What Developers Think About District Energy: A Mental Models Approach

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ABSTRACT

A district energy system has been proposed for a mixed-use downtown neighborhood currently under re-development in Vancouver (Canada). Based on renewable energy sources, the proposed system has lower environmental impacts than conventional building-specific energy supplies. To be viable economically, however, district systems typically need sufficient numbers of buildings to connect. Split incentives and other institutional barriers may deter developers of new buildings from integrating district systems into their plans. Designing a district energy system for new buildings therefore requires a clear understanding of the influences on developers' decisions to connect (or not). This paper presents the initial findings of a research project which tracks the perspectives of both the sponsoring municipality and the new building developers over the course of the proposed district system's design. Findings from open-ended interviews are represented as 'mental models' which encapsulate the lines of causality and influence on developers' decisions to connect to the district system. Comparison of the mental models over time, as well as between the municipality and developers, allows the importance of key design features to be identified. A repeat set of interviews will be carried out once final decisions have been taken with respect to the district system.

Research Background: District Energy in Vancouver

The False Creek Precinct

A major brownfield development for a mixed-use residential and commercial neighborhood is currently underway adjacent to the downtown core of Vancouver. The area is centered around the False Creek inlet, encompassing about 200 ha of land historically zoned for light and heavy-industrial use. Development of this 'False Creek Precinct' is sub-divided into distinct neighborhoods and timescales. Phase 1 (2005-2010) of the rezoning and development comprises both public (20 ha) and private (12 ha) lands in the Southeast False Creek neighborhood. The public lands contain the site of the Olympic Village for the Winter Olympics to be held in Vancouver in 2010. Phase 2 (2010-2015) comprises adjacent public lands in Southeast False Creek, together with some initial developments eastwards in the False Creek Flats. The remainder of the False Creek Precinct is anticipated to be built out in Phase 3 (2015-2020) according to current rezoning plans. Approximately 0.35 million m^2 of new building floor area is anticipated by 2010 (Phase 1), rising to a total of 1.45 million m^2 by 2020 (Phases 1-3). The Phase 1 developments are predominantly high-rise multi-unit residential buildings (70% of new floor area) with some office (26%) and retail space (4%). Phases 2 and 3 contain some major institutional developments, including a hospital and a university campus, and also some light industrial space. By 2020, the projected new floor area breaks down as residential (43%), office (30%), hospital (14%), other (13%). Thermal energy loads are projected to be around ~12 MW_{peak} (~33 GWh) by 2010, rising to ~64 MW_{peak} (155 GWh) by 2020. Electricity loads are projected to be around ~15 MW_{peak} (~31 GWh) by 2010, rising to ~31 MW_{peak} (~195 GWh) by 2020.

The Proposed District Energy System

This contemporaneous development of adjacent high density neighborhoods prompted proposals for the City of Vancouver ('the City') to explore a district energy system ('DES') as an efficient means of providing heating, cooling and emergency power services in the False Creek Precinct. The main rationale for the system is to contribute to the City's greenhouse gas ('GHG') emission reduction goals. In particular, the Official Development Plan for Southeast False Creek set out that: "a neighborhood energy system be developed … that advances district energy production through sustainable technologies … with the goal of creating a GHG neutral energy system that has the capacity to grow …". *(March 2005)*

Framed by these environmental objectives, an initial study completed in March 2005 recommended geo-exchange (ground source heat) and sewer heat recovery to service base heating loads, with peak loads and back-up heat provided by high-efficiency gas boilers, and a hot water distribution system coupled with in-building hydronic (radiant) heating. In February 2006, a comprehensive feasibility study confirmed the technical and economic viability of sewer heat recovery with peaking gas boilers, as well as biomass combustion (subject to permitting). Geo-exchange heat and an emergency power micro-grid were rejected on cost grounds. Economic analysis concluded that a neighborhood energy utility ('NEU') set up to operate and manage the system could recover capital and operating costs through a tariff structure that would be competitive with current market rates for energy services while providing adequate returns on investment to the City. Significant GHG emission reductions were also projected relative to a business-as-usual ('BAU') scenario characterized by the use of electric-resistance heating (see Section 4). In March 2006, the City committed to the DES/NEU by agreeing to the design and construction of the first phase of the heat distribution system in Southeast False Creek.

