Protocol and assessment tool for performance evaluation of light-frame building envelopes used in residential buildings

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ABSTRACT

In the Canadian climate, the performance of wood-frame building envelopes is affected directly by moisture management as well as by the quality of design, construction workmanship, and maintenance. Trapped moisture reduces the thermal performance of the envelope and can lead to mould growth that deteriorates building materials and contaminates the indoor-air. The means to evaluate the impact of these factors on the overall performance of the envelope are limited. Computer models that exist are still, for the most part, reserved for researchers or have not been validated to a sufficient comfort level for the designer. Till now large scale testing that would provide realistic results have been limited due to the lack of facilities and the lack of evaluation procedures.

This research project develops a protocol that facilitates the evaluation of the performance of light-frame building envelopes. The protocol evaluates the building envelope as a system under the following main issues: air-tightness, moisture management performance, thermal performance, energy performance, structural stability of building envelope, acoustic performance, fire response performance and quality of workmanship. It sets the internal and external loads that affect that performance and develops a procedure for evaluation. The evaluation protocol includes performance criteria, associated standards, and compliance evaluation methods.

The second part of this study involves developing an assessment tool that uses data generated by the above evaluation procedure. This assessment tool is designed to provide a fast check of the building envelope system compliance against performance requirements. Intended to be comprehensive and user-friendly for professionals, this tool can also be used by producers and exporters of factory-made houses in Canada to examine existing designs and to verify the performance of new designs.

The validation of the protocol and the assessment tool is done by evaluating the performance of five different building envelope assemblies: one modular prefabricated house designed and built in conformance with the requirements of NBC and Québec Energy Code (A-standard house), one modular prefabricated house designed to conform to requirements of Novoclimat program (A-Novoclimat house), one panellised high performance house (M-Thermo house) and two Advanced houses: NOVTEC Advanced house and Innova Advanced house. The results of validation show that the protocol and the assessment tool are effectively used to establish the performance profiles of these five case studies, demonstrating in each case the adequacy of each parameter. The results also demonstrate that the protocol provides a means of comparing the relative performance of respective parameters across case studies.

RÉSUMÉ

Dans le contexte du rude climat canadien, les performances des constructions à ossature de bois sont directement affectées par la gestion de l'humidité dans la structure, par la qualité de la conception, de la main d'œuvre ainsi que celle de la maintenance. L'humidité emmagasinée implique non seulement une réduction considérable des performances thermiques de l'enveloppe, mais peut induire aussi la croissance de moisissures qui détérioreraient les matériaux de construction au fil des années, et engendreraient une contamination de l'air intérieur de l'habitation. Les moyens permettant d'évaluer l'impact de ces facteurs cités sur les performances globales des enveloppes sont limités. Certes, plusieurs modèles mathématiques et logiciels ont été développés dans le but de simuler la portée de ces facteurs. Toutefois, la majeure partie de ces outils de simulation est spécifiquement destinée à la recherche et nécessite une validation plus rationnelle auprès des constructeurs. À date, les tests à grandes échelles qui tentent de reproduire la réalité en prenant en considération les différents facteurs impliqués dans les performances de l'enveloppe sont très limités. Ceci est principalement dû au manque d'équipements de recherche appropriés et à l'absence de procédures d'évaluation nécessaires à cet effet.

Ce projet de recherche se veut un développement d'un protocole qui faciliterait l'évaluation des performances des enveloppes de bâtiments à charpente légère. Le protocole considère l'enveloppe en tant que système global affecté par plusieurs facteurs, à savoir le contrôle de l'humidité et de l'étanchéité, la performance thermique et acoustique des murs, l'efficacité énergétique, la stabilité de la structure, la résistance au feu, et enfin, la qualité de la main d'œuvre. Cette recherche implique d'une part la détermination des charges internes et externes affectant les performances de l'enveloppe et d'autre part, le développement d'une procédure permettant leurs évaluations. Le protocole d'évaluation qu'on propose inclue les critères de performance, les standards qui y sont associés, ainsi que la conformité de ces méthodes d'évaluation.

La deuxième partie de cette étude comprend le développement d'un outil d'appréciation basé sur des données générées par la procédure d'évaluation qu'on propose. Cet outil est conçu pour fournir une vérification rapide de l'enveloppe et pour tester sa conformité avec les exigences de performance. Sensé être facile à comprendre et convivial, l'outil proposé peut être aussi destiné aux manufacturiers et aux exportateurs de maisons préfabriquées au Canada, leur permettant non seulement d'examiner des conceptions existantes, mais aussi de vérifier les performances des nouvelles.

La validation du protocole et de l'outil d'évaluation a été réalisée en testant la performance d'assemblages d'enveloppes de cinq constructions différentes. La première étant une maison modulaire préfabriquée conçue et réalisée selon les exigences du code national du bâtiment et le règlement québécois sur l'économie de l'énergie dans les nouveaux bâtiments (maison A-Standard). La deuxième est une maison modulaire préfabriquée conçue et fabriquée selon le concept Novoclimat (maison A-Novoclimat). La troisième est une maison à haute performance à panneaux (maison M-Thermo). La quatrième et la cinquième maison sont respectivement la maison performante NOVTEC et la maison performante Innova. Les résultats de la présente recherche montrent que le protocole ainsi que l'outil d'évaluation qu'on propose permet d'établir d'une manière efficace les profils de performances des cinq maisons testées, justifiant dans tous les cas, le choix adéquat de chaque paramètre d'évaluation. Les résultats prouvent également que le protocole développé permet de comparer les performances des maisons étudiées respectivement sur la base de paramètres spécifiques.

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LIST OF ABBREVIATIONS

ANSI – American National Standards Institute

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASTM – American Society for Testing and Materials

BBA – British Board of Agrément

BEE – Building -Environmental Efficiency

BEPAC – Building Environment Performance Assessment Criteria

BEPAT – Building Envelope Performance Assessment Tool

BOPs – Builder Option Packages

BRE – Building Research Establishment, UK

BREEAM – Building Research Establishment Environmental Assessment Method

CASBEE – Comprehensive Assessment System for Building Environmental Efficiency

CCMC – Canadian Construction Materials Centre, Canada

CEI-Bois – Confédération Européenne des Industries du Bois

CEN – Comité Européen de Normalisation (European Committee for Standardisation), EU

CGSB – Canadian General Standards Board

CMHC – Canada Mortgage and Housing Corporation

CSA – Canadian Standards Association

CSTB – Centre Scientifique et Technique du Bâtiment, France

DfE — Design for Environment

DHW – Domestic hot water

DIBt – Deutsches Institut für Bautechnik, Germany

DIN – Deutches Institut für Normung (German Institute for Standards)

DOE – Department of Energy, US

EOTA – European Organisation for Technical Approval, EU

EPA – Environmental Protection Agency, US

ETAG 007 – European Technical Approval Guidelines, EU

GBC – Green Building Council

HERS – Home Energy Ratings Systems

HQAL – Housing Quality Assurance Law, Japan

HRV – Heat recovery ventilator

HUD – Housing and Urban Development (Department of), US

ICS – International Classification of Standards

IEA – International Energy Agency

ISO – International Organisation for Standardisation

JETRO – Japan External Trade Organisation

JSA – Japanese Standards Association

LEED^{TM} – Leadership in Energy and Environmental Design

MEC – Model Energy Code

NAHB – National Association of Home Builders, US

PATH – Partnership for Advancing Technology in Housing, US

SHGC – Solar Heat Gain Coefficient

SHQ – Societé d'habitation du Québec

SIPs – Structural Insulated Panels

SP – Statens Planverk: National Board of Physical Planning and Building, Sweden

VDR – Vapour diffusion retarder

CHAPTER 1: STATEMENT OF RESEARCH PROBLEM

INTRODUCTION

Since the early 1990s, Canadian housing manufacturers and exporters have been widely present in overseas markets. In countries such as Japan, Germany, Spain, United Kingdom, as well as in Latin America, Canadian homes have been well recognised by local builders and homebuyers. However, in recent years, housing exporters from Scandinavian countries have taken over the leadership as providers of quality housing in a very short time. Swedish housing exporters market their product by the quality stamp called P-mark, which is a result of a performance evaluation and quality assurance program. Similar quality performance assurance protocols have been developed in Japan and in the European Community. Several initiatives to evaluate housing performance are currently under development in the United States. The need for developing a similar kind of evaluation program that can potentially lead to a quality certification was voiced by Canadian manufacturers and exporters of prefabricated homes in a survey conducted jointly by researchers at Concordia University and Forintek Canada Corp., which resulted in the report entitled: *The Assessment of the Prefabricated Building Industry (Fazio at al., 2000).* It was considered that recognition of superior quality in terms of performance, materials, and workmanship would be an asset in marketing the product on domestic and, particularly, export markets, where Canadian home manufacturers are facing competition from local builders and their Swedish, Japanese and/or American counterparts.

State of the art

The building envelope is part of the building that is constantly exposed to various and extensive loads: it must control heat, air and vapour flow, it serves as a barrier and protects occupants and goods from cold, heat, rain penetration, solar radiation, outside noise, pollution, smoke and fire-spreading. In addition, the envelope must be structurally sound, durable, aesthetically pleasing and economical *(Hutcheon, 1966)*. In case of small buildings, such as housing, the building envelope also contains the structural component, which carries the vertical loads of the building itself, snow, occupants, furniture and appliances, as well as wind and seismic lateral loads. It is a complex system, where each component has a different role and it is composed of different materials. In some cases, when put together, these components may mutually contradict and, consequently, diminish overall performance of the entire envelope. For example, impermeable sheathing can trap the moisture inside the assembly, and if there is no possibility for drying, accumulated moisture can reduce thermal performance of the insulation, facilitate mould growth and in severe cases cause rotting of wooden structural elements of the building envelope. That is why, in order to properly evaluate its performance, the building envelope has to be considered as a system.

Wood-frame building envelopes are used mainly in small buildings, especially in housing, and they should be evaluated under performance requirements specific for residential use. At present, there are several programs that evaluate the overall performance of the whole house, and in them, the performance of the building envelope is covered to various extents. These programs are: the P-mark from Sweden, the Housing Quality Assurance Law (HQAL) from Japan, and the European Technical Approval Guidelines (ETAG 007) from the European Community. In Canada, there are the R-2000 program and, recently, the Novoclimat program; however, both of these programs focus on the total energy performance of the house. In addition, there is a recent trend of assessing and rating environmental performance of buildings and their impact on the surroundings: several evaluation programs and assessment tools have been developed lately all over the world, such as LEED^{TM} in the United States, BREEAM in the UK, CASBEE in Japan, and GBTool (Green Building Challenge), which is an international initiative. Even though these tools consider aspects that are at a different level than the topic of this work, they are relevant because these tools employ various methodologies in evaluating and assessing that are partly applicable in this case. These programs are reviewed in greater detail later in Chapter 2.

Since the holistic approach to the performance evaluation of buildings and building systems emerged relatively recently, published documents on the topic are limited. Annex 32 - Building Envelopes in Holistic Perspective was one of the first initiatives to look into an integral building envelope performance assessment *(Hendriks and Hens, 2000).* This document, however, deals with the assessment mostly at the conceptual level; it gives recommendations, but does not specify a procedure for evaluation.

Generally, most of the performance evaluation is done for single materials and/or components by laboratories and research institutions. Evaluations of the assemblies have been done mostly for specific performance, such as thermal response (steady state or transient), moisture response, fire or seismic resistance, etc., and sometimes as a combination (e.g. hygrothermal performance of the assembly), however, often in small scale specimens.[1] While these types of works undoubtedly bring invaluable contributions to the understanding of the behaviour of building components and assemblies under certain conditions, there is a need to look at the larger picture.

Large-scale testing in the environmental chamber, such as the one developed by Fazio at al. at Concordia University, encompass observing and measuring occurrences on full-size specimens in real or accelerated time, with the advantage of controlled environment, something that is not available in the field

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[1] Hygrothermal – involving moisture and heat; from Greek: *hygros* – wet and *thermē* - heat.

tests *(Fazio et al., 1997).* Also, by controlling conditions in the chamber, different seasons or even different climates can be simulated. In addition, in chamber testing, a considerably larger number of sensors can be installed than in the field tests, and therefore, the monitoring and understanding of the observed occurrences is more accurate. Examples of large-scale testing done so far in this laboratory include the completion of several graduate theses and resulted in various publications. The topics covered include: measuring the moisture occurrence in roof assemblies with cellulose fibre insulation during the simulated 1-year cycle of wetting and drying *(Derome, 1999; Derome & Fazio, 2000)*; impact of added insulation on the hygrothermal performance of leaky walls *(Desmarais, 2000; Desmarais et al., 1998)*; and, recently, thermal performance tests that involve air leakage, thermal transmittance and condensation resistance for curtain walls under different steady state and cyclic winter conditions for Montreal *(Ge, 2002),* as well as current tests that evaluate the drying performance of wood-frame wall assemblies with different sheathings that are wetted by simulated rain infiltration *(Teasdale-St-Hilaire et al, 2004; Teasdale-St-Hilaire et al, 2003).* The conditions in the chamber simulate the weather from spring to early summer, which is the time when drying occurs in Montreal.

These in-depth research projects undoubtedly bring valuable contributions to the knowledge of hygrothermal performance of different building envelope assemblies and their behaviour under different loads, which can be more readily transferred to industry through the use of the protocol and assessment tool developed in this work.

Problem

General problem

A protocol to evaluate the overall performance of the building envelope is not yet available in Canada. Consequently, neither the manufacturer nor the client can be sure of the performance of the unit over time. This uncertainty is a deterrent in marketing Canadian housing systems to regions with varying climates. This issue has also been raised in the domestic housing market.

Specific problems

Well-performing building envelopes are expected to be failure-free, i.e. durable under given conditions. According to reports published by BRE (Building Research Establishment), UK, 90% of all building failures have their origin in faults in design and construction, with design faults being responsible for 50% of all failures *(Parand & Bloomfield, 1991).* APCHQ (Association provinciale des constructeurs d'habitations du Québec) states that approximately 23% of total recalls that homebuilders receive in Quebec are failures of building envelopes

(Silva Rivera, 2003). In the US, 22% of all claims against building designers in 1989 were related to failures in external walls, waterproofing and masonry. Estimates of repairs run to the hundreds of millions of dollars, with some individual cases costing millions *(Chown, 1996).* Canada Mortgage and Housing Corporation (CMHC) estimates that over half of Canadian condominiums develop serious problems within two years *(Ibid.).* These failures can approach catastrophic proportions as was recently experienced in the Vancouver area, where the main cause of deterioration was rain penetration in the exterior walls. The final reconstruction bill to mitigate this failure was originally estimated at $500-800 million *(Culyer and Edgar, 1998).* The final amount was never officially published; some consultants involved in the project estimated that it exceeded 1,5 billion $.

In the Canadian climate, the performance of wood-frame building envelopes is directly affected by energy effectiveness and moisture management, as well as by quality of design, construction workmanship and maintenance. Inadequate design and detailing and inferior workmanship can increase the effect of natural driving forces that bring the moisture into the building envelope. In addition, increased air-tightness of the new homes and the use of materials with low water vapour permeability create the possibility of moisture retention within the envelope assembly. Trapped moisture reduces the thermal performance of the envelope and can lead to mould growth that deteriorates building materials and that contaminates indoor-air. The mitigation of mould-infected buildings is so costly that some insurance companies are at present looking into ways of exempting it from their insurance policies *(Reinsurance, 2002)*.

The means to evaluate the impact of these factors on the overall performance of the envelope are limited. The computer models that exist have still, for the most part, been reserved for researchers or have not been validated to a sufficient comfort level of the designer. Large-scale testing that would provide realistic results have been limited due to the lack of facilities, the lack of evaluation procedures, and associated costs. In Canada, the gap between the research community and their advanced accomplishments in the area of building envelope performance, and home building practice, where building envelopes are expected to meet only prescriptive requirements of building code, is still very large.

The construction industry and especially the housing industry are very slow and reluctant to introduce changes and innovations. A major reason for this reluctance is the inability of the design teams to assess the performance of new technologies, and to control the systems and their interaction *(McLean, 1991)*.

RESEARCH OBJECTIVES

General objective

The general objective of this study is to develop a protocol for the evaluation of the performance of wood-frame building envelopes as integrated subsystems of entire buildings.

Specific objectives

Specific objectives include:

- establishing an overall performance of the wood-frame building envelope as a system with a set of criteria for assessing the different types of envelope assemblies;
- setting the conditions, both internal and external, that affect the overall performance of wood-frame building envelopes;
- developing a quantitative definition of building envelope performance in the light of the protocol;
- developing a strategy to evaluate the performance of wood-frame building envelopes and, by that, a building envelope rating system;
- implementing these results in a user-friendly tool that can provide practitioners with the possibility of evaluating and better understanding the building envelope performance.

PROPOSED APPROACH

In order to bridge the gap that exists between research and practice and to follow the world trends in certification and rating programs that serve to improve the overall performance of buildings, this research project attempts to develop a protocol for evaluating the overall performance of light-frame building envelopes, and a corresponding tool that would employ the results of the evaluation protocol in the appropriate assessment tool that would be user-friendly for designers, builders and other practitioners. This protocol is intended mainly as a means to improve the evaluating process, but could be extended to certification.

This protocol will focus on light-frame building envelopes used in housing (i.e. predominantly wood-frame, but also steel-frame and other systems that can be used in the housing industry, both pre-engineered factory-made and conventional site-built). This project will also focus exclusively on requirements specific to Montreal: climatic and other loads, technical practices and socio-economic issues that affect building practices in this region. However, such a protocol and assessment tool can serve as a framework for developing similar protocols for different regions.

The first step will include detailed reviews of similar and related programs that deal with the performance of buildings. Next, the loads and other issues specific to the Montreal region that need to be taken into consideration will be identified. The parameters that characterise the performance will be established in the form of performance and operative requirements and their corresponding criteria. The standards, test methods, calculations, computer programs' simulations and other means of evaluation will be associated with these parameters, as well as whether the building envelope fulfils these requirements. Then, it will be established how the data obtained can be used to assess the performance of the building envelope.

The next step involves the development of the assessment tool that will employ the data generated by the protocol described above. The values obtained will be compared with benchmarks established for the purpose, and a scoring system will be introduced to distinguish between the different levels of performance obtained. Next, the weighting system will be developed to reflect priorities among parameters. The assessment tool will automatically calculate scores, multiply them with the relevant weights, and produce the total score that will represent the level of performance of the building envelope compared to the benchmark, in this case the requirements of the National Housing Code of Canada 1998.

The final step will include testing the protocol and assessment tool by evaluating several case studies in order to get feedback on the level of comprehensiveness, accuracy of the scoring and weighting system, quality and usefulness of results' outputs and overall validity of the protocol and the tool.

CHAPTER 2: LITERATURE REVIEW – EXISTING CERTIFICATION PROGRAMS AND PERFORMANCE ASSESSMENT TOOLS FOR RESIDENTIAL BUILDINGS

INTRODUCTION

There is a global trend in understanding and evaluating the total performance of buildings. In several countries programs have been or are being developed to assess the overall performance of buildings and, in some cases, the impact of buildings on their surroundings. Besides the assessment, the objective of these programs is to aid designers in their decision-making process in order to achieve failure-free, durable, healthy and environmentally-friendly buildings. Even though this trend started for the evaluation of commercial buildings, in recent years their focus also includes the performance evaluation of housing. Some programs were even developed specifically for housing.

Different programs deal with the issues differently: some are more performance oriented, and others can be strictly prescriptive. Some of them only focus on evaluating the performance of selected aspects, such as energy efficiency and the quality of materials and workmanship (i.e. Swedish P-mark, Canadian R-2000, Quebec's Novoclimat, US Energy Star®), with only PASS and FAIL categories of assessment. These programs focus on conventional practices and are therefore more likely to be immediately applicable in the housing industry, which can be very conservative.[2] Others, such as UK's BREEAM, US LEED™, Japan's CASBEE and international GBC (Green Building Challenge) programs evaluate the environmental impact of the building and its level of sustainability. Even though sustainability is not the main focus of this research, these programs are relevant for this project because they introduce different methods of assessment. Their outcome usually results in several categories of performance and, thus, building rating systems. Therefore, they provide valuable base knowledge for the development of this particular assessment tool.

While some of them, such as the Swedish P-mark and Canadian R-2000 programs, have been in use for several years, others, like the Japanese Housing Quality Assurance Law (HQAL), the European Community's ETAG 007 and Quebec's Novoclimat, are at the stage of early implementation; consequently, there is not yet sufficient information on the results of their application.

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[2] A detailed review of these programs and their treatment of housing durability was presented in a publication entitled *Durability in Housing: a Review of Quality Certification Programs and Recommendations (Horvat M, P. Fazio and L. Poliquin, 2002)*, a report prepared for the Societé d'habitation du Québec.

PROGRAMS AND TOOLS

P-mark system (Sweden)

The P-mark system is a voluntary program that was established in Sweden in 1989 at the initiative of manufacturers of factory-made homes who wanted the certification program to cover the design stage as well as the performance of the finished house.[3]

The P-mark is a comprehensive quality assurance program, backed up by inspections, which takes advantage of prefabrication to streamline quality control procedures *(Anneling, 1998)*. Besides performance requirements for the finished house, it covers the quality system and the quality plan and supervisory inspections by the National Board of Physical Planning and Building—Statens Planverk (SP). Some of the performance requirements for the finished house include the air-tightness of building envelopes, air exchange rates, air-tightness of ducts, sound pressure levels, heat requirement and mean U-value, thermal comfort and radon concentration. For each requirement, there is a test method for verification of compliance. The P-mark system also gives the design rules for crawl space and concrete slab foundations, basement walls, external walls, kitchen, bathrooms, etc. In addition to this certification, SP authorities carry out unannounced factory inspections twice a year. They also inspect and conduct

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[3] Almost 75% of all houses built in Sweden are factory made by one of approximately 35 key home manufacturers *(Fazio & Poliquin, 2000).*

measurements in about 5% of the finished houses, randomly chosen. In these inspections, the following points are tested: air-tightness of the house, air-tightness of ventilation ducts, and ventilation. Inspections cover the performance of the heating and of the ventilation system, and the quality of work in toilets and kitchens to prevent water leakage *(ibid.)*.

After several years of operation, manufacturers of prefabricated homes believe that the main effect of the P-mark system has been a reduction in the number and severity of failures, hence a reduced number of complaints from customers, as well as better feedback from the building site and better control of subcontractors. Some local authorities offer lower building permit rates for P-marked houses, therefore encouraging prospective homeowners to buy these high-quality homes *(ibid.)*.

HQAL - Housing Quality Assurance Law (Japan)

Standards for Evaluation Methods under the Housing Quality Assurance Law (HQAL) were developed primarily to improve the quality and the performance of residential units. This most comprehensive program is intended for all types of residential buildings: from detached houses to apartment buildings; prefabricated or site-built; wood, steel or concrete-based. Specific types of performance characteristics include the following main groups:

- structural stability

- fire safety
- reduction of deterioration
- consideration of maintenance
- thermal environment
- air quality
- lighting—a visual environment;
- sound environment
- consideration for senior citizens and others with special needs

Dwelling units are evaluated and ranked from 1 to 3 (some categories have rank 4), where rank 1 certifies that the building codes and regulations are met, while higher ranks represent superior quality. This unique ranking system provides buyers with a rough mechanism to relate selling price to expected building performance; at the same time, it allows builders of superior-quality houses to gain recognition for the performance of their products (and, presumably, higher prices). HQAL is the only program that directly addresses durability, in the form of reduction of deterioration and expected service life. The countermeasures envisaged to achieve the required durability and service life involve prescribing the type of wood and wood products used in the structure (i.e. framing and sheathing), treatments applied for resistance to decay and termites, adequate waterproofing, and insulation; as well as prescribing ventilation of crawl spaces and attics, in order to remove excessive moisture *(Standards, 2000)*. Even though it is described as performance-based, HQAL seems to have retained a number of prescriptive criteria, particularly in the areas of durability and energy efficiency. Since its implementation started only in April 2001, it is too early to have significant feedback on its effect on the Japanese housing industry.

ETAG 007 (EU)

ETAG 007—European Technical Approval Guideline for Timber-frame Building Kits was drawn by the EOTA[4] Working Group, which at the time consisted of 11 EEC members: Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, Norway, Portugal and the United Kingdom. In addition, Denmark, Iceland and Slovenia have been corresponding members, together with members appointed by CEI-Bois[5]. This approval guideline represents the main document that collects technical requirements that need to be met for building wood-frame houses in the European Union. In addition, due to differences in regional climates and other requirements, this document is supplemented with local building codes and regulations.

The guideline provides performance requirements for timber-frame building kits used in building construction, methods to evaluate performance, methods to assess performance for the intended use, and assumed conditions for the design

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[4] EOTA – European Organisation for Technical Approval.

[5] CEI-Bois (Confédération Européenne des Industries du Bois) is the European confederation of woodworking industries. Its members are either national or European trade organisations from the woodworking sector.

and installation of the kits into a building *(ETAG 007, 2001)*. Performance requirements are organised into the following groups:

- mechanical resistance and safety
- safety in case of fire
- hygiene, health and environment
- safety in use
- protection against noise
- energy economy and heat retention
- aspects of durability, serviceability and identification

The ETAG 007 recognises that the main factor likely to affect the durability of wood-based building systems is excessive moisture, which may cause unacceptable growth of microorganisms, thereby inducing decay and mould growth. The ETAG 007 states that durability is best ensured by good design and that excessive moisture penetration from various causes (vapour diffusion, air leakage or rain penetration) should be prevented primarily by adequate construction details.[6] Also, the chemical treatment of wood in order to prevent fungi attack should be the last possible resource. Instead, the natural durability of wood species and wood-based products should be identified and adequate wood products should be used in appropriate hazard classes. In addition, the document covers fasteners, also divided into three service classes, which could

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[6] The program includes the list of 38 key architectural details that need to be inspected at the design stage, and at the construction stage.

rust if exposed to excessive moisture for a long period of time and therefore affect the overall durability of the structure.

Unlike other programs described in this chapter, ETAG 007 is not voluntary. To be considered for approval, the housing "kit" (or the housing package), has to include the structure, exterior envelope and internal walls, and may also include windows, doors, cladding, roofing, stairs and interior finishes. The approval procedure is undertaken by a 3rd party, such as one of the approval bodies recognised by EOTA, e.g.: BBA (British Board of Agrément) in the U.K., CSTB (Centre Scientifique et Technique du Bâtiment) in France, or DIBt (Deutsches Institut für Bautechnik) in Germany. Canadian institutions are not yet recognised as equal approval bodies *(New, 2003).*

ENERGY STAR® (US)

The ENERGY STAR® is a nationally recognised symbol of superior energy efficiency and quality in the US, developed and operated by the US Environmental Protection Agency (EPA) and the US Department of Energy (DOE). Its vast portfolio includes certifying home appliances, lighting fixtures, home electronics, office equipment, heating and cooling equipment, etc. Recently, this initiative has included the program for evaluating and certifying newly built residential units, both single-family and multi-family homes that are up to three storeys high; this program is called ENERGY STAR® Qualified New Homes.

To earn the ENERGY STAR® label, a home must be verified to be at least 30% more energy-efficient in its heating, cooling and water heating than a comparable home built to the 1993 Model Energy Code (MEC), and 15% more efficient than the state energy code *(What, n.d.)*. This program applies to conventionally site-built residential units as well as modular, system-built (e.g. insulated concrete forms, structurally insulated panels—SIPs), and HUD-code manufactured homes (formerly known as mobile homes) *(ENERGY STAR®, 2001; Energy Star-Modular, n.d.; Energy Star-SIPs, n.d.)*.[7]

The attributes of ENERGY STAR® Qualified New Homes are:

- tight construction (reduced air infiltration)
- tight ducts
- improved insulation
- high-performance windows
- energy-efficient heating & cooling equipment

In order to build ENERGY STAR® homes, the builder must sign an agreement to become an ENERGY STAR® Partner and must build at least 85 homes annually. Together with the EPA- authorised 3rd party verifier, they select specific

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[7] Existing homes can also be upgraded to qualify for ENERGY STAR label; however, due to the strict requirements of this program, it might not always be cost-effective *(What, n.d.)*.

measures (options) needed to meet or exceed ENERGY STAR® requirements based on the worst-case scenario for the specific location. The set of measures can be identified based on:

- HERS rating (Home Energy Ratings Systems) of individual plans for each model in the subdivision, where the energy efficiency of the rated home is compared to a computer-simulated reference house of the same shape and size that meets the minimum requirements of the Model Energy Code (MEC). The HERS rating includes a score between 0 and 100, with reference house scoring 80 points; or
- EPA-approved Builder Option Packages (BOPs).

Builder Option Packages (BOPs) are sets of prescriptive measurements that need to be implemented in order for the home to meet ENERGY STAR® requirements. There are 19 BOPs, developed according to specific climatic zones.[8] Within one BOP, there are several packages of measurements that builder can choose from. These packages connect features such as maximum window area, window U-value and SHGC (solar heat gain coefficient) with corresponding minimum insulation requirements (attic, exterior walls, floor above unheated space, basement walls, etc.), and minimum equipment requirements (gas furnace heating / electric cooling or electric heating / electric cooling) *(Builder Options, n.d.)*.

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[8] These 19 zones do not always correspond to thermal zones in the HUD Standards nor do the boundaries of ENERGY STAR zones coincide with state boundaries *(ENERGY STAR®, 2001)*. The exception is the state of California, where ENERGY STAR label requirements are based on a revised threshold tied to the state energy code.

After the first three homes are built within the subdivision, the 3rd party verifier performs full testing (fan pressurization test for the building envelope and testing of the duct-work) and detailed inspection. If any of the homes fails, this initial testing will continue until three consecutive homes pass. Then, after the subdivision is completed, the 3rd party verifier randomly selects a minimum of 15% homes from the subdivision and re-tests them. All homes must pass in order for the whole subdivision to pass. If one fails, the cause of failure is investigated and it must be repaired in every home in the subdivision. In this case, all the homes must receive the full testing in order to receive the ENERGY STAR® label *(Energy Star-Sampling, n.d.).*

Collaboration between the builder and his sub-contractors with the EPA authorised 3rd party verifier from the early design stage to the completion of the housing development ensures the implementation of all required features as well as consistency in specifications and the quality of workmanship. Still, this system might be unfavourable and too expensive for small builders, i.e. those who build fewer than 85 homes per year. Since this program is still in early stages of implementation, there is no available information on how many ENERGY STAR® homes were actually built and at what level they proved to be cost-effective.

There were several other initiatives in the United States in recent years that were intended to deal with the implementation of advanced technology to radically improve the quality, durability, environmental performance, energy efficiency, and affordability of American housing. However, the home building industry in the United States is very segmented and the majority of players operate independently from one another. These occurrences reflect on the implementation of these initiatives: for example, PATH (Partnership for Advancing Technology in Housing) was one of the leading initiatives several years ago, but it was marginalised by funding cuts from the US government, while at the same time ENERGY STAR® and LEED™ were promoted. Also, there are several documents developed or in the final stage of development that deal with some kind of certification of its sub-systems, if not of the house as a system. Some of these documents are: *Quality Assurance System for Wood Framing Contractors*, developed by NAHB Research Center; *Durability Condition Assessment of Existing Housing*, also by NAHB Research Center; and *Protocol for Durability Assessment of Innovative Building Products and Systems*, under development by National Evaluation Service Inc. The latter uses an approach similar to CCMC's[9] guidelines in the sense that it evaluates a product or system against a set of "best practice" criteria, with no testing or inspection in the finished house. The emphasis is still on materials and building components and, until now, there is still no program that would evaluate the house as a system.

