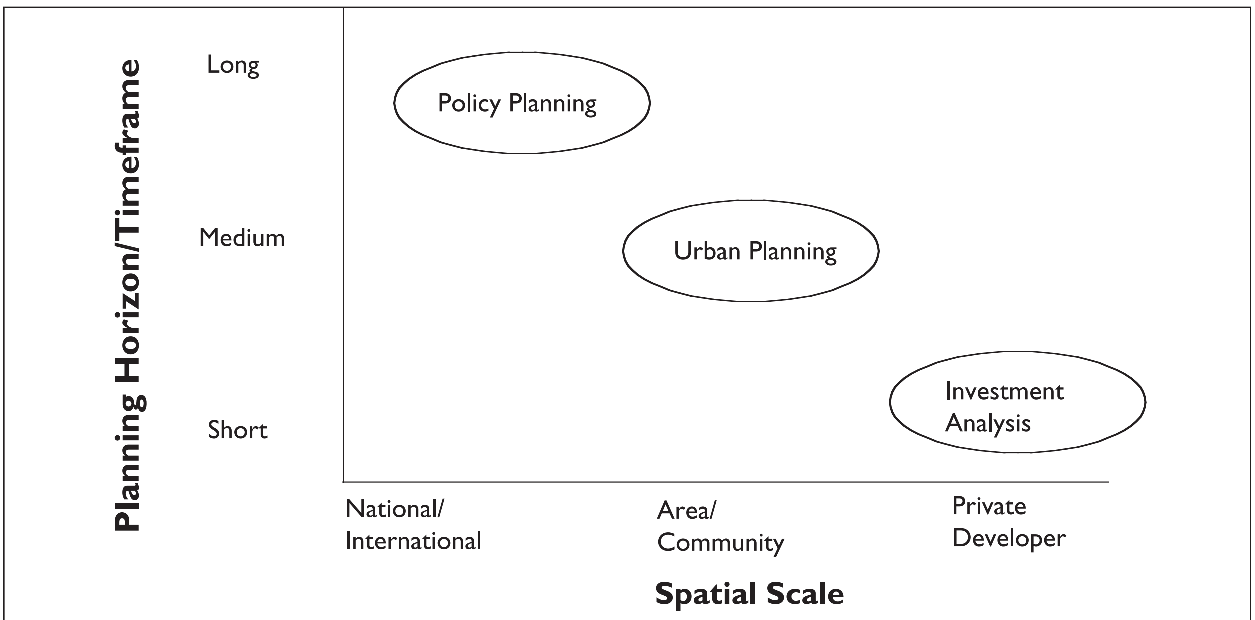

Figure 4 *Spatial Scale and Planning Horizons*

from local to national scales.

Stock Aggregation is suitable for spatially dispersed sets of buildings. For example government agencies responsible for public buildings may have developed extensive databases on their buildings - wherever they are located. A number of such agencies are now beginning to batch process all their buildings through energy analysis tools like DOE 2.1. Spatially dispersed sets are more difficult to model due to the greater variety of infrastructure systems and environments.

National Applications

In most countries, the main responsibility for energy and environmental policy is at the national level, and it is here that the greatest benefits of Stock Aggregation are usually experienced. The building stock represents the largest financial, physical and cultural capital of industrial societies, and stock aggregation can help to manage this basic resource more sustainably.

Most recently national plans to meet Kyoto targets for greenhouse gas reductions have required a number of countries to create a detailed database on their building stock, and to use energy modeling tools on representative buildings. The lack of data on composition of stocks has limited the effectiveness of such planning. However the need for evaluating many specific policy options, and achieving quantifiable targets, has necessitated a Stock Aggregation approach.

Utility Applications

Stock Aggregation methods may be appropriate for utilities that want to better analyze their customer base. Traditionally utilities have estimated demand for services by using simple coefficients for each customer type, based upon past performance. For example, if population is expected to grow, a utility planner will use a standard demand factor for each household. This type of top-down analysis doesn't provide insight into the impacts of new technologies, or changes in economic base. Nor can the utility planner investigate potential for offsetting demand through load management programs, or through services that improve conservation and efficiency. With the emerging market for greenhouse gas offsets, and the increased competition in the energy sector, utilities can benefit from a deeper understanding of their customer demands.

Stock Aggregation offers utilities a more sophisticated and accurate means for:

- local area load management;
- long term load forecasting;
- capacity constraint analysis;
- investment planning;
- business expansion (new territories, and new building-related services);
- integrated resource planning (with optimization of supply and demand options); and,
- monitoring impacts of policy and programs.

An example of a utility-sponsored analysis of energy demand, using Stock Aggregation, is shown in Figure 5. The chart compares the increased demand for electricity as a resort community expands from current consumption (Phases I) to Phase IV with many more hotels and houses. Two scenarios have been created using Stock Aggregation: a business as usual growth pattern, using similar technology to existing hotels and houses, and a Conserver scenario using the most cost-effective building envelopes and heating systems. Each scenario is compared with the capacity thresholds for the electrical supply system, and with options for increasing the capacity. In this way it becomes possible for the resort corporation to optimize investments between improved buildings and increased capacity.

Community Applications

In the future, Stock Aggregation may be especially suitable for towns and cities that are trying to manage the impacts of growth, or prepare building regulations and guidelines that help the community meet its environmental goals. Stock Aggregation can be especially effective at the local level because:

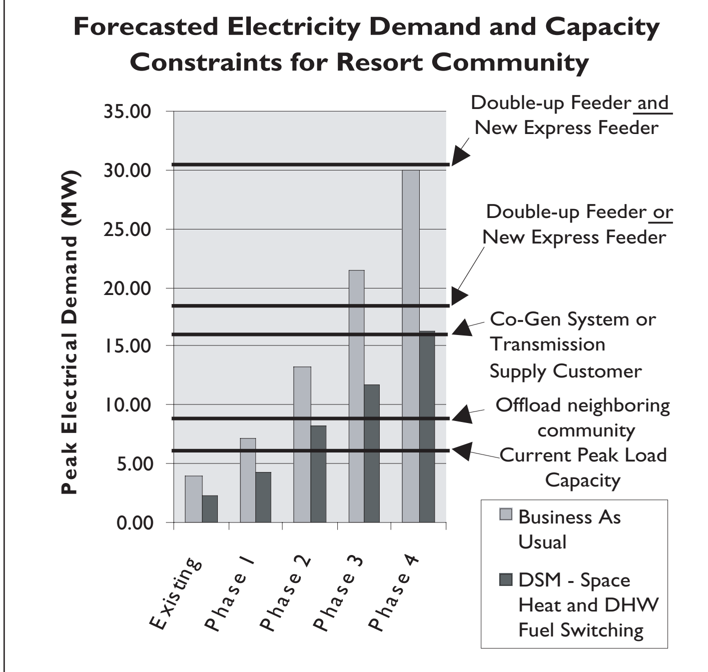

Figure 5 *Optimizing Supply and Demand Investments*

i. physical resource scarcities and ecological constraints often vary greatly from one locality to the next, and may necessitate locally appropriate building designs and policies;

ii. differences in the pace and direction of structural changes in the local economy may vary from one community to another;

iii. different population growth rates at the local level will affect the significance of building energy and resource use;

iv. cost and adequacy of municipal and utility infrastructure may vary with different building designs and geographic locations. For example, regional energy supplies may be sufficient for meeting the needs of a growing building stock, but power availability may be limited at the local level due to limited wire capacity, voltage, transformers, and rights-of-way.

v. A local database on buildings, with bottom-up forecasts, can empower local citizenry and provide a rational basis for democratic environmental policy development.