This paper describes preliminary findings from a research project that asks: why would the private developers of new residential high rise buildings in the False Creek Precinct decide to connect to the district energy system? Section 2 summarizes the research question, objectives, and methods, including a brief literature review of previous work in this area. Section 3 sets out in more detail the research methodology used which is adapted from the mental models approach to risk communication. Section 4 of this paper addresses the data requirements of this approach and describes the research findings to-date (the project is still ongoing). Section 5 draws some initial conclusions.

Research Question & Objectives

Why Do Buildings Connect to District Energy Systems?

The economic viability of district heating is driven by: scale economies in heat generation plant costs and efficiencies; plant sizing to achieve high utilization rates; and reduced peak:base load ratios by aggregating diverse loads (Gochenour 2001; IEA 2002). Consequently, a major business risk for a new or expanding district heat system is the availability of a sufficient number of diverse loads. This availability depends on the areal distribution of existing buildings or new building developments, and the ability of the district heat system to secure their connection. As these building development and connection risks are not easily managed privately, municipalities tend to play a lead role in developing district energy.

This research concerns the ability of district schemes to secure necessary loads, or simply: why do buildings decide to connect to district energy systems? This has been explored in some depth for retrofits of existing buildings from the perspective of building owners and occupants (Summerton 1992; Henning 2005). The decision context for the False Creek Precinct district energy system ('DES') is distinct in two ways. Firstly, the decisions of the building developers are not anchored by existing in-building heating systems as the DES can be incorporated into the new buildings from the design stage rather than through a retrofit. Secondly, the decision agents are building developers not owners / occupants. As the buildings are mainly slated for sale, principal agent issues are introduced with respect to the recovery of any incremental capital costs that may be incurred (Brown 2001). Principal agent problems occur where information or incentives are asymmetrically distributed between an agent, and a principal who bears the consequences of that agent's actions. In the case of the DES, the developer (i.e., the agent) seeks to minimize capital costs to maximize returns on investment but in so doing, may impose higher operating costs on the building occupant (i.e., the principal) over the long-run. In the absence of any profit- or risk-sharing arrangements, the agent has no clear incentive to take the principal's position into account (Shavell 1979; Miller 2005).

Research Objectives

Although the DES planned for the False Creek Precinct is centered on the Olympic Village and other public developments in Southeast False Creek for which connection is assured, the system's viability is significantly improved by expansion into the adjacent private lands to be developed over the next 5-15 years. Securing the connection of these new buildings is the key outcome of a decision process initiated by the City in March 2005 to engage private developers. The City recognizes that connection should be attractive to private developers on its own merits, and so envisages incorporating developer concerns into the technical and institutional design of the system subject to its own objectives being met. The decision process therefore involves information exchange between the City and private developers on ongoing design issues and their impacts on the cost-benefit profile of the DES, as well as on any barriers to connection from the developers' perspectives.

Taking this decision process as a case study, a research project was developed with two objectives: (1) to identify the influences on private developers' decisions to connect to a district energy system; (2) to assess the effectiveness of information exchange during the design process of a district energy system in reconciling diverse institutional perspectives. This paper speaks to the first of these two objectives. The second objective requires the decision process to be completed. Private developers' final decisions to connect to the DES are expected by the summer/fall of 2006 for Phase 1 of the Southeast False Creek redevelopments.

Research Methodology: An Adapted Mental Models Approach

Selecting a Research Methodology: Mental Models in Risk Communication

The 'mental models' approach to risk communication was selected as an appropriate research methodology as it has been used to explore both individual perspectives of an issue and how information might be used to alter these perspectives. Mental models are a metaphor for the complex of beliefs, perceptions, framing, emotions, and understanding of any given issue, and have a long tradition in cognitive psychology (e.g., Gentner & Stevens 1983; Rouse & Morris 1986). The mental models approach to risk communication is a methodology for structuring information provided by an 'expert' agency to a 'lay' public on risk issues typically related to health, environment, and technology (Byram, Fischhoff et al. 2001; Morgan, Fischhoff et al. 2002). The objective is to provide the public with the information they need to make informed choices based on a comprehensive prior understanding of people's beliefs and perceptions rather than a hierarchical form of instruction based on expert opinion. The mental models' approach is centered on influence diagrams that encapsulate open-ended interview data.