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[9] CCMC: Canadian Construction Materials Centre

R-2000 Program (Canada)

Developed in Canada, the R-2000 Home Program started in 1982 as a voluntary program encouraging builders to build energy-efficient houses that were environmentally friendly and healthy to live in; this program bears a resemblance to the Swedish P-mark system. The R-2000 Home Program includes an energy-efficiency standard for new houses that is continuously updated; comprehensive training and education courses for house builders; testing and certification for new houses; and promotional activities *(R-2000, 1999).* The R-2000 standard is performance-based, specifying an energy consumption target for a house and a series of technical requirements, such as:

- minimum envelope requirements
- ventilation system requirements
- combustion system requirements
- energy performance target
- lights and appliances
- indoor air quality
- environmental features/eco-management

Despite its obvious merits for individual homeowners and Canadian society as a whole, and its overall influence on Canadian building practice, the R-2000 Home Program has not attracted as many registrations as expected. The main obstacle to the popularity of R-2000 homes appears to be their higher initial cost:

in view of a 6-10% higher initial cost than conventional houses, and, notably, because of relatively low prices of energy at the time, long-time savings were just not considered enough by homebuyers. The success of the program was also affected by R-2000 “clones” built by not-certified builders, which failed to include important features. For example, failing to include properly balanced HRVs (heat recovery ventilators) led to moisture problems, less than expected energy savings, and other deficiencies *(Adair, 1996, Ask, 1996).*

Novoclimat (Canada, Québec)

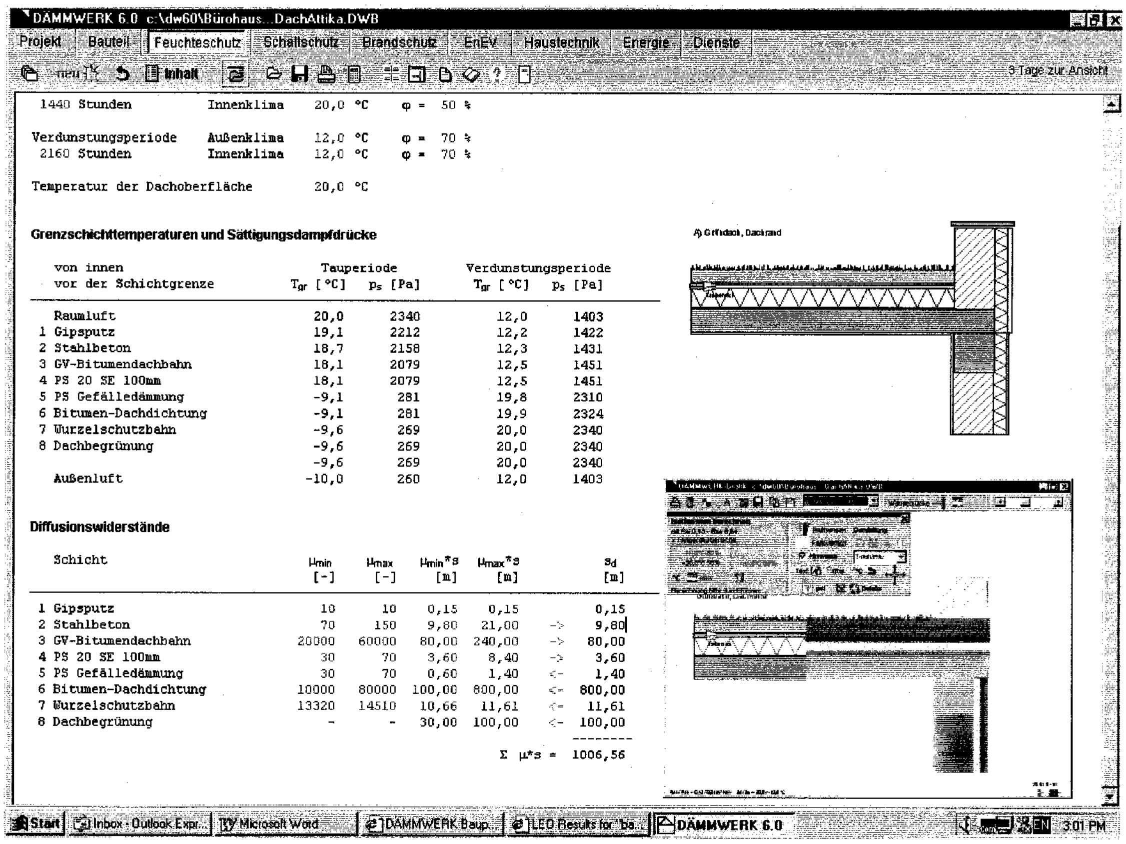
Novoclimat was developed by the *Agence de l’efficacité énergétique du Québec* (Quebec Agency for Energy Efficiency), inspired by Canada’s National Model Energy Code and the R-2000 program. The main objectives of the program are to decrease energy consumption, improve occupants’ comfort, and ensure good indoor-air quality. It also aims to support thermal envelope durability, and to introduce a building envelope quality control procedure based on infiltration measurements. Like the R-2000, Novoclimat is applied on a voluntary basis, and only licensed builders can build and certify Novoclimat houses *(Novoclimat, 2001)*. This is a new program, and it is too early to say how it will be accepted in the housing market. However, Novoclimat is the only performance certification program that actually connects energy efficiency and air-tightness to the durability of the building envelope, thereby acknowledging moisture as the main factor in the durability of wood-frame building envelopes.

DÄMMWERK (Germany)

DÄMMWERK is a building physics software application that has been developed and is commercially available in Germany. It evaluates building envelope assemblies at the design stage and compares them to local DIN and European EN ISO standards and codes. The evaluation is performed on the following aspects:

- hygrothermal performance: this part of the software calculates temperature and water vapour pressure gradients, water vapour diffusion resistance and condensation occurrence within assembly. The results are presented in tabular and graphic format (Figure 1). The method of calculation is two-dimensional, steady state;
- acoustic performance of building envelope: room acoustics, calculations of reverberation times, impact sound insulation, protection against external noise and resulting sound reduction indices, airborne sound insulation, etc.;
- fire protection of building envelope: fire-proofing for reinforced concrete, steel, wood and masonry structural elements;
- energy consumption: this is the most important and the most elaborate section of the DÄMMWERK software that calculates total expected energy consumption, primary energy need and transmission heat losses, solar gains, losses to cold bridges and to the soil, water heating, etc. The output can be presented in the form of monthly, quarterly or yearly balances, or energy profiles, and/or as a tabular/graphic comparison of two buildings or

calculation variants. The results are compared against Germany's energy savings regulation En EV 2002[10];



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 1440 Stunden         Innenklima    20,0 °C     φ =  50 %

Verdunstungsperiode   Außenklima    12,0 °C     φ =  70 %
 2160 Stunden         Innenklima    12,0 °C     φ =  70 %

Temperatur der Dachoberfläche       20,0 °C

Grenzschichttemperaturen und Sättigungsdampfdrücke

   von innen                         Tauperiode        Verdunstungsperiode
   vor der Schichtgrenze          Tgr [°C]  ps [Pa]    Tgr [°C]  ps [Pa]

   Raumluft                         20,0     2340        12,0     1403
 1 Gipsputz                         19,1     2212        12,2     1422
 2 Stahlbeton                       18,7     2158        12,3     1431
 3 GV-Bitumendachbahn               18,1     2079        12,5     1451
 4 PS 20 SE 100mm                   18,1     2079        12,5     1451
 5 PS Gefälledämmung                -9,1      281        19,8     2310
 6 Bitumen-Dachdichtung             -9,1      281        19,9     2324
 7 Wurzelschutzbahn                 -9,6      269        20,0     2340
 8 Dachbegrünung                    -9,6      269        20,0     2340
                                    -9,6      269        20,0     2340
   Außenluft                       -10,0      260        12,0     1403

Diffusionswiderstände

   Schicht                      μmin    μmax  μmin*s  μmax*s          sd
                                [-]     [-]     [m]     [m]          [m]

 1 Gipsputz                      10      10    0,15    0,15         0,15
 2 Stahlbeton                    70     150    9,80   21,00   ->    9,80
 3 GV-Bitumendachbahn         20000   60000   80,00  240,00   ->   80,00
 4 PS 20 SE 100mm                30      70    3,60    8,40   ->    3,60
 5 PS Gefälledämmung             30      70    0,60    1,40   <-    1,40
 6 Bitumen-Dachdichtung       10000   80000  100,00  800,00   <-  800,00
 7 Wurzelschutzbahn           13320   14510   10,66   11,61   <-   11,61
 8 Dachbegrünung                  -       -   30,00  100,00   <-  100,00
                                                                --------
                                                   Σ μ*s =   1006,56
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Figure 1: DÄMMWERK Building Physics Software: hygrothermal performance of one building envelope element: flat roof *(DÄMMWERK, n.d.)*

- energy counselling: in addition, the DÄMMWERK software calculates the local energy costs, amortisation (savings over investments over the years), determines the pollutant emissions, points out cold bridges and other weak points in the system, and generates recommendations for improvements *(DÄMMWERK, n.d.)*.

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[10] Energie-Einspar-Verordnung En EV 2002 *(En EV 2002, n.d.)*

The starting input is mostly graphic – the designer builds an envelope assembly from DÄMMWERK's extensive database of building materials and products, and after the internal and external conditions are set, the calculations and evaluations are done. The individual layers within the assembly can easily be replaced with another material, in order to select the best solution.[11] Recent versions allow the import of DXF files (CAD drawings), which can then be saved in DÄMMWERK's database of materials and assemblies for future use *(ibid.)*.

Introduced in the early 1990s, the DÄMMWERK software has been constantly improved – the reviewed latest version 6.0 is from October 2003; the databases of materials and building components are updated almost every six months; the changes in standards and regulations are immediately taken into account; new, more complex and more accurate calculation methods are implemented. A user-friendly interface and comprehensible output make it a valuable tool for architects and building envelope designers, although, applicable only in Germany.

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[11] The author had a chance to evaluate only a demo version of this software, which is available at no charge from the Internet (the value of the full commercialised version of DÄMMWERK 6.0 is € 1,240). Limited capabilities of the demo version, coupled with a language barrier (DÄMMWERK is available in German only) may have prevented the author from fully exploring this performance evaluation software.

BREEAM (UK)

Building Research Establishment Environmental Assessment Method (BREEAM) was developed in the UK in 1990. The primarily purpose of this voluntary program was to assess indoor environmental quality and the environmental impacts of commercial buildings; however, it has been constantly evolving ever since to stay current with new design methodologies and building and materials research *(Ecolabeling, n.d.)*.

BREEAM is a tool that allows building owners, users and designers to review and improve environmental performance throughout the lifespan of the building. It establishes benchmarks for environmental performance. The assessments can be carried out in three stages: building fabric/services, design quality and procurement quality (optional), and building management and operating methods (optional and done only in occupied buildings). Even though it is created by BRE (Building Research Establishment), the actual assessments are done by licensed assessment organisations under BREEAM label, so the consistency in evaluation and results is assured *(ibid.)*.

BREEAM assesses new, existing and retrofitted buildings: offices, homes (also known as EcoHomes), industrial and commercial (retail) buildings; however, other building types are also possible to evaluate using a custom made version of BREEAM. It evaluates performance in the following areas:

- management: overall management policy, commissioning site management and procedural issues;
- energy use: operational energy and carbon dioxide (CO_2) issues;
- health and well-being: indoor and external issues that affect the health and well-being of the occupants;
- pollution: air and water pollution issues;
- transport: transport related CO_2 emissions and location-related factors;
- land use: greenfield and brownfield sites;
- ecology: ecological values conservation and enhancement of the site;
- materials: environmental implication of building materials, including life-cycle impacts;
- water: consumption and water efficiency *(BREEAM, n.d.).*

EcoHomes is the version of BREEAM tailored for new, converted and renovated dwellings that covers environmental performance of both houses and multi-unit apartment buildings. The issues assessed are grouped into seven categories: energy, water, pollution, materials, transport, ecology and land use, and health and well-being. Some of the issues are optional, which provides flexibility for targeting specific developments. The publicly available document *Rating Prediction Checklist* gives an example of a simplified version for quickly evaluating the likely rating to be achieved under a formal EcoHomes assessment; however, the complete assessment can be done and is valid only if conducted by a Registered Assessor *(Rating, 2003).* The assessment is done by comparing the issues with conventional practices and levels of performance. Credits in the form of pre-weighted points are awarded depending upon the level at which the particular performance exceeds relevant building regulations, e.g. improving the energy performance of the building envelope compared to the part L of the 2002 Building Regulations: 3% improvement – 2 points, 6% improvement – 4 points etc. The credits can also be awarded for implementing certain features, e.g. the provision of drying space within the building envelope – 2 points, or the provision of low energy consumption of external lighting fixtures – 2 points *(ibid.)*. The awarded credits are added together and the final overall score is rated on a scale of PASS, GOOD, VERY GOOD or EXCELLENT. Since the program is voluntary, the certificate issued can be used for promotional purposes only *(BREEAM, n.d.)*.

LEED™ Green Building Rating System (US)

Developed by the U.S. Green Building Council in 2000, The LEED (Leadership in Energy and Environmental Design) Green Building Rating System™ is a voluntary certification program that provides a complete framework for assessing building performance and meeting sustainability goals. Its objectives include: defining "green building" by establishing a common standard of measurement; promoting integrated, whole-building design practices; recognising environmental leadership in the building industry; and raising consumer awareness of green building benefits. Currently, it is available for commercial, institutional and high-rise residential new construction and major renovation projects (LEED-NC). The LEED^{TM} for existing building operations (LEED-EB), LEED^{TM} for commercial interior projects (LEED-CI) and LEED^{TM} core and shell projects (LEED-CS) are at the stage of pilot versions, while LEED^{TM} for homes is under preparation *(Leadership, n.d.)*.

LEED^{TM} covers environmental actions in the following aspects:

- sustainable sites
- water efficiency
- energy and atmosphere
- materials and resources
- indoor environmental quality

LEED^{TM} also adds bonus credits for process and design innovation *(LEED^{TM} Policy, 2003)*.

There are three principal types of requirements within all LEED^{TM} standards:

- Prerequisites list the required elements that must be fulfilled before a project can be considered for LEED^{TM} Certification;
- Core Credits – one or, sometimes, more – are given for meeting (or exceeding) the requirements in the five areas listed above;
- Innovation Credits are extra credits given for exemplary performance beyond core credits, or for innovative solutions that improve performance that are not covered otherwise in this rating system.

The sum of all accumulated points gives the level of LEED^{TM} Certification. However, in order for the Certification to be issued, all prerequisites must be satisfied. The relation between LEED^{TM} certification levels and achieved core credits is shown in Table 1:

Table 1: Leed^{TM} Certification levels

LEED^{TM} Certification level	Core Credits achieved
LEED^{TM} Certified	≥ 40%
LEED^{TM} Silver	≥ 50%
LEED^{TM} Gold	≥ 60%
LEED^{TM} Platinum	≥ 80%

Even though this rating system employs a simple additive approach in credits accumulation, according to the creators, future revisions of the LEED^{TM} might include weighting of credits to better reflect their relative impacts on sustainability *(ibid.)*.

Despite the fact that it was introduced only about three years ago, LEED^{TM} has gained considerable popularity and acceptance since obtaining US government endorsement; general services administration buildings were supposed to be built to meet LEED^{TM} certification beginning in 2003. In addition, California, Pennsylvania, Maryland, Massachusetts, New Jersey, New York and Oregon also declared that all state government projects will be LEED^{TM} certified *(Malin, 2003)*.

BEPAC (Canada)

Building Environmental Performance Assessment Criteria (BEPAC) is a method developed in the early 1990s by the *Environmental Research Group* at the School of Architecture, University of British Columbia, sponsored and supported by the collaboration of B.C.'s building industry. Inspired by U.K.'s BREEAM program for the environmental labelling of buildings, BEPAC provides voluntary evaluation of existing and new office buildings and their environmental merits on three levels: global, local, and indoor environment *(BEPAC, 1993)*.

The main principle of BEPAC is that the building environmental performance depends not only on the design of the building and its major sub-systems, but also on the manner in which the building is used and managed by its occupants. Hence, the BEPAC assessment is done in two stages: one for the *base building*, and the other for the *tenancy*, each resulting in a separate certificate *(ibid.)*.

The BEPAC method consists of four modules: Base Building Design, Base Building Management, Tenancy Design, and Tenancy Management (Table 2). Each module offers a set of evaluation criteria and sub-criteria, structured in five major topic groups:

- ozone layer protection
- environmental impacts of energy use
- indoor environmental quality (includes indoor-air quality, lighting quality and acoustic control)

- resource conservation
- site and transportation

Table 2: BEPAC modules and five main evaluation topic groups

	BEPAC modules			
	Base Building		Tenancy	
Evaluation topic groups	Base Building Design	Base Building Management	Tenancy Design	Tenancy Management
Ozone layer protection	●	●	●	●
Environmental impacts of energy use	●	●	●	●
Indoor environmental quality	●	●	●	●
Resource conservation	●	●	●	●
Site and transportation	●	-	●	●

Scoring: 0 to 10 points are allocated to each criterion, based on the relation with current prevailing standards, accepted good practices or existing market conditions.[12] Then, these scored points are multiplied by the weighting factor that represents the significance of the criterion compared to other criteria within the same group. The weighting is only done within each group; however, the topic groups are not weighted against each other due to fundamental differences between them. Accordingly, there is no one final score or total sum of credits; the separate scores for each criterion together present a *profile of building performance (ibid.)*

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[12] Current prevailing standards at the time when BEPAC was developed (1993).

There is a very limited amount of published information on BEPAC and its implementation. This program laid the foundation for the development of the GBTool, an international initiative for assessing the environmental impact of the building.

GBTool (International)

GBTool is a software application that has been developed by Natural Resources Canada (NRCan) on behalf of the International Initiative for Sustainable Built Environment (iiSBE) and the Green Building Challenge (GBC). GBC is an international initiative that attempts to address environmental aspects of building performance. In 2002, 21 countries were participants in GBC[13] *(Cole & Larsson, 2002).*

GBTool provides an assessment of the predicted or potential environmental performance of a building before occupancy. Developed in Excel, this tool evaluates new and retrofitted buildings: commercial, institutional (i.e. schools) and multi-unit residential buildings. The assessment is done against performance benchmarks that are relevant to the particular region and building occupancy in seven general performance issues:

- resource consumption

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[13] GBC 2002 participants were Australia, Austria, Brazil, Canada, Chile, PR China, Finland, France, Greece, Hong Kong, Israel, Italy, Japan, Korea, Norway, Poland, South Africa, Spain, Sweden, U.S. and Wales.

- loadings
- indoor environmental quality
- quality of service
- economics
- pre-operations management
- commuting transportation[14]

Further, these issues are divided into performance criteria and sub-criteria, the latter being the level upon which the scoring is performed. The performance scores range from –2 to +5, where 0 represents minimum industry practice, +3 best practice and +5 the best achievable without regard to cost-effectiveness *(Larsson, 2000).*

Then, each score is weighted according to a predetermined weighting system. The key components of GBTool are shown in Figure 2. Certain flexibility is permitted in customising the weighting, for example, adjusting the weight according to the particular characteristics of the context (i.e. presence of Radon in the soil). Still, any changes in weights ought to be set at the level of GBC national teams in order to provide uniformity and comparability throughout the region *(Cole & Larsson, 2002).*

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[14] Not yet in operation at the time of publication of the 2002 GBTool User Manual *(Cole & Larsson, 2002).*

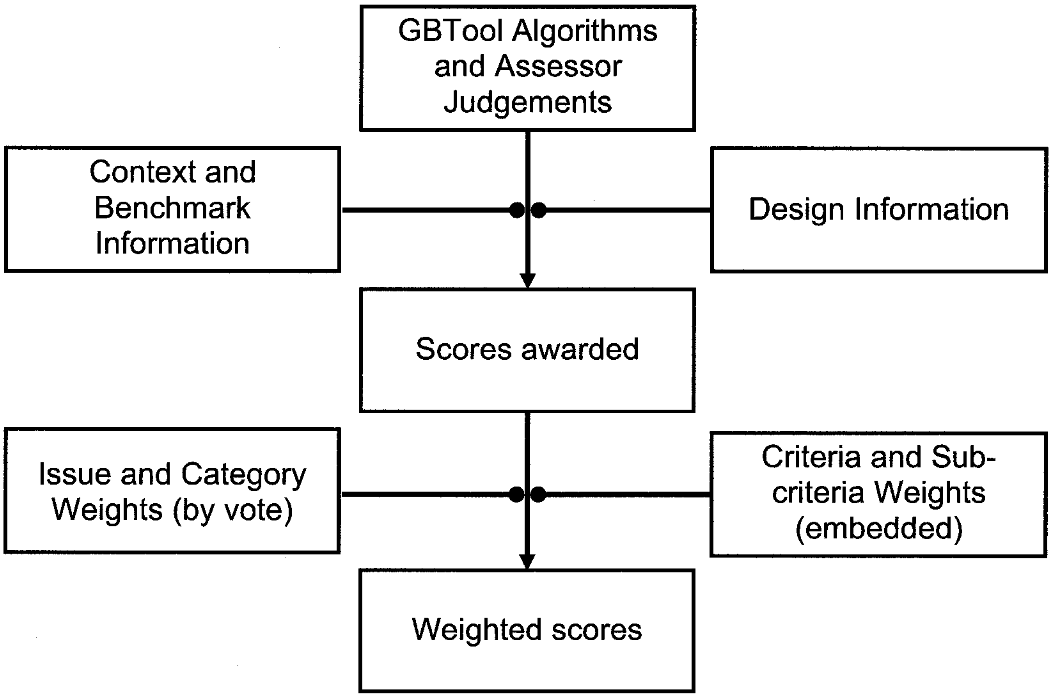

Figure 2: Key Components of GBC Assessment ***(reproduced from Cole & Larsson, 2002)***

The final results of GBTool assessment are presented as a table and/or a bar chart where the level 0 indicates the benchmark level of performance, or performance that would be expected as a minimum for a comparable building in the applicable region (Figure 3).

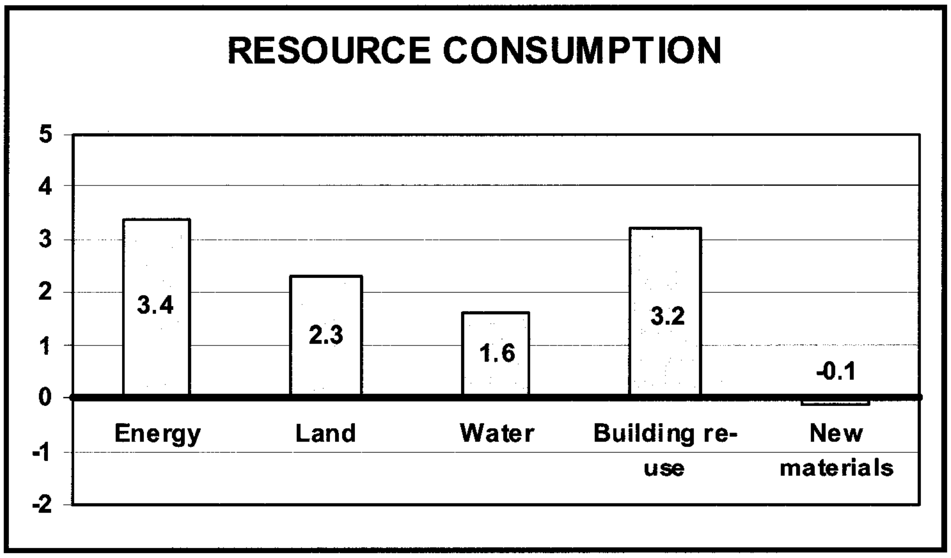

Figure 3: The presentation of final results of one of the GBTool's categories. The 0-line represents benchmark *(reproduced by author from GBTool, 2002)*

CASBEE (Japan)

The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) is Japan's response to worldwide trends of programs and systems for assessing the environmental impact of buildings. This initiative is presently being developed under Japan Sustainable Building Consortium, and involves the academic community, industry and government institutions *(CASBEE , n.d.).*

CASBEE assesses the building on the following aspects:

- energy efficiency
- resource efficiency
- local environment
- indoor environment

At this point, CASBEE is intended to be used for different types of new buildings, i.e. offices, schools and multi-unit apartment buildings. It is included in the design process from the very beginning, and it helps all parties involved to design a building so that it can achieve specific targets. In order to do so, the CASBEE system uses a variety of assessment tools designed for this purpose:

- Tool-0: Pre-design Assessment Tool enables owners and planners to identify the basic context of the project, such as suggesting proper site selection and the basic impact of the project;
- Tool-1: DfE (Design for Environment) Tool is a simplified self-evaluation checklist for architects and engineers to improve Building Environmental Efficiency (BEE) relevant to the project. DfE carries out the assessment at three stages: the basic design stage, the design development stage and the construction completion stage;
- Tool-2: Eco-labelling Tool rates the building in terms of BEE after completion;
- Tool-3: Sustainable Operation and Renovation Tool provides building owners and managers with information on how to sustain and/or improve the BEE during the post-design process *(CASBEE Tools, n.d.)*

What sets CASBEE apart from the other assessment systems reviewed so far is the unique approach to achieving the final result. While other assessment tools provide a simple additive approach (the final result is the simple sum of points scored, such as LEED^{TM}, or BREEAM), or an improved additive approach (i.e.

GBTool, where scores are multiplied by weighting coefficients and then the products are added), CASBEE introduces the concept of Building Environmental Efficiency (BEE) as a quotient between Building Environmental Quality & Performance and Building Environmental Loadings:

$$\text{Building Environmental Efficiency (BEE)} = \frac{\text{Building Environmental Quality \& Performance}}{\text{Building Environmental Loadings}}$$

Specifically, the four main aspects of CASBEE (energy efficiency, resources efficiency, local environment and indoor environment) are comprised of a total of 80 sub-items (requirements), which are further re-categorised into two main groups: Q (Quality), and L (Loadings), Figure 4.

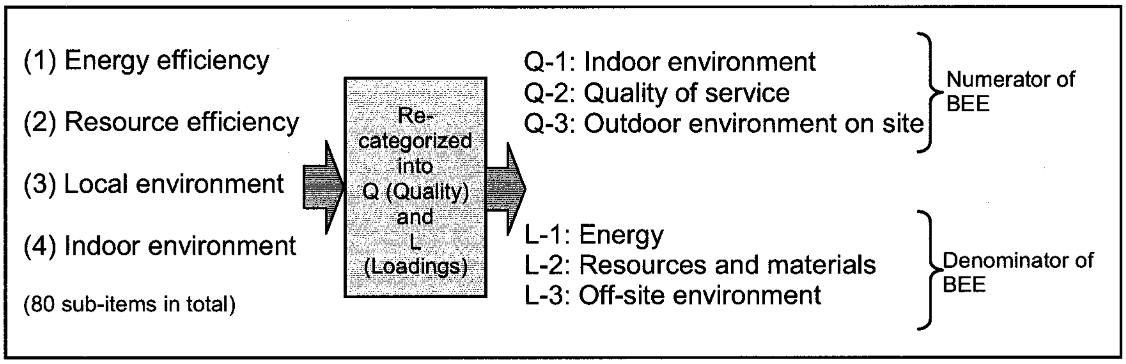

Figure 4: Concept of Building Environmental Efficiency (BEE) ***(reproduced by author from CASBEE – Concept, n.d.)***

These two groups are further broken down into the following categories: Q-1 (Indoor Environment), Q-2 (Quality of Service), Q-3 (Outdoor Environment on Site), LR-1 (Energy), LR-2 (Resources and Materials) and LR-3 (Off-site

Environment). Each category is then divided to sub-items (requirements). The evaluation is done by assigning points for each sub-item according to the scoring criteria that take into consideration the level of technical and social standards at the time of the assessment. The scores ranges from 1 to 5, where 3 indicates the average practice. Then, each assessment category such as (Q-1, Q-2 and Q-3) is weighted – multiplied with the weighting coefficient. All weighting coefficients within one category (in this case Q) sum up to 1.0. The total BEE is then calculated from the results of dividing Q and L, and labelled according to the diagram as class C, class B-, class B+, class A and Class S (Figure 5).

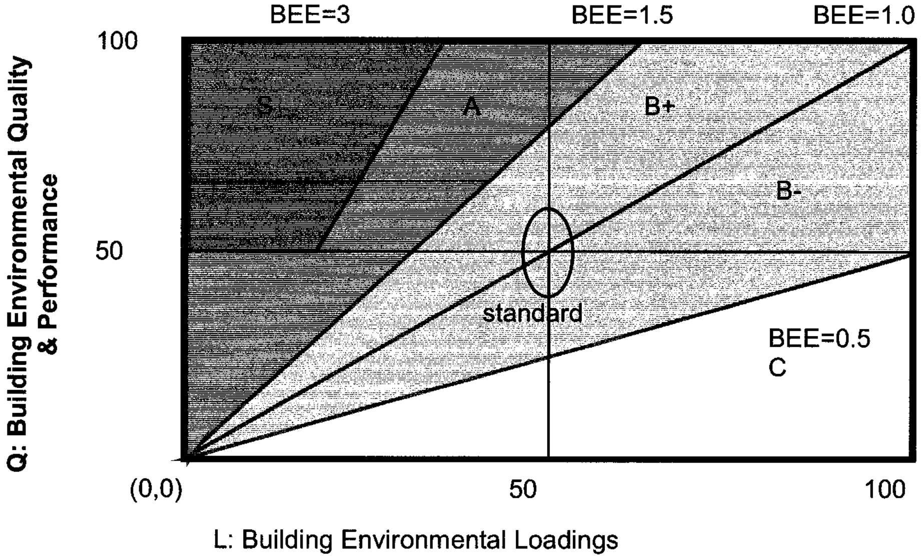

Figure 5: Environmental labelling based on BEE *(reproduced by author from CASABEE – Concept, n.d.)*

Since CASBEE is still under development, there is no feedback on its implementation thus far. Still, its innovative scoring and weighting system represent an interesting approach in assessing a building's environmental performance by evaluating it against environmental loads and, thus, obtaining more realistic final scores.

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In addition, there are other certification programs and evaluation tools for assessing the environmental impact of buildings, such as:

- EcoProfile, developed in Norway in 1999, for commercial buildings;
- HK-BEAM, from Hong Kong, for commercial and residential buildings, where the criteria are linked to local regulations as benchmarks;
- ESCALE, from France, initially developed through a PhD thesis in collaboration between CSTB (Centre Scientifique et Technique du Bâtiment) and the University of Savoie;
- EcoEffect, from Sweden, still under development. The results are expressed as relative impact based on the average impact per capita in the country *(Todd et all, 2001)*.

Since all these programs are similar in scope to GBTool, including them here would add little new information to this review[15].

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[15] A comparative assessment of these tools with GBTool is presented by Todd et al., 2001.

OTHER LITERATURE

Extensive research is being done on standards, test methods, analysis, review procedures and other methods that can be included in the evaluation procedure that is under development. These evaluation methods are categorised and presented later in this dissertation in Chapter 4 and in Appendix A.

In addition, documents regarding the development of performance-based building codes are reviewed, as well as Annex 32 – Building Envelope in Holistic Approach which was one of the first initiatives to look into an integral building envelope performance assessment *(Hendriks, 2000).* This document, however, deals with the assessment mostly at the conceptual level; it gives recommendations, but does not specify procedure for evaluation. Therefore, even though it provided valuable background knowledge for developing this performance evaluation protocol and assessment tool, it will not be directly included in this review.

DISCUSSION

This chapter has presented a review of several certification programs for buildings (primarily for housing) that exist or are in the final stages of development in different countries and regions. Even though they can be quite different in scope and objectives, what connects these programs is the intent to reach beyond the mere requirements of building codes, introduce new goals in performance achievements, improve existing practices and building performance as a result of these practices, and have these improvements recognised through the evaluation method established for that purpose.

What is immediately noticeable is that all the programs and tools described can be divided in two groups. The first group is closer to conventional building practices, and focuses on the building itself, without much regard to the relation to its surroundings. Programs that belong in this group are: ENERGY STAR® (US), P-mark (Sweden), R-2000 (Canada), Novoclimat (Québec, Canada), DÄMMWERK (Germany), ETAG 007 (EU) and HQAL (Japan). The programs in the second group are more complex and elaborate. They consider the environmental performance of the building and its impact on the surroundings from the use of resources and contextual fit, to indoor climate and recyclability. Their modes of assessment are also better developed, including the scoring and weighting systems that distinguish priorities among the parameters. The programs in this group are: BREEAM (UK), LEED™ (US), BEPAC (Canada), GBTool (International) and CASBEE (Japan) (Table 3).