One of the benefits of applying Stock Aggregation at the level of individual communities, is that it becomes possible to create a tiered approach, in which results are first aggregated at a local level (i.e. block, neighbourhood or municipality), and then further aggregated to create regional or national statistics. Synergy may be achieved, since the same database can be created and managed for different purposes, at lower cost for all parties.

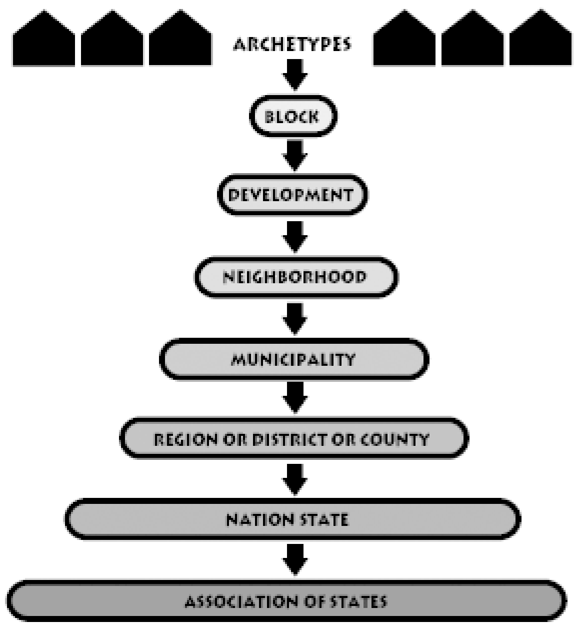

Figure 6 *A tiered structure for building stock databases*

How Building Designers Benefit From Stock Aggregation

Although not currently practiced, it is conceivable that building designers could use Stock Aggregation to assist in their design work. Several benefits are suggested:

Avoiding the risk and cost of overloading the local infrastructure

Ideally the capacity constraints of infrastructure need to be understood before the best choice of technology can be made for a specific building. For example, if the energy supply system is operating near capacity, it makes sense to avoid technologies that increase peak demands on the system, even if they appear to be the least cost option for the individual building. By considering the aggregate impacts of design decisions, the building designer achieves three benefits:

- the building can be marketed as more sustainable and more locally appropriate;
- permission to build may be easier to obtain from the local authorities; and,
- the building owner will be less exposed to the risk of disruptions in service, or sudden increases in taxes, fees, or other costs.

Creating opportunities for cooperative investments between building owners or developers

Stock Aggregation can also be used to justify new business ventures by determining the break-even scenarios, and the life cycle returns on collaborative investments. For example, a threshold number of buildings or level of service is necessary before a developer or planner can justify investing in district energy storage or supply. Stock Aggregation can be used to assess if and when this threshold demand is likely to exist. This type of analysis is especially valuable with larger building developments, where developers are increasingly likely to realize financial returns from on-site infrastructure.

Providing clear, rigorous arguments for socially responsible decisions

Stock Aggregation can be used to show how individual design decisions influence the overall ability of a community to achieve specific goals. This makes it easier for developers and others to satisfy regulations from a performance basis, rather than requiring prescriptive regulations and red tape in order to ensure compliance. Performance modeling is particularly warranted for demonstrating sustainable communities that may want to exploit the added market value or goodwill for ecologically sensitive urban development.

Stock Aggregation and Environmental Management Systems

Stock Aggregation methods provide an essential foundation for development of Urban Environmental Management Systems (EMS) and Urban Forecasting Information Systems (FIS).

An Urban EMS works similarly to the industry standards for EMS like ISO 14001, except that the management system operates upon a geographical entity like a city or region, and not a single corporation or agency. The urban environment is far more complex than any industrial facility or product line, and contains many site-specific interactions and relationships. However the ingredients of Urban EMS are no different than industrial EMS, and include:

1. data collection, organization and analysis;
2. monitoring of performance;
3. setting appropriate and challenging targets for environmental improvement and restoration; and
4. creating feedback systems for ensuring responsibility and accountability.

Urban EMS is a proactive approach to sustainable development, which goes beyond more traditional Environmental Impact Assessments, and State of the Environment reporting used by many cities. Rather than simply trying to mitigate environmental damage through goal statements and periodic assessments, an EMS fully integrates environmental goals into the ongoing policy and management of an urban area. The building stock is of course the most significant element.

Historically, the single greatest obstacle to evaluating buildings within their urban context has been access to data on the composition and condition of the stock, and the relationship between buildings and the surrounding infrastructure. It is far beyond the capacity of the average design professional to collect data on the carrying capacity, costs and environmental impacts of the urban infrastructure that makes their building function. Each location is different, and even urban planners, utility engineers and economists do not have a good understanding of how changes in demand for building services correspond to long-term infrastructure costs and resource requirements.