Related methodologies are used in public program evaluation. Logic models, for example, are causally-linked sequences of the different elements of a program that provide a simple and transparent visual representation to facilitate communication, monitoring and assessment (McLaughlin & Jordan 1999). Market effects diagrams are similarly used to represent and evaluate the activity-actor-effect sequence of market transformation initiatives (Schweitzer & Brown 2001). In general, the objective of such tools is to assess the contribution of program activities and outputs to intended outcomes. While broadly analogous to the research objectives set out above, the sole outcome of interest here is developers' decisions to connect. In this decision-focused context, influence diagrams are more appropriate representational tools, as they show how different elements (known, uncertain or as yet unresolved) may impact the outcome of a decision.

Conventional applications of the mental models approach to risk communication follow a stepwise methodology shown in the left-hand column of Table 1. Influence diagrams are used to represent experts' views of a particular risk. A sample of the public is then interviewed using a protocol designed to avoid leading questions or other sources of bias while covering all the aspects of the risk issue. The differences between the public's mental models and the expert model inform the design of an effective risk communication strategy to reinforce the public's beliefs if pertinent or discourage them if misleading. The basic objective is to improve the public's understanding of the risk by bringing them closer to the expert view.

Adapting the Mental Models Approach to Evaluate Informed Decisions

There are two key differences between this research context in which the City is seeking to influence developers' decisions to connect to the DES, and contexts in which the mental models approach to risk communication has typically been applied. Firstly, the relevant actors are not technical experts and the lay public, but the City as project sponsors (supported by technical experts) and private developers. Secondly, communicating information is not the *outcome* of the process but is *part of it*; the aim is not to design a communication strategy *in advance*, but to assess it *retrospectively*. Consequently, the mental models approach has been adapted, as shown in the right-hand column of Table 1.

The major adaptations are similarly two-fold. Firstly, the 'expert' and mental models are assigned to the City and the private developers respectively, and interviews are carried out at both the beginning and end of the decision process to characterize both sets of mental models, and how they change as information becomes available. This covers stages 1-4 of the methodology. Findings to-date are described in Section 4. Secondly, information provided by the City throughout the decision process is documented so that its role in influencing developers' mental models can subsequently be evaluated. This covers stages 5-6 of the methodology, and will be completed once the decision process is completed (summer/fall 2006).

Table 1. Methodological Stages of the Mental Models Approach

	Mental Models Approach to Risk Communication (Morgan, Fischhoff et al. 2002)	**Adapted Mental Models Approach to Decision Process Evaluation**
1	**Build Expert Model** Conduct full review of expert knowledge from all perspectives. Build influence diagram to represent expert model & iterate with experts.	**Build *Initial* City 'Expert' Model** <u>Similar to risk communication approach, but:</u> The City's knowledge is incomplete and evolving as the DES is in the design phase
2	**Characterize Mental Models** Incorporate all aspects of expert model into an open-ended interview protocol & carry out interviews with a sample of lay public. Identify important beliefs, significant misconceptions, critical terms.	**Characterize *Initial* Developer Mental Models** <u>Similar to risk communication approach, but:</u> Interviews with private developers not lay public. As sampling frame = population, confirmatory questionnaire in stage 3 is not required.
3	**Confirmatory Questionnaire** Test understanding of issues identified in mental models on wider population. Assess representativeness of sample mental models.	**Update to *Midway* & *Final* City 'Expert' Model & *Final* Developer Mental Models** <u>Different to risk communication approach:</u> As City and developer mental models may change through the decision process as more information becomes available, interviews are repeated midway (City only) and at the end of the decision process.
4	**Evaluate Mental Models** Code mental models based on nodes in expert model. Compare mental models against expert model / identify similarities and differences (e.g., non-salient, erroneous, peripheral beliefs, missing beliefs).	**Evaluate Mental Models** <u>Similar to risk communication approach, but:</u> Identify changes in developer mental models through the decision process. Compare initial and final developer mental models against City 'expert' model.
5	**Design Communication Strategy** Provide information to reinforce pertinent beliefs & discourage incorrect beliefs. Use logical & causal structure, respectful, neutral, authoritative & scientific tone; seek not to persuade but to facilitate informed choice.	**Track and Document Information Provision** <u>Different to risk communication approach:</u> Track and document the content, framing, and channels of information provided by the City to developers throughout the decision process.
6	**Evaluate Communication** Test communication effectiveness on a sample of participants, and iterate with stage 5 as required. Carry out prior to delivering communication to public.	**Evaluate Information Provision** <u>Different to risk communication approach:</u> Attribute changes in developer mental models to information provided through decision process and/or other factors influencing change in mental models. Assess effectiveness of information provided through decision process at reconciling developer and City 'expert' models.