The common characteristic of all the programs in the first group is that they are all based on a PASS/FAIL assessment method. The only exception is the Japanese HQAL, which offers the pre-weighted point system that distinguishes the level at which certain performance exceeds conventional practice, or, in this case, the requirements of local building codes (Table 3).

Table 3: Comparison of reviewed certification programs for housing: methods of assessment and scopes

			Reviewed certification programs for housing											
			I group							II group				
			Conventional building practices							Environmental impact and sustainability				
			ENERGY STAR® (US, 2001)	P-mark (Sweden, 1989)	R-2000 (Canada, 1982)	Novoclimat (Québec, 2001)	DÄMMWERK (Germany, 1990)	ETAG 007 (EU, 2001)	HQAL (Japan, 2001)	BREEAM (UK, 1990)	LEED™ (US, 2002)	BEPAC (Canada, 1990)	GBTool (Internl., 2002)	CASBEE (Japan, in devel.)
Methods of assessment	Pass/Fail		■	■	■	■	■	■						
	Additive approach	Simple (1 for 1)									■			
		Pre-weighted credits							■	■				
		Weighted after scoring										■	■	
	Special													■
Aspects examined in evaluation process			Energy*	Energy* and indoor air quality			Energy*, acoustic and fire	Energy*, acoustic, fire, structural, safety, durability		Co-relation between building and environment				
			Note: the term "energy" here refers to hygrothermal performance together with predicted energy efficiency											

The majority of the programs reviewed are voluntary; the only exceptions are the Japanese HQAL and ETAG 007.[16] Some of them, such as ENERGY STAR®, are very prescriptive in nature and narrowly focused on improving only the features that influence energy consumption (i.e. building envelope and mechanical system). Others, like the R-2000 program, P-mark and Novoclimat, besides energy conservation and hygrothermal performance, introduce indoor-air quality

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[16] ETAG 007 will be the mandatory building code for wood-frame housing on the territory of the European Community. Among other reasons, this is because in some parts of the EC there are no local codes that deal with this building system, since there is no tradition in building in light-frame.

issues. Predicted energy consumption, costs, long term savings, amortisation and even energy counselling are further improved in the German DÄMMWERK building physics software; in addition, the issues of acoustics and fire-resisting performance are added in the building evaluation. As already mentioned, ETAG 007 and HQAL are the most elaborate. They deal with all aspects of the building from structural, hygrothermal, acoustic and fire resistance performance, to durability and safety in use issues.

This evolution of evaluating programs from simple to more complex can be followed through the timeline of their creation (also in Table 3): in the early days (late 80s and early 90s), they focused mostly on energy conservation. Over time, the programs also have become more complex. The only exception is the recently developed ENERGY STAR® that deals only with improving energy consumption and is quite prescriptive; this program is less elaborate than, for example, the Canadian R-2000 developed more than 15 years ago. This might be explained by the effort of the ENERGY STAR® creators to overcome implementation challenges that characterise the US housing industry and housing market. For example, the introduction of the concepts of energy conservation and sustainability in the United States is lagging behind Europe. The abundant resources of the US and inexpensive energy made the US housing industry and homebuyers less sensitive to conservation, unlike Europe with very high prices of energy and Canada with extreme climatic conditions, which forced inhabitants of these regions to deal with the issue much earlier.

Another challenge is the extremely fragmented structure of the housing industry, which makes it difficult to introduce such programs on a widespread basis. In addition, the developers' philosophy of reducing initial costs and fast profit recovery often prevents architects, engineers and builders from exploring innovative solutions and implementing them; the result is often bland architecture with clichéd technical solutions. Issues such as energy savings over the lifetime cost of a building have little meaning; it is a tenant or future homeowner who pays the energy bill after all. The sustainability is still, in most cases, an issue for enthusiasts. This is especially noticeable in the housing industry, which is one of the most conservative industries: the acceptance of new technologies and innovations is, generally, very slow. Based on all of the above factors, it is understandable why the creators of ENERGY STAR® took a step back and designed a program that would be simple and more easily accepted in such an environment. A similar approach is taken with the creation of the LEED™ program. Even though it is developed recently, it is much more basic in structure and methodology of evaluation than its predecessors such as BREEAM or BEPAC. However, LEED™ owes its fast rising popularity and acceptance to the fact that it is backed up by federal government institutions and other building industry authorities. Such support proves to be valuable in bridging the gap between the developments of the research community and the solutions applied in practice.

The programs in the second group are more elaborate: they observe not only the building itself, but also its impacts on the surroundings, the use of resources to build it and to operate it, as well as its impact on the occupants: on their lifestyle, well-being, costs, etc. Some, like BEPAC, include even the operational management schedule in order to evaluate (or at least, to attempt to predict) the impact of users on the building itself. More importantly, the programs in the second group propose more advanced methodologies of evaluation with various systems of scoring and weighting credits in order to establish the priorities among the categories and their impact on the final result of evaluation. Using such methodologies, these programs are accomplishing more realistic results in building performance evaluation. The only exception is the US LEED^{TM} program, with its relatively simple scoring methodology. However, recognising the importance of distinguishing the impact of various requirements, its creators are proposing further development of its evaluation system by introducing a weighting system.

Since the programs in the second group deal with issues of sustainability, which is the concept that in most regions still penetrates mainstream construction practices too slowly, they are still not widely applied. They are voluntary programs. Their results can be used only for promotional purposes. Still, they bring valuable knowledge to the designers and builders in the decision-making process and serve as a learning tool that helps to define, understand and predict the overall performance of buildings.

CONCLUSION

By presenting and comparing several building performance evaluation programs that exist in different regions of the world, this review follows the evolution of different rewarding methodologies, from the simple additive approach to pre-weighted credits and post-scoring weighting which intend to accomplish more realistic results in evaluating building performance. A building is a very complex system, with all its sub-systems, various materials, and their different functions and operations that need to be synchronised in order to perform well as a whole. The relations between separate sub-systems within a building, and the relation of the building itself with its surroundings, are rarely linear. The performance assessing method needs to reflect that complexity. It also needs to be flexible enough to accommodate specific needs, those being of technical, economical, social or other nature. The assessment methods that are used in the programs that evaluate environmental performance of buildings seem to better represent the overall results, because the levels of priorities and the importance of specific issues are established by introducing the weighting of scores.

Such an assessment approach could be employed to evaluate building performance (in this case housing performance) in the program that is closer to conventional practice, since such a program does not yet exist in today's Canadian housing industry. Therefore, the intention of this work is to bridge this gap by developing a performance evaluation program which combines the functional requirements considered in conventional building practices with an advanced assessment methodology of scoring and weighting.

CHAPTER 3: METHODOLOGY

INTRODUCTION - THE CONTENT OF THE PROTOCOL

The state-of-the-art review in the previous chapter presents diverse ways of considering and assessing building performance in different evaluation programs in various countries and regions. More importantly, it points out the gaps that exist among these programs: the extent of the issues that they are covering, if they are prescriptive or performance-based, etc. It was noted that programs that are closer to conventional practices in most cases employ a simple PASS/FAIL evaluation method. Such programs are: Canada's R-2000 and Novoclimat, Sweden's P-mark, Japan's HQAL, the European Community's ETAG 007, the US's ENERGY STAR®, and Germany's DÄMMWERK. The second group of programs that deals more with environmental issues and sustainability introduces more elaborate and complex scoring and weighting systems in their assessment tools. The second group consists of the UK's BREEAM, the US's LEED™, Canada's BEPAC, the international GBTool and Japan's CASBEE. Since the relations between specific functional requirements that define building performance are rarely linear, the introduction of priorities among the requirements by weighting the achieved scores seems to better represent the overall results.

Therefore, the new protocol and assessment tool should combine the functional requirements of the first group (programs closer to conventional practices) with an advanced system of scoring and weighting. Such a comprehensive protocol in terms of issues covered does not exist in Canada at the moment, although it is desired by the industry based on the survey of the industry completed at Concordia *(Fazio et al., 2000)*.

Given the typical constraint of a Ph.D. project, the focus of this protocol and the assessment tool is limited to the building envelope. This protocol, however, is potentially extendable to the whole building.

STEPS IN THE DEVELOPMENT OF THE RESEARCH PROJECT

After the literature survey of the current state of the art in the area of performance evaluation and certification programs that was presented in the previous chapter, the following key steps in the development of this project were identified:

Step 1 - Identifying the aspects:

This step defines the list of aspects that characterise the overall performance of the building envelope. The literature review identified that what is missing in Canada today is a performance evaluation program that will focus on conventional building practice of houses, the program that will introduce the scoring and weighting system that will realistically determine the overall performance and the program that is the most comprehensive in terms of included aspects. Therefore, the list of aspects included: air tightness, moisture management performance, thermal performance, energy performance, structural stability of building envelope, acoustic performance and fire response performance of building envelope.

Step 2 - Identifying the format of the protocol:

A supplementary survey of the literature on performance-based codes and other regulatory programs was required to obtain the knowledge base of different ways of structuring such programs and to help define the format of this protocol and evaluation tool.[17]

Step 3 - Identifying requirements:

Based on the identified key issues that define the performance of the building envelope, the list of functional requirements, such as air tightness, thermal performance, moisture management performance, energy performance, etc., is developed. These functional requirements are further branched into their performance requirements and sub-requirements. For each sub-requirement, the appropriate criterion for minimum acceptable performance is defined.

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[17] The results of this survey are presented later, in Chapter 4, which describes the development of the protocol.

Step 4 - Standards, tests, calculations and other verification methods:

An additional survey of available standards, tests, calculations, computer modelling, inspections and other verification methods is undertaken. From a study of the documents the procedures of proving the compliance of different sub-requirements are identified, such as air tightness of the opaque parts of the building envelope, air tightness of windows, etc., with their corresponding criteria. Appropriate standards and test methods are selected to be included in the Protocol, for example: the ASTM E779 - 99 Standard Test Method for Determining Air Leakage Rate by Fan Pressurisation is selected for verifying the air leakage of the finished house. This additional survey also identifies possible knowledge gaps and provides valuable recommendations for future research.

Step 5 - Defining the parameters:

Based on the previous two steps, the parameters as stipulated by the documentation reviewed that are necessary for evaluation are identified: properties of materials and components, what measurements will be taken, under what types of loads and surrounding conditions; what types of sensors and equipment are to be used, and the position of sensors to be specified. This step also defines what data can be calculated from measurements taken and how such data can be used to assess the performance of the envelope.

Step 6 - Defining the particular methods of evaluation for specific sub-requirements and their parameters:

This step involves assigning appropriate methods of evaluation (calculation, tests, computer modelling, visual inspection, etc.) to specific sub-requirements and their corresponding criteria. With this step, the core of the evaluation protocol is completed.

Step 7 - Defining the schedule of evaluations:

The performance evaluation protocol also includes prescribing the schedule of the evaluation by stages (e.g. laboratory tests, after design stage, after installation, after completion of the building envelope in the field), and as well how to compile these partial results in one final evaluation process.

Step 8 - Defining the roles and responsibilities of evaluators:

In cases where the protocol is used to certify building envelope systems, it is necessary to define who would be authorised to perform the official evaluation in order to provide objective and unbiased results, their roles and responsibilities, and their relations to other participants in the project (i.e. designer, manufacturer of prefabricated building envelope systems, builder, etc.). In case of unofficial evaluation (which can serve as a self-check tool for the participants), it is also necessary to define the level of training in order to avoid possible misuse of the evaluation results.

Step 9 - Development of the assessment tool:

This step involves the development of the assessment tool that uses data generated by the evaluation procedure mentioned above. This assessment tool introduces the scoring and weighting system in order to reflect the user's priorities among the specific performance requirements. The tool also defines the types of outputs, i.e. how the results of the assessment are to be presented. Such a tool is developed in Microsoft Excel. Figure 6 presents the structure and relations between the performance evaluation protocol and the assessment tool.

Step 10 – Validation:

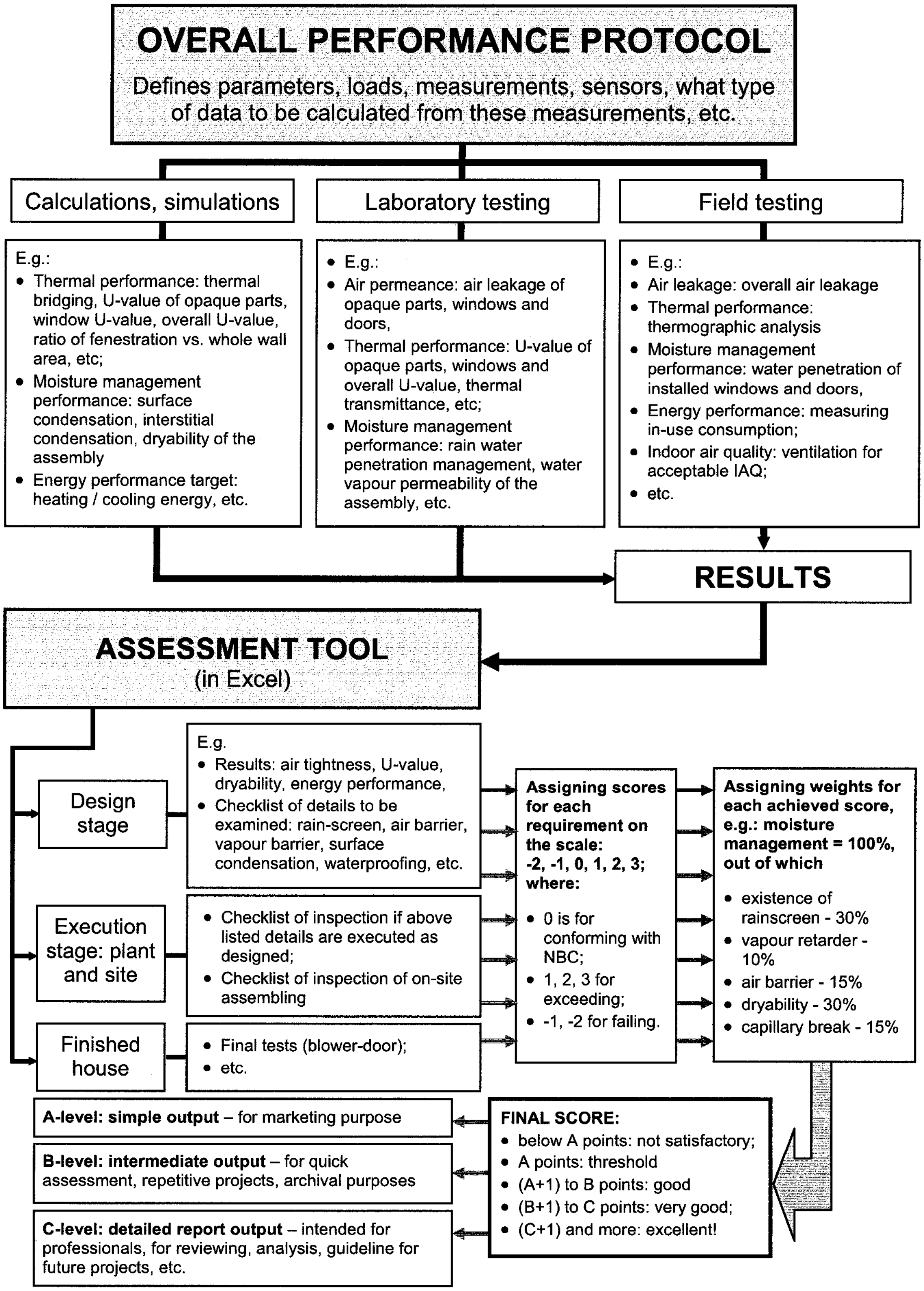
In order to test the validity of the Protocol and the Assessment tool, several case studies, houses with different building envelope configurations, are evaluated. Several home builders and prefabricated home manufacturers were approached for collaboration on this project. Also, some existing houses are included, such as two Advanced houses that were built in early 1990s as demonstration projects for innovative building practices.

Step 11 - Analysis of the validation results:

In this step, the analysis of the validation results is carried out by the author in order to identify merits and shortcomings of the performance evaluation process. Based on this analysis the revisions to the Protocol and to the Assessment Tool may be made.

Step 12 - Drawing conclusions and recommendations for future work:

Finally, based on the results of this research project, conclusions are drawn, contributions to existing knowledge are identified, and the remaining knowledge gaps are identified for future research.



OVERALL PERFORMANCE PROTOCOL

Defines parameters, loads, measurements, sensors, what type of data to be calculated from these measurements, etc.

Calculations, simulations

E.g.:
- Thermal performance: thermal bridging, U-value of opaque parts, window U-value, overall U-value, ratio of fenestration vs. whole wall area, etc;
- Moisture management performance: surface condensation, interstitial condensation, dryability of the assembly
- Energy performance target: heating / cooling energy, etc.

Laboratory testing

- E.g.:
- Air permeance: air leakage of opaque parts, windows and doors,
- Thermal performance: U-value of opaque parts, windows and overall U-value, thermal transmittance, etc;
- Moisture management performance: rain water penetration management, water vapour permeability of the assembly, etc.

Field testing

- E.g.:
- Air leakage: overall air leakage
- Thermal performance: thermographic analysis
- Moisture management performance: water penetration of installed windows and doors,
- Energy performance: measuring in-use consumption;
- Indoor air quality: ventilation for acceptable IAQ;
- etc.

RESULTS

ASSESSMENT TOOL
(in Excel)

Design stage

E.g.
- Results: air tightness, U-value, dryability, energy performance,
- Checklist of details to be examined: rain-screen, air barrier, vapour barrier, surface condensation, waterproofing, etc.

Execution stage: plant and site

- Checklist of inspection if above listed details are executed as designed;
- Checklist of inspection of on-site assembling

Finished house

- Final tests (blower-door);
- etc.

Assigning scores for each requirement on the scale: -2, -1, 0, 1, 2, 3; where:
- 0 is for conforming with NBC;
- 1, 2, 3 for exceeding;
- -1, -2 for failing.

Assigning weights for each achieved score, e.g.: moisture management = 100%, out of which
- existence of rainscreen - 30%
- vapour retarder - 10%
- air barrier - 15%
- dryability - 30%
- capillary break - 15%

FINAL SCORE:
- below A points: not satisfactory;
- A points: threshold
- (A+1) to B points: good
- (B+1) to C points: very good;
- (C+1) and more: excellent!

A-level: simple output – for marketing purpose

B-level: intermediate output – for quick assessment, repetitive projects, archival purposes

C-level: detailed report output – intended for professionals, for reviewing, analysis, guideline for future projects, etc.

Figure 6: The structure of the Performance Evaluation Protocol and Assessment Tool

CHAPTER 4: PROTOCOL FOR PERFORMANCE EVALUATION OF LIGHT-FRAME BUILDING ENVELOPES

INTRODUCTION

As described earlier, this work was preceded by two studies conducted at Concordia in collaboration with Forintek Canada Corp., the results of which directly influenced the scope of this project. The first study, entitled *The Assessment of the Prefabricated Building Industry,* voiced the industry's need for a performance evaluation program that could possibly lead to quality certification *(Fazio et al, 2000).* The second study dealt with durability in wood-frame housing, which resulted in the report entitled *Durability in Housing: a Review of Quality Certification Programs and Recommendations (Horvat et al, 2002).* In this report several existing programs that treat the performance of the building envelope to various degrees were reviewed and compared, and recommendations for addressing durability in housing were issued. These recommendations were the starting point for the development of the protocol for performance evaluation.

Even though the original outline of the protocol focused on aspects related to the durability of the wood-frame building envelope in the Canadian climate, such as hygrothermal performance, energy efficiency, service life issues, quality control of materials, and workmanship and maintenance, it became clear that if the intention is to observe the performance of the building envelope as a system within the housing system, other aspects of building envelope performance need to be included because of their interrelations and mutual dependency. Thus, the list of characteristics was expanded to include: structural stability of the building envelope, acoustic resistance, and fire response of the building envelope.

A more detailed description of the content of the protocol will be provided later in this chapter.

FORMAT OF THE PROTOCOL

The other initial decision in creating the protocol was to follow the global trends of the development of performance-based building codes and standards. In order that the Protocol is performance-based to the greatest possible degree, the format of the *Nordic Five Level System* is followed. This five-level structure, originally developed by the Nordic Committee on Building Regulations in 1976, was also adopted by CIB Task Group 11, an international group of scientists whose task was to exchange information about the development of performance-based building codes and to produce an outline of a practical approach to performance-based building regulatory systems *(Final Report, 1997)*.

In order to achieve the main goal/objective (Level 1), a list of necessary functional requirements needs to be developed (Level 2), as seen in Figure 7. As these functional requirements represent a qualitative statement that establishes the user need or expectation for the item being addressed, it is also necessary to define a performance (or operative) requirement, and its corresponding *criterion*: a quantitative (and/or qualitative) statement defining the level of performance required to meet user needs or expectations for the item being addressed (Level 3). The *verification* (or *evaluation*) will present test methods and/or other documentation upon which a judgement of compliance with the criterion can be based. This part of the protocol states the standards, inspection methods, analysis, review procedures, historical documentation, test methods, in-use performance, engineering analysis and models which may be used in evaluating whether or not the criterion has been satisfied (Level 4). In some cases, where there is no other means of verification, this part should be supplemented with prescriptive solutions, i.e. the examples of acceptable solutions; these prescriptive solutions forms the Level 5, which can be actually considered as a supplement to Level 4. Finally, the commentary, if necessary, will include any background information or rationale behind the selection of specific data or any other information that might be valuable.

The following table (Table 4) explains functions of particular levels of this regulatory system. The right column of the table presents how the Nordic Five Level System translates in the case of this overall performance protocol.

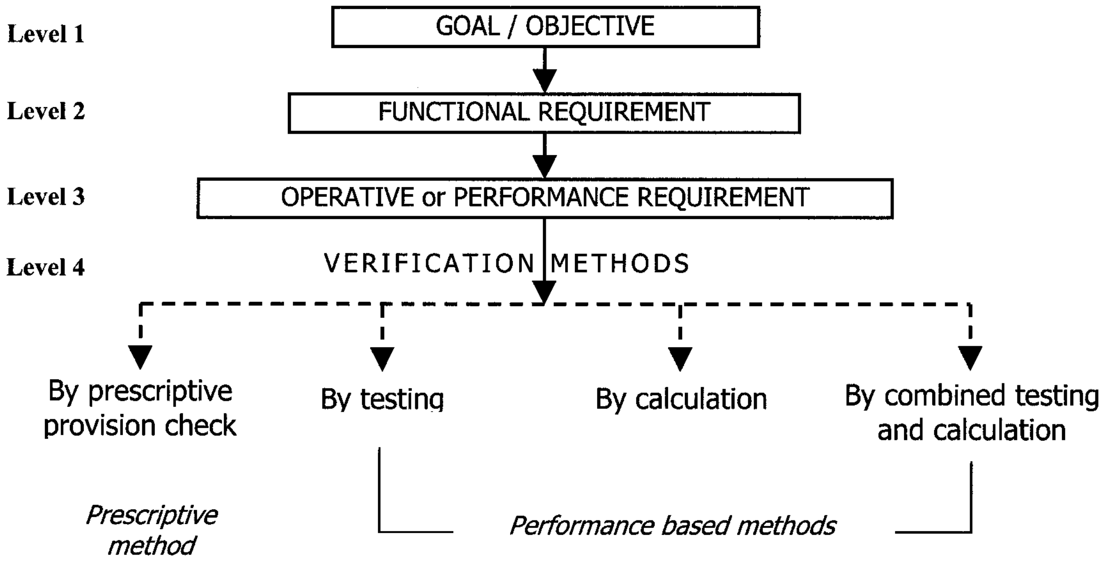


Figure 7: General four-level regulatory framework (Source: Foliente, 2000)

Table 4: Global format of the overall performance protocol as it follows the Nordic Five Level System for Performance Building Codes

THE NORDIC FIVE LEVEL SYSTEM		OVERALL PERFORMANCE PROTOCOL
Level 1	GOAL The goal addresses the essential interests of the community at large with respect to the built environment and/or the needs of the user-consumer.	GOAL The satisfaction of requirements of this protocol ensures that the design, building (in-plant), and installation (on-site) will result in good performance of the wood-frame building envelope.
Level 2	FUNCTIONAL REQUIREMENT - addresses one specific aspect of the building or a building element to achieve the stated goal.	FUNCTIONAL REQUIREMENT E.g.: Thermal performance - steady state
Level 3	OPERATIVE or PERFORMANCE REQUIREMENT - specifies the actual requirement to be satisfied, in terms of performance criteria or expanded functional description.	OPERATIVE or PERFORMANCE REQUIREMENT E.g.: U-value of an opaque panel assemblies; U-value for doors and windows; Whole envelope U-value.
Level 4	VERIFICATION Instructions or guidelines for verification of performance.	VERIFICATION E.g.: Calculating overall thermal resistance (ASHRAE 1997 - chapter 22.8); ASTM C1363-97 Standard Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus;
Level 5	EXAMPLES OF ACCEPTABLE SOLUTIONS Supplements to the regulations with examples of solutions and the specifics of meeting the goal.	EXAMPLES OF ACCEPTABLE SOLUTIONS Design guidelines

Converted into a concrete example, the one instance of the protocol is shown in Table 5. The air tightness of the building envelope (functional requirement) is divided into its operative (performance) requirements, in this case: the air permeance of the opaque parts of the wall panels, air leakage of windows, air leakage of doors and finally, the overall air leakage of the finished house.

Table 5: Example of performance requirement, its criterion and corresponding verification method

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	
FUNCTIONAL REQUIREMENT	**OPERATIVE or PERFORMANCE REQUIREMENT**	**CRITERION**	**EVALUATION (VERIFICATION) methods**	**COMMENT**
AIR TIGHTNESS	**Air permeance of the opaque panel assemblies**	$\leq$ 0.02 L/s·m^2 @ 75 Pa (a)	ASTM E1677-95(2000) Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls;	Design stage
			CMHC / AIR-INS Inc. Test Method for Determining the Air Permeance of Building Materials at Various Pressure Differentials (25 - 100 Pa) (1988);	Laboratory test
	Air leakage of windows	$\leq$ 0.77 L/s·m' of sash crack @ 75 Pa (b)	CAN/CSA-A440-M90 Windows; ASTM E1424-91 (Reapproved 2000) Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen	Laboratory test
	Air leakage of doors	$\leq$ 2.5 L/s per m^2 of door area @ 75 Pa* $\leq$ 17 L/s per meter of door crack @ 75 Pa** (b).	ASTM E1424-91 (Reapproved 2000) Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen;	Laboratory test
	Air leakage of the finished house	$\leq$ 0.7 cm^2/m^2 or $\leq$1.5 ACH @ 50 Pa (c)	CAN/CGSB 149.10-M86 Determination of the Air-tightness of Building Envelopes by the Fan Depressurisation Method; ASTM E779 - 99 Standard test Method for Determining Air Leakage Rate by Fan Pressurisation;	Finished house

* for sliding glass door and non-whether stripped doors;
** for all other doors.
(a) *National Housing Code of Canada 1998;*
(b) *Quebec Energy Code, 1992;*
(c) R-2000 Program.

The criteria for evaluation (i.e. benchmarks for minimum satisfactory performance) represent the requirements of the local building codes or usual acceptable practice in an observed area, which, in this case, reflects the internal and external conditions for Montreal. Level 4, the verification method, states the test method or other mean of evaluation, and, finally, the comment column states at which stage the evaluation is to be done. This column can also state other information that is necessary to further explain issues in question.

SCOPE OF THE PROTOCOL

The Protocol for overall performance evaluation of light-frame building envelopes is intended for all types of building envelopes used in various types of housing: single-family detached homes, semi-detached, row homes, as well as for multi-story apartment buildings. It can evaluate both prefabricated and conventionally built on-site building envelopes. It is specifically developed for newly built building envelopes, but it can also be used for evaluation of retrofitted envelopes.

Since the protocol covers the entire process of building envelope creation, it is divided into five main sections:

- design stage
- execution stage in plant (for prefabricated building envelopes), as well as on-site

- laboratory tests
- field tests upon finishing the house, but before moving in
- occupancy

The same division is followed later in the development of the assessment tool, which utilises the data collected from tests and calculations prescribed by the protocol and performs the final assessment of the building envelope performance. The assessment tool will be presented in the next chapter of this work.

As mentioned earlier, the original idea of looking only into the durability performance of the building envelope was expanded to include other aspects as well, because of their interrelations and the different ways that they affect the overall performance of the building envelope. In order to achieve the most accurate picture of building envelope performance, it is necessary to look into a building envelope in the holistic manner, and take into account as many aspects as possible. Thus, the list of aspects that influence building envelope performance was ultimately expanded to include:

- air tightness
- moisture management performance
- thermal performance
- energy performance
- structural stability of building envelope

- acoustic performance
- fire response of the building envelope

The issues of service life, quality of materials and workmanship are included as well, but indirectly, through appropriate requirements and criteria related to the sub-groups of the abovementioned aspects.

One can argue that there are other functions and aspects of building envelope performance that are not included in this protocol, such as the issues of lifecycle, safety in use (other than response to fire and structural stability), economics and aesthetics. These issues were also seriously considered during the creation of this protocol, but were finally excluded for various reasons, mostly because of their complexity and extensiveness. For example, the constant fluctuations of the prices of building materials and components on today's market would make setting the criteria for the lifecycle very difficult, and the database would have to be updated daily. In addition, the inclusion of the lifecycle costs for instance, would put the innovative practices in an unfavourable position, because such practices are typically (but not always) more expensive in their initial stage of application compared to conventional practices due, in part, to the need to educate the available labour force. Therefore, these higher initial costs would have to be weighed against the performance benefits achieved. As the innovative practice becomes widespread and the workforce becomes more familiar with such practice, labour prices will decrease. This relation is complex and would need additional work, which would exceed the scope of this research project. Evaluating the aesthetics of the building envelope would also be difficult because it would be difficult to establish a set of objectives and widely accepted criteria for evaluation and to avoid subjective input of the evaluator. Safety in the use of the building envelope (other than the response to fire and structural stability) would refer to the required height of openable windows' parapets and other safety guards against accidental falls; these issues are already mandatory in building codes. A recent trend that emerged in some regions is to look into the resistance of building envelopes to blasts; from the point of view of light-frame building envelopes that are used mostly in residential construction the author finds this requirement too excessive and not applicable. Therefore, these aspects have been excluded from this protocol; however, some of them are likely to be included and expanded into future versions of the protocol.

CONTENT OF THE PROTOCOL

In this section, the functional requirements along with their corresponding operative (performance) requirements are listed by stages. The entire protocol, together with performance criteria and verification methods, is presented in table form in Appendix A.

Design stage

At the design stage, the following issues are considered in the protocol for performance evaluation of the building envelope:

Table 6: The list of requirements and corresponding sub-requirements considered at the design stage

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENTS		Criteria	
			Quantitative	Qualitative
Air tightness	Air permeance of the opaque parts of building envelope	Exterior walls	■	
		Roof	■	
		Joints – taping boards and membranes		■
		Joints – gaskets around windows and doors		■
		Joints – sealing protrusions		■
		Joints – other		■
	Air leakage of windows		■	
	Air leakage of doors		■	
Moisture management performance	Use of kiln-dried wood		■	
	Water vapour permeability of the assembly		■	
	The occurrence of interstitial condensation – calculated condensation rate		■	
	The occurrence of surface condensation – internal surface temperature of exterior walls		■	
	Drainage of precipitation and surface runoff	Surface grading		■
		Building external drains		■
		Impermeable cap over backfill		■
		Free-draining backfill (drain screen)		■
		Waterproofing barriers /membranes		■
		Subgrade drainage system		■
		Control joints		■
	Limiting the intrusion of precipitation	Sloping of the roof planes		■
		Size of the drainage area		■
		Reducing the rain deposition on exterior walls		■
		Water tightness of windows and sliding glass doors	■	
	Rain penetration management – the use of rain screen principle			■
	Capillary suction	Capillary control below grade		■
		Capillary control above grade		■

To be continued

Contd.