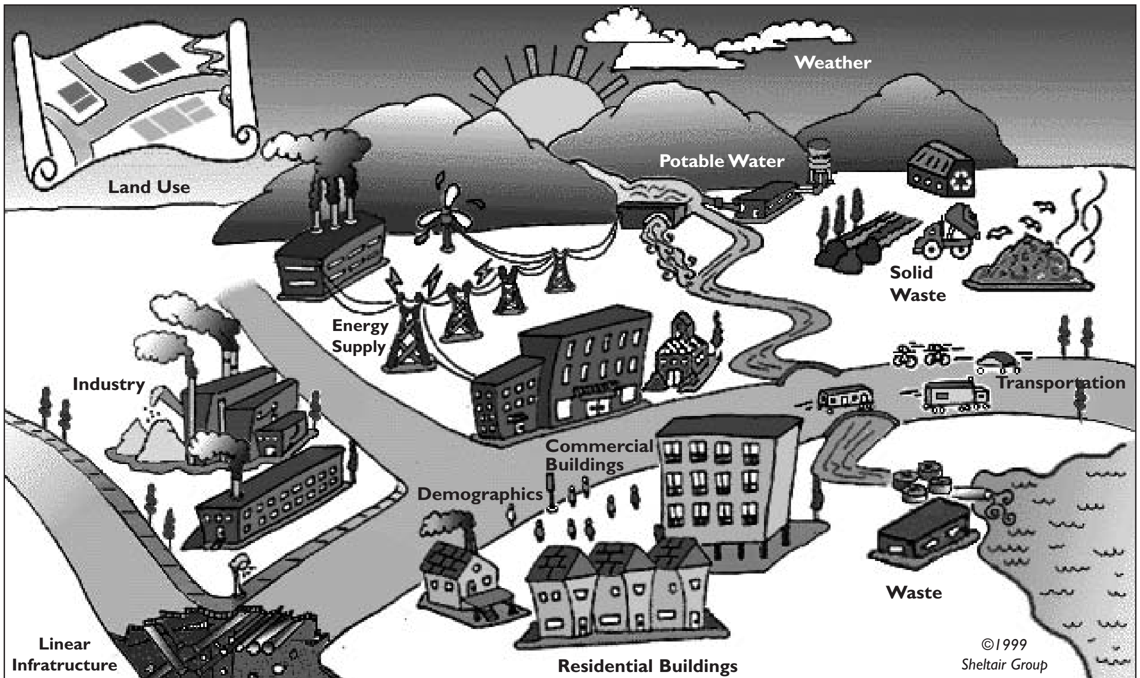

Figure 7 *Graphic representation of Files required for an Urban development plan*

Ultimately what is required is an interconnected database that includes detailed data at both the building and the urban scales. These databases need to fit together, like a series of Russian dolls, at increasingly larger scales. A minimum level of detail is needed for each of these databases to permit some degree of urban modeling as part of building design and renovation plans. A comprehensive model needs basic data in at least the key elements of an urban system including weather, infrastructure systems, population, linear infrastructure, and of course, buildings. These files are common to urban development plans anywhere in the world, and are graphically displayed in Figure 7.

Buildings represent more that half of the energy, water, land, materials and waste flow for the urban system, and thus any Urban EMS must satisfy the minimum data requirements for describing and analyzing performance of the building stock.

Once a community database is organized and entered, it can be used with modeling and Stock Aggregation tools to profile the performance of the city for the key energy and resource flows, and for the associated costs and emissions. For practicality, a building stock database must be designed for easy updates and additions, and to interface with Geographic Information Systems. Once operational, an EMS can automate environmental reporting on the stock, providing planners and public with regular feedback on performance of specific neighbourhoods, or the city and region as a whole. An example of solid waste indicators and benchmarks, shown in Figure 8, has been taken from a web-based version of an EMS database.

A bottom-up database on urban stock and infrastructure also enables an Urban Forecasting Information Systems (FIS). The underlying purpose of an Urban FIS is to enable designers and planners to estimate the direct and indirect performance of buildings at varying spatial scales, in a variety of futures. This is accomplished through enabling the generation and comparison of any number of urban development scenarios, complete with different scenarios for how the stock is extended, transformed and replaced.

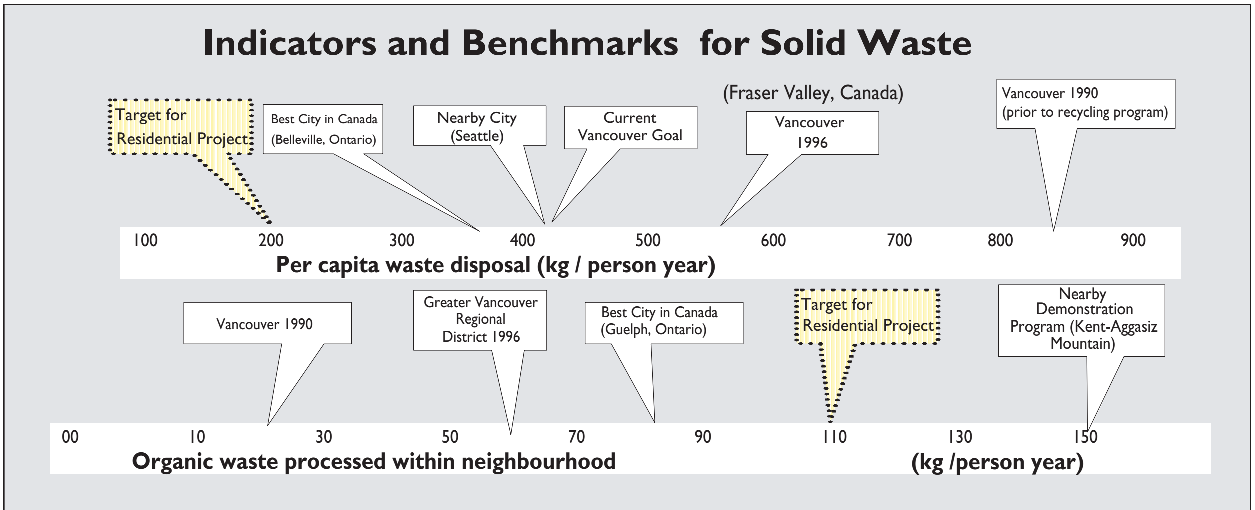

Figure 8 *Example of Benchmarking for Stock Performance*

For example, imagine a designer who wishes to minimize the negative impacts of energy emissions over the lifecycle of a housing development. Different scenarios might entail:

- adding more energy-efficient envelopes,
- recycling and reusing waste materials in new construction,
- using more on-site and renewable energies,
- providing more work-at-home facilities, and
- adaptive re-use of existing structures.

Different futures might include:

- a change in economic conditions like the imposition of carbon taxes,
- a change in demographics like an influx of immigrant families, or
- a change in the surrounding infrastructure like the extension of a light rapid transit system.

Since all of these futures are plausible, and since they are also outside of the control of the designer, the objective is to use FIS to identify the design scenario which performs best in the largest number of ‘plausible’ futures. Without computerized FIS tools, such planning is impossibly expensive and time consuming. With such tools it becomes possible to creatively explore the relative performance of different scenarios, and to use this feedback to set appropriate targets and manage the stock.

Unlike the common two-dimensional Geographical Information Systems (GIS), Urban FIS is designed to create scenarios and present data in “four” dimensions. If the first two dimensions are location, then the third dimension is the dynamic performance of the objects (buildings), and the fourth dimension is the performance of objects at different points in time. Scenarios can be described for urban development and growth, by altering the data on the stock. Energy and resource flows can be forecast and compared against targets and limits. In these ways Urban FIS allows planners and design professionals to quantify and compare the environmental performance of urban development options.