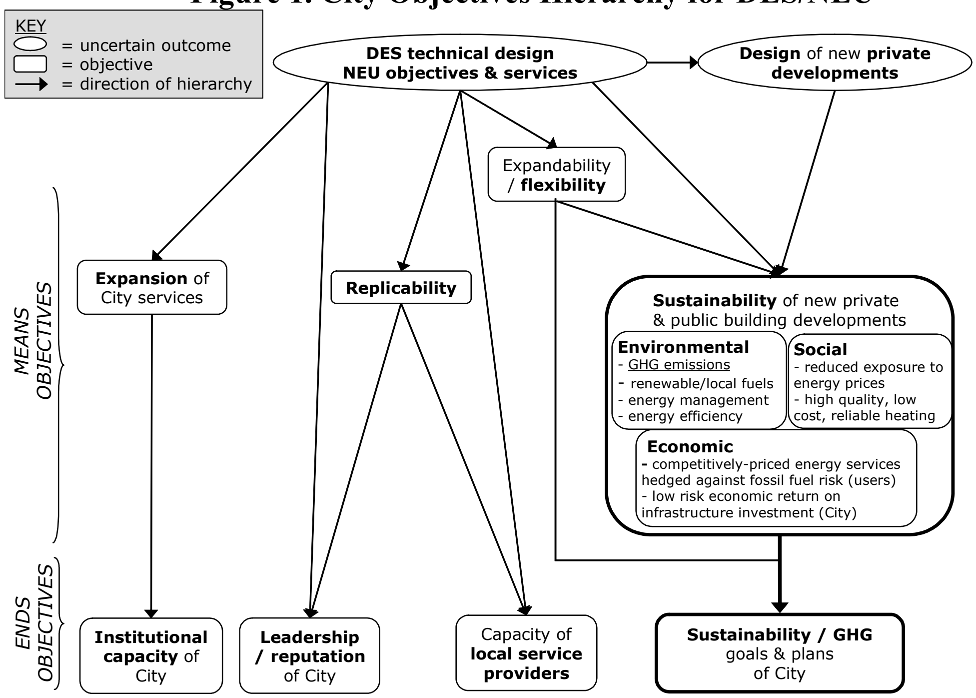
Research Findings

City 'Expert' Model: Objectives

The City's perspectives on the DES comprises two distinct but inter-related components. The first component is the City's own objectives in pursuing the DES for the False Creek Precinct. This frames the second component: the City's understanding of developers' perspectives on the DES, which in turn informs the way information provided through the decision process is structured to encourage developers to connect. While the second component is integral to the mental models methodology (see Table 1), the City's objectives are also critical as they limit the flexibility of the DES design process simply to accommodate all the developers concerns so as to ensure connection.

The City's objectives have been articulated both explicitly and implicitly in a series of documents, meetings, workshops, and interviews with City staff. They are shown in Figure 1, organized as an objectives hierarchy. This distinguishes ends and means objectives. The attainment of means objectives represents progress towards (rather than achievement of) the ends objectives that ultimately motivate the decision (Keeney 1992).