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENTS		Criteria	
			Quantitative	Qualitative
Thermal performance	Thermal resistance of opaque parts of building envelope (design values)	Roof	■	
		Above grade exterior walls	■	
		Below grade exterior walls	■	
		Floors above non-heated spaces	■	
		Slab-on-grade with embedded pipes	■	
		Slab-on-grade without pipes	■	
		Basement floor	■	
		Crawl space floor	■	
Thermal performance (contd.)	Thermal resistance of windows and doors	RSI values for any glazed areas separating heated form unheated space	■	
		Existence of shutters		■
	Thermal bridging	% of studs for 1m of wall length	■	
	Fenestration vs. opaque wall area – Ratio in elevation		■	
Energy performance	Energy rating	Of windows	■	
		Of glass sliding doors	■	
	Estimated annual energy consumption for heating and cooling		■	
	Emissions and embodied energy		■	
Structural stability of building envelope	Resistance to vertical loads		■	
	Resistance to wind loads	Of opaque parts of building envelope	■	
		Wind load resistance rating of windows and glass sliding doors	■	
	Resistance to lateral loads - seismic		■	
Acoustic performance	Building envelope resistance to outdoor noise			■
	Building envelope performance against aircraft noise		■	
Fire control of building envelope	Spatial separation of buildings		■	
	Location of skylights			■
	Maximum % area of unprotected openings in exterior walls		■	
	Minimum construction requirements for exposing faces		■	

Besides listing the performance requirements for the design stage, Table 6 also shows if the available criteria for each requirement are quantitative or qualitative in their nature. Even though the nature of performance-based codes and standards dictate that criteria are expressed quantitatively, for some requirements it was just not possible, either because there is no acceptable value or just because it is simply not quantifiable. However, those unquantifiable requirements (i.e. qualitative criteria) still needed to be included in this protocol, since they greatly impact the design of the building envelope. These cases are mostly related to design issues that affect hygrothermal performance of the building envelope and therefore have considerable significance on the overall performance of the building envelope in Montreal climatic conditions. In addition, they serve as a checklist for the designer in order to verify the design of critical points of building envelope, and avoid possible failures.

Execution stage – Installation (in-plant and on-site)

The content of the protocol that deals with the execution stage of the project, both in-plant – for prefabricated building envelopes – and on-site for conventionally, site-built building envelopes, as well as for the site installation of prefabricated envelopes, is identical to that in the design stage, and it will not be repeated here (please refer to Table 6 of this chapter).

The purpose of the protocol at the execution stage is to ensure that the building envelope is built according to the design. Possible changes could be introduced only to improve features of the building envelope, but not to include components of lesser performance. Evaluation at this stage, therefore, also serves as a quality of workmanship control and as verification.

Laboratory tests

At the laboratory tests stage, the protocol for performance evaluation of the building envelope considers the following issues:

Table 7: The list of requirements and corresponding sub-requirements considered at the laboratory test stage

Air tightness	Air permeance of the opaque parts of building envelope	
	Air leakage of windows	
	Air leakage of doors	
Moisture management performance	Moisture content of structural lumber	
	Water vapour permeability of the opaque parts of building envelope	Exterior walls
		Roof
	Precipitation penetration and leakage of building envelope	Exterior walls above ground
		Roof
		Windows
		Doors
Thermal performance	Thermal resistance of opaque parts of building envelope (measured values)	Roof
		Above grade exterior wall assembly
		Below grade exterior wall assembly
		Floors above non-heated spaces assembly
		Slab-on-grade with embedded pipes assembly
		Slab-on-grade without pipes assembly
		Basement floor assembly
		Crawl space floor assembly
	Thermal resistance of windows and doors	RSI values for any glazed areas separating heated form unheated space

Continued on the next page

Structural stability of building envelope	Structural properties of wall constructions	Compressive load
		Tensile load
		Transverse load - specimen horizontal
		Transverse load - specimen vertical
		Concentrated load
		Racking load (dry materials)
		Racking load (wet materials)
		Shear capacity of framed wall supported on rigid foundation
		Relative resistance to impact loading
Acoustic performance	Sound Transmission Class (STC) of building envelope	
Fire resistance	Allowed time of flashover of building envelope	
Service life	Expected service life of building envelope components	Structural components of exterior walls
		Structural components of roofs
		Insulation in exterior walls
		Insulation in roofs
		Exterior finishes of building envelope
		Interior finishes of building envelope
		Windows
		Doors

Because of the complexity, costs and time required for the design and performing, laboratory tests are not required for every project, especially if the type of building envelope used has been proven to perform for given conditions. The laboratory tests are necessary for new designs if innovations are introduced to the design, and if new materials and components are used, where there are no sufficient data available on the overall performance of the design.

The laboratory tests are to be performed by institutions that have the appropriate facilities and expertise and are accredited to do so. Once the innovative building envelope is tested, the results of laboratory tests can be used for several projects, or this part of evaluation and assessment can be entirely omitted. In these cases, however, the appropriate referencing to previous testing has to be included in the final output of the performance evaluation.

Finished house stage – field tests

At the field tests stage, the following issues are considered in the protocol for performance evaluation of the building envelope:

Table 8: The list of requirements and corresponding sub-requirements considered at the field testing stage

Air tightness	Overall air leakage of the finished house	
	Detection of the points of air leakage	
Moisture management performance	Moisture content of wood components – in situ measurements	
	Rain water penetration management	Windows
		Glass sliding doors
Thermal performance	Thermal irregularities in finished building envelope - qualitative	Missing or improperly installed thermal insulation
		Presence of moisture in the exterior walls
Acoustic performance	Sound transmission class (STC) – field test	
	Sound transmission loss coefficient ranks for openings on exterior walls	
Quality workmanship	By measuring the overall air leakage of the entire house	

The field testing is to be done upon the completion of the house, but before the occupancy. In cases where some of the sub-requirements do not comply with the given criteria, the necessary corrective measures are to be taken to correct omissions and irregularities.

Occupancy

The overall performance of the building envelope will also be affected by the occupancy of the house: primarily by regular and quality maintenance of the building envelope, but also by the daily behaviour of the occupants. Indoor environment conditions of the house that directly influence the indoor loading of building envelopes (predominantly the air temperature and relative humidity) are immediately influenced by social factors such as the demographics and lifestyle of the occupants *(Hitchcock, 1991)*. The demographic group of factors that influence the indoor environment conditions include: number of occupants, age and income. Lifestyle (i.e. occupants' behaviour) group of factors include: number of hours spent at home, leisure activities, personal level of comfort, attitude towards energy consumption and knowledge about maintaining comfortable indoor conditions. For example, many homeowners are not aware of the necessity for reducing elevated indoor relative humidity by natural and/or mechanical ventilation. High indoor relative humidity is the result of cooking, showering, washing and drying clothes, large number of indoor plants and occupants' breathing. Besides imposing additional loads on building envelopes, high indoor relative humidity provides the suitable environment for mould growth that can also affect occupants' health. Therefore, it is recommended to include the follow-up on occupants' behaviour in order to determine its impact on the building envelope. Such a follow-up includes recording indoor air temperature and relative humidity levels at significant times of the day (morning, midday, early evening and later in the evening), for at least one month during each season. Such records will not only help to detect possible extreme conditions that can affect building envelope performance, but also help occupants to recognise their behaviour patterns that can possibly effect loadings on the building envelope and the management of energy consumption.

Since the indoor relative humidity levels have more impact during cold winter months in Canada, CMHC developed recommendations for acceptable RH levels in their Homeowner's manual *(Homeowners, 2000).*

Table 9: Recommended levels of humidity *(Homeowner's manual, 2000)*

Outside Air Temperature	Recommended maximum indoor relative humidity at indoor temperature of 21°C
-29°C	20%
-24°C	25%
-18°C	30%
-12°C	35%
-7°C	40%

Other issues in the occupancy stage involve other building envelope maintenance that needs to be done on a regular basis. These issues can be divided into short, medium and long-term maintenance schedules.

Table 10: Building Envelope maintenance schedule for occupancy as recommended by CMHC's Homeowners manual

Term	Occurrence	Issue
Short	Several times a year	Checking gutters and downspouts and cleaning if needed
		Inspecting basement or crawl space for signs of seepage/leakage
		Ensuring good slopes away from foundation walls
		Cleaning windows, screens and hardware
		Airing out damp basement on dry days or using dehumidifier
		Checking exterior finishes
		Checking exterior wood for deterioration
		Checking caulking and weather-stripping, including around entry door from garage and house
		Cleaning leaves out of eavestroughs
		Checking roofing and flashing for signs of wear or damage
Medium	Annually	Checking attics for signs of moisture
Long	2 to 5 years	Recaulk if necessary

BENCHMARKING – SELECTING THE CRITERIA

The other important issue in creating this protocol was selecting criteria that would serve as benchmarks for comparison. Criteria are directly dependent on the region where the building envelope will be built: its climatic conditions, laws and construction regulations, typical building practices, general habits and the lifestyle of the occupants in the region, etc. All these parameters could vary from region to region. The criteria for this protocol have been developed for Montreal conditions. If the building envelope should be built in another region, the evaluator (i.e. the authorised independent body) should verify and revise all criteria that apply for that region. Therefore, this protocol serves as a framework for establishing similar protocols for other regions.

In most cases, the minimum benchmark criteria were drawn from local building codes and standards, for example: the National Building Code of Canada 1995 – Part 9, the National Housing Code of Canada 1998, the Québec Energy Code 1992 and Energy Performance Evaluation of Windows and Sliding Glass Doors Standard CAN/CSA-A440.2-98. In this way, it is ensured that the building envelope meets the basic requirements of these regulations. For some requirements, higher levels of performance already exist, defined by other programs such as R-2000, Novoclimat, Advanced House program, etc. Whenever available, such performance levels are also included in this protocol, in order to reward a superior performance for a particular requirement. For example, the benchmark for the RSI-value of the opaque part of above grade exterior wall is 3.4 $m^2 \cdot K/W$, which is the value required by the Québec Energy Code for Montreal, and the minimum for every new house built in this region. However, another criterion for this requirement is also included: it is the Novoclimat value of 4.31 $m^2 \cdot K/W$. If the RSI-value of the opaque part of above grade exterior walls is higher than the required 3.4 $m^2 \cdot K/W$ but lower than 4.31 $m^2 \cdot K/W$, this better performance will be rewarded with extra points. If it is equal to or higher than 4.31 $m^2 \cdot K/W$, it will receive additional reward points. This concept is further developed in the assessment tool, and will be explained in detail in the following chapter.

This part of the research revealed that in many cases there are no available criteria for evaluation in local building regulations and standards. In these cases, the selection of the criteria was guided by looking into a typical building practice for the region. In some cases, such as predicted energy consumption or aircraft noise sound insulation, the criterion cannot be expressed as one universal value; the evaluation can be made only by a comparison of such performance with the model house (i.e. reference house); this method is called the *yardstick method (Kennedy & Bartholomew, 1991)*. Therefore, prior to evaluation, the evaluator needs to calculate the criterion based on the reference house that is of the same size, shape and orientation, but with commonly used features for that area. For example, for predicted energy consumption, the reference house will be a virtual house, generated by HOT2000 software, which is the same size, shape, orientation and the number of occupants as the evaluated house, with features common to the Montreal region, such as electrical baseboard heating, mixed ventilation and other default values that the HOT2000 program provides. The calculated predicted energy consumption for this virtual reference house will be a benchmark for evaluation, and comparison will show the level at which the evaluated building envelope exceeds (or not) the energy performance of conventional practice. The same process is to be used for calculating emissions and embodied energy performance by EEE software[18].

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[18] The energy and emission estimator (EEE) is a prototype tool that can be used by engineers and architects to estimate the energy use, greenhouse gas emissions, and cost associated with the life cycle operation of a house and the construction of its exterior envelope *(Baouendi et al., 2005)*

Also, since the acoustic performance of the building envelope (e.g. building envelope resistance against outdoor noise or building envelope performance against aircraft noise) is not covered by building codes, the selected benchmark criteria were derived from the guidelines and recommendations from other research projects *(Bradley, 1998)*.

WHO IS TO DO THE EVALUATION?

In order to exclude biases and to ensure consistency in the results of the evaluation among all the projects across the region that are designed and built by different companies, it is necessary for evaluation to be done by an authorised and independent 3rd party, who would have the expertise and equipment to carry out the entire evaluation. However, the design of this protocol and the assessment tool makes it possible for those who are directly involved in the project to do a preliminary and informal partial evaluation. In this way, it would be possible for them to recognize potential mistakes and overlooked details, and correct them prior to the next stage of the project. These preliminary partial evaluations can, therefore, serve as checklists of compliance for participants in the project, as well as serve as an educational tool for the future. This task assignment is presented in Table 11.

Table 11: Task division among the participants for informal, preliminary evaluation and final, official evaluation

	Who is to do evaluation?	
	Informal, preliminary evaluation, for internal purposes	**Final, official evaluation**
Design stage	Designer	Authorised independent 3rd party
Execution stage in-plant (for prefabricated building envelopes)	Floor manager, technical supervisor in plant	
Execution stage on-site (for conventionally site-built homes as well as for on-site assembly of prefabricated building envelopes)	Construction manager, technical supervisor on-site	
Laboratory tests	-	Institutions with adequate lab facilities that are recognised by authorised independent 3rd party evaluator
Final test (upon completion, but before occupants move in)	Construction manager, technical supervisor on-site	Authorised independent 3rd party
Occupancy (monitoring) voluntary	Occupants	-

EVALUATION SCHEDULE

An important feature of this evaluation protocol is that it follows the development of the building envelope through all the stages of its making: from the design stage, through the execution, both in-plant and on-site, until completing the whole house, and partly upon occupancy. Therefore, the evaluation schedule should follow this process. The final, official evaluation, done by an authorised 3rd independent party, could be done in two ways:

- upon finishing each stage (e.g. after design stage, after execution stage, after completing the house), or

- one final evaluation, after the completion of the project, where the evaluator will examine all the documentation and data provided by the participants in the project.

The second method can bring certain inconsistencies since the 3rd party evaluator has to rely on data collected by unauthorised and possibly biased persons and, therefore, result in not entirely accurate results; thus, it is not recommended. By contrast, in the first method omissions can be noticed and corrected prior to proceeding to the next step of the project.

Informal, preliminary evaluations which are done by immediate participants can be done any time during the process (design stage, execution stage), since their purpose is solely to have internal control and verification of the design and construction.

The evaluations are to be done in the chronological sequence of the stages: first the architectural design stage; second, the execution in-plant (if applicable), followed by the execution on-site; third, the evaluation upon completing the house, but before the occupancy, and finally, the follow-up and monitoring during the occupancy. The only exception is the laboratory stage testing. Due to the complexity of the process, the costs, availability of experts, facilities and time, laboratory testing is to be done only if a new building system is introduced, such as: a new type of wall assembly, new materials, etc. There is no need for repetition of these tests in every project; the results obtained can be used in following projects, provided that there were no changes to the design of the building envelope. Laboratory tests are to be done first, before the architectural design of the house, in order to verify that the new building system complies with the requirements. In this way, any initial and substantial failures of the innovative building system can be avoided. Simultaneously, all features in which the performance of the new building system exceeds that of conventional practice can be qualified and (possibly) quantified.

The evaluation schedule, depending on the stage of the project and whether the evaluation is informal or official, is presented graphically in Figure 8.

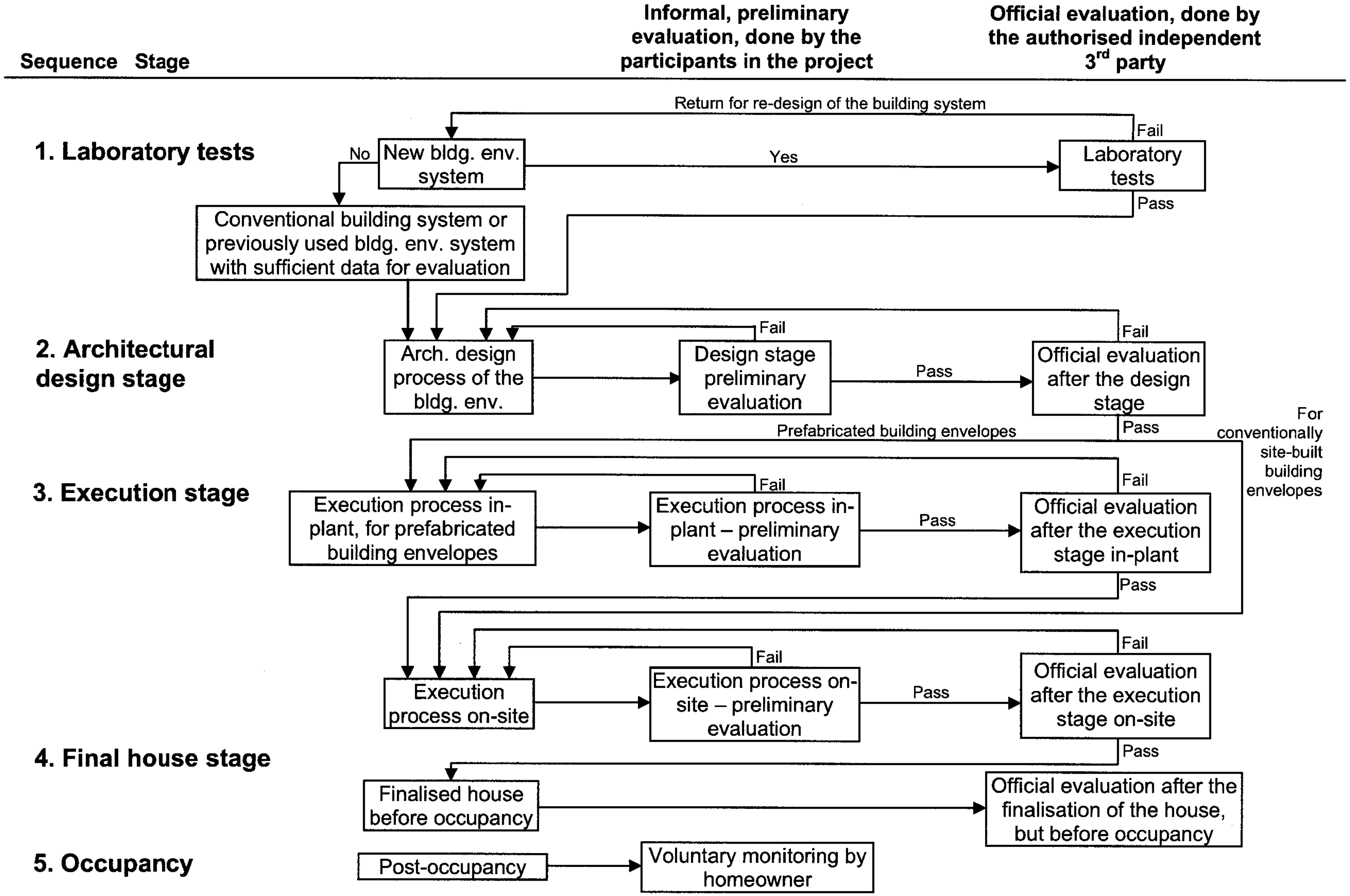

Figure 8: The evaluation schedule by sequences, stages and evaluators

DATA COLLECTION

In order to obtain accurate and realistic results from the performance evaluation of the building envelope, the correct collection of data upon which the evaluation will be performed is essential.

Note: For all data collection, the units used should be SI units.

Design stage: The main sources of the data in this stage are architectural drawings, specifications and calculations provided by the architect, which should show the shape of the building envelope, all dimensions, orientation, with specifically stated types of components used such as doors, windows, sliding glass doors, and their characteristics provided by manufacturers (i.e. energy ratings, wind loads resistance ratings, watertightness ratings, etc.). The architectural drawings should also provide details of building envelope assemblies, with clearly stated components and materials used (e.g. type and thickness of water vapour retardant, thermal insulation, sheathing, cladding etc.). In addition, any changes to the original design should be precisely recorded and only final solutions should be used as data for official evaluation. This is the stage where calculation analyses are carried out to ensure that the building system meets the criteria – energy, structural stability, acoustic, fire, etc.

Execution stage (both in-plant and on-site): the data source for these stages should be the final architectural drawings, with all changes to design, specifications and other subsequent information included, as well as a visual inspection of assembly and construction work on-site in order to verify if the work is carried out according to the final designs.

Laboratory tests: data collection in the laboratory should follow the procedures prescribed in each test and other verification methods (see the final version of the protocol in Appendix A). The following information is required:

- for air tightness: measured air permeance of opaque parts of the building envelope, air leakage of windows, doors and glass sliding doors;
- for moisture management: water vapour permeability of opaque parts of the assembly, rain penetration of the opaque parts of the assembly, windows and glass sliding doors;
- for thermal performance: thermal resistance of opaque parts of building envelope, thermal resistance of windows, doors and glass sliding doors;
- for structural performance: structural properties of wall construction: compressive loads, tensile loads, transverse loads for horizontal and vertical specimens, concentrated loads, racking loads (for wet and dry specimens), shear capacity of framed wall supported on rigid foundation and relative resistance to impact loading. Also, in case of introducing a new type of pre-engineered studs, the following data should be obtained: flexure, compression parallel to grain (short column, no lateral support), compression

parallel to grain (crushing strength of laterally supported long member), tension, sheer modulus and torsion;

- for acoustic performance: sound transmission class (STC) of building envelope;
- for fire performance: allowed time for flashover of building envelope[19].

Finished house – field tests: the following information is required:

- total air leakage of complete building envelope measured by blower door at 50 Pa;
- in case of detected air-leakage, detecting points of air leakage;
- thermal irregularities in finished building envelope measured by thermographic camera (qualitative);
- sound transmission class (STC) of building envelope.

Occupancy: the following information is recommended:

- indoor relative humidity monitoring;
- indoor air temperature monitoring;
- energy consumption monitoring;
- long, medium and short-term maintenance activities log.

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[19] Flashover: the rapid transition to a state of total surface involvement in a fire of combustible materials within an enclosure. *(ASTM E 176, 1999)*

FINDINGS

The development of the protocol revealed knowledge gaps, since for some performance requirements, quantitative criteria and/or corresponding evaluation methods are not available (Table 12). The reason is that for some requirements there are no scientifically and/or professionally accepted quantitative values, or simply because some requirements cannot be expressed quantitatively but only qualitatively. An example that represents the first group can be stated as follows: Is there an acceptable maximum level of moisture that can be stored in the insulation material and/or sheathing without the permanent degradation of critical physical and thermal properties? Ideally, the moisture level should be zero, because any amount of moisture will reduce thermal resistance properties of the insulation; however, the experience from practice shows that a certain amount of moisture can be retained within assembly for a short time provided that there is sufficient time for it to dry off before new moisture is introduced. In some cases, such as for the energy performance expressed through the estimated annual energy consumption of the house, there is no available criterion that needs to be met; the performance can only be compared to the energy performance of the control example house of the same size and shape in order to find out if the energy performance of the new design exceeds or not the performance of the conventional design of the building envelope.

Table 12: Functional and performance requirements and the level of definition of corresponding criteria and verification methods

Functional requirements	Operative or performance requirements	Criterion	Evaluation
Air tightness	of opaque parts of the envelope	■	■
	of windows	■	■
	of doors	■	■
	of finished house	■	■
Thermal performance – steady state	Thermal bridging: temp. ratio: studs vs. insulation	▨	■
	U-value of the opaque parts	■	■
	U-value of windows	■	■
	Whole envelope U-value	▨	■
Moisture management performance	Moisture content of the solid lumber	■	■
	Rain penetration details	■	■
	Rising damp (capillarity)	■	■
	Hygroscopicity of bldg. envelope components	□	□
	Water vapour permeability	■	■
	Surface condensation	▨	■
	Interstitial condensation	▨	■
	Dryability of the assembly	▨	■
	Waterproofing against ground water	■	■
	Waterproofing of roofs	■	■
	Watertightness of wet rooms	▨	■
	Indoor RH levels	■	■
Energy performance	Energy rating of window and glass sliding doors	■	■
	Estimated annual energy consumption for heating and cooling	▨	■
	Emissions	▨	■
	Embodied energy	▨	■
Structural stability of building envelope	Resistance to vertical loads	■	■
	Resistance to wind loads – opaque parts of building envelope	■	■
	Wind load rating of windows and glass sliding doors	■	■
	Resistance to lateral loads - seismic	■	■
Acoustic performance	Resistance to outdoor noise	▨	■
	Resistance to aircraft noise	▨	■
Fire control of building envelope	Spatial separation of buildings	■	■
	Location of skylights	■	■
	Max % are of unprotected openings	■	■
	Minimum requirement for exposing spaces	■	■
	Resistance to fire for 1 hour (as in separation walls)	□	□
Quality materials	Mandatory use of kiln-dried wood	■	■
	VOC emitting materials	▨	■
Quality workmanship	Quality management system	■	▨
	Quality control at the design stage	■	▨
	Quality control at execution stage	■	▨
	Quality control – final test, upon completion of the house	■	▨
Maintenance	Ongoing (daily) maintenance	■	□
	Short-term maintenance (1-5 years)	■	□
	Medium-term maintenance (5-10 years)	■	□
	Long-term maintenance (10 years and more)	■	□

LEGEND

Defined ■
Partially defined ▨
Not defined □

In the second case, requirements can be defined only as qualitative measures, as, for example, there is no accepted criterion for the level of outdoor noise that is allowed to penetrate through the building envelope; still, outdoor noise can be significantly reduced by following specific guidelines in designing the envelope. Similarly, there are several instances in moisture management performance that deal with properly designed architectural details that facilitate a reduction in rain water penetration, waterproofing of certain parts of the building envelope, flashings etc. In these cases, the criterion needs to be expressed as a “Yes”/”No”/”Not applicable” statement that responds to requirements expressed as questions that describe these details. For example, for capillarity control the question would read: “Does your design include a capillary break between the sill plate and the top of the foundation wall?” Cases like this are, obviously, entirely prescriptive; however, it was necessary to include them because certain requirements could not be defined differently.

The additional advantage of including such prescriptive requirements and criteria is that they form a checklist of details that need to be examined and verified first by the designer at the drafting table and later by the superintendent on the site who verifies that they are executed according to the design. Therefore, these verification procedures also form the quality of workmanship part of the protocol.

It has also been noticed that the majority of test methods and standards that are presently available in North America deal with individual materials and/or components, and that only few consider the behaviour of the whole assembly under specific conditions. Clearly, there is a lack of available evaluation methods (tests, calculation methods and computer simulation models) that can verify whether the envelope assembly meets the performance requirements of certain regions. The example of the latter would include the lack of existing large-scale testing procedures that can be used to verify the results of analytical procedures so that eventually the need for testing can be reduced.

CHAPTER 5: BUILDING ENVELOPE PERFORMANCE ASSESSMENT TOOL – BEPAT

INTRODUCTION

The second stage of this project includes the development of the assessment tool whose purpose is to synthesise and analyse the data generated by the Protocol in a user-friendly manner and to provide the final output of performance evaluation. The Tool utilises data obtained by the following procedures in the previously described overall performance evaluation protocol (as seen in Figure 6, in Chapter 3: Methodology, p.57), compares them with the benchmark values, and assigns score points, which are then weighted to reflect the priority among the requirements.

Developed in Microsoft Excel, this tool performs certain internal calculations. However, in some cases it uses data generated by other models, calculation methods and computer programs as prescribed by the protocol, such as HOT2000, Condense, EEE, FRAME, Vision, IBANA etc.

SCOPE

The Building Envelope Performance Assessment Tool (BEPAT) follows the scope of work already defined by the Protocol for the performance evaluation of light-frame building envelopes used in residential buildings in all their performance requirements and sub-requirements. It covers the entire process of building envelope making: from the design stage, to the execution and installation (both in-plant for pre-fabricated, and on-site for conventionally built building envelopes), field tests and occupancy monitoring.

Besides the introductory section, the BEPAT tool consists of three main parts (Figure 9):

- data input
- processing: scoring and weighting
- output

The introductory part provides general information about the Tool, such as: the intended use, a brief description of the tool and how it works, an explanation about data entry, benchmarking, principles of scoring, weighting, and the type of outputs, depending of their intended use. It also includes information about the evaluated project, such as: the name of the project, location, important dates, companies involved, authorised personnel, as well as information about the evaluators. The entire content of these parts is presented in Appendix B.

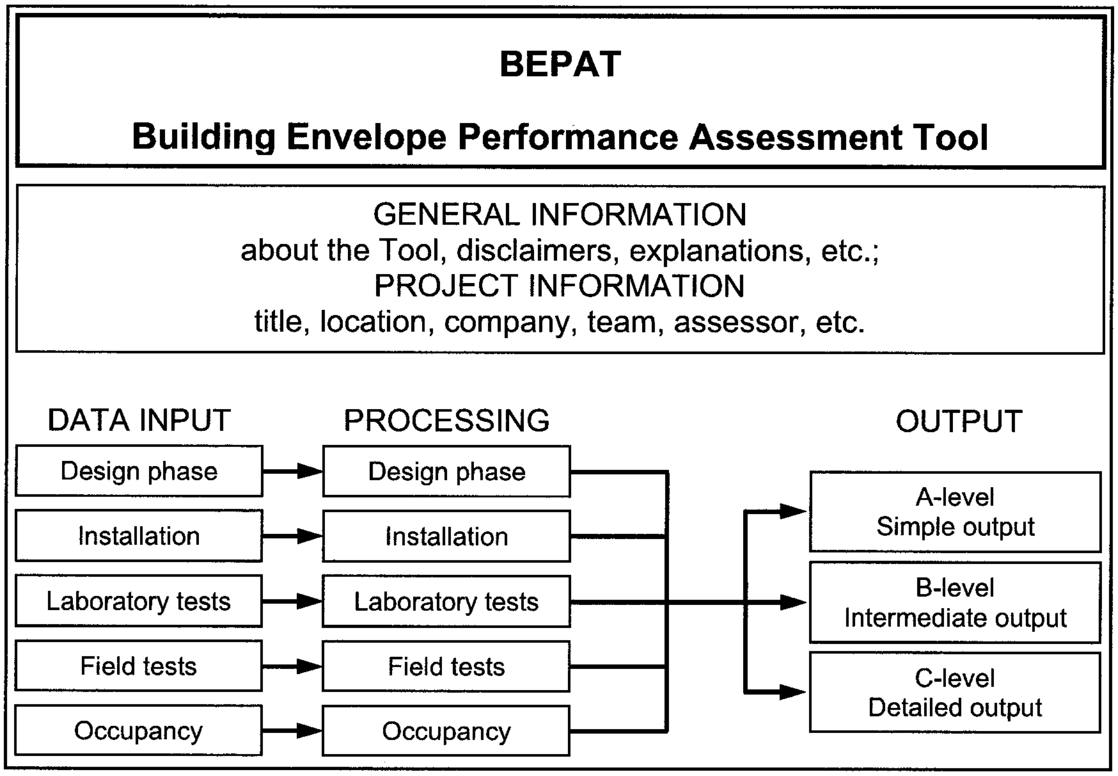


Figure 9: The structure of the BEPAT tool

The Data Input part of BEPAT is divided into five stages, according to the stages of the evaluation process: design phase, installation, laboratory tests, field tests and occupancy monitoring. The same division is followed in the second part of the Tool – the Processing – where achieved scores are automatically transferred and multiplied by assigned weights and where the results of these sub-requirements are totalled to give the score for each requirement. Finally, these results are again automatically transferred to the output stage, which formats them to the printable results to be used for different purposes (Figure 9). More detailed explanations will be provided later in this chapter.