Bottom-up and top-down approaches

A top-down approach begins with the macro-economic data that is collected as part of a statistical input-output matrix on the economy. All businesses collect to varying degrees, and all countries aggregate the data as part of national economic statistics.

Traditionally the energy use and emissions associated with a building stock are determined through such records of economic exchange. The analysis begins at the top, with the total quantities of energy or other resources sold to buildings by suppliers. For example, a particular stock of buildings may have purchased an annual total of 1,000,000m3 natural gas. This total flow is apportioned between all possible end uses, including boilers and furnaces, service water heating, gas-fired chillers, cooking stoves and ovens, and so on. Allocating the portions between such related end-uses is typically accomplished by regression modeling, which analyzes each technological system in isolation from other end uses.

Stock Aggregation and top-down analyses are two quite different approaches to obtaining information on physical resource flows through the building stock. Each possesses a range of (complementary) strengths and weaknesses. The choice of approach will depend on a number of issues, including:

- The reason the analysis is being performed in the first place and the level of detail required;
- The availability, accuracy and level of detail of the existing data;
- The need to capture indirect and direct energy flows; and
- The scale (spatial and temporal) of the analysis.

It is not necessarily a choice between a top down versus bottom up approach. Analysts frequently rely on a hybrid strategy employing the two methods.

Strengths and weaknesses of top-down methods

Top-down methods are useful because the sum total values for the stock performance are based upon empirical data, and are likely to be reasonably accurate and robust. Most suppliers will have accurate figures on how much product was sold in total, even if they do not know how the product was actually used.

Another advantage to top-down methods is that stock evaluations are faster and more affordable, due to the reduced requirements for collecting detailed descriptive data on buildings. Further savings in time and effort are realized during analytical work. There is no need to process many buildings through 'micro' models and generate data for aggregation purposes. Such processing time can be substantial in cases where micro models involve hour-by-hour simulations of individual buildings.

Top-down data commonly suffer problems due to incorrect categorization, and inappropriate bundling of data into average values. For example, many apartment buildings may lack separate meters for each dwelling unit. An entire university complex may be a single meter. Data may be averaged over the year, rather than measured seasonally. Actual occupancy of buildings may vary greatly from the legal or official designation.

The lack of dynamic modeling in top-down methods can also cause errors. For example, if improved lighting systems are proposed for a building stock, it is difficult to know how the energy efficiency will affect waste heat from lighting systems, which in turn affects the space heating and cooling demands for the buildings. Regression models require that the relationship between technologies either be ignored, or fixed in the model as a standard "adjustment" on the results. If adjustments are used, they are typically based upon past trends, or supply and demand models, and not on the known relationships between the changing technologies in buildings.

Strengths and weaknesses of bottom-up methods

Stock Aggregation offers two major benefits:

i. Improved understanding of how resources are – or will be -used

By using a disaggregated database it is possible to include or exclude specific types of resources, services, or buildings and thereby target those impacts of greatest interest or relevance. For example, by using a database that contains thermal simulations of all the buildings, it becomes easy to separate the electricity used for space heating from electricity used for all other building services. Predicting the impacts of changes in technology, or use of alternative fuels, is also much easier. As older portions of the stock turn over, for example, the dynamics within the stock change, with predictable results. And as new equipment is introduced, it can be introduced only to those portions of the stock where its use would be practical. In these ways the scenarios can more accurately mirror the likely penetration of new technology in the stock, and incorporate the dynamic relationships between different energy and resource end uses at the building level.

ii. Potential for greater accuracy

If high quality data and analysis is available at the individual building level, and the expected variations are in the stock are well understood, then a bottom-up approach can achieve higher accuracy than by analyzing statistics on gross energy or dollar flows.