Figure 1. City Objectives Hierarchy for DES/NEU



The oval nodes at the top of Figure 1 show uncertain outcomes. 'DES technical design' refers to the physical configuration of the proposed system, while 'NEU objectives & services' refers to the neighborhood energy utility ('NEU') which will manage and operate the system and provide energy services to end users. The other uncertain outcome relevant to the City's objectives concerns the design of the private developments are designed, which is turn is influenced by the design of the DES (e.g., in determining the requirements for in-building energy systems). At the very bottom of Figure 1 are the ends objectives for the City to which the DES/NEU is expected to contribute.

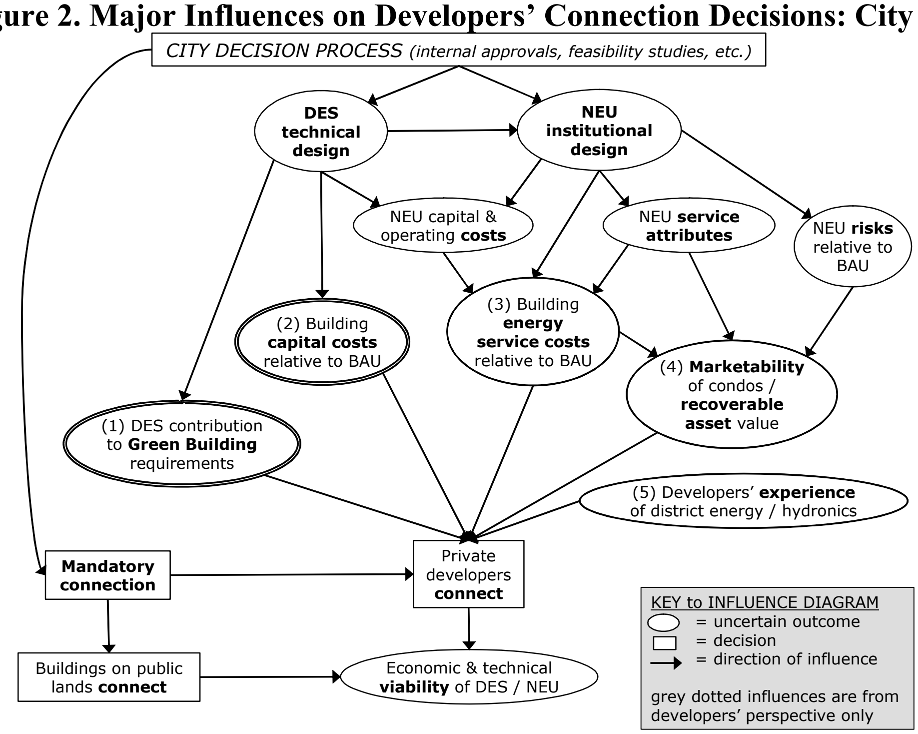
The most emphasized objectives were the City's sustainability goals (ends objective, bottom right of Figure 1) to which the new developments in the False Creek Precinct would directly contribute at the neighborhood scale. The large box shows the means through which these ends would be achieved: environmental, through the use of renewable fuels with lower GHG emissions in a more efficient system; economic, through attractive rates of return on infrastructure investments for the City; and social, through the provision of high quality and low price risk heating services for building users.

Leadership and reputation of the City were also commonly cited ends objectives. Development of the City's institutional capacity and of local service providers' knowledge and experience with district energy (as a potentially exportable skill set) were raised more in the context of City Council hearing and approvals than by City staff. These ends are achieved via various means: the expansion of City services to include an energy utility (a wholly new role for the City of Vancouver); the replicability or transferability of the DES/NEU within Vancouver, adjacent municipalities, and beyond; and the technological flexibility (e.g., to incorporate new renewable supply sources) and ease with which the DES can be expanded.

Connection Decision Influence Diagram

The second component of the City's expert model is the influence diagram shown in Figure 2. This represents the City's perspective on what determines whether developers will decide to connect to the DES. Influence diagrams are useful ways of representing the different elements (shown as nodes) that comprise a decision, as well as how they inter-relate. Oval nodes represent uncertain states of knowledge, or events whose outcomes exert an influence on (or are relevant to) other decision elements as shown by the arrows. Decision nodes are rectangular. The outcome of a decision will be influenced by all the nodes which connect to it. However, it is important to stress that influence diagrams should not be interpreted in a deterministic or causal sense like flow charts. Rather, influence diagrams seek to represent all the information relevant to a given decision without implying a temporal or causal sequence (Clemen & Reilly 2001).