INTENDED USERS OF BEPAT AND ASSESSMENT SCHEDULE

As defined by the Protocol and already explained in detail in the previous chapter, this assessment tool can be used as:

- the tool for the official assessment done by authorised and independent 3rd party evaluators; and also
- as a tool for unofficial verification at individual stages (e.g. design, installation, etc.). In this case, a “working version” of the Tool is to be used by the designer at the design stage, and/or by the project manager at the construction stage to verify whether the building envelope is built according to design. This case scenario has the added advantage of serving as internal quality control of the design and execution phases of the project; it can also serve as a communication tool between the designer, on-site construction manager, and building inspector.

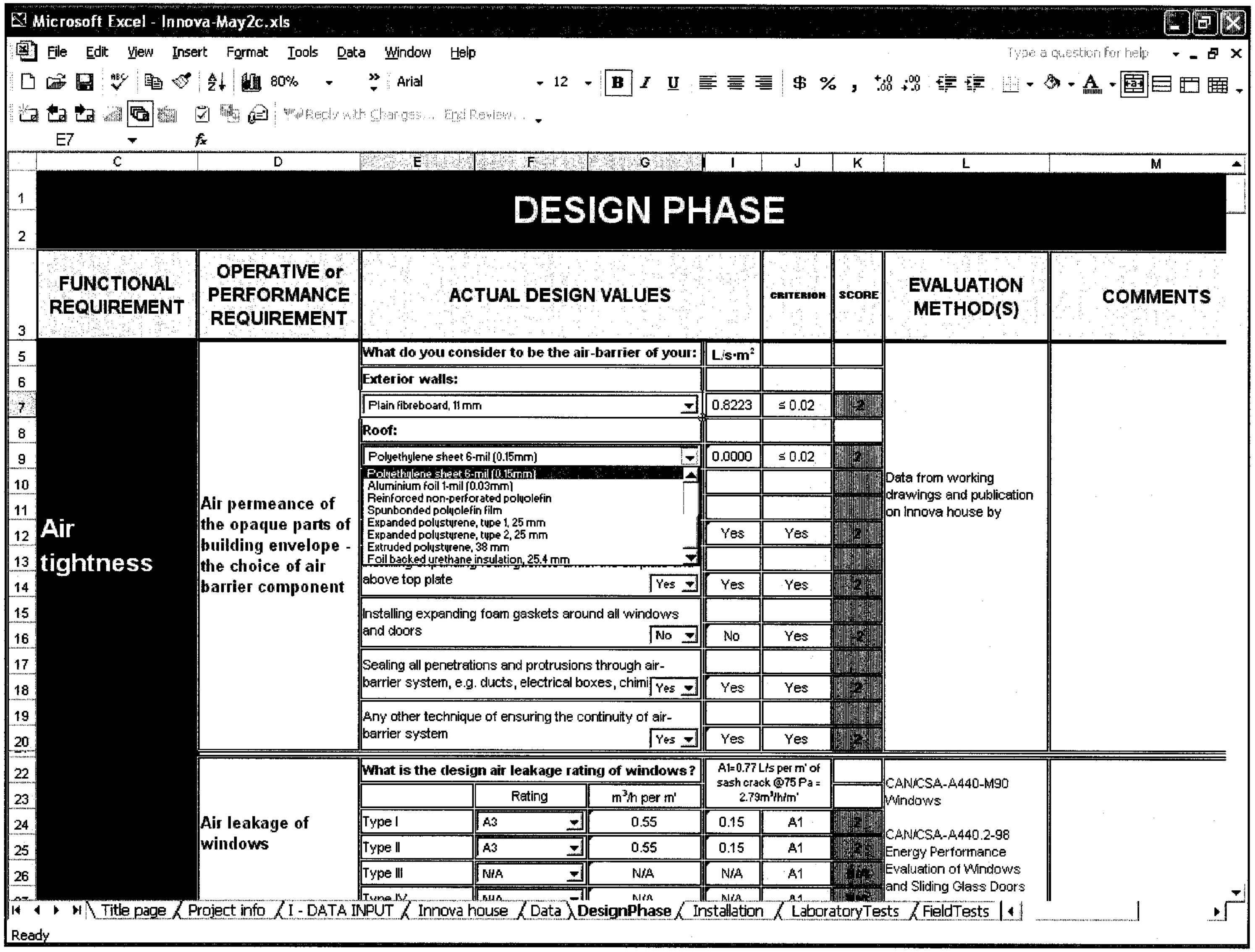
The assessment schedules to be followed are also described in the Protocol. (Figure 8, Chapter 4, p.83).

DATA INPUT

There are two main modes of data input in this assessment tool:

- numerical values, which are the results of calculations, computer models, measurements, readings, specifications, etc., in all cases where criteria could be expressed quantitatively;
- selection from pull-down menus:
    - in cases where criteria must be defined in a qualitative manner, as a description of component or in a Yes/No mode;
    - in cases where criteria are defined quantitatively, but for the purpose of simplifying the data entry process for the user (e.g., water vapour permeance of water vapour retarders). In these cases, the Tool automatically provides the numerical values and compares them with the given criteria (Figure 10).

Where certain operative requirements have no application or relevancy, the user can leave them blank, and these fields will not be incorporated into the final calculations (e.g. the requirements that consider characteristics of a sloped roof when the designed roof is flat or vice versa).



DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES				CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component	What do you consider to be the air-barrier of your:			L/s·m²			Data from working drawings and publication on Innova house by	
		Exterior walls:							
		Plain fibreboard, 11 mm			0.8223	≤ 0.02	-2		
		Roof:							
		Polyethylene sheet 6-mil (0.15mm)			0.0000	≤ 0.02	2		
		Polyethylene sheet 6-mil (0.15mm) Aluminium foil 1-mil (0.03mm) Reinforced non-perforated polyolefin Spunbonded polyolefin film Expanded polystyrene, type 1, 25 mm Expanded polystyrene, type 2, 25 mm Extruded polystyrene, 38 mm Foil backed urethane insulation, 25.4 mm							
					Yes	Yes	2		
		above top plate		Yes	Yes	Yes	2		
		Installing expanding foam gaskets around all windows and doors		No	No	Yes	-2		
		Sealing all penetrations and protrusions through air-barrier system, e.g. ducts, electrical boxes, chimi		Yes	Yes	Yes	2		
		Any other technique of ensuring the continuity of air-barrier system		Yes	Yes	Yes	2		
	Air leakage of windows	What is the design air leakage rating of windows?			A1=0.77 L/s per m' of sash crack @75 Pa = 2.79m³/h/m'			CAN/CSA-A440-M90 Windows CAN/CSA-A440.2-98 Energy Performance Evaluation of Windows and Sliding Glass Doors	
			Rating	m³/h per m'					
		Type I	A3	0.55	0.15	A1	[illegible]		
		Type II	A3	0.55	0.15	A1	[illegible]		
		Type III	N/A	N/A	N/A	A1	N/A		
		Type IV	N/A	N/A	N/A	A1	N/A		

Figure 10: Example of the pull-down menu where the Tool automatically provides numerical value and compares it to the given criterion

At this stage, the first part of the evaluation process is calculated: the BEPAT tool automatically compares the value entered to the stated criterion and assigns points that reflect the level at which the criterion is exceeded (or not). The result produced is shown as a score for that requirement. Simultaneously, the score result is transferred to the second stage of BEPAT – Processing, where it will be processed further, i.e. weighted and summed (a more detailed explanation follows later in the text). The advantage of showing scores at the data entry stage is that the evaluator can immediately learn about meeting (or not) the given requirement for the specific criterion. Designers can rethink their design decisions and change them if necessary.

TYPES OF EVALUATION

Ideally, the evaluation should be done by comparing the measured/calculated/design value to the given criterion. However, since not all the requirements could be expressed in a quantitative manner, different approaches to the evaluation had to be employed for specific cases. The following types of evaluation are incorporated into the BEPAT tool:

- for quantitative criteria the evaluation is done by direct comparison of the measured/calculated/design values to the given criterion – e.g.: $x \geq C$, $x \leq C$, $C_1 < x \leq C_2$, etc.; where x represents the measured, calculated or design value and C represents the numerically expressed criterion.

- for qualitative criteria:
    - as a statement of compliance with the requirements that had to be expressed descriptively, e.g.: a "Yes/No/N/A (Not Applicable)" mode;
    - as a ranking of preferable features, recommended by guidelines in absence of quantitative criteria, e.g.: brick veneer over vinyl siding in cases in which outdoor noise must be reduced.

SCORING

At the scoring stage the points assigned for each requirement response reflect how well the evaluated performance satisfies (or not) the given criterion.

The points assigned range from -2, -1, 0, +1, +2, where 0 is assigned when the performance meets the local building codes, regulations, or professionally accepted practice (in the absence of an appropriate code requirement); +1 and +2 indicate that the performance exceeds the requirement, and -1 and -2 indicate that the envelope performs below expectations. For example, in the case of overall air leakage of the finished house, 0 points would be assigned for measured air leakage of 3.0 to 3.99 ACH at 50 Pa (average for current new houses in the Montreal region), +1 for leakage from 1.51 to 2.99 ACH and +2 for air leakage of less than 1.50 ACH at 50 Pa (R-2000 criterion). Accordingly, -1 would be assigned for air leakage from 4 to 5.99 and - 2 for more than 6 ACH at 50 Pa.[20]

However, due to the different available criteria (i.e. qualitative, quantitative) it was not always possible to apply the described scoring scheme; therefore, other variances of scoring had to be developed for certain requirements. These other variances are based on this model of scoring as much as possible, in order to ensure consistency. Here are examples of different scoring schemes depending on criteria:[21]

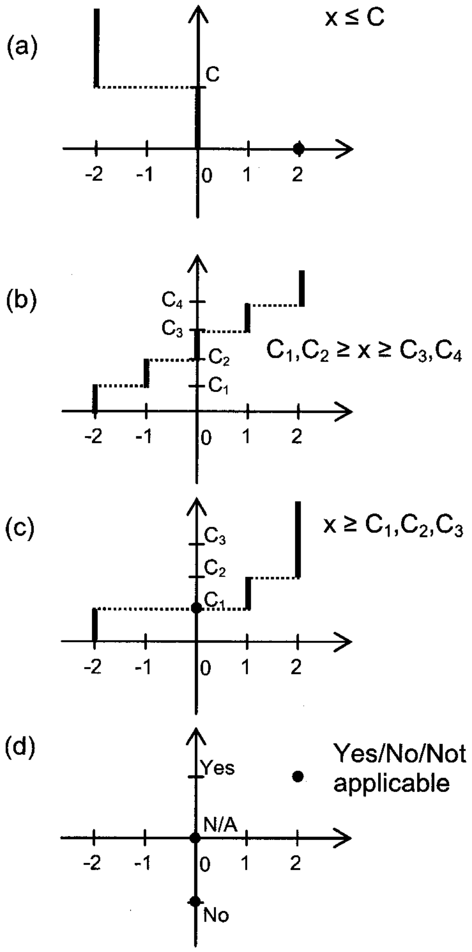


Figure 11: Different scoring schemes depending on the type of criterion

- Comparing measured values to quantitative criterion – simple: $x \leq C$ in cases when the building code or accepted/recommended practice provide only one value (e.g. air permeance of opaque parts of the building envelope as $x \leq 0.02$ L/s·m^2, or allowable air leakage for doors as $x \leq 17$ L/m' of door crack @75 Pa). Not meeting these requirements results in -2 points; being in the range below the

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[20] In this example, the criteria are adopted as a combination from existing programs such as R-2000 and usual building practices, since present building codes do not provide this criterion.

[21] C represents a numerically expressed criterion value.

criterion results in 0 points (because that is what the code requires anyway; therefore, it is the benchmark value). In an ideal case, if the air permeance achieved is 0 L/s·m^2, 2 points are awarded for excellence (Figure 11-a).

- Comparing measured values to quantitative criteria – complex: C1,C2 ≤ x ≤ C3,C4 as in the case of overall air leakage of the whole house already described, or C1,C2 ≥·x ≥ C3,C4 (e.g. RSI values of opaque parts of building envelope), or x ≥ C1 ,C2 ,C3 the distinction between levels of performance is employed whenever such categorisation is possible, again, to encourage choosing components and practices of superior performance compared to basic code requirements (Figure 11-c and Figure 11-d).
- Comparing values to qualitative criteria: “Yes/No/Not applicable”; in these cases, the scoring scheme could not be expressed as a linear function, but only as a point on the graph, i.e. as: -2, 0, +2, depending on the code requirements. For example, if the code does not require a particular feature, the default is “No”, and the score awarded is therefore 0 points. However, if the same feature would improve overall performance of the building envelope, then incorporating such a feature would yield the answer “Yes” and, therefore, a score of +2 points (Figure 11-e).[22] Vice versa, if the code requires a specific feature, Yes = 0 and No = -2 points. The N/A (Not applicable) option is possible (e.g. in cases where characteristics of a sloped roof are described while the design being evaluated incorporate a flat roof)

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[22] An example for this case would be attaching shutters to windows and glass doors to reduce heat loss and/or gain, insulating basement walls on the outside, etc.

and it brings 0 points. So it does not negatively affect the overall result for that particular case.

As Microsoft Excel was used to develop the assessment tool, this program can be used to perform internal calculations in a scoring process. The most used function is the IF function, which is generally used to conduct conditional tests on values and formulas: the IF function returns one value if a specified condition is evaluated as TRUE and another value if the condition is evaluated as FALSE. The basic syntax for the IF function is as follows:

IF(logical_test,value_if_true,value_if_false)

where the "logical test" refers to comparing the measured/calculated/design value x to the given criterion C (as in $x \leq C$) and "value_if_true" and "value_if_false" set appropriate scores for particular cases. Developed for each particular case, the calculation looks as follows:

If $x = C$, then $S = 0$

If $C \leq x < 1.2xC$, then $S = 1$

If $x \geq 1.2xC$, then $S = 2$

If $C \geq x > 0.8xC$, then $S = -1$

If $x \leq 0.8xC$, then $S = -2$

where:

x is the performance value, either measured as in the case of ACH, or calculated as in the predicted energy consumption;

C is the threshold in performance value which must be met, and typically given by codes and standards;

S is the score value given to the performance

The second most used function in the BEPAT tool is the VLOOKUP function, which is utilised in the creation of pull-down menus. When the user selects the reference from the menu, this function will search for it in the database and return the appropriate value relevant to this choice to be displayed in the worksheet. The database that the VLOOKUP function uses had to be created especially for this purpose and it contains lists of materials and their properties (such as air permeability, or water vapour permeability), and other numerical or qualitative information relevant to the different requirements and criteria in this tool.

The basic syntax for this function is:

VLOOKUP(lookup_value,table_array,col_index_num,range_lookup)

where “lookup_value” is the value (or a reference or a text string) to be found in the first column of the array and the “table_array” is the table of information in which data is looked up, relevant for the specific case.

The VLOOKUP database is also placed in the “Data” worksheet that is hidden from the user in the final version of the tool for reasons already described.

For the result of the VLOOKUP function, the returned value is displayed in the appropriate box in the main worksheet as the data entry for that requirement. It is then compared to the given criterion and further processed (scored and weighted) in the same manner as other data entries in this tool.

WEIGHTING SYSTEM

The next step in the data processing in the BEPAT tool is weighting the achieved scores. The weighting system is developed to reflect priorities among the parameters, because not all the parameters equally affect the overall performance of building envelopes under the specified conditions. For example, in Montreal climatic conditions, the hygrothermal performance of the building envelope carries more weight in overall performance than in the acoustic performance of the building envelope (except in cases when the building is located in proximity of the airport or highway). Also, within the functional requirement of moisture management performance, various operative (performance) requirements are ranked differently: the amount of moisture brought within the building envelope assembly by rain penetration is greater and therefore more dangerous than the amount of moisture brought in by air leakage, which is, in turn, greater than amount of moisture brought in by water vapour diffusion, etc. Therefore, the weighting is a declaration of importance among the parameters and it greatly influences the final score.

The main problem in developing a weighting system is the lack of scientifically established factors of impact on these requirements. In the example given above, we know that the amount of water that can penetrate building envelope assemblies by rain penetration is greater than that which can come in by air leakage, but we do not know exactly how much greater it is: 5 times, 10 times? It is difficult to measure such occurrences because they depend on many different factors, from design, material used, to the quality of workmanship in any particular case. Even two same assemblies exposed to the same conditions can perform differently because of small inconsistencies in workmanship, which is difficult to control on site.

In addition, since the weighting system reflects the priorities among the parameters that influence the overall performance of the building envelope, another question is raised: are priorities the same among different participants involved in the making of the building envelope: the designer, the contractor, the inspector, the researcher, the evaluator and even the homeowner, as a future user of the building in question? The answer to this is probably "no"; even though they share the final goal, the well-performing and durable building envelope, all of these participants probably have different approaches to achieving this goal. So, in order to provide the most objective weighting system that will accurately reflect all these different points of view as much as possible, all these participants should be involved in the creation of the weighting system.[23] However, since the scope and the time needed for such additional study greatly exceeds the limits of this project, it was decided to adopt a simple approach in the development of the weighting system and to recommend the development of the in-depth weighting system as a separate research project.

Hence, in the light of the described concerns and limitations, the development of the weighting system had to rely on recommendations and guidelines provided by other research, on best practices proven to be effective over a certain period of use, and, sometimes, on the common sense and the experience of the author, since the purpose here is to provide an exercise and an example of how the system works as a framework. Later, the weights can be changed but only as a product of agreement between all participants.

Every functional requirement is divided into its operative (or performance) requirements, which are in turn divided into sub-requirements. Each sub-requirement has its criterion (or benchmark of performance) that needs to be met. As was described earlier, input data is evaluated against its corresponding criterion and scoring is performed. Each result represents a sub-score that reflects the level at which certain data meets the criterion for that particular sub-

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[23] A similar approach was used in the development of the BREEAM weighting system where the creators of the BREEAM program asked 60 building industry authorities (professionals, academics, building legislation authorities, etc.) to offer suggestions and their points of view on how much a particular sub-criterion should weight (Dickie & Howard, 2000).

requirement. The weights are then assigned to each sub-score. Each weight is then multiplied with its corresponding sub-score to provide the *weighted score* for the specific sub-requirement. However, in obtaining the final total result of evaluation, simply adding all weighted scores proved to be inadequate, since this process would sometimes provide comparison of mutually incomparable issues. For example, is it possible to compare air leakage through the window cracks to earthquake resistance performance? Therefore, the results of weighting had to be separated according to the main functional requirements. Another consideration was how to avoid uneven distribution of the final scores, since some functional requirements have more sub-requirements than others and would automatically obtain higher total scores. For that reason, it was decided to develop a system that would involve weighting (and, therefore, comparing) sub-requirements that are relevant to each other within one functional requirement, and to express them as relative to each other within that group.

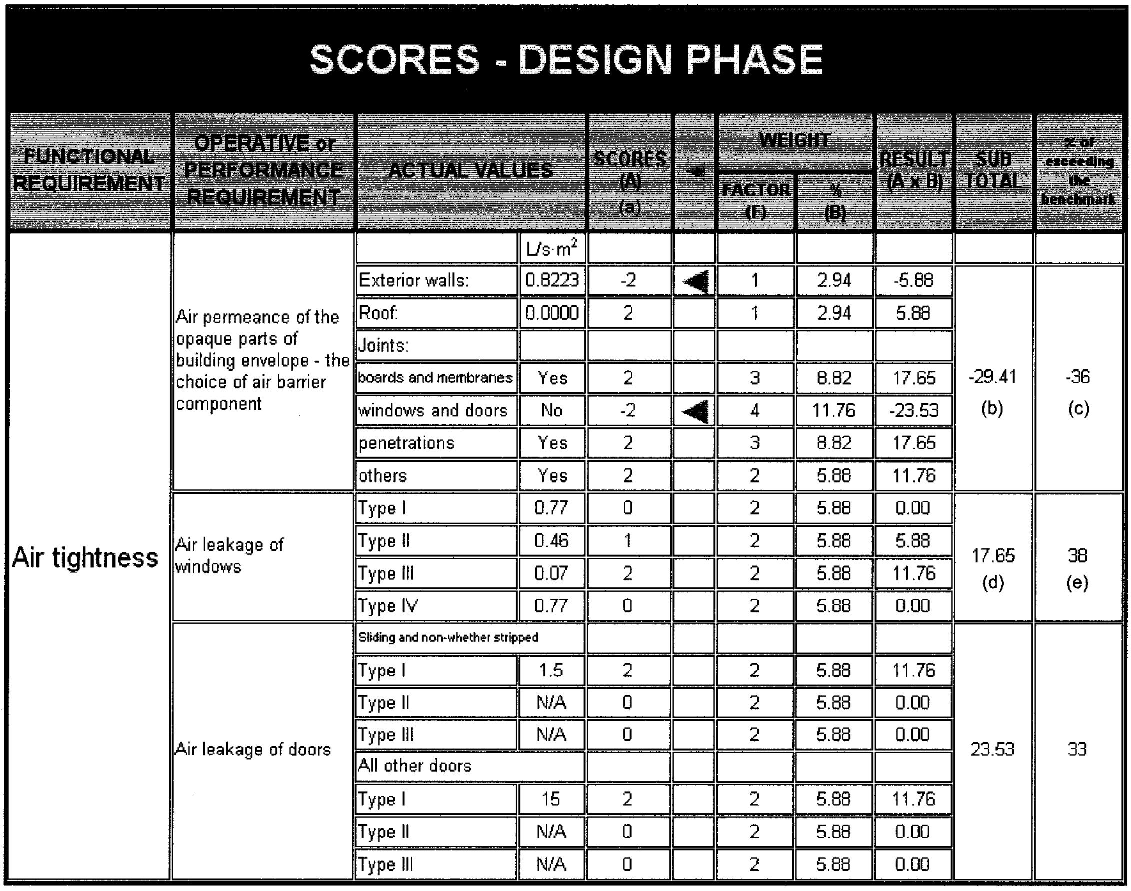
The weight factor assigned to each sub-requirement is expressed as a percentage of the total sum of all weight factors for that particular functional requirement. Sub-scores obtained from direct evaluation against given criteria are actually multiplied by weights expressed as percentages. Obtained values are then totalled to express the overall result for that particular functional requirement. The overall result is also expressed in the form of a percentage: it shows the level at which a given sub-requirement exceeds the minimum required performance, where 0% means that it meets minimum required performance, while 100% represents the maximum level of performance obtainable for that particular functional requirement. In this way, each functional requirement is represented as a separate entity. Later, in the second stage of the process, the functional requirements can be weighted against each other if so required (i.e. hygrothermal performance over acoustic performance, etc.).

Figure 12 shows the part of the worksheet in the assessment tool where data processing (i.e. scoring and weighting) is performed. The appropriate values from the "Data entry" group of worksheets are transferred to the columns entitled "Actual values" and "Scores". The next column, "◄", emphasizes the negative scores and draws attention to the sub-requirements that did not meet the given criteria, and gives the designer the opportunity to verify and correct the deficiencies. The following columns show the weight, expressed as a factor (F) and as a percentage (B), of the total sum of all weight factors for a given functional requirement. The percentage value B was calculated for each instance by the following equation:

$$B = \frac{F \times 100}{\sum F} \quad \%$$

For example, for the instance "Air permeance of the opaque parts of building envelope – penetrations" (the highlighted row in Figure 12), the assigned factor F is 3; therefore, the weight expressed as a percentage B equals:

$$B = \frac{F \times 100}{\sum F} = \frac{3 \times 100}{34} = 8.824$$



SCORES - DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL VALUES		SCORES (A) (a)	◄	WEIGHT		RESULT (A x B)	SUB TOTAL	% of exceeding the benchmark
						FACTOR (F)	% (B)			
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component		$L/s{\cdot}m^2$							
		Exterior walls:	0.8223	-2	◄	1	2.94	-5.88	-29.41 (b)	-36 (c)
		Roof:	0.0000	2		1	2.94	5.88		
		Joints:								
		boards and membranes	Yes	2		3	8.82	17.65		
		windows and doors	No	-2	◄	4	11.76	-23.53		
		penetrations	Yes	2		3	8.82	17.65		
		others	Yes	2		2	5.88	11.76		
	Air leakage of windows	Type I	0.77	0		2	5.88	0.00	17.65 (d)	38 (e)
		Type II	0.46	1		2	5.88	5.88		
		Type III	0.07	2		2	5.88	11.76		
		Type IV	0.77	0		2	5.88	0.00		
	Air leakage of doors	Sliding and non-whether stripped							23.53	33
		Type I	1.5	2		2	5.88	11.76		
		Type II	N/A	0		2	5.88	0.00		
		Type III	N/A	0		2	5.88	0.00		
		All other doors								
		Type I	15	2		2	5.88	11.76		
		Type II	N/A	0		2	5.88	0.00		
		Type III	N/A	0		2	5.88	0.00		

$\Sigma F=34$ $\Sigma B=100\%$

$$B=\frac{F\bullet 100}{\sum F}$$

Legend:

(a) Scores are transferred from "Data entry" group of worksheets;

(b) In cases where there are negative results (meaning there are sub-requirements that are below minimum acceptable benchmark), only the sum of these negative results for this particular performance requirement is displayed;

(c) Subtotal expressed as a percentage compared to the benchmark for this particular performance requirement, i.e.

$$c=\frac{\sum(A\times B)_{\text{Negative for this perf. req.}}\times 100}{\sum(A\times B)_{\text{Max for this perf. req.}}}=\frac{-29.41\times 100}{82.35}=-36\%\ ;$$

where denominator represents the sum of maximum scores (2 points in all cases);

(d) If all results are equal to or higher than 0, the results are simply added together;

(e) Subtotal for this performance requirement expressed as percentage, where 0% represents minimum requirement and 100% represents maximum performance achievable by this performance evaluation tool, calculated as:

$$e=\frac{\sum(A\times B)_{\text{Actual for this perf. req.}}\times 100}{\sum(A\times B)_{\text{Max for this perf. req.}}}=\frac{17.65\times 100}{47.04}=38\%$$

Figure 12: Scores, weights and calculation of performance evaluation results for one functional requirement

In the "Result" column, the achieved score is multiplied by weight expressed as a percentage (A x B), and that represents the result for a particular sub-requirement. Following the same example, the achieved score for this same instance (A) is 2 points; therefore A x B gives the result of 17.65.

In the "Sub-total" column, all the results from the previous column for one performance requirement are added together. However, it was noticed during the development of the Tool that the simple addition of sub-requirement results is not sufficient in cases where even one of the scores in column A is negative. That means that in at least one instance, the basic requirements of the building codes are not met, and that makes the design of the project unacceptable, not only for this evaluation but in general. It could also happen that even if some instances score in the negative, when added together with others, the overall score can be positive and even relatively high; such a score would represent a false picture of the overall performance of the building envelope. For example, in one of the exercises carried out during the development of the assessment tool, the overall performance of the building envelope showed to be 34% above conventional practice; however, the detailed examination of the results showed that the design of the thresholds of the balcony door did not include flashing and sealing. Even though the weight factor for this sub-criterion was the highest possible and therefore provided a high negative score for that instance, the other positive results overcompensated this value and resulted in the high overall performance. Such methodology provided the false picture of building performance excellence; hence, a different approach had to be used.

Such occurrences led to a decision to accept the additive approach only if all the results for sub-requirements are positive. If any of them are negative, then only this negative value is displayed. If there are two or more negative results, only these are added and displayed as a final result to emphasize the inadequate level of performance.

In the last column (Figure 12), the results from the previous column are expressed as percentages in a scale where 0 represents the minimum building code requirement that must be met, and 100 represents the maximum points that can be achieved for such a performance requirement. This manner of expressing the results is used later in the outputs for the graphic presentation of the results.

OUTPUTS

There are three different levels of building envelope performance assessment outputs, depending on the prospective user and the intended use of these results:

- A-level: simple output
- B-level: intermediate output
- C-level: professional output

A-level: Simple output

This level of output is to be used for commercial and advertising purposes only. It is intended for non-professionals, i.e. prospective homebuyers and real estate agents. This simple output presents only final results by eight main functional requirements: air-tightness, moisture management performance, thermal performance, energy performance, structural stability of the building envelope, acoustic performance, fire response of the building envelope, and quality of workmanship. The performance for each category is expressed as a percentage, on a scale from 0 to 100, where 0 level represents minimum building code requirements, and 100 represents the maximum available performance for each category. Negative values indicate that building codes are not met and the

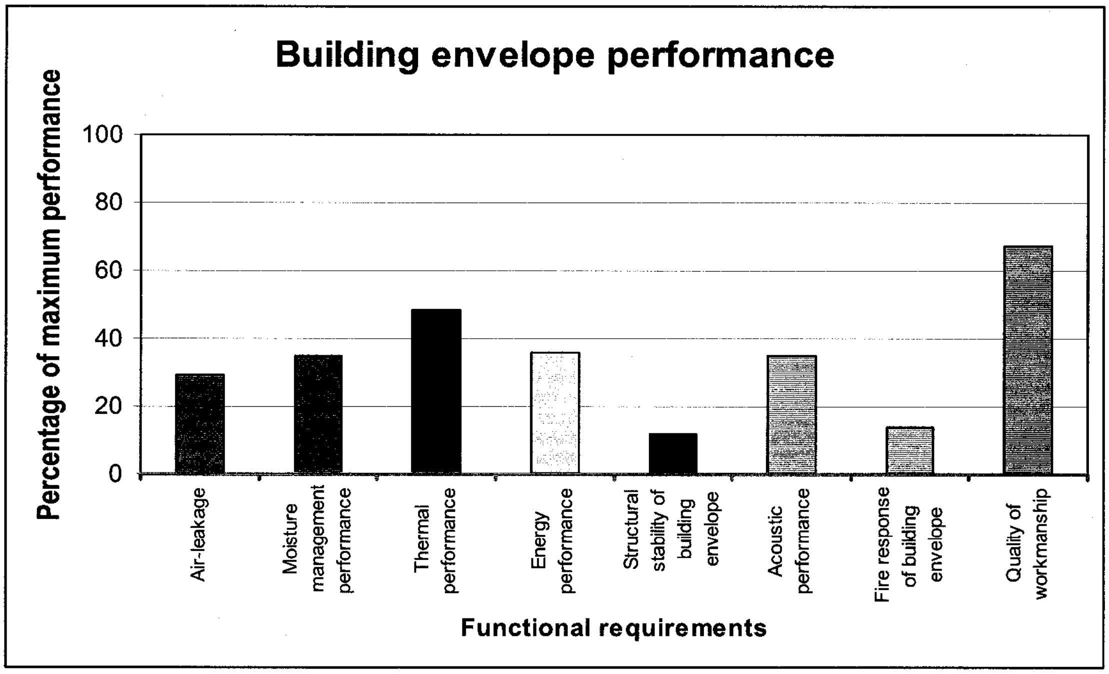


Figure 13: Presentation of the final results of building envelope performance evaluation in A-level: simple outputs

building could not be accepted for use. It is assumed that all inadequacies are already corrected by the designer, builder, and manufacturer. Presented as a graph, this output shows the level by which minimum requirements of the building codes are exceeded (Figure 13).