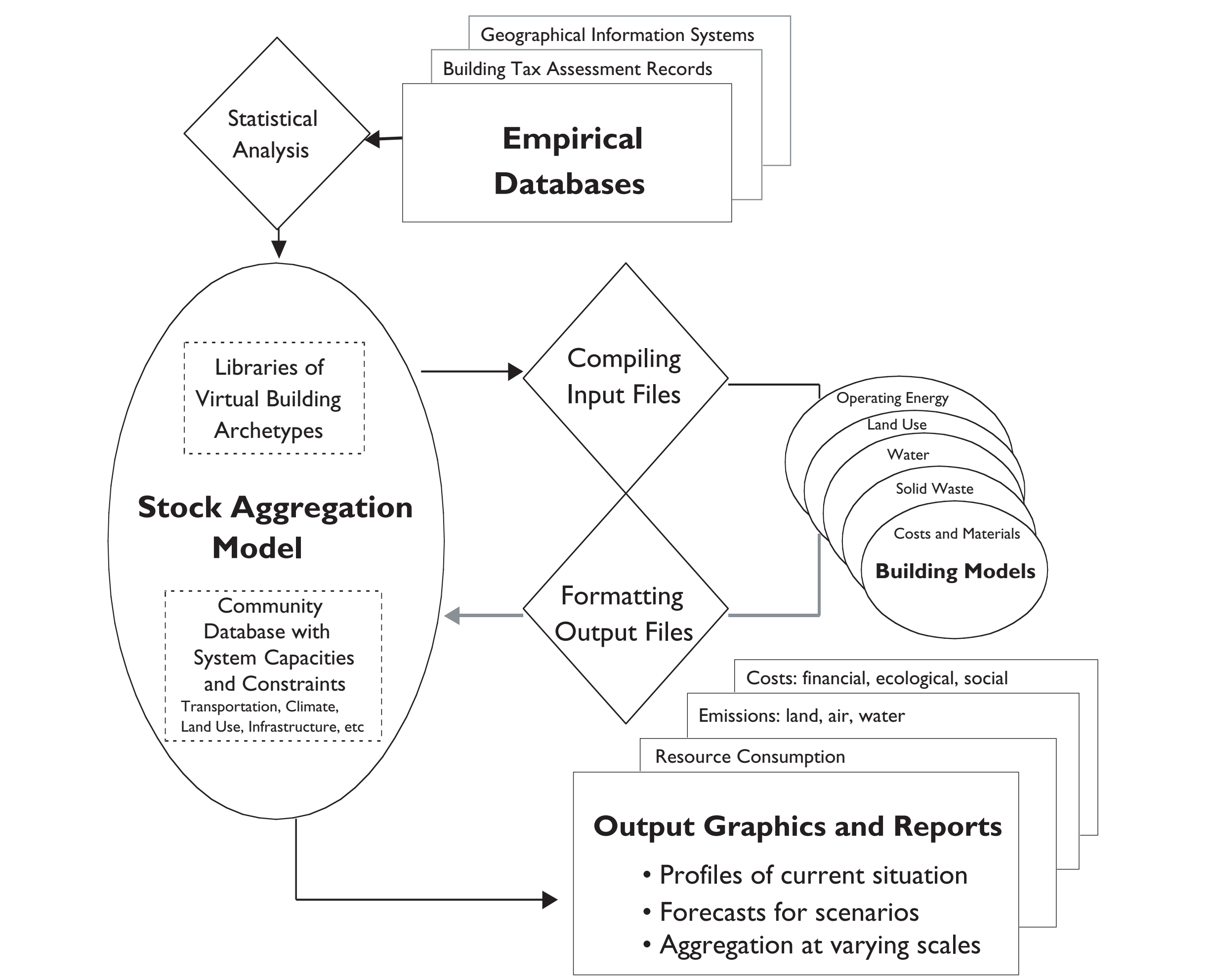

Figure 9 *Schematic of Bottom-up Model for Stock Aggregation*

Stock Aggregation methods also suffer from a number of weaknesses relative to top-down methods. The biggest problem is possible errors in categorization arising from incorrect descriptions of the existing building stock. If the stock is incorrectly categorized, the aggregation process can lead to gross errors.

The lack of data on the characteristics of the entire stock can also create problems with uncertainty in the Stock Aggregation results. For example, if Stock Aggregation methods use data from a sample of buildings, it will be unclear whether the sample is statistically representative of the entire stock. Only a truly representative sample can produce an estimate of the characteristic in question to within a known percentage of the "true" value.

Hybrid methods using top-down and bottom-up data

It can be worthwhile to combine Stock Aggregation with regression models to improve forecasting abilities. A few notable examples are:

Top-down economic forecasting
Predicting the economic dynamics of the marketplace is not possible as part of Stock Aggregation. However, economic dynamics can influence such variables as fuel pricing, house construction, choice of fuels, and occupant behaviour. Therefore to improve the accuracy of Stock Aggregation models it may be useful to use a regression model to estimate the impact of economic dynamics. The results can then be used to better describe the features of the future building stock.

Disaggregating and correcting national statistics
It is helpful to clarify exactly what is included and excluded from the gross top-down energy calculations at the national level, and how these variables compare from one country to another. Stock Aggregation can then be used to vary the top-down data, for example, by estimating the relative impact of including or excluding specific end uses. Or it can be used to estimate the impact of changing the boundaries of the model, for example, to include or exclude embodied energy, or transportation energy.

Calibrating bottom-up models with top-down data
A number of studies using Stock Aggregation at the community and utility scale suggest it is possible to estimate total energy flows within +10% of the actual metered consumption recorded by the energy suppliers. However if the metered consumption values are to be trusted, and the total stock size is directly comparable, it is generally worthwhile to calibrate a bottom-up model to ensure complete agreement between the total estimated flow, and the metered quantities actually consumed. In this way, even if there is a discrepancy on first analysis, it can be resolved before the bottom-up method is used for planning and policy formulation.

Two methods exist for calibrating Stock Aggregation estimates against metered consumption:

1. **A universal fudge factor**

   A fudge factor achieves agreement by simply increasing or decreasing the energy and resource flows by the ratio between the bottom-up estimate and the metered consumption. This approach may improve the accuracy of the bottom-up method, if for example, the buildings were consistently characterized as having more or less demand. However a fudge factor is no guarantee of accuracy since the bottom-up data may include compensating errors. Compensating errors can propagate when forecasting stock performance, and should be avoided if possible.

2. **Revisions to building stock descriptions**

   The stock descriptions are reviewed and analyzed for why a discrepancy might exist of a particular size and direction. Alterations can then be made to the building description data in those areas where the greatest uncertainty exists. For example, thermal loads for buildings are often inaccurately modeled due to uncertainty about:

- internal temperature variations for different zones within a building,
- heat loss through foundation slabs;
- air leakage variations seasonally;
- the tendency of occupants to increase heating comfort after envelope improvements, instead of reducing energy demand;
- unaccounted for living quarters in basements and attics; and
- unaccounted for supplemental electric heating systems or, secondary heating systems using wood.

Data Collection Methods

As with other LCA methods, analysis can easily be frustrated by lack of data, or by data that is inappropriate for the spatial boundaries, time periods and types of technology under study. Some techniques to improve data availability and quality for Stock Aggregation are described below:

Coordinating data collection and accessibility

Tremendous amounts of building-related data exist in utility records, GIS files, census statistics and municipal planning departments. Many tax assessment authorities and building inspection departments are developing up-to-date electronic databases with detailed information on floor areas and equipment. In addition, electronic metering is providing more specific and timely data on individual building resource use. Most of this type of data is never used to assist in urban planning or the design and regulation of building technology.

Thus the first step towards improved Stock Aggregation is a coordinated data collection strategy among the agencies now involved. In the future, communities cannot afford to have multiple inspectors and databases. It may make sense for the property assessment database to expand to include the full set of statistical information related to building performance and infrastructure. Unfortunately the process commonly breaks down due to two problems:

- inappropriate terms and categories used by valuators who often know nothing about building science; and
- concerns about privacy and confidentiality.

Privacy concerns are typically driven by a need to protect owners from commercial harassment. However the restrictions often prevent important non-commercial access needed by planners and designers. Regulators may lack awareness about how intimately buildings are dependent upon the surrounding community infrastructure. As long as buildings are connected to this infrastructure, information on the building will need to be accessible for Stock Aggregation purposes.

Database management and maintenance

The creation of a database and its on-going maintenance can be difficult because of the constantly expanding data needs as more information is requested on energy-related environmental effects. For example, energy consumption can contribute to smog in summer in large urban areas. However to assess the impact of a specific quantity of energy use on this hazard, it is necessary to know not only the type of energy, but also the type of pollution abatement technology involved (if any), and the time of year and general location for the energy consumption.

One method of minimizing complexity in database design and maintenance is to focus on collecting and storing only the data needed for inputs into micro-models. Another approach is to establish a core set of performance indicators, with calculation protocols, and only collect the data required for these calculations. In general it may be worthwhile to collect and organize data the same way as a quantity surveyor, and avoid duplication of effort for all new buildings.

Upgrading data quality

To improve data quality it is sometimes necessary to borrow data sets from similar communities or stocks and use these as defaults. Another technique is to conduct quick field surveys of the stock for data that is not otherwise available. Field surveys can lead to other problems however: they are expensive, data sets are frequently incomplete, and the data can quickly become out of date.