Figure 2. Major Influences on Developers' Connection Decisions: City 'Expert' Model



The oval nodes in Figure 2 show outstanding uncertainties or unresolved issues. At the top are nodes representing the technical design of the DES, and the institutional design of the neighborhood energy utility ('NEU') which will provide energy services to connected buildings based on a tariff structure, management objectives and so on. Note that the outcome of these nodes also determine the extent to which the City's objectives are met and so also appear at the top of Figure 1. At the bottom in the centre is the key decision node: 'private developers connect.' The outcome of this decision taken by the different private developers will determine the thermal demand supplied by the DES, and consequently its economic viability (see discussion above). Note also that a 'mandatory connection' decision node is included (bottom left) as the City has raised the possibility that connection to the DES could be made mandatory through the rezoning process although this is both undesirable and would require changes to the City's governing Charter.

There are five major uncertainties that directly influence the key decision node of whether private developers decide to connect. These are shown by the double-lined oval nodes numbered 1-5. They were all either emphasized (repeatedly stated) or cited (stated at least once) in the wide range of documents, meetings, workshops, and interviews with City staff that comprehensively cover the City's perspectives throughout the decision process.

1. DES contribution to Green Building requirements *(emphasized).*
   All buildings to be developed in the first phase of the False Creek Precinct must meet stringent green building performance criteria. The extent to which the DES may contribute to these criteria is uncertain and subject to ongoing discussions with the Canadian green building standards agencies (see Figure 3 below for further details).
2. Building capital costs relative to BAU *(emphasized).*
   The implications of the DES on developers' capital costs is uncertain. Potential savings may arise from foregone space requirements for in-building boilers. Potential costs may arise from the hydronic heating system. Any impact on capital costs is relative to a 'BAU' or business-as-usual development scenario in the absence of the DES (see section below & also Figure 3 for further details).
3. Building energy service costs relative to BAU *(emphasized).*
   The City has consistently argued that heating services provided to building occupants by the NEU will be at rates competitive to BAU services provided by electricity and gas utilities. Moreover, the cost of these services will be relatively insulated against future energy commodity price rises. However, the tariff structure to be offered by the NEU is uncertain (see Figure 4 below for further details).
4. Marketability of condos / recoverability asset value *(cited).*
   Condos in the new residential developments will likely be sold. The impact of the DES on the buildings' marketability is uncertain, as is the extent to which any additional capital costs can be recovered through a price premium on market rates. This relates closely to point 2 above.
5. Developers' experience of DES / hydronics *(cited).*
   Any prior experience the developers have had with either district energy or hydronic (radiant) heating may influence their decisions to connect their new buildings in the False Creek Precinct to the DES. In particular, the City sees hydronic heating as a high quality and therefore premium heating technology.

Also shown in Figure 2 are the specific design features of the DES/NEU that influence these five major influence nodes: it's capital and operating costs, which determines the tariff structure offered to end users; its service attributes, for example, whether offsets are purchased to guarantee GHG neutral energy service provision; and, its risk profile, both on the fuel cost side, and also in terms of operating and technology risks.

Business-As-Usual & Green Building Requirements

The influence of the DES/NEU on developers' capital costs and buildings' energy service costs can only be assessed relative to a counterfactual scenario in which buildings' energy systems are developed conventionally. Extensive residential building developments in Vancouver allow this 'BAU' or business-as-usual scenario to be clearly defined: electric resistance heat (~70%) or gas-fired heat (~30%), standard efficiency equipment (including generation, distribution, and end use), and suite-metered electricity but building-metered gas. The preference of building owners / operators for electric-resistance heat is driven by the low capital costs of electric baseboards (for developers) and the rising cost differential of gas over (predominantly hydro) electricity in British Columbia.