B-level: Intermediate output

Intended for professionals, this level of output provides more detailed information on the building envelope performance evaluation. It presents main functional

PERFORMANCE EVALUATION OUTPUT B - LEVEL (INTERMEDIATE)			
DESIGN STAGE			
Functional requirement	**Performance requirement**	**Sub-totals**	**%**
Air tightness performance	Air leakage of the opaque parts of building envelope	-29.41	-36
	Air leakage of windows	17.65	38
	Air leakage of doors	23.53	33

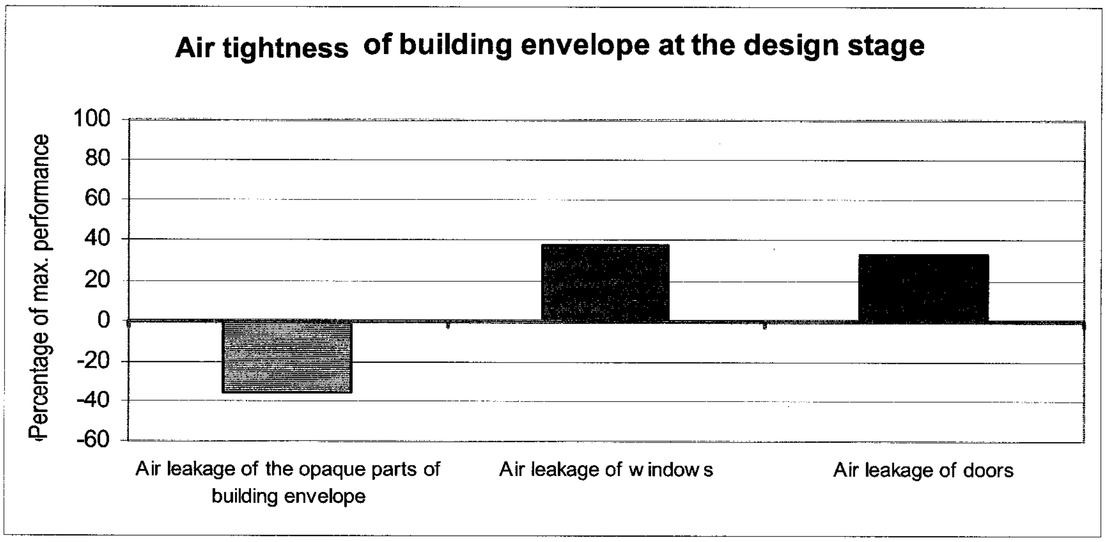


Figure 14: Presentation of building envelope performance evaluation in B-level: intermediate output

requirements and their performance requirements, divided by stages of the project (i.e. design stage, execution stage, etc.). This level of output provides a quick overall impression of building envelope performance. Besides the results of the evaluation calculations, it presents the level by which specific performance requirements exceed (or not) minimum requirements of the building codes (i.e. 0 level on Y axes, Figure 14). Negative performance values are accepted in this output in cases of unofficial (working) evaluation, presuming that these instances will be corrected before the final evaluation of the building envelope. The results are presented in both tabular and graphical form (Figure 14). The full printout of B-level outputs is provided in Appendix C of this thesis.

C-level: Detailed report output

C-level output is the most comprehensive of all and provides the most detailed insight into the results of the building envelope performance evaluation. It is intended for use by professionals only. Divided into the stages of the project (i.e. design stage, installation stage, laboratory tests, field tests, etc.), it presents the results of processing according to main functional requirements, their performance requirements and sub-requirements in tabular form (Figure 15).

PERFORMANCE EVALUATION OUTPUT
C - LEVEL (DETAILED)

DESIGN STAGE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL VALUES		SCORES (A)	◄	WEIGHT		RESULT (A x B)	SUB TOTAL	% exceeding th benchmark
						FACTOR	% (B)			
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component		L/s·m^2							
		Exterior walls:	0.00	2		1	4.35	8.70	147.83	100
		Roof:	0.00	2		1	4.35	8.70		
		Joints:								
		boards and membranes	Yes	2		3	13.04	26.09		
		sillplate/top plate gaskets	Yes	2		3	13.04	26.09		
		windows and doors	Yes	2		4	17.39	34.78		
		penetrations	Yes	2		3	13.04	26.09		
		others	Yes	2		2	8.70	17.39		
	Air leakage of windows	Type I	0.46	1		2	8.70	8.70	17.39	50
		Type II	0.46	1		2	8.70	8.70		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
	Air leakage of doors	Sliding and non-whether stripped							0.00	0
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		All other doors								
		Type I	15	0		2	8.70	0.00		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		

* For explanation of calculations in this figure, please refer to Figure 12, p. 108 of this document

Figure 15: Presentation of the performance evaluation results in the C-level: detailed output

In this level of output, the values for each sub-requirement are presented; they are automatically transferred from the "Data input" worksheets. Next, the results of scoring and weighting are given, transferred from the appropriate boxes in the "Processing" worksheets. The following columns provide sub-totals for the entire performance requirement and the same result expressed as percentages of maximum performance, also transferred from the "Processing" phase. If any changes occur at the "Data input" stage, the appropriate changed results will be automatically transferred to the C-level output worksheet (as well as in A-level and B-level), so that these worksheets are ready to be printed at any moment of the evaluation.

The C-level output also provides a graphic presentation of the results, like in the B-level output (Figure 14). The entire C-level output is presented in Appendix E of this thesis.

FINDINGS

The Building Envelope Performance Assessment Tool (BEPAT) was developed in order to synthesise and analyse the data generated by the Protocol in a user-friendly manner, and to provide final outputs of the performance evaluation. The Tool utilises data obtained by the Protocol, compares them with the benchmark values, assigns score points, which are then weighted to reflect the priority among the requirements. The weighting system greatly influences the final results of the performance evaluation; the approach used in this work reflects the points of view of the author and it may be characterised as subjective. The follow-up study is recommended in the form of a survey of different participants (e.g. architects, engineers, contractors, building inspectors and homeowners) in order to find out the similarities and differences in priorities among these groups and to develop a more objective weighting system.

The Tool provides three levels of output of the final results of the performance evaluation: A-level (simple output), to be used for commercial purposes; B-level (intermediate output) provides more information on the performance of specific functional requirements; and C-level (detailed output), intended for professionals, provides a detailed overview of all functional requirements and their sub-requirements and is intended for close examination of the building envelope performance.

In addition, the Building Envelope Performance Assessment Tool (BEPAT) contributes to the design and operation of the building envelope system and to the communication between people involved:

1) BEPAT* as performance assessment tool: this user-friendly tool is to be used by designers, architects, engineers, technicians, homebuilders, building inspectors, and 3rd party independent evaluators for the performance assessment of light-frame building envelopes and, furthermore, for building envelope performance rating;

2) BEPAT* as design tool: using the design stage part of the Assessment Tool, the designer can immediately check the design choices by comparing them with provided criteria, and make appropriate changes at this stage;
3) BEPAT* as learning tool: by identifying and correcting mistakes (either at the design or execution stages), professionals can simultaneously learn from them and avoid similar errors in the future;
4) BEPAT* as communication tool between designer, contractor, developer, building inspector, homeowner: since the Tool assesses the project at all stages from the design to the occupancy, the results from each stage assessment can be circulated among the participants in the process in order to improve the communication between them;
5) BEPAT* as a management tool, in terms of building operation management and maintenance scheduling: the occupant (homeowner) can continue to record regular maintenance, minor and major renovations and other interventions into the building envelope for additional evaluation and future record that can be used at the time of reselling the house;
6) BEPAT* as a public education tool: if made an official certification program the information about it can help raise public awareness on issues such as better building envelope performance, energy conservation, energy consumption, etc., and improve homebuyers' knowledge about the house as a system.

CHAPTER 6: VALIDATION – IMPLEMENTING THE PROTOCOL AND ASSESSMENT TOOL

INTRODUCTION

The next step in this study was to test the Protocol and the Assessment Tool by evaluating several existing building envelopes of varying configuration. The goal was not primarily to make a comparison between different building envelope assemblies but to get feedback on the protocol, and especially on the assessment tool. The objective was to find out the following:

- How comprehensive is the assessment tool?
- How difficult (or not) is it to use?
- What is the level of clarity of data entry phase?
- How clear is the whole process of evaluation, scoring and weighting?
- Are there any inconsistencies in the evaluation process as well as in the scoring and weighting system that may lead to misleading results?
- What is the level of satisfaction with the results of the evaluation, such as the clarity and usefulness of different levels of outputs, etc.?

It was difficult at this point to validate the entire assessment tool, because validation would have to include all the laboratory tests as well as following the building from the design stage to occupancy. For that reason, validation is done only for one part of the assessment tool, that is, for the design stage. More elaborate validation that would include following the entire process through the design, installation (execution), and field test stages is recommended for future study, for example, as a technical report by a graduate student.[24]

To obtain a different level of results in building envelope performance, and to provide the possibility of comparing and verifying evaluation results based on existing data, several case studies of existing houses were chosen for validation. These are:

1) One modular prefabricated house designed and built according to requirements of the NBC and the Québec Energy Code by manufacturer A as their standard model. In further text, it will be referred as: A-standard house;
2) One modular prefabricated house designed and to be built by the same manufacturer to conform to requirements of the Novoclimat program. It will be referred as: A-Novoclimat house;
3) One panellised prefabricated house with highly insulated building envelope configuration that is currently being built by manufacturer M. It will be referred as: M-Thermo house;
4) Two Advanced houses: NOVTEC Advanced house and Innova Advanced house. These houses were built in the early 1990s as demonstration homes under National Resources Canada's (NRCan's) Advanced Houses Program

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[24] At this point (summer 2005), a follow-up research project is to be commenced that deals with the adaptation of the Protocol and the Assessment Tool for the requirements of the Ontario Building Code and Toronto climatic condition. This project will attempt to carry out evaluation at the design stage, installation, and field tests (prior to occupancy).

in order to explore and test innovative methods in reducing energy consumption, improve indoor-air quality and reduce environmental impact.

Originally, it was also planned to include at least one conventionally site-built house in this simulation. However, the author was unable to find a home-builder from the Montreal area that would be willing to participate in this study at the time of completion of this study.[25]

CASE STUDIES – DESCRIPTION OF DIFFERENT BUILDING ENVELOPES

Manufacturer A is a large Québec manufacturer of prefabricated homes. This manufacturer specialises in modular homes, but can do panelised homes if required, usually in cases where easier transportation needs to be facilitated. The architectural design of the house can be personalised according to customer needs and preferences. In terms of building envelope, they offer two variations: standard (designed according to the requirements of the Québec Energy Code), and an enhanced performance type of building envelope, built according to

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[25] The most common reason for declining the collaboration was the lack of time and/or interest. In one case, however, the homebuilder claimed that since he usually contracts out different trades (framers, window installers, etc.), he could not provide all the necessary information needed for this exercise, since contractors work independently. This remark reveals that some members in the homebuilding industry still fail to consider the building envelope as a system within a system (entire house). It also points to a possible lack of communication between trades, and possible incompatibility of components in building envelope assembly that eventually may cause building envelope deficiencies and failures.

Novoclimat requirements. For the purpose of this project, they provided us with both designs.

A- Standard

This house is a 2-storey + basement, single-family house built about 100 km east of Montreal. It is a 3-bedroom house with about 130 m^2 (1398 sq ft) of habitable area (basement not included). Designed as a modular house, 4 modules are built in the plant, transported to the site, and assembled on an already built foundation and basement walls.

Exterior walls are 38x140 mm (2x6") kiln-dried lumber studs at 400 mm (16") o/c, with mineral wool insulation between studs of RSI- 3.52 (R-20). Exterior sheathing is 11 mm oriented strand boards (OSB). An unspecified housewrap membrane is placed on the exterior side of the insulation, with 19x 64 mm (1x3") exterior furring attached to the studs that also provides exterior air space for ventilation. Canexel, type 5 medium-density hardboard siding that has a textured surface with a primed or finished coat is used as exterior siding. A Type 1 vapour retarder membrane is placed on the interior side of the insulation (no particular type is specified). Interior 19x 64 mm (1x3") furring is holding 12.5 mm (½") the interior gypsum board finish and also forms the interior air space. In addition, 63 mm (2 ½") rigid insulation is added on the perimeter of the floors, between pre-engineered floor trusses to avoid cold bridging. When modules are assembled together, expandable foam gaskets are placed in so-called “marriage walls” between modules to ensure air-tightness and continuity of the building envelope.

All windows on this house are double-glazed, air-filled openable casement windows, with energy level EL3.

Sloped roof assembly is conventional: 300 mm (12”) mineral wool insulation placed between roof-trusses (RSI-7.0, R-40). Oriented particle board, 11 mm, #15 building paper and asphalt shingles compose the roofing. Type 1 vapour retarder is placed on the warm side of insulation, with 19x 64 mm (1x3”) interior furring and 12.5 mm (½”) gypsum boards as interior finish. As in the exterior walls, interior furring provides air space for electrical installations, so that the integrity of the vapour retarder is not compromised.

Basement walls are left to be finished later, by the homeowner. It is recommended by manufacturer A that basement walls be insulated by 63mm (2½”) rigid insulation (RSI-1.76, R-10), placed between 38x64 mm (2x3”) studs at 400 mm (16”) o/c, with type 1 vapour retarder and gypsum boards added on the inside. The basement concrete slab is not insulated, with only 6 mil polyethylene sheet underneath it for damp-proofing and 200 mm (8”) thick crushed stone layer for capillary break of ground moisture.

A-Novoclimat

This small one-storey, single-family house contains 98 m^2 (1046 sq ft) of habitable area. It has one bedroom, one bathroom, an office, a kitchen, and dining and living rooms on the ground floor, with a proposed second bedroom, second bathroom and recreational room to be built in the basement once it is finished. Designed according to requirements of the Novoclimat program, the building envelope of this house has enhanced performance compared to conventional houses. Also built as a modular house, it consists of two modules built in plant that will be joined on site, placed on a previously built concrete foundation and basement walls.

Most of the exterior wall assembly is the same as in the standard model: 38x140 mm (2x6") kiln-dried lumber studs at 400 mm (16") o/c, with mineral wool insulation between studs of RSI-3.52 (R-20). Eleven mm OSB sheathing is placed on the outside of the studs, with unspecified housewrap material. Canexel siding is attached over the 19x64 mm (1x3") exterior furring. However, on the interior side of the studs 19 mm (3/4") thick AP Foil Faced Polyisocyanurate Foam Sheathing boards are installed. These boards bring additional RSI-0.79 (R-4.9) to the overall thermal resistance of the assembly and reduce thermal bridging at the framing members. Reflective foil reduces the conductance of interior air space and acts as a water vapour diffusion retarder with permeance of only 2 $ng/Pa{\cdot}s{\cdot}m^2$. As in the standard model, interior gypsum boards are attached to 19x 64 mm (1x3") interior furring, and all electrical installations are run through this space. The nominal RSI value of the whole exterior walls assembly is 5.6 m^2·K/W (RSI-4.9 m^2·K/W effective).

The roof is of the same configuration as in the standard model, with 300 mm (12") mineral wool insulation and nominal RSI value of 7.5 m^2·K/W.

All windows in this house are double-glazed, low-E and Argon filled, with insulated spacers. These openable casement windows have energy level EL4[26]. Windows are uniformly distributed on all facades except on the north side, which has no windows at all.

In most cases the basement walls are to be finished later by the homeowner. However, because this house must meet the requirements of the Novoclimat program, manufacturer A specified the interior finishes. Sprayed urethane insulation 63 mm (2 1/2 ") thick is to be installed between 38x64 mm (2x3") studs at 400 mm (16") o/c, with type 1 VDR and 12.5 mm (½") gypsum board. The nominal RSI value for below-grade wall assembly is 3.7 m^2·K/W. Also, 31 mm (1 1/4 ") rigid insulation boards are to be installed under the whole surface of the basement slab.

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[26] Energy levels are calculated by the author using FRAME 5.1 software based on information provided by home manufacturer A.

M-Thermo house

One of the Québec's largest manufacturers of prefabricated homes, based in Québec City, developed a new exterior wall system called Polar Thermo Plus in order to enhance building envelope performance beyond the requirements of the Québec Energy Code. The house presented here is to be built during the spring and summer of 2005 and will also serve as their model house for this advanced building envelope system.

This house is a duplex with two independent apartment units within the same house. A smaller, 2-bedroom unit totals 70.7 m^2 (760 sq.ft.) of habitable area. The larger apartment has two bedrooms, two and a half bathrooms, an office, a library, a family room, an atelier, living and dining rooms, and a kitchen. It totals 140.2 m^2 (1510 sq.ft.). The smaller apartment occupies half of both the basement and ground floor, while the larger apartment occupies the remaining halves of the basement and ground floor, and the entire second floor.

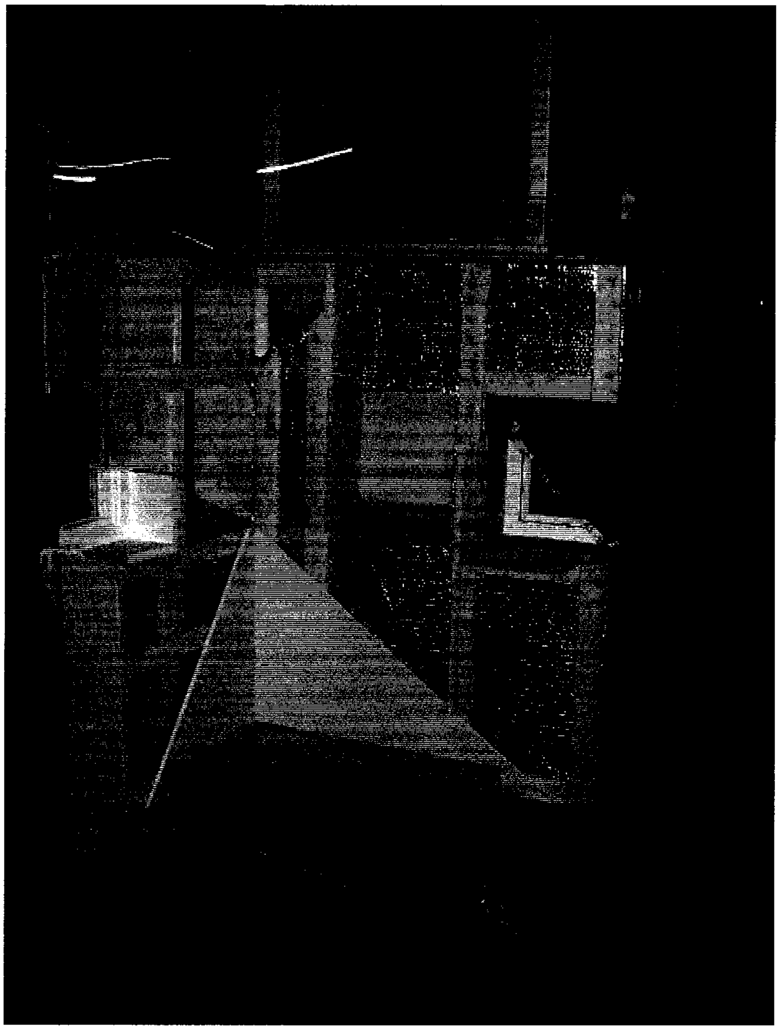

Figure 16: The model of M-Thermo exterior wall/roof assembly

The exterior walls of this system consist of 38x180 mm (2 x 8") kiln-dried solid lumber studs, spaced at 400 mm (16") o/c and 140 mm (8") thick layer of mineral wool insulation placed between studs. 25 mm (1") rigid polystyrene CodeBord is added on the outside. Tyvek sheets with taped joints are used as a housewrap. Exterior furring, 19x64 mm (1x3"), forms the air space and holds the Canexel exterior siding. A Thermafoil vapour retarder is attached on the interior of the studs, with 19x64 mm (1x3") interior furring and gypsum boards as interior finish. The total RSI value of this assembly is 7.93 $m^2 \cdot K/W$ (R 45). In addition, compressed seal gaskets are inserted in pre-grooved top and bottom sill plates, to reduce air leakage (Figure 16).

The windows to be incorporated in this building envelope are PVC casement windows with triple-glazing, low-E, filled with krypton gas and insulated spacers, with energy level EL7, as calculated by the author using FRAME 5.1 software.

The roof assembly for this house is built on the conventional principles; however, the mineral wool insulation that is placed between the prefabricated roof trusses is in two layers with a total of 600 mm (24") thickness, which results in an RSI value of 9.06 $m^2 \cdot K/W$ (R 56).

The concrete basement walls are to be insulated on the inside with 51 mm (2") rigid polystyrene boards. There is no insulation specified to be placed underneath the slab. Having in mind that, due to the sloped terrain, a considerable part of the basement walls will be exposed, this level of insulation seems to be much lower in comparison to the rest of the house.

NOVTEC Advanced House

The NOVTEC Advanced House was built in 1993 in Laval, a suburb of Montreal. It was an award-winning design by an NRCan-formed consortium called AIMS (Advanced Integrated Mechanical Systems). The goal was to demonstrate that the stringent energy, indoor-air quality and environmental requirements of the Advanced Houses Program could be achieved through the use of readily available building materials and equipment, as long as a house-as-a-system approach was used *(Gerbasi, 2000)*.

The NOVTEC Advanced House is a 222 m^2 (2390 ft^2), single-family detached house. It is 2½ storeys high, with 3 bedrooms. An innovative building envelope coupled with advanced mechanical systems contributed to achieving strict requirements for advanced houses: that a) the total purchased energy target was approximately 25% of that of a conventionally-built house according to the 1975 NBCC; and b) there is improved indoor-air quality, water conservation and eco-management (*ibid.*).

The exterior walls of the NOVTEC Advanced House consist of 38x89 mm (2x4) wood studs spaced at 400 mm (16") o/c, with batt insulation between studs and interior gypsum board finish. The interior finish is coated with one layer of latex emulsion primer and a second layer of alkyd pearl enamel paint, which results in type II vapour barrier protection. On the exterior side, two layers of shiplapped rigid insulation, each 38 mm (1½") in width with 12.5 mm (½) exterior plywood in between layers, are attached to the studs. The overall nominal RSI of the whole assembly is 5.5 $m^2 \cdot K/W$. The exterior finish is 13 mm thick clay brick facing, factory laminated to the outer face of the rigid insulation. The design team wanted to demonstrate that through the use of an airtight EIFS wall assembly, moisture migration is minimised and that there is no need for the traditional air cavity behind the brick, nor the need for building paper or a polyethylene vapour retarder (*ibid.*).

Windows in the NOVTEC Advanced House are double-glazed, low-E coated and argon-filled windows, with energy level EL4.[27] A large south-facing atrium, which consists of 50% of the total south façade, consists of triple-glazed, low-E coated windows with thermally broken aluminium frames and energy level EL5 (*ibid.*).[28]

This house does not have a basement: slab-on-grade foundation is insulated from the ground using one 51 mm (2") layer of rigid insulation underneath the centre of a slab and two layers (102 mm (4") thick and 610 mm (24") wide) underneath the perimeter of the slab and wrapped around its edges. Radiant floor heating is incorporated in the concrete slab, which results in a more uniform indoor temperature and higher comfort for occupants.

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[27] This energy rating was determined by the author of this thesis using FRAME 5.1 software, based on the information provided in the main source that were described according to the old version of CAN/CSA A440 Standard: thermal resistance of RSI-0.6, the energy rating of windows of -13, an overall window U-value of 2.15 $W/m^2 \cdot K$, and a solar heat gain coefficient of 0.48. (*Gerbasi, 2000*).

[28] The atrium has an energy rating of -8, an overall U-value of 2.05 $W/m^2 \cdot K$ and a solar heat gain coefficient of 0.52 (*ibid.*).

The sloped parts of the roof are of the conventional assembly: gypsum boards attached to 19x89 mm (1x4") furring that are fastened to roof joists, with batt insulation of RSI value 8.5 $m^2 \cdot K/W$ (R48) between joists. Exterior sheathing boards, building paper and asphalt shingles form the roofing.[29]

Besides an innovative building envelope, what makes this house's overall performance superior to conventional houses are its mechanical systems: dual ground source heat pumps, home automation, an energy management system, a water filtration system, etc. Since the objective of this study is the evaluation of the building envelope only, these systems are not covered in this thesis.

Innova House

The Innova House, also known as the Ottawa Advanced House, was opened in February 1993 as one of the 10 Advanced Houses built across Canada.[30] It is a 4-bedroom, single-family detached house with 203.5 m^2 floor area on two floors: ground floor and basement. The design of the Innova House incorporates new

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[29] Neither working drawings for the NOVTEC house nor the other literature specify what type of exterior sheathing boards are used, which is unfortunate because certain properties such as air permeance needed for evaluation were not known. In addition, the working drawings do not specify a vapour retarder in the roof assembly; we can assume that it is the same as in exterior walls: gypsum boards are coated with one layer of latex emulsion primer and a second layer of alkyd pearl enamel paint, which results in type II vapour barrier protection.

[30] Even though it is located in Ottawa's suburb of Kanata, the Innova house is included in this study because of its proximity to Montreal and its climatic conditions, which will make it eligible for this Protocol and Assessment Tool.

products and construction details, which are easily adapted to conventional wood-frame practices (*Innova House, 1996*).

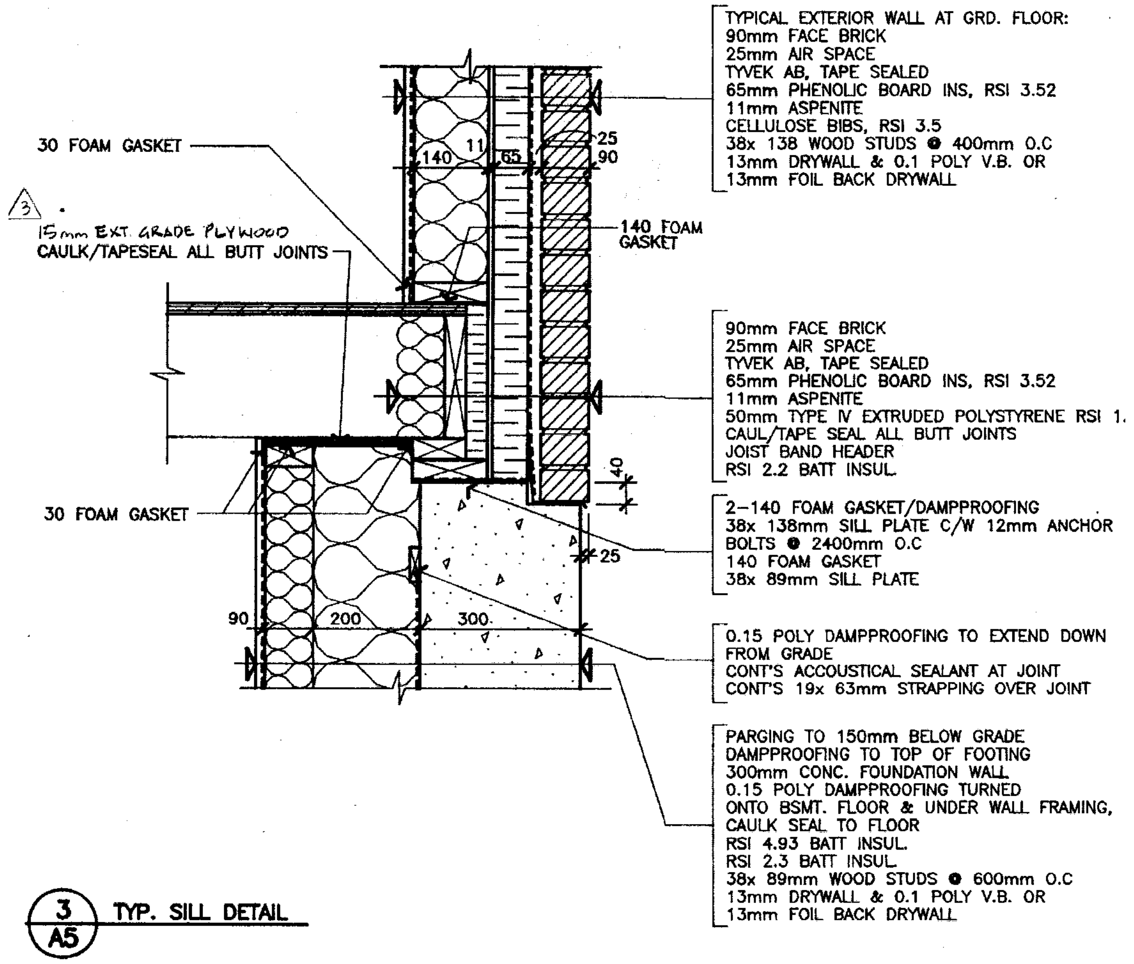

Figure 17: Exterior wall section of the Innova House. (*Source: Innova House working drawings. NRCan*).

Exterior walls of the Innova House consist of 38x140 mm (2x6") wood studs at 400 mm (16") o/c, with blown-in cellulose bibs insulation between studs (RSI 3.5), Figure 17. The interior finish consists of 13 m foil back Fiberbond boards with VDR (vapour diffusion retarder) primer[31]. The 8 mm aspenite boards are attached to the exterior side of the studs, and 63 mm phenolic boards are added as exterior insulation (RSI 3.52). A Tyvek house wrap with taped joints serves as a weather barrier and exterior cladding is 13 mm exterior plywood with acrylic coating and brick (*ibid.*).

All windows used in the Innova House are triple-glazed with two 12.7 mm spaces filled with krypton gas, with vinyl clad wood frames. The energy rating, according to the CSA 440 standard version that was valid at the time, for fixed window units is 17.11 W/m^2, and for casement units is: 3.95 W/m^2. Re-evaluated by FRAME 5.1, these windows achieved energy level EL7 (in compliance with CAN/CSA A440, 2003 edition).

Basement walls (300 mm thick poured concrete) are insulated from the interior with 200 mm batt insulation (RSI 4.93) and additional 90 mm batt insulation between 38x89 mm (2x4") wood studs (RSI 2.3), which provide a total of RSI 7.13 m^2·K/W for the basement walls. The 0.15 mm (6 mil) polyethylene moisture barrier is placed between the insulation and concrete wall to prevent moisture penetration from concrete to the batt insulation. The interior finish consists of 12.7 mm foil back Fiberbond boards with VDR primer. The basement floor is a 75 mm concrete slab with 0.15 mm polyethylene dampproofing, 75 mm type IV exterior polystyrene board insulation underneath the whole slab, and a 150 mm

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[31] Foil had to be applied to the back side of all wallboards because the local building official would not accept the VDR primer as a vapour barrier alternative to polyethylene sheet (*Innova House, 1996*).

layer of crushed stone to prevent capillary rising damp from the ground. One of the innovations of this project is 38 mm high-density mineral fibre insulation inserted as a drainage layer at the perimeter joint between the foundation wall and the slab. Drainage is continued between the footing and the extruded polystyrene insulation under the slab (*ibid.*).

The roof of the Innova House differs from conventional roofs only in increased thermal insulation: 435 mm blown cellulose insulation is placed between engineered roof trusses, with 13 mm exterior plywood and hardboard shingles as a roof cover. On the interior side, 12.7 mm foil-backed Fiberbond boards with VDR primer are attached to 19 x 89 mm (1x4") wood strapping, which is fastened to the bottom of the roof trusses.

Additional air tightness features of the Innova House include: sealed stacks and service penetrations, 140 x 6 mm foam gaskets under wall sill plates, 50 mm type IV extruded polystyrene at the edges of wood floor platforms, 12.7 x 4 mm adhesive-baked closed-cell foam gaskets at wall edges under drywalls and air-tight electric boxes.

As with the NOVTEC Advanced House, other features of the Innova House involve advanced mechanical systems for heating, cooling and ventilation, low consumption appliances, water filtration systems and much more. Since this is only an evaluation of the building envelope, their performance will not be included in this validation.

CASE STUDIES – EVALUATION RESULTS

Assumptions and boundary conditions

The main sources of input data for all evaluated building envelopes were working drawings of the above-described houses. In addition, for both Advanced houses, the sources also included publications on these projects, by NRCan and Concordia University: Innova House (1996) and Gerbasi (2000), respectively. For other case studies, in cases where working drawings were not sufficient, the author contacted the home manufacturers for clarifications and additional information.

All loads applied to the evaluated building envelopes and assumptions necessary for evaluation were identical. These include:

- An outdoor temperature of -23°C, 90% relative humidity (RH) and indoor temperature of 21°C, 35% RH;
- The site and the wind exposure to be suburban surroundings;

- Occupancy is to be a family of 4: two adults and two children that stay at home about 50% of the time on average;

- Since the focus of this evaluation is the building envelope only and not the overall performance of the entire house, all mechanical systems and other features for reducing overall energy consumption were not taken into account. This applies especially to NOVTEC and Innova Advanced houses. Instead, it is assumed that all case studies use electricity for heating (baseboards) and domestic hot water (DHW) supply and a conventional AC system for cooling in summer[32];

- In cases where design targeted air tightness was specified by the designer/manufacturer, this specified value was used in calculations.[33] In other cases, the average air tightness level of 4.5 ACH@50 Pa was assumed;

- In cases where the orientation of the house was not specified in working drawings, it was assumed that the main façade faces east;

- In cases where brands of windows, balcony/patio sliding doors, and entrance doors were not specified, and thus the exact ratings for air-tightness, water-tightness, wind load resistance and energy level could not be obtained from window/door manufacturers, assumptions were made as follows:

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[32] These assumptions were used in the predicted energy consumption for heating and cooling, calculated by the HOT2000 program.