Improved computer input and interfaces

Computer applications are evolving that make it much quicker and easier to obtain comprehensive, accurate assessments of energy and resource use, and the related environmental effects, for specific types of buildings. Computer applications speed up the collection of data, through improved interface design, analysis of data, and through more powerful modeling programs.

How to Analyze and Simplify a Building Stock Database

All Stock Aggregation methods attempt to calculate total energy and resource statistics by analyzing empirical data on buildings and infrastructure. Methods vary in terms of how much empirical data is used, and the techniques used to convert empirical data into energy and resource quantities and impacts.

At one extreme it is possible to avoid sampling of the stock by collecting measured data for every energy and resource service, in every building. Each building can then be modeled, as necessary to better describe the nature of the resource consumption, and then the values can be totalled to arrive at a Stock Aggregation. Such a data-intensive approach is usually too expensive and time consuming for any but the smallest building stocks.

At the other extreme it is possible to represent the entire building stock using only a handful of representative buildings, each of which is modeled and analyzed as if it were an actual building. The proxies or building archetypes are used to estimate the characteristics of an entire population.

Between these two extremes are various compromises between quantity of data and the ease of data base management and scenario forecasting.

Using Reference Buildings for Each Building Category

To simplify the process of Stock Aggregation, it is usually worthwhile to create separate databases of reference buildings for each category of building within the stock[1]. These reference buildings can be thoroughly and accurately described, and selected to represent the full spectrum of features and sizes within the category. The reference databases can be monitored and updated as required. Reference buildings avoid problems from poor data quality. They also greatly simplify the process of analyzing a stock, since the number of reference buildings needed for statistical modeling may be only a small fraction of the total stock.

A particularly useful feature of reference buildings is that they can be summarized in different ways for different sorts of analysis and modeling. The range of diversity within the stock is maintained, which is not the case if only a single, statistically averaged composite building represents each category within the stock.

Another advantage to creating reference-building databases is that they can be open-ended, and absorb additional buildings, as the data becomes available. It may even be possible to provide mechanisms by which building inspectors and private contractors can contribute data sets on an on-going basis, in exchange for analytical information or rating values on each building they contribute.

Creating Archetypes for Each Building Category

An archetype is a statistical composite of the features found within a category of buildings in the stock. Archetypes are always more complex than actual buildings since they include bits of many different materials, technological systems, and energy and water sources.

Depending on the focus of the investigation, archetypes can be normalized as a building (or household) for the residential stock, and as one square meter of typical floor area for the commercial/institutional stock.

Archetypes are especially important in Stock Aggregation, because they make it possible to easily describe and analyze the stock, and create new scenarios. The amount of simplification involves careful trade-offs. It is possible to create a single, highly complex building archetype to reflect the entire stock of residential buildings, for example. However such a large amalgamation of building types is rarely useful, since the benefits of dynamic modeling are lost. At the same time it is beneficial to minimize the number of archetypes in order to facilitate scenario planning. It is much easier to change assumptions for just 20 representative buildings than for 50 or 100.

Normally separate archetypes are created to reflect the different use categories for buildings, and the fixed long-term differences in the stock. For example, differences in age, attachment type, and foundations are fixed variables used for residential archetypes, and can be easily identified from national statistics.

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[1] Kohler, N., Schwaiger, B, Sustainable Management of Buildings and Building Stocks, Proceedings of the Green Building Challenge, CIB, Vancouver, 1998

Stock Aggregation with archetypes involves two steps:

i. Sub-totaling by multiplying the results from each archetype by the number of buildings or by the floor area it represents, and
ii. Totaling the sub-totals for each archetype to arrive at a Stock Aggregation.

Archetypes can be created from

- expert opinion,
- top-down statistics on characteristics of the stock,
- an empirical database of the entire stock of buildings, or
- an empirical database of well-classified reference buildings.

Using an empirical database of reference buildings is usually the most reliable method. It may be necessary to use the same referenced buildings for creating several archetypes, depending upon the scope of modeling and analysis. An archetype for energy modeling may not be suitable for analyzing the flow of physical materials or water through the stock.

Sometimes an extensive empirical database is available that describes the physical features of the stock, and can thus be used to create archetypes. The data must be sufficiently detailed to generate the specificity needed for any models that will be applied to each archetype.

Empirical data can also be used to directly estimate the energy and resource flows for archetypes. For example, programs like PRISM[2] and FASER can be used to convert energy billing data into base thermal loads for space conditioning and domestic hot water.

More commonly the empirical databases suffer from poor data quality, and are inappropriate for establishing energy and physical resource flows. Empirical data typically needs to be corrected for incorrectly categorized energy, and for inappropriate levels of aggregation. For example, many large older homes may have accessory suites, yet these suites may be unofficial, and overlooked by statistical data. Or energy billing data may have been averaged over the year. Or buildings with natural gas heating equipment may also incorporate extensive amounts of supplementary electrical resistance heating.

Once archetypes are defined, they can be used in combination with micro-models and utility records to derive specific and accurate estimates of energy and physical resource flows. It is possible to combine in one archetypal building different fuels, envelope types, and fractions of mechanical systems in ways that would never be possible in reality. As long as the completed archetype is capable of being modeled and analyzed as if it were a real building, it can effectively represent a known class of building types.

The variations between archetypes must reflect the opportunities available for managing the stock. For example, older buildings have different turnover rates, and quite different conservation options, than do newer buildings. Combining the two age groups into one archetype can make it difficult to see how policies might become more effective by targeting just one of these age groups. Also, cost benefit calculations can be distorted by combining many expensive small opportunities with a few large, profitable opportunities.

[2] Commercially available software products for improving energy simulations of buildings.

One useful principle to apply when creating archetypes is to analyze which parts of buildings are most amenable to change. As a rule of thumb, features or characteristics of buildings that are unlikely to change over time, and that have little influence over potential improvements to other features of the building, can be combined together into a single average value without much loss in functionality for the database. Examples of such immutable features are lot size, orientation, and location of rooms. Conversely, those features that are influential in determining how building energy use might change over time should be used to differentiate the archetypes. Examples are building age and attachment type.

In other cases it is not so much the analysis that differentiates archetypes from individual buildings, but the data collection and inputting requirements. A restaurant, for example, may contain specialized equipment and the archetype must permit such equipment to be included and modeled.