Discussions between the City and developers have used this BAU scenario to evaluate the cost impact of connection to the DES. However, significant uncertainty is added by the green building criteria required by the City for all new developments in the first phase of the False Creek Precinct. These criteria require buildings to qualify for 'CBIP' (Commercial Building Incentive Program) by demonstrating in design-phase modeling simulations that energy consumption is 25% or lower than a baseline building which meets the model national energy code. Buildings must also achieve a 'LEED' Silver rating or equivalent (Leadership in Energy and Environmental Design) which requires a broader suite of environmental design considerations. Being mandatory, the net cost impact to developers of meeting these green building criteria should comprise part of the BAU scenario. However, as the developers with sites in the False Creek Precinct have little or no previous experience with building to CBIP &/or LEED Silver standards, any cost increments from connection to the DES are being considered relative to a BAU scenario without these green building requirements. This risks inflating the perceived cost impact of connecting to the DES.

City 'Expert' Model: Details

Figure 2 is *comprehensive* in that it encapsulates all the major uncertainties and influences on developers' decisions as articulated by the City, while also remaining *comprehensible* by omitting many intermediary nodes. These intermediary nodes are explored in more detail in Figures 3 & 4 below, which expand on the major direct influences from Figure 2. Nodes and arrows shown in grey are influences considered resolved or no longer relevant when the City's expert model was updated at the midway point of the decision process when City Council approved build out of the DES (see stage 3, Table 1).

Figure 3 shows the main influences on whether connection to the DES may help developers meet the green building requirements for Southeast False Creek: the design of the DES (in terms of its environmental performance); the design of in-building energy systems that interface with the DES; and, the evolving rules on the applicability of DES towards CBIP / LEED criteria subject to the green building requirements for Southeast False Creek (see above). The need for individual suite metering as an influence on building design ceased to be relevant as the City dropped the requirement on cost grounds.

Figure 3 also shows the influences on building capital costs relative to BAU. Minimizing capital costs is typically perceived as the key driver of developers' decisions. Capital cost increments required for green buildings, as well as net benefits over the buildings' life cycle, have consequently been researched in some depth (e.g., Kats, Alevantis et al. 2003). The cost impact of connecting to the DES will be influenced by the design of the in-building energy systems (hydronic heating system, pipe network, heat exchangers, any mechanical plant including heat exchangers, etc.). Two cost mitigants, included in Figure 3, are the potential for sub-market rate loans and CBIP incentives to cover or reduce the 'green' cost increment.

Figure 3. Influences on Developers' Connection Decisions: Green Building Requirements & Capital Costs

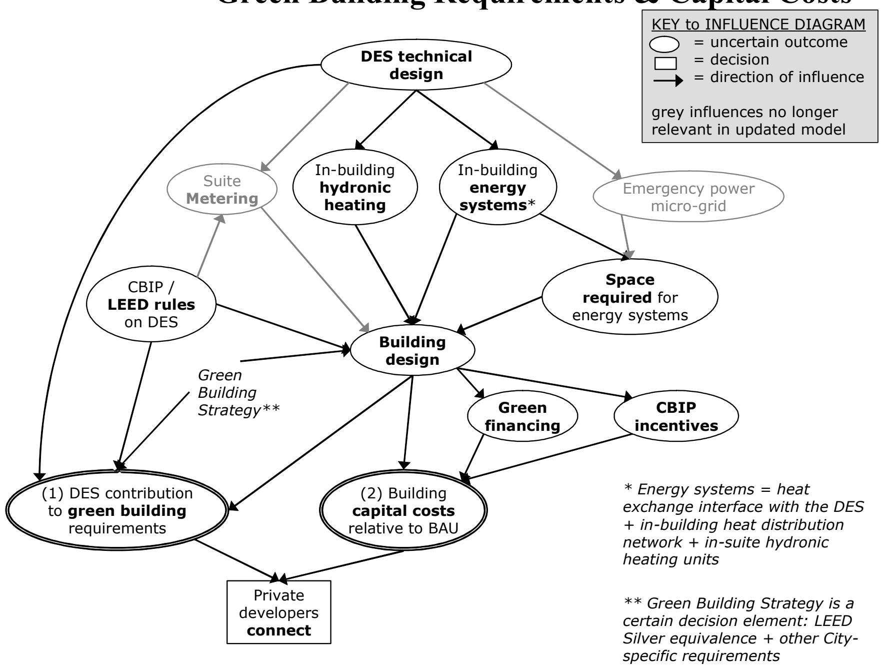


Figure 4. Influences on Developers' Connection Decision: Operating Costs & Marketability