[33] Actual achieved air tightness can only be verified in the field by testing the finished house with a fan pressurization test.

  - Air-tightness rating is A1 (as per CSA A440.00 for the Montreal climatic zone);
  - Water-tightness rating is B2 (*ibid.*);
  - Wind-load resistance rating is C2 (*ibid.*);
  - Energy level ratings were calculated by the author based on available data using FRAME 5.1 software;
- Evaluation of the structural performance of the building envelope was not conducted in any of the case studies, because all structural systems used (i.e. wood-frame) are already approved by the National Building Code;
- Since the Protocol and the Assessment Tool were designed to use the SI system, all information provided in Imperial units was converted.

Evaluations – 1st run

The first evaluation run of all case studies generally showed expected overall results. However, some unexpected results were noticed in certain instances. For example, Figure 18 and Figure 19 present evaluation results for NOVTEC and Innova houses respectively. While in the majority of categories their performance achieves the maximum level for these categories, in others the results show that they are below even the benchmark values, i.e. below the

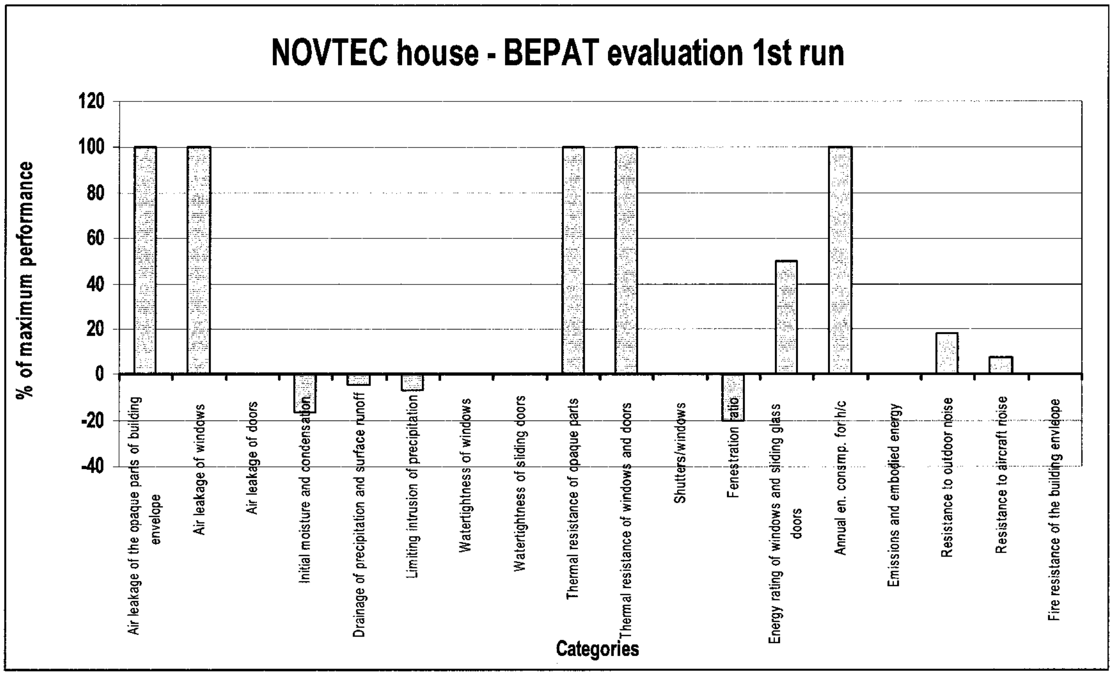

Figure 18: BEPAT Evaluation, 1st run: NOVTEC House

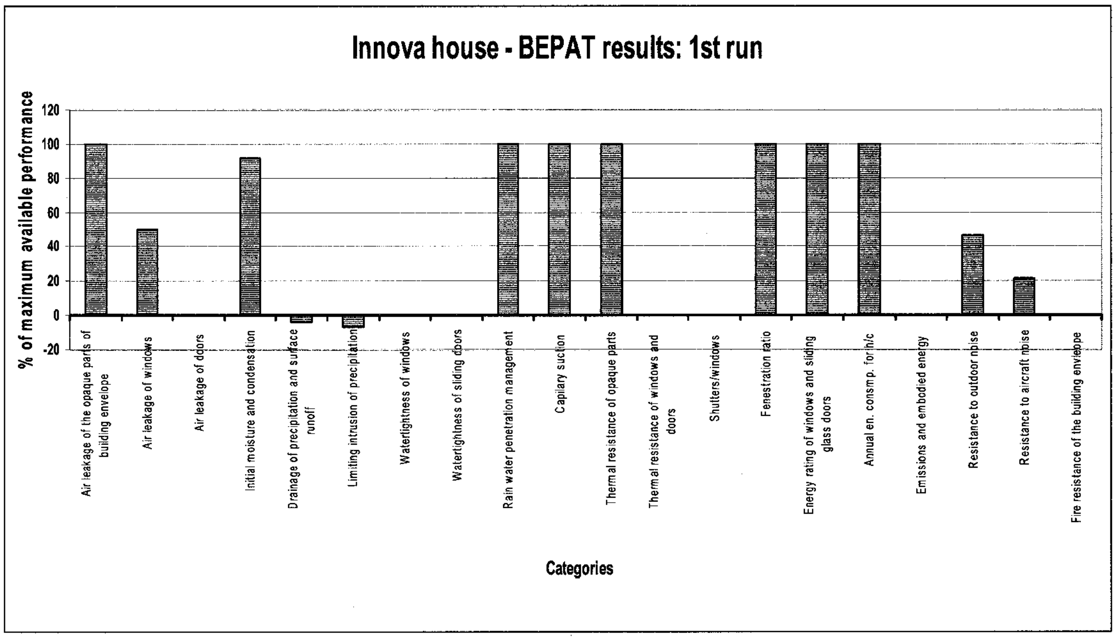

Figure 19: BEPAT evaluation, 1st run: Innova House

minimum requirements of the National Building Code Canada. Such results are obviously invalid, because both houses were built in the early 1990s, approved by building authorities, studied in detail by researchers and practitioners, and have been use for more than a decade. Similar results appeared in other case studies. It was obvious that there was a fault in the Assessment Tool that rendered results in an inadequate way and provided a faulty picture of the performance of the evaluated building envelopes.

A detailed review of the scoring and weighting system revealed the probable cause for this fault. While in cases of requirements that have quantifiable criteria, the evaluation tended to be straightforward; in other cases that have qualitative criteria certain problems occurred. This is also supported by the outcomes of the 1st run evaluation (Figures 18 and 19), which show that negative results appear in the same group of requirements, specifically in the subgroups: “Drainage of precipitation and surface runoff” and “Limiting intrusion of precipitation”.

These subgroups contain requirements that are based on guidelines and recommended practices used to improve moisture management, to reduce loads in building envelopes, to reduce risk of failures, and to improve durability. Furthermore, their implementation is not required by the building code or any other program currently available in Canada. Failing to incorporate the majority of requirements from these subgroups will not violate any building regulation; therefore, they should not be considered as negative scores. However, the objective of good design is to achieve strong overall performance and not simply to satisfy code requirements. Hence, the evaluation would be better made against performance values. For that reason, the scoring and weighting system of the Building Envelope Performance Assessment Tool should be corrected to reflect these inconsistencies.

Another difficulty in running the Tool was the lack of comprehensive input data required by the Tool. The working drawings provided for all case studies were occasionally vague in describing certain components of the building envelopes to be evaluated. For example, stating that assembly contains a Type 1 Vapour Diffusion Retarder certainly meets the requirements of the building code. However, when calculating water vapour transmission through the assembly by diffusion, specifying which product is actually used could improve results from “satisfactory” to “excellent” (Table 13). Similarly, in the case of thermal insulation, more accurate results can be achieved if the product is described more specifically than only as “rigid insulation board”. A lack of sufficient information was also encountered while evaluating components such as windows and doors.

Table 13: Different impacts of using various types of VDR for evaluated assembly

Type 1 VRD ≤ 15 ng/Pa•s•m2	The flow in 24 hours [g/m2]
15	0.52
6	0.30
2	0.12

A similar lack of information in working drawings was encountered while inputting data into subgroups of requirements already mentioned, such as: “Drainage of precipitation and surface runoff” and “Limiting intrusion of precipitation”. In most cases, such details were not visible from working drawings; however, it does not necessarily mean that some of these improved practices were not planned to be incorporated anyway, such as installing gutters to collect rain water, sloping the ground away from the exterior walls to prevent ponding next to foundation walls, or installing gaskets under the sill-plates and above top-plates to reduce air leakage. Documenting such features in working drawings would earn additional points and significantly contribute to the overall performance score.

For all such cases of insufficient data, the minimum required building code and/or standard’s values were entered as default values, i.e. watertightness of windows as B2 (the minimum acceptable rating for the Montreal region according to the CAN/CSA A440.00 Standard). This may have affected the evaluation results of case studies with higher overall performance, such as Innova and Novoclimat, Figures 18 and 19. For example, the final results for air tightness of opaque parts of building envelopes and windows are 100%, and for doors is 0%, which is a minimum requirement of the code. One can assume that higher performance doors were also installed in those houses, but cannot speculate on the actual values to input into the Tool.

Evaluation – 2nd run

After identifying the causes for the faulty results from the evaluation, the strategy for dealing with these groups of sub-requirements was changed. It was decided that failing to incorporate these features should not be penalised in the evaluation process, but should be rewarded only if they are incorporated. Also, one negative point was given for each instance of unclear or missing information from working drawings; however, these negative points were not taken into account in the calculation of the final score. They are shown in the output chart, though, in order to point out to the designer and homebuilder where there is a need for clarification, and possible immediate improvement of the performance score. An example of this is shown in Figure 20: the negative scores only indicate that

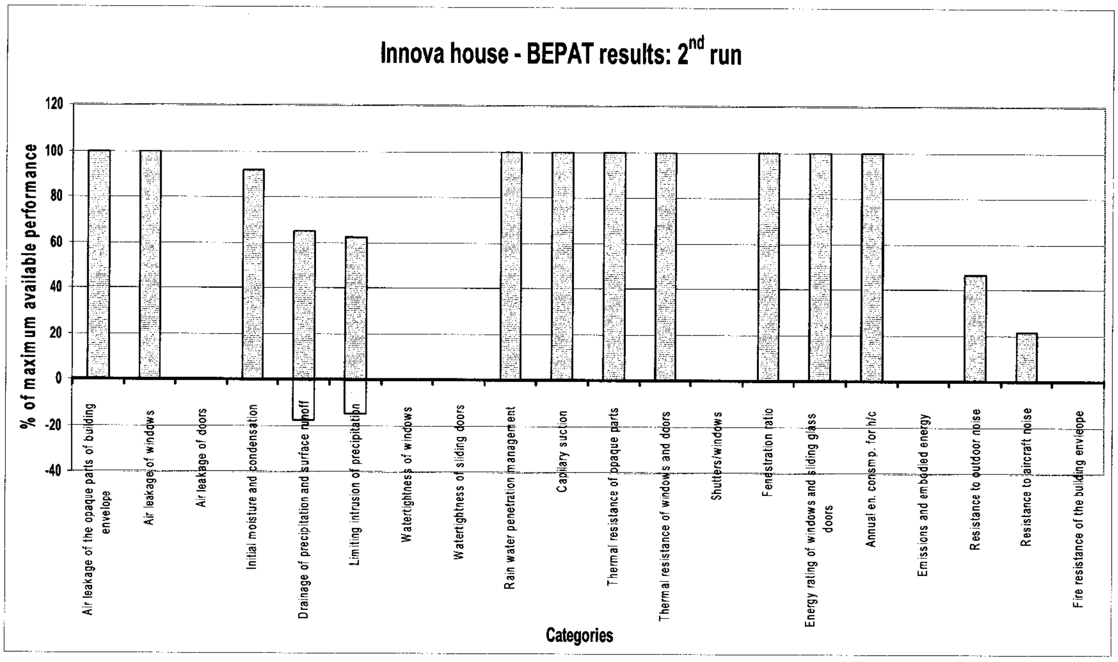

Figure 20: BEPAT evaluation, 2nd run: Innova House

there is an opportunity for improvement. It is clear that this correction was necessary in order to achieve more realistic results from the performance evaluation.

The next step for the designer is to examine the C-level (detailed) output and to determine exactly which sub-requirements provide an opportunity for immediate improvement. Figure 21 shows the excerpt from the C-level detailed output that presents that the sub-requirements that resulted in negative scores in this case were those which provided no information in working drawings, even though one can assume that the contractor probably incorporated these features during the construction process. Therefore, the designer can easily go back to working drawings and correct them. The complete C-level output for the 2nd run of the Innova House evaluation is presented in Appendix E of this thesis.

PERFORMANCE EVALUATION OUTPUT C - LEVEL (DETAILED)										
DESIGN STAGE										
FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMAN. REQMNT.	ACTUAL VALUES		SCORES (A)	◄	WEIGHT		RESULT (A x B)	SUB TOTAL	% of exceed. the benchmark
						FACTOR	% (B)			
Moisture management performance	Limiting intrusion of precipitation	Roofs:							51.55	63
		Planes sloped away	Yes	2		4	4.12	8.25		
		Sloped roof slope > 1:6	Yes	2		2	2.06	4.12		
		Valleys lead away	Yes	2		4	4.12	8.25		
		Flat roof slope >1:X	N/A	N/A		4	N/A	N/A		
		Flat roof valleys >1:Y	N/A	N/A		4	N/A	N/A		
		Required drainage area	N/A	N/A		5	N/A	N/A		
		Flashings for penetrations	Yes	2		4	4.12	8.25		
		Deposition on walls								
		Overhangs' size	40 - 60 cm (16' - 24')	1		2	2.06	2.06	-12.37	-15
		Gutters at roof edges	No info	-1	◄	2	2.06	-2.06		
		Downspouts	No info	-1	◄	5	5.15	-5.15		
		Sloped balconies	No info	-1	◄	2	2.06	-2.06		
		Tresholds' flashings	Yes	2		4	4.12	8.25		
		Junctions' flashings	Yes	2		4	4.12	8.25		
		Sloped window sills	Yes	2		2	2.06	4.12		
		Sill drips	No info	-1	◄	3	3.09	-3.09		
		Coping drips	N/A	N/A		3	N/A	N/A		

Figure 21: Excerpt from the C-level output from the BEPAT evaluation, 2nd run for Innova house

The same applies for the evaluation results of the remaining case studies. The evaluation results of the remaining case studies are shown in Figures 22, 23, 24 and 25.[34] As in the previous graphs, y = 0% represents the minimum requirements of the NBC 1995, National Housing Code Canada 1997 and the Québec Energy Code, while y = 100% represents the maximum level of performance that can be achieved by this Protocol.

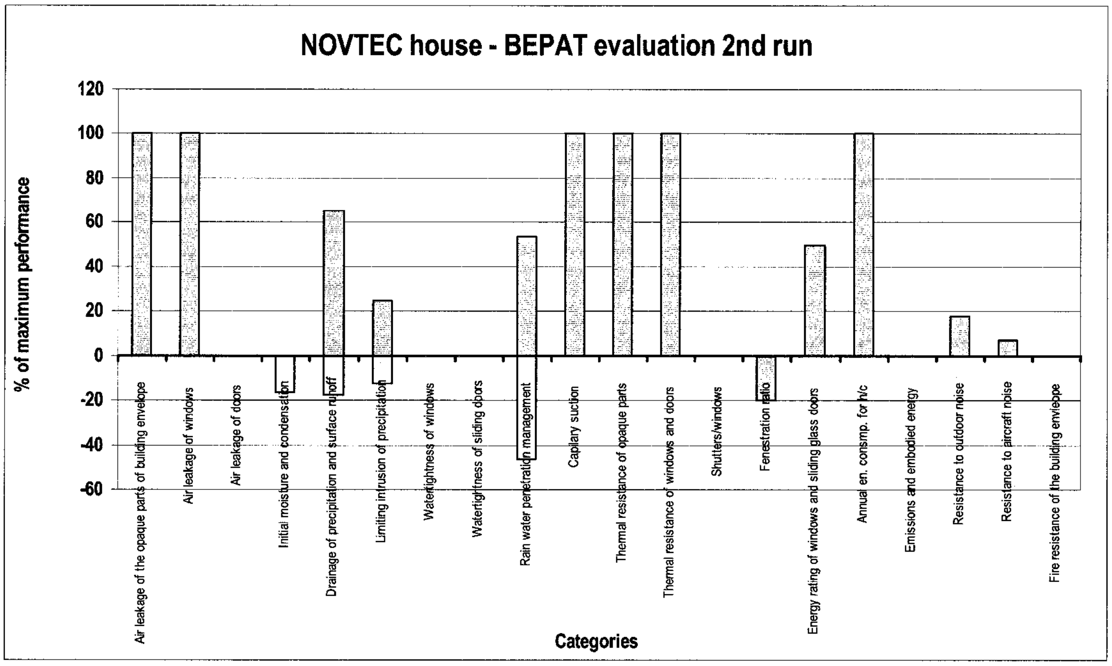

Figure 22: BEPAT evaluation, 2nd run: NOVTEC House

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[34] The performance results outputs for the remaining 4 case studies that were sources for generating these charts are presented in Appendix F of this thesis.

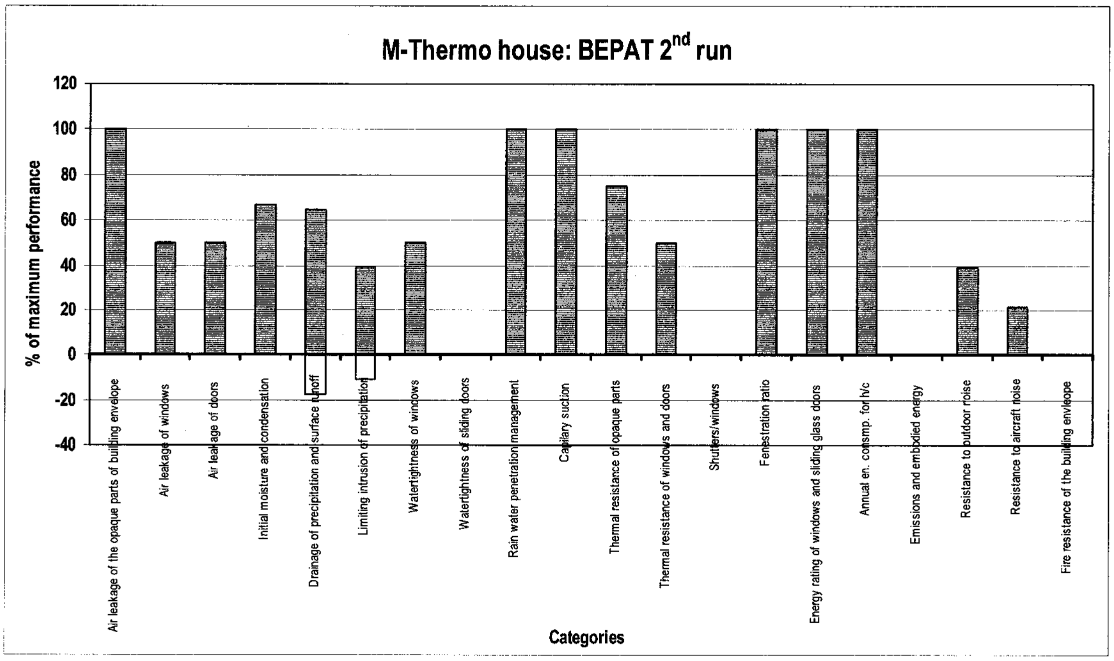

Figure 23: BEPAT evaluation, 2nd run: M-Thermo House

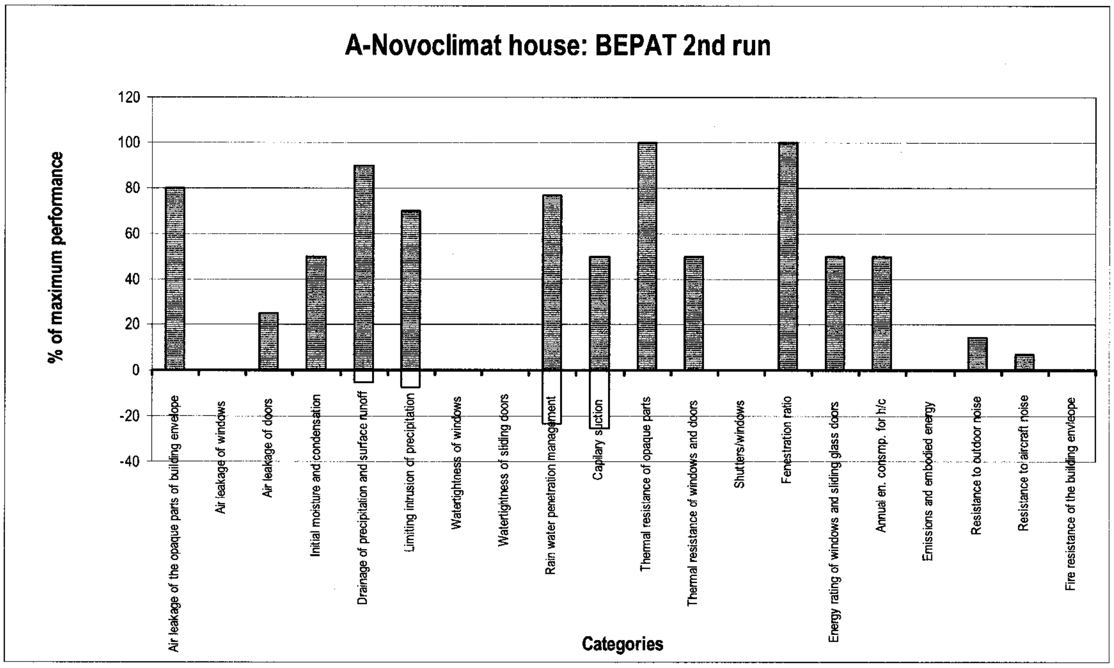

Figure 24: BEPAT evaluation, 2nd run: A-Novoclimat House

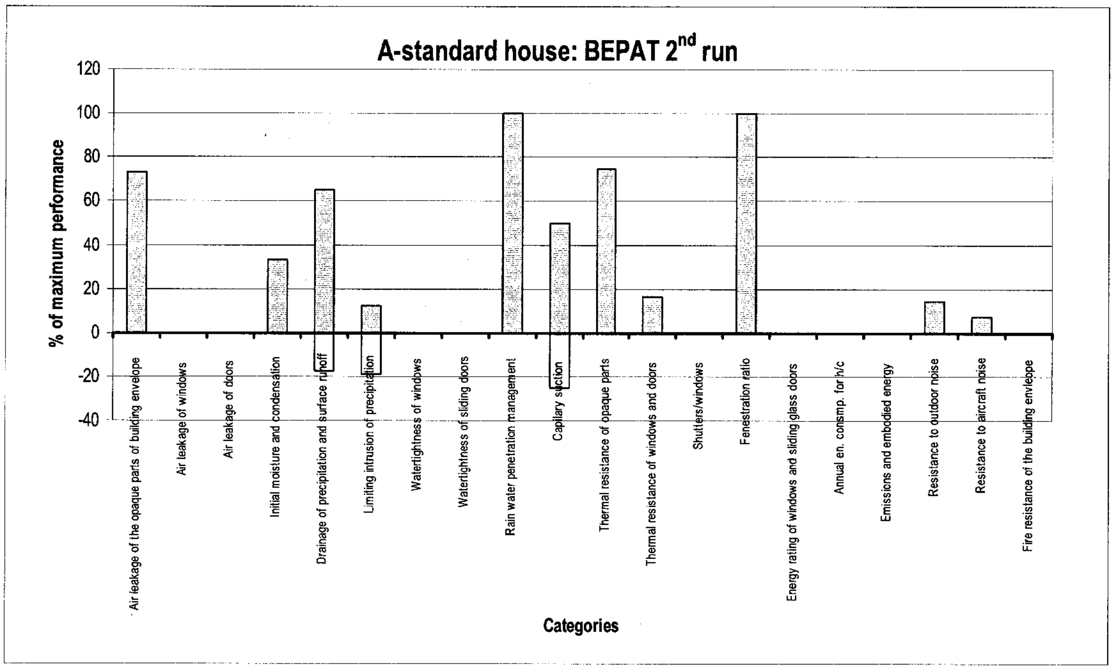

Figure 25: BEPAT evaluation, 2nd run: A-standard House

The next step was to combine the results of all case studies, to compare them and to examine how these case studies relate to each other. Figure 26 shows the results of all BEPAT performance evaluations, grouped together by categories at the B-level of output.

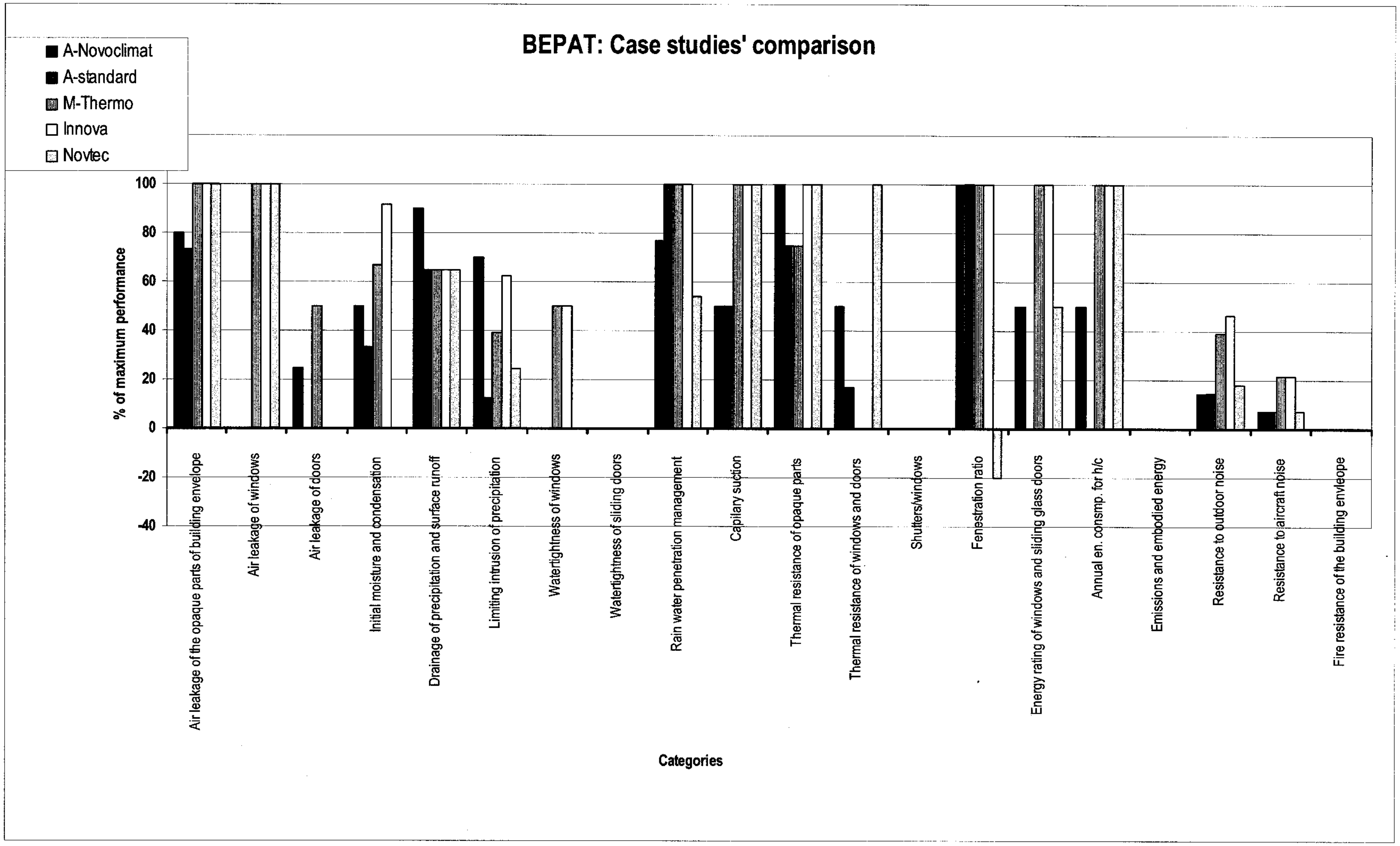

Figure 26: BEPAT evaluation results: all case studies comparison, 2nd run

It is immediately noticeable that all case studies achieved high scores at the performance evaluation, especially in categories of hygrothermal performance and energy efficiency. Even the Advanced houses – Innova and NOVTEC – do not excel in the results of the evaluation compared to other case studies as much as could be expected. There are possibly two reasons for this: when Innova and NOVTEC houses were built, in the early 1990s, they were advanced in comparison with other average houses built at that time.[35] New, innovative technologies were incorporated into these projects and high results were achieved in their performance evaluation. However, since then, many of these innovations, such as increased air tightness, an increased level of insulation, better quality windows, etc., have been gradually adopted by the mainstream housing industry. Second, the remaining three case studies that were evaluated were provided by home manufacturers who are not average home builders, but who constantly look into new advancements and are ready to incorporate improvements into their products. Even the standard model that is being offered by manufacturer A exceeds the minimum requirements of the NBC and the Québec Energy Code in terms of thermal performance and the quality of workmanship. It would have been useful for this exercise for the purpose of comparison to incorporate at least one conventionally site-built house, but, as mentioned earlier, collaboration with other homebuilders could not be obtained.

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[35] When built in the early 1990s, the Advanced houses were consuming only 25% of the energy, compared with the energy consumption of the conventionally built house of the same size.

Another detail that can be noticed in Figure 26 is that, according to this performance evaluation, the NOVTEC House fails to meet the building code requirements in the “Fenestration ratio” category. The criterion adopted for this sub-requirement was adopted from the National Housing Code of Canada 1977, which limits the percentage of glazing area vs. façade area. The NOVTEC House, however, has a large glazed area on its south façade, in order to take advantage of solar heat gain. In the HOT2000 energy performance evaluation as well as in years of use, this proved not to be a deficiency. The code also states that glazed vs. opaque area ratio can be exceeded if a higher level of insulation is provided in the opaque parts of the envelope, but it does not specify a numerical criterion. The original code ratio was adopted as a criterion for lack of a better solution. However, the weight of this sub-criterion is lesser in calculating the total thermal performance, so it does not greatly affect the overall score. This will be shown later in this chapter.

Evaluation – final scores

The evaluation results that were shown up until this point were the B-level type of output (i.e. intermediate level) where all performance requirements were shown.[36] As it was discussed before, this level of output is intended for

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[36] Except for structural performance; this category was not evaluated at this time since there was no innovative structural system employed in any of the case studies. They all used a conventional wood-frame structure.

professionals so they can go into detail and find out what particular instance did or did not provide expected results. It was also important for this exercise to start with this level in order to detect faults in the assessment tool based on the detailed results.

However, there is also a need to present the final results, on the level of functional requirements, i.e. the main categories of performance: air tightness, overall thermal performance, moisture management performance, energy consumption, acoustic performance, and fire resistance performance. To achieve final scores, a similar methodology was used as in the weighting system development. A weighting factor was assigned to each performance requirement in order to reflect the level of importance or priority within its group, i.e. the functional requirement. Each weight was expressed as a percentage of 100 within its group (Table 14).[37]

Then, each percentage is multiplied with its corresponding achieved level of performance (from B-level), and all results are added together within the functional requirement (e.g. air tightness). The final score is expressed as a percentage of the maximum score that can be achieved by this Protocol.

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[37] As described in Chapter 5, the weight factors are assigned subjectively by the author of this work and may not provide an absolutely objective representation of the total performance. The development of a more objective weighting system is recommended for future research.