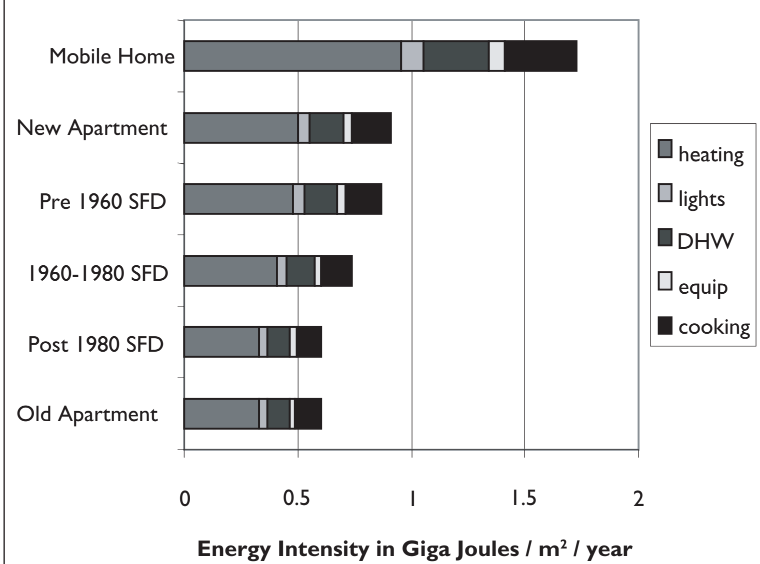

Figure 10 *Energy Consumption by end use for different archetypes*

If survey data is being used to define archetypes, then the numbers of archetypes may need to reflect the quantity of data available. For example, the descriptions of the archetype must be based upon a large enough sample to calculate the degree of accuracy that is desired (e.g. "accurate to plus or minus 3.2% 19 times out of 29)".

In general, the object is to create a discrete number of unique archetypes that reflect the entire stock under analysis, within the constraints of the data available. To achieve flexibility in forecasting resource use, it is usually necessary to create 30 to 50 archetypes, to represent any given building stock. Within each archetype, there may be multiple "generations" or age categories. Even more archetypes may be required if the forecasting incorporates the possibility for highly innovative new building types or renovation concepts. As a rule of thumb, the shorter the forecast timeframe, the smaller the number of archetypes necessary to model the stock.

Often 5 or 10 percent of the stock is so unusual that it cannot be easily represented by the standard archetypes. However including these exceptional building types in a "catch-all" archetype does not normally introduce significant error, since they are a small fraction of the total, and their consumption is constant over time.

Residential Energy Archetypes	Commercial Energy Archetypes
Urban/Rural	Existing / New
Full basement/Crawl Space or Slab	
	• Warehouse
o Single family detached	• Warehouse - Refrigeration
• advanced	• Elementary School
• new	• Secondary School
• post 1970	• Hotel motel
• 1945-1969	• Restaurant
• pre 1945	• Fast Food
	• Hospital
o Row and town and duplex	• Office pre'79, <2000m2
• advanced	• Office pre '79 2000 to 10000 m2
• new	• Office pre '79, >10000 m2
• post 1970	• Office post '79, <2000 m2
• 1945-1969	• Office post '79, 2000 to 10000 m2
• pre 1945	• Office post '79, >10000 m2
	• Retail, non food mall
o Apartment, Condominium	• Retail, part of building
• advanced	• Retail stand alone
• new	• Grocery
• post 1970	• Supermarket
• 1945-1969	• Shopping Center
• pre 1945	• University/ College/Vocational
	• Hotel/motel
o Mobile	• Hospital
	• Industrial/Manufacturing
	• Mall
	• Religious worship
	• Gas bar

Table 2 *Sample List of Building Archetypes*

It is possible to cut the stock different ways, creating different sets of archetypes for analyzing different aspects of energy use. For example, the entire building stock could be represented by 10 archetypes for the purpose of calculating transportation energy, by 30 archetypes for thermal energy, and by 5 archetypes for lighting. However the numbers of each archetype will change over time, due to turnover, renovation and new construction. This complicates calculations.

Another useful approach is to create a small series of "templates" or (primary archetypes) for modeling purposes, and then split each of these templates into a number of variants (or secondary archetypes) for calculating resource flows and costs over time. This hybrid approach is sometimes used for saving time in cases where complex simulations are needed to estimate impacts. By modeling a few templates, instead of the many archetypes, the results can simply be transferred to the archetypes within each class of template.

Archetypes must include, at a minimum, the building sectors that are present in the area of study, or that will be present during the period to be forecasted. It is sometimes useful to create separate archetypes for rural and urban locations, due to the large differences in resource use. Practicality, data availability, and the capabilities of the modeling personnel will ultimately limit the numbers of archetypes.

In addition to creating archetypes for buildings, it is also possible to create archetypes of equipment and occupant behaviour, and "attach these" to the buildings. These sub- archetypes can simplify the analysis, by making it easier to change key aspects of a group of building archetypes over time.

For example, the vehicle can be classified as a group of archetypes. A typical family vehicle in a suburb could be composed of part car, part van, and part truck in proportions that typify the stock of vehicles used by occupants of the suburban building archetypes. In this way the fuel efficiency, and the air emissions, can be tracked as commuting distances, or the numbers of suburban building archetypes, change over time.

Occupant behaviour is another variable that may be archetyped, and attached to buildings for specific periods of time. In this way it becomes easier to track the impacts of demographic shifts such as changes in family composition, or ethnic lifestyles, that may influence the operation of buildings. In residential archetypes the occupant behaviour can affect indoor temperatures, lighting use, cooking appliances, hot water consumption, and so on. In commercial archetypes the occupancy can affect the hours of use and numbers of people.

Infrastructure costs and resource flows

In this context infrastructure refers to all of the community systems that are required by a building by virtue of its technology and location. This includes roads, pipes and wires, generating plants, sewage treatment facilities, landfills and so on. Portions of the energy and resource costs associated with each of these systems can be allocated to reference buildings, or to archetypes, in proportion to their share of the total usage.

Each part of the infrastructure needs to be defined and described in terms of average and marginal costs, resource consumption and emissions per unit of service. Each building can then be allocated a portion of these infrastructure costs, with the percentage allocation reflecting the actual breakdown for that category of building.

For example, an archetype that represents old apartment blocks is likely to include a wide variety of heating systems, operating at varying efficiencies, and using different sources of energy. Once the thermal load for the archetype is known, the actual energy consumption, by type, can be calculated by using a breakdown such as that shown in Table 3. Actual energy consumption is a combination of the many systems that supply this portion of the stock, including all the energy contained in the energy chains for the infrastructure.