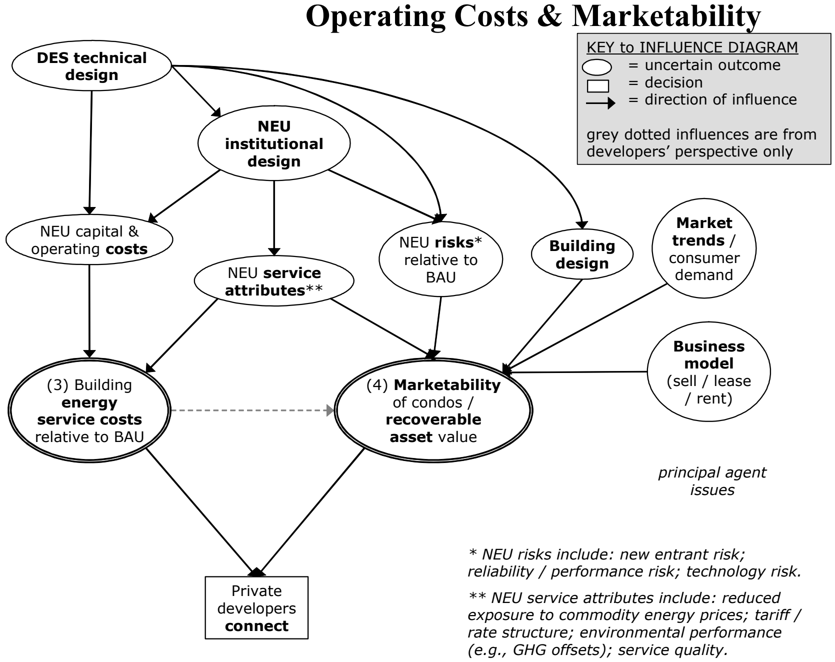


Figure 4 shows the influences on building energy service costs relative to BAU, and on the marketability of condos. The main influences on the energy service costs relate to the institutional design of the neighborhood energy utility ('NEU') that will determine the tariff structure needed to recover its capital and operating costs. The main influences on developers' ability to market the condos are more related to trends in consumer demand for hydronic heating and environmentally efficient energy services, as well as broader green building design features.

Developer Mental Models

The initial mental models interviews have been carried out with developers in Phase 1 of the False Creek Precinct (stage 2, Table 1). The interview transcripts were coded using a template comprising all the elements of the City's expert model. Influences not considered by the City but raised by developers were added to the template. The results were compared against the City's expert model and are shown in summary form in Table 2 for the five major influences set out above. As the City has maintained open dialogue with the developers, differences are more ones of emphasis than omission. Further analysis of the coded mental models' interviews is needed for a full comparison of the City's expert model with the developers' mental models, and to identify significant differences between developers.

Table 2. Comparison of City's Expert Model & Developers' Initial Mental Models

Major Influence	City	Developers	Comments
DES contribution to Green Building requirements	emphasized	cited	At the outset of the decision process, developers were unfamiliar with how the DES might contribute to green building criteria.
Building capital costs relative to BAU	emphasized	emphasized	Developers' prime concerns and recognized as such by the City.
Building energy service costs relative to BAU	emphasized	not cited	Not considered relevant by developers due to principal agent issues, although stressed by the City.
Marketability of condos	cited	emphasized	The same issue as building capital costs for developers. Hydronic heating as a premium service not considered.
Developers' experience of DES / hydronics	cited	not cited	Developers considered market trends as the only major driver of in-building heating systems & these had moved away from hydronic systems to electric baseboards. No developer had prior experience of district energy systems.

Conclusions

The mental models approach to risk communication is a proven methodology for characterizing and representing individuals' perceptions, beliefs, and understanding of a particular risk issue. Here it is applied in a decision-making context to represent stakeholders' mental models of the influences on the decision. The resulting influence diagrams are a useful visual form for communicating and contrasting stakeholders' perspectives. The next steps in the research are to compare these mental models in more detail in order to assess the effectiveness of information in reconciling any notable differences.

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