Thermal Load	Technical System	Energy Source
10%	o Coal fired boiler @65%AFUE	o brown coal delivered by truck
30%	o Natural gas boiler @70% AFUE	o gas piped to site
3%	o Natural gas boiler @97% AFUE	o gas piped to site
5%	o Space heaters	o fuel oil trucked to site
15%	o Electric resistance heating	o electricity from local power grid
5%	o Heat pump COP 3.1,	o electricity from local power grid
32%	o Steam pipes	o coal-fired district system heat
100%		

Table 3: *Example Allocation of Heating Energy Infrastructure to an Archetype*

Proprietary Tools for Stock Aggregation

Micro Tools

Micro tools are the building-specific tools that can be used to analyze the performance of each building or archetype. Almost all micro tools now used for estimating resource consumption, environmental impact and costs of buildings can assist with Stock Aggregation. These tools have been well described elsewhere in Annex 31 reports.

The choice of micro tools should be dictated by the value of the information produced, and by the practicalities of use. Some micro level tools require extensive data on buildings, and their use may be impractical. Sometimes it is reasonable to use a micro tool only if the user establishes default values for those data that are difficult to obtain, or that have little impact on the issues of interest.

Currently micro tools are widely available for estimating energy use and the related air emissions. Many tools are also available for estimating direct building costs. Less readily available are tools for estimating the full life cycle energy for building types, and the associated mass flow of materials and solid waste. Very few tools exist for analyzing water consumption at the building level, or for estimating production of household waste. And no tools exist for estimating building-related transportation as a function of the building location and design.

As more tools become available for accurate modeling of resource use by buildings, and for estimating impacts on municipal infrastructure, the value of Stock Aggregation methods will increase. The slow progression of computerized tool design features suggests convergence towards a more comprehensive application suitable for Stock Aggregation work.

These progressions are outside the scope of this paper, but the changes in direction are worth noting:

- from tools dealing only with operating energy to tools that address materials, water, land use, and most recently, solid waste;
- from tools focused only on the building to those that include many of the indirect (or upstream) effects and infrastructure costs;
- from tools developed by the public sector to tools that incorporate the public sector work into more user-friendly proprietary software;
- from tools that emphasize rigorous methods to tools that emphasize easy-to-understand reports; and
- from tools that focus on research and analysis to tools that are carefully designed to fit into the decision-making process, including design, sales and approvals.

Macro tools intended for Stock Aggregation

Recently a number of tools have been developed to assist with the modeling and aggregating of buildings or archetypes, and in some cases accounting for the municipal infrastructure. These tools tend to be based upon urban models created from GIS applications, and containing layers of information on buildings and resource use. Examples of such tools are listed in Table 4. Most of these tools use data generated from micro models, in order to create the default values for each building type within the community. As yet, none of the tools are integrated with micro models for more dynamic and 'scalable' modeling.

Name	Description of Tool	Contact Information
CitiesGreen	ArcView application with ACCESS database.	www.Sheltair.com
SmartPlaces	ArcView application.	www.epscweb.com/env_smartplaces.html
EEP (Energy & Environment Prediction model)	ArcView application	www.cf.ac.uk/uwcc/archi/research/sbe.html
INDEXArc	View application	www.crit.com
LEAP and Polestar	Virtual Basic.	www.Tellus.org
CITYgreen	ArcView application	www.americanforests.org

Table 4 *Examples of stock aggregation software tools for urban environmental management and forecasting*

Probably the biggest challenge now facing the evolution of computerized tools for Stock Aggregation is how best to use models to design better integration between buildings and the municipal infrastructure. A well-designed urban environment will have many forms of integration that may significantly affect the net environmental performance of buildings. For example:

- Integration occurs between the end-use demands (e.g. a toilet) and the supply infrastructure (e.g. a water reservoir).
- Integration occurs between technologies within buildings; (e.g. the energy used for lighting also contributes significantly to space heating).
- Integration occurs between sectors (e.g. the location and design of housing and other buildings influence the transportation sector).
- Integration occurs between different resources, (e.g. because one of the biggest energy sources in some communities is the energy used to pump water; water consumption is linked to energy consumption, greenhouse gas emissions, electricity costs and power generation requirements).

These types of dynamic relationships still need to be defined before it will be possible to accurately model the long-term impacts of buildings at the urban scale.

Conclusions

Stock Aggregation methods are clearly a useful application for many of the new methods and tools now available for evaluating the environmental performance of a building. Through Stock Aggregation, it becomes possible to use the same tools at many scales, from the nation to the neighbourhood. Stocks can be assessed in similar fashion to individual buildings. The results can be used to identify trends, and create profiles, forecasts, and benchmarks of performance.

Stock Aggregation methods contribute to decision-making in two ways:

1. by assisting designers of individual buildings to understand how their design choices might affect – or be affected by - the overall stock performance, and
2. by providing planners and policy-makers at varying scales (local to national) with a richer, more powerful database on building costs, energy and resource use, and environmental effects.

Stock Aggregation is often the best method for evaluating building stocks because it can capture the dynamic relationships within buildings that significantly affect energy and mass flows. The methods are now being used at the National level, and are likely to be increasingly important as countries attempt to satisfy the Kyoto commitments for greenhouse gas reductions.

Stock Aggregation methods appear especially appropriate for use by utilities and by communities. Ideally, a nested database is created that permits the same data to be used at different scales, and also by private and public owners of partial stocks. Once a database is available at the community level, then Stock Aggregation can provide a foundation for new and powerful planning methods, including Urban Environmental Management Systems, and Urban Forecasting Information Systems. Such systems may provide design professionals with information that can influence individual buildings, including information on:

- Avoiding the risk and cost of overloading the local infrastructure;
- Creating opportunities for cooperative investments between building owners or developers; and
- Providing clear, rigorous arguments for socially responsible decisions.

Stock Aggregation is best used in combination with top-down models. The top-down models can help to predict the impact of prices and regulations on supply and demand. Census statistics, input-output accounts, and utility records can also be used to calibrate Stock Aggregation methods.

Much more effort is required to coordinate collection of standardized, up-to-date data on the building stock, especially the tax assessment data, and for making such data accessible for Stock Aggregation purposes. To facilitate easy planning and forecasting work, it is useful to develop specific high quality empirical databases of reference buildings for different categories of buildings in the stock. The reference databases can be used to generate archetypal buildings that can simplify and speed up the evaluation of the stock, especially when micro modeling tools are applied. As well data needs to be organized on the costs and resource flows associated with the municipal infrastructure.

At present no commercially available tools exist specifically for Stock Aggregation purposes. However the evolution of micro models suggests that it should soon be possible to create dynamic urban-scale models of the stock. A number of GIS applications are currently available which used the results from micro models to populate layers of data on houses and commercial buildings, and to provide easy aggregation of data within user-defined spatial boundaries. Such tools can provide planners with aggregated data on the performance of building stocks, and with rudimentary forecasts. In the future the most difficult challenge for Stock Aggregation methods is allowing for greater integration of different resources, of different sectors, and of buildings with the community infrastructure.