Table 14: Weighting factors and their expression as a percentage of the total value within its group

Functional requirements	Performance Requirements	WEIGHT	%
Air tightness	Air leakage of the opaque parts of building envelope	1	20
	Air leakage of windows	2	40
	Air leakage of doors	2	40
Moisture management performance	Initial moisture and condensation	1	5
	Drainage of precipitation and surface runoff	3	19
	Limiting intrusion of precipitation	3	19
	Watertightness of windows	2	13
	Watertightness of sliding doors	2	13
	Rain water penetration management	4	25
	Capillary suction	1	6
Thermal performance	Thermal resistance of opaque parts	4	45
	Thermal resistance of windows and doors	3	33
	Shutters/windows	1	11
	Fenestration ratio	1	11
Energy performance	Energy rating of windows and sliding glass doors	1	17
	Annual en. consmp. for h/c	3	43
	Emissions and embodied energy	2	40
Acoustic performance	Resistance to outdoor noise	2	67
	Resistance to aircraft noise	1	33
Fire resistance performance	Fire resistance of the building envelope	1	100

The combined results of all the case studies obtained from the final performance evaluation scores for the six main categories, i.e. the functional requirements, are shown in Figure 27. All case studies produced very good results, exceeding the basic requirements of the NBC. However, the goal of this exercise was not to compare case studies to each other, but to verify the evaluation process, to examine the scoring and weighting system, and to compare the validity of parameters across case studies. This goal has been achieved.

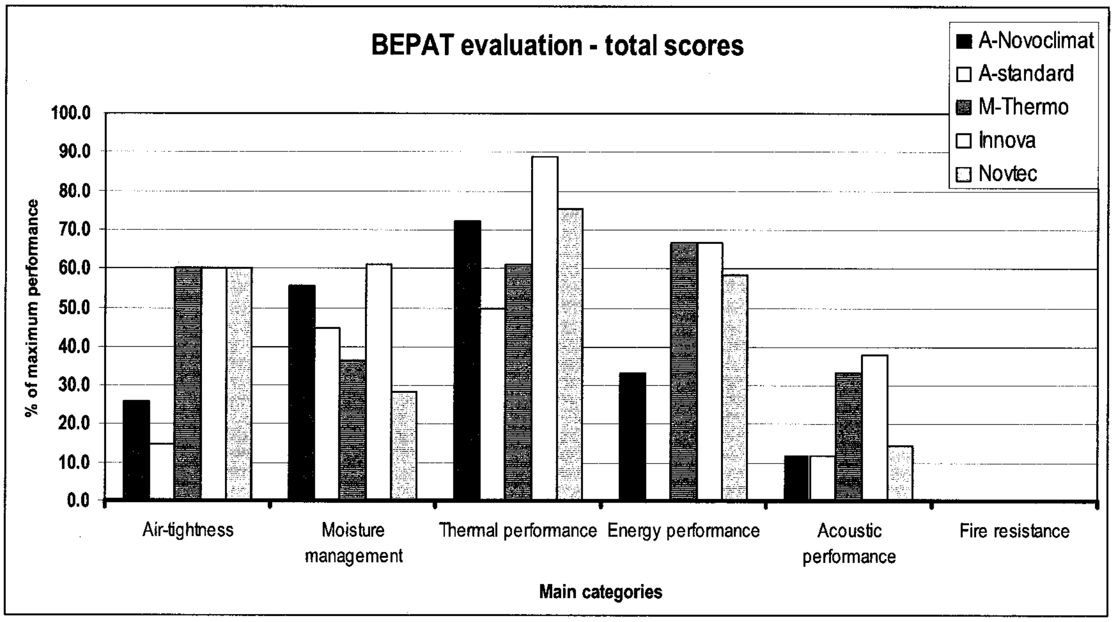

Figure 27: BEPAT evaluation: total scores – A-level

CONCLUSIONS

The Protocol and the Building Envelope Assessment Tool (BEPAT) was tested using five case studies of different houses of various building envelopes configurations. The main objective of this exercise was to test the validity of the Protocol and Assessment Tool and to detect possible inconsistencies and deficiencies. The test was done only for the "Design stage" of the Protocol, since it was impossible to follow the whole construction, pre- and post-occupancy stages. Such a total evaluation could be pursued as one possibility for future research projects.

It was found that the level of detail required for data input exceeds the information given in working drawings, and additional clarifications were needed. Also, the 1st run of the evaluation revealed that some of the approaches in the scoring and weighting system were inaccurate. Corrections were made and the 2nd run of the evaluation yielded more reliable results.

The Protocol has been used to establish the performance profiles of five case studies, demonstrating in each case the adequacy of each parameter, thus providing the designer with the opportunity to improve the design and to achieve greater performance.

The Protocol also provides a means of comparing the relative performance of respective parameters across the case studies.

The weighting system provides an overall rough yardstick to compare different building systems. Since the weighting factors are arbitrary, comparison between cases is not absolute.

CHAPTER 7: CONCLUSION, CONTRIBUTIONS AND RECOMMENDATIONS

CONCLUSION

The work of this thesis was designed to develop a protocol and an assessment tool for evaluating the performance of wood-frame building envelopes as integrated subsystems of entire buildings. The work was undertaken on the premise that a holistic approach to performance evaluation would provide more realistic representation of the overall performance of the building envelopes as opposed to existing approaches that evaluate either specific components of the building envelope and/or specific aspects of the performance (i.e. air tightness or thermal performance, energy performance, etc.). This objective has been achieved.

This thesis presents a review of several certification programs for housing that already exist or are under development in different regions of the world. It was recognised that in most cases the programs that deal with conventional building practices employ simple "Pass/Fail" evaluation systems, while those which deal with environmental impact and sustainability seem to better represent the overall results of performance evaluation, because levels of priority and the importance of specific issues are established by introducing weighted scores. This finding directly influenced the approach to this work. This thesis developed a performance evaluation program that combines the functional requirements considered in conventional building practices with an advanced assessment methodology of scoring and weighting.

Given the length and complexity of the work required, the development process was broken down into several steps, as follows:

An overall performance technique of the wood-frame building envelope has been established

In light of the holistic approach to performance evaluation, the overall performance of light-frame building envelopes as systems was established by the development of the Protocol for Building Envelope Performance Evaluation. The Protocol most comprehensively integrates different aspects (i.e. functional requirements) of building envelope performance by including: air tightness, thermal performance, moisture management performance, energy performance, acoustic performance, fire response and, indirectly, the quality control of design and workmanship. Each functional requirement consists of the set of sub-requirements, i.e. operative or performance requirements, with their corresponding criteria or benchmarks for the minimum acceptable performance. The establishment of criteria was based on setting the internal and external conditions specific to the Montreal region such as climatic condition, type of energy supply, common building practices, etc. Criteria or benchmarks are quantitative values, in most cases based on the requirements of the National Housing Code Canada 1998, National Energy Code of Canada for Houses 1997, Québec Energy Code 2005 edition, and other programs currently available. In other cases, when quantitative value could not be set as a criterion, qualitative values are adopted based on guidelines of recommended practices. The Protocol also establishes a method of evaluation for each particular performance requirement (e.g. test method, calculation procedure, visual assessment, etc.) in order to obtain results that are then compared to the given criterion or benchmark. The evaluation methods also define the parameters that are included in evaluations such as boundary conditions, loads, measurements, sensors used for measuring, what type of data to be calculated from these measurements, etc. The Protocol for performance evaluation, its structure, internal and external conditions, and criteria set for these conditions result in a quantitative and qualitative definition of building envelope performance for the Montreal region. This Protocol also establishes a framework for the development of similar protocols for other regions. In addition, it provides a foundation for the development of a certification program for light-frame building envelopes, both prefabricated and site-built.

A strategy to evaluate the building envelope performance has been developed

The Protocol sets the stages of evaluation from the design stage of the whole house, installation stage both in-plant and on-site, laboratory tests for innovative building envelope systems, field tests prior to occupancy, and a monitoring schedule during occupancy. It also defines the levels of evaluation such as unofficial, internal evaluation and official, external evaluation. Internal evaluations, to be done by designer and contractor or site manager, have the purpose of detecting errors in early stages that can be easily corrected and to improve communication between these participants in the construction process. These also serve as an internal quality control of design and workmanship. External evaluation is to be done by an independent 3rd party evaluator and its purpose is to provide objective and impartial results of the performance evaluation that can be used to obtain a certification stamp.

The holistic approach to overall performance evaluation can be achieved only by following the performance evaluation throughout all stages of the Protocol.

A scoring and weighting system has been adopted.

At the scoring stage the points assigned to each sub-requirement response reflect if and at what level a given response satisfies (or not) its corresponding criterion. The points assigned range from -2, -1, 0, +1, +2, where 0 is assigned when the performance meets the local building codes, regulations, or professionally accepted practice (in the absence of an appropriate code requirement); +1 and + 2 indicate that the performance exceeds the requirement, and -1 and -2 indicate that the envelope performs below expectations. Then, a weighting system was created, in which each sub-criterion's score is assigned a weight factor that reflects a level of importance, or priority, of a given sub-requirement within its own group. A sub-criterion's scores are then multiplied by their corresponding weight factors, and the results of these multiplications are then added together to form a total score for that particular aspect (i.e. a functional requirement, such as air tightness, thermal performance, etc.). This total score is also expressed as a percentage, where 0% represents minimum requirements of building codes, and 100% represents the maximum performance level that can be achieved on this protocol's scale. This weighting system enables the stakeholders to introduce their priorities and a value system into the evaluation and/or selection of the particular building system.

A Building Envelope Performance Assessment Tool (BEPAT) has been implemented in the protocol

The strategy for evaluation, scoring, and weighting is implemented in the user-friendly tool called BEPAT (Building Envelope Performance Evaluation Tool). Developed in Excel, this tool performs the scoring and weighting processes described above and presents the results in tabular and graphic form. There are three levels of output: A-level (simple output) which provides only the overall final scores for each aspect of performance; B-level (intermediate output) which provides more detailed information drawing a quick overall picture of the performance; and finally C-level (detailed report output), intended for professionals, that presents the results of the performance evaluation for each sub-requirement in great detail for closer examination. The tool BEPAT puts this work in the hands of participants for ready use in the evaluation process of building envelope systems.

The Protocol and BEPAT have been validated

The validation of the protocol and the assessment tool was done by evaluating the performance of five different building envelope assemblies: one modular prefabricated house designed and built according to the requirements of the NBC and the Québec Energy Code (A-standard house), one modular prefabricated house designed to conform to requirements of the Novoclimat program (A-Novoclimat house), one panellised high performance house (M-Thermo house) and two Advanced houses: NOVTEC Advanced House and Innova Advanced House. Due to time constraints, the validation was done for the design stage only. The results of the validation show that the protocol and the assessment tool are effectively used to establish the performance profiles of these five case studies, demonstrating in each case the adequacy of each parameter. The results also demonstrate that the protocol provides a means of comparing the relative performance of respective parameters across case studies.

CONTRIBUTIONS

The development of the Building Envelope Performance Evaluation Protocol and the Assessment Tool provide significant contributions to existing knowledge.

1) The performance evaluation Protocol is the first and, so far, only protocol to comprehensively integrate different aspects of building envelope performance in Canada, by including the following aspects of evaluation: air tightness, thermal performance, moisture management performance, energy performance, acoustic performance, fire response and, indirectly, the quality control of design and workmanship;
2) The Protocol establishes the performance requirements and their corresponding criteria for the specific conditions of Montreal, and in this way it defines the expectations of minimum acceptable performance for light-frame building envelopes used in this region;
3) The Protocol defines the parameters included in evaluations, such as: boundary conditions, loads, measurements, sensors used for measuring, type of data to be calculated from these measurements, etc.;
4) The Protocol defines evaluation (verification) methods such as various testing methods, calculation procedures, etc. It relies on standards and test methods that are already in use in North America and, therefore, can be applied immediately;

5) The Protocol also identifies knowledge gaps and thus defines future research needs. Examples of knowledge gaps are:
    a) The lack of available criteria: for some performance requirements it was found that there are no scientifically established criteria for an acceptable level of performance (Table 12, p.88). In some cases, the adopted criteria were typically accepted by professionals, i.e. values that were proven to be adequate over many years of practice. However, for some requirements even those values were not possible to define. In addition, cases were identified where the criteria could not be defined in a quantitative manner, but only as a qualitative measure;
    b) The lack of available testing and evaluation procedures: similarly, for some performance requirements it was found that there are no standardised test procedures and evaluation methods available. This is mostly the case in testing large scale wall/roof assemblies;
6) The Protocol defines a strategy for performance evaluation by setting the schedules for evaluation and defining the roles and qualifications of all participants in the evaluation process;
7) Developed for the specific conditions of Montreal and near surroundings, this Protocol establishes a framework for the development of similar protocols for other regions;
8) This Protocol provides a foundation for the development of a certification program for light-frame building envelopes, both prefabricated and site-built;

9) This Protocol also served as the basis for developing the assessment tool. The Protocol, the strategy for evaluation, and the scoring and weighting system developed for this purpose are implemented together in the user-friendly tool called BEPAT (Building Envelope Performance Evaluation Tool) that can be used by professionals (designers, architects, engineers, builders, building inspectors and other participants) in the building and performance evaluation processes.

In addition, the Building Envelope Performance Assessment Tool (BEPAT) contributes to the design and operation of building envelope systems and to the communication between the parties involved. For example, using the design stage part of the Assessment Tool, the designer can immediately check the design choices by comparing them with provided criteria and make appropriate changes at this stage. Simultaneously, by identifying and correcting mistakes (either at the design or execution stages) professionals can learn from them and avoid similar errors in the future. BEPAT can also serve as a communication tool between designers, contractors, developers, building inspectors, and homeowners: since the Tool assesses the project at all stages from design to occupancy, the results from each stage assessment can be circulated between the participants in the process in order to improve communication between them.

RECOMMENDATIONS FOR FUTURE WORK

This research work has opened avenues for several further research projects. For example:

1) The development of an assessment tool as a user-friendly computer program: this project is already under development as a Master's thesis at the Department of Building, Civil and Environmental Engineering, Concordia University, by student Hua Sheng He, under the supervision of Dr. Paul Fazio and Dr. Amin Hammad;
2) Further expansion of the moisture management aspect, both in the design and execution phases, in the form of developing a checklist of details of critical points of the building envelope, where air leakage and/or rain penetration will likely occur. It could be developed as a database of detailing option principles and possibly presented in the form of drawings. This could be a research project at the Master's level for a student with an architectural background;
3) Experimental validation of the part of the protocol that addresses laboratory testing applicable to newly designed and innovative building envelope assemblies. This project could be at the Master's level for a student with a background in building science, building, civil or mechanical engineering;
4) The development of similar protocols and assessment tools for different climatic conditions: e.g. cold and dry climates, hot and humid climates, hot and dry climates, etc., using the existing protocol and assessment tool as a

framework. These projects can be carried out as Master's thesis projects or extended technical report projects for students with backgrounds in architecture or building engineering and with knowledge of other regions' climatic, technical and sociological conditions and different building practices;[38]

5) Further development of scoring and weighting systems by undertaking a survey of various participants in the building process (e.g. architects, engineers, contractors, building inspectors and even homeowners) in order to establish the differences in priorities between these groups. This project can be carried out as a Master's thesis for a student with a background in architectural science or building engineering;
6) Further development of the post-occupancy monitoring part of the protocol, in order to explore how occupants' behaviour affects building envelope performance. The results of this study could lead to the development of an improved maintenance manual for owners/occupants. This research project can be carried out as a Master's thesis or extended technical report by a student with a background in architecture or building engineering;
7) Both the Protocol and the Assessment Tool can be further expanded into other areas that were outside of this author's expertise:
    a) structural performance;

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[38] Such project has already been commenced by the author at the Department of Architectural Science, Ryerson University in summer 2005, in order to adapt the Protocol and BEPAT to conditions in the Greater Toronto Area.

b) acoustic performance, e.g. developing criteria for the resistance of building envelopes to outdoor noise and to aircraft noise, and the means of evaluation to this end;

c) service life prediction criteria and their means of evaluation;

d) cost estimations criteria and methods of evaluation; the relation between the construction cost and building envelope performance as well as initial costs vs. lifetime costs of a high-performance building envelope.

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ASTM C1199-00 Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using hot box Methods

ASTM C1303-00 Standard Test Method for Estimating the Long-Term Change in the Thermal Resistance of Unfaced Rigid Closed Cell Plastic Foams by Slicing and Scaling Under Controlled Laboratory Conditions

ASTM C1320-99 Standard Practice for Installation of Mineral Fiber Batt and Blanket Thermal Insulation for Light Frame Construction

ASTM C1363-97 Standard Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus;

ASTM C1373-01 Standard Practice for Determination of Thermal Resistance of Attic Insulation Systems Under Simulated Winter Conditions

ASTM C687-96 Standard Practice for Determination of Thermal Resistance of Loose-Fill Building Insulation

ASTM C755-97 Standard Practice for Selection of Vapor Retarders for Thermal Insulation

ASTM D198-02 Standard test methods of static tests of lumber in structural sizes

ASTM D4442-92(1997)e1 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials

ASTM D4442-92(1997)e1 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials

ASTM E1105-96 Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Static Air Pressure Difference;

ASTM E1186-98 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Retarder Systems

ASTM E1332-90(1998) Standard Classification for Determination of Outdoor-Indoor Transmission Class;

ASTM E1423-99 Standard Practice for Determining the Steady State Thermal Transmittance of Fenestration Systems

ASTM E1424-91 (Reapproved 2000) Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen

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ASTM E1677-95(2000) Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls

ASTM E1803-99 Standard Test Methods for Determining Structural Capacities of Insulated Panels

ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings

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ASTM E331-96 Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference;

ASTM E514-90 (Reapproved 1996) Standard Test Method for Water Penetration and Leakage Through Masonry

ASTM E547-00 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference

ASTM E564-00e1 Standard Practice for Static Load Test for Shear Resistance of Framed Walls for Buildings

ASTM E603-01 Standard Guide for Room Fire Experiments

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ASTM E72-02 Standard test Methods of Conducting Strength Tests of Panels for Building Construction

ASTM E779 - 99 Standard test Method for Determining Air Leakage Rate by Fan Pressurization

ASTM E90-02 Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements

ASTM E96-00e1 Standard Test Methods for Water Vapour Transmission of Materials

ASTM E966-02 Standard Guide for Field Measurements of Airborne Sound Insulation of Building Facades and Facade Elements;

ASTM WK305 Test Method for Room Fire Test of Wall and Ceiling Materials and Assemblies, Draft Under Development

CAN/CGSB 149.10-M86 Determination of the Air-tightness of Building Envelopes by the Fan Depressurization Method

CAN/CGSB 149-GP-2MP Manual for Thermographic Analysis of Building Enclosures;

CAN/CGSB 82.1-M89 Sliding Doors

CAN/CSA-A440.2-98 Energy Performance Evaluation of Windows and Sliding Glass Doors

CAN/CSA-A440-M90 Windows

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DIN 52611-1 Determination of thermal resistance of building elements; laboratory method

DIN EN 12354-4 Building acoustics - Estimation of acoustic performance of buildings from the performance of products - Part 4: Transmission of indoor sound to the outside;

DIN EN 12865 Hygrothermal performance of building components and building elements - Determination of the resistance of external wall systems to driving rain under pulsating air pressure;

EN 673 Glass in Building - Determination of thermal transmittance (U value) - Calculation method

IRC test: A test method to determine air flow resistance of exterior membranes and sheathings by M. Bomberg and M. K. Kumaran *(still to be found);*

ISO 10211-1:1995 Thermal bridges in building construction -- Heat flows and surface temperatures -- Part 1: General calculation methods

ISO 10211-2:2001 Thermal bridges in building construction -- Calculation of heat flows and surface temperatures -- Part 2: Linear thermal bridges

ISO 12491:1997 Statistical methods for quality control of building materials and components

ISO 140-5:1998 Acoustics -- Measurement of sound insulation in buildings and of building elements -- Part 5: Field measurements of airborne sound insulation of facade elements and facades

ISO 14683: 1999 Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values

ISO 6781: 1983: Thermal Insulation - Qualitative Detection of Thermal Irregularities in Building Envelopes - Infrared Method

ISO 6781: 1983: Thermal Insulation - Qualitative Detection of Thermal Irregularities in Building Envelopes - Infrared Method

ISO 6946: 1996 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method

NHCC - National Housing Code Canada1998

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NT ACOU 102 (App.1999-06) Building Elements - Façade Elements and Facades: Field Measurement of Airborne Sound Insulation - Loudspeaker Method Using MLS (Maximum Length Sequence) Noise Signals

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NT BUILD 434 (App. 1995-05) Roofing Membrane Underlay (Insulation Material): Ageing Due to Increased Humidity and Heat

NT BUILD 495 (App. 2000-11) Building Materials and Components in the Vertical Position: Exposure to Accelerated Climatic Strains

prEN ISO 10077-1 (Final draft) March 1999: Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 1: Simplified method (ISO/FDIS 10077-1:1999)

prEN ISO 13788:1997 Hygrothermal performance of building components and building elements -- Internal surface temperature to avoid critical surface humidity and interstitial condensation -- Calculation methods

User's Guide - NBC 1995 Structural Commentaries (Part 4)

APPENDIX A : PROTOCOL TABLE

PROTOCOL FOR PERFORMANCE EVALUATION OF LIGHT FRAME BUILDING ENVELOPES

Design stage

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Air tightness	Air permeance of the opaque panel assemblies	≤ 0.02 L/s per m^2 @ 75 Pa	ASTM E1677-95(2000) Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls
	Air leakage of windows	≤ 0.77 L/s per m' of sash crack[39] (≤ 2.79 m^3/h per m' = A1)	CAN/CSA-A440-M90 Windows CAN/CSA-A440.2-98 Energy Performance Evaluation of Windows and Sliding Glass Doors
	Air leakage of doors - sliding doors and non-weather stripped doors	≤ 2.5 L/s per m^2 of door area @75 Pa[40]	CAN/CGSB 82.1-M89 Sliding Doors CAN/CSA-A440.2-98 Energy Performance Evaluation of Windows and Sliding Glass Doors
	Air leakage of doors - all other doors	≤ 17 L/s per m' of sash crack[41]	
Moisture management performance	Initial (construction) moisture content of structural lumber	Mandatory use of kiln dried wood: <19% at the time of installation National Housing Code of Canada 1998, 1.4.2.5	ASTM D4442-92(1997)e1 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials

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[39] Quebec Energy Code
[40] Quebec Energy Code
[41] Quebec Energy Code

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Rain water penetration management	Mandatory rain screen: existence of drainage space, drainage plane and flashing	Control of design (drawings)
	Rain water penetration management (cont.)	Not allowed to penetrate into a backwall (part of the wall behind cladding and air-space)	ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings
	Rain water penetration management	Roof slopes, gutters, *evaluation through details in assessment tool*	*DIN 18460 - External rainwater pipes and eaves gutters; concepts and design principles (FOREIGN STANDARD)*[42]*.*
	Rain water penetration management	sealing *evaluation through details in assessment tool*	*DIN 18540 Design and sealing of joints in external walls of buildings (FOREIGN STANDARD)*[43]
Moisture management performance	Water vapor permeability of the assembly	Mandatory vapour barrier installed on the warm side of insulation, with initial permeance < 45 ng/(Pa·s·m^2) or < 15 ng/(Pa·s·m^2), if sheathing or cladding on the exterior side have low permeance. (National Housing Code of Canada 1998)	ASTM C755-97 Standard Practice for Selection of Vapor Retarders for Thermal Insulation

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[42] The standard deals with terms and definition as well as principles for the dimensioning of roof gutters and external rainwater pipes, which serve to drain the rainwater away from roofs, balconies and loggias.

[43] This document applies to the requirements on and the testing of joint sealants as well as for the design of exterior wall joints and their sealing with sealants.

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Surface condensation (depends on indoor RH levels)	Not allowed	Computation: Dew-Point Method- ASHRAE Fundamentals, 1997 - 22.18 CONDENSE software pr EN ISO 13788:1997 Hygrothermal performance of building components and building elements -- Internal surface temperature to avoid critical surface humidity and interstitial condensation -- Calculation methods[44]
Moisture management performance	Interstitial condensation[45];	<50,000 ng/s·m^2[46] Moisture limit[47]	Computation: Dew-Point Method- ASHRAE Fundamentals, 1997 - 22.18 CONDENSE software prEN ISO 13788:1997 Hygrothermal performance of building components and building elements -- Internal surface temperature to avoid critical surface humidity and interstitial condensation -- Calculation methods[48]

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[44] There is 2001 version.

[45] Computation of water vapor movement and temperature and pressure drops across the assembly;

[46] Hutcheon, N. *Building Science for a Cold Science;* - however, he gave this value out of experience, it is not scientifically proved.

[47] By *moisture limit*, it is meant the maximum level of water content that can be contained in an insulation material without degradation of critical physical and thermal properties.

[48] There is 2001 version.

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	*Dryability* of the assembly: allowing trapped moisture to escape: setting the levels of water vapor permeance for layers	Mandatory vapour barrier installed on the warm side of insulation, with initial permeance < 45 ng/(Pa·s·m^2) or < 15 ng/(Pa·s·m^2), if sheathing or cladding on the exterior side have low permeance. (National Housing Code of Canada 1998)	Control of design (drawings)
Moisture management performance	Drainage of precipitation and surface runoff	Surface grading:	Control of design (drawings),
		Building external drains	Control of design (drawings),
		Impermeable cap over backfill	Control of design (drawings),
		Free-draining backfill (drain screen)	Control of design (drawings),
		Waterproofing barriers / Membranes:	Control of design (drawings),
		Subgrade drainage system (drainage pipes)	Control of design (drawings),
		Control joints	Control of design (drawings),

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Limiting intrusion of precipitation (roofs)	Roof planes sloped away from building	Control of design (drawings),
		Roof planes sloped more than 1:6 (NBC)	Control of design (drawings),
		Roof valleys sloped away from the building	Control of design (drawings),
		Flat roof planes sloped minimum 2%	Control of design (drawings),
		Flat roof valleys sloped more than 0.5%[49]	Control of design (drawings),
		Flashings and additional sealing for all penetrations through water shedding roof membranes	Control of design (drawings),
	Limiting intrusion of precipitation: reducing deposition on exterior walls	The size of roof overhangs	Control of design (drawings),
		Gutters at all sloped roof perimeters	Control of design (drawings),
		Design size of rainwater downspouts	Control of design (drawings),
		Balconies, terraces and decks sloped away from exterior walls	Control of design (drawings),
		Flashing and sealing of balconies thresholds	Control of design (drawings),

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[49] NHC 1998 does not have this requirement. This is from DIN codes

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Limiting intrusion of precipitation: reducing deposition on exterior walls	Flashing and sealing of junctions of exterior walls with large horizontal surfaces (decks, balconies, roofs)	Control of design (drawings),
		Window sills sloped away from the window	Control of design (drawings),
		Drip on window sills	Control of design (drawings),
		Drip on copings	Control of design (drawings),
Moisture management performance	Limiting intrusion of precipitation: Water-tightness rating of windows	B2[50]	Control of design (drawings),
	Limiting intrusion of precipitation: Water-tightness rating of glass sliding doors	B2[51]	Control of design (drawings),
	Rain water penetration management	Drainage space behind cladding: air space of min. 1 in	Control of design (drawings),
	Rain water penetration management	Drainage plane	Control of design (drawings),
		Flashings	Control of design (drawings),
		Weep holes	Control of design (drawings),

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[50] CSA A440.2-98 Energy performance of Windows and Other Fenestration Systems
[51] CSA A440.2-98 Energy performance of Windows and Other Fenestration Systems

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Capillary suction - control below grade	3/4 in layer of crushed stone below basement slab	Control of design (drawings),
		capillary break over the top of the footing, placed prior to construction of perimeter foundation walls	Control of design (drawings),
		dampproofing the exterior surface of basement walls	Control of design (drawings),
		capillary break between the sill plate and the top of foundation wall	Control of design (drawings),
	Capillary suction - control above grade	capillary break in porous cladding materials (e.g. horizontal wood siding)	Control of design (drawings),

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Thermal performance - steady state	Thermal resistance of opaque parts of the envelope (as built values)	Roof: RSI 5.3 Above grade walls: 3.4 Bellow grade walls: 2.2 Floors above non heated space: 4.7 Basement floor: 0.0 Crawl space floor: 0[52] Slab-on-grade with embedded pipes 1.6 Slab -on-grade without pipes 1.2	Computation of overall thermal resistance of opaque parts of the envelope: ASHRAE Handbook - Fundamentals, 1997 - chapter 22.7, parallel-path and/or isothermal planes -equations 1-5); CONDENSE software; ISO 6946: 1996 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method
	Thermal resistance of installed windows	RSI = 0.35 m^2 C/W[53]	Calculating overall thermal resistance of windows: ASTM E1423-99 Standard Practice for Determining the Steady State Thermal Transmittance of Fenestration Systems prEN ISO 10077-1 (Final draft) March 1999: Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 1: Simplified method (ISO/FDIS 10077-1:1999) EN 673 Glass in Building - Determination of thermal transmittance (U value) - Calculation method
Thermal performance - steady state	Thermal resistance of installed doors	RSI = 0.70 m^2 C/W[54]	Calculating overall thermal resistance: Hot2000 software

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[52] Quebec Energy Code Values
[53] ibid.
[54] Quebec Energy Code Values

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Transient thermal response	Ratio of fenestration vs. whole wall area elevation	Total glazing area < 15% of the floor area - Quebec Energy Code values, point 61;	Computation
Energy performance	Energy level rating of windows and glass sliding door	EL3[55]	Control of design (drawings),
Energy performance	Annual energy consumption for heating and cooling	in kWh/year (to be compared with reference house)	Design: NRC-ENERGY CODE FOR HOUSES-BINDER-97: National Energy Code of Canada for Houses 1997 Computation: Hot2000, current version of the software[56]
Energy performance	Emissions	to be compared with reference house	EEE software

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[55] CSA A440.2-98 Energy Performance of Windows and Other Fenestration Systems

[56] Also: EN 832: 1998 Thermal performance of buildings - Calculation of energy use for heating - Residential buildings; prEN ISO 15927- 4:2000 - Hygrothermal performance of buildings - Climatic data - Part 4: Data for assessing the annual energy demand for cooling and heating systems (ISO/DIS 15927-4:2000)

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Structural stability of building envelope	Resistance to vertical loads	Live loads: Bedrooms:1.4 kN/m^2 Other rooms: 1.9 kN/m^2 Dead loads: depending on structure-refer to CSA O86-01 and NBC	CSA O86-01 Engineering Design in Wood WoodWork Design Office 2002 - software
Structural stability of building envelope	Wind-load resistance of opaque parts	Specified external pressure or suction on part or all of the surface of building: $p = q\ C_e \cdot C_g \cdot C_p$ for Montreal: $p=0.37 \cdot 1.0 \cdot C_g \cdot C_p$[57] [kPa]	NHC - National Housing Code 1998 User's Guide - NBC 1995 Structural Commentaries (Part 4) CSA O86-01 Engineering Design in Wood WoodWork Design Office 2002 - software
Structural stability of building envelope	Wind-load resistance of windows and glass sliding doors	C2[58]	Control of design (drawings),
Structural stability of building envelope	Resistance to horizontal loads - seismic	Acceleration-related seismic zone Z_a = 4 Velocity-related seismic zone Z_v = 2[59]	CSA O86-01 Engineering Design in Wood WoodWork Design Office 2002 - software

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[57] $C_g \cdot C_p$ to be chosen from NBC 1995 Structural Commentaries (Part 4), from Figures B-7 to B-14, depending on the orientation and the size of the element in question, the shape of the building etc.

[58] CSA A440.2-98 Energy Performance of Windows and Other Fenestration Systems

[59] NHC - National Housing Code of Canada 1998;

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Acoustic performance of building envelope	Resistance to outdoor noise - design guidelines	The choice of materials and components	Control of design (drawings)
		Siding - add mass to the exterior walls. Heavy cladding prefered over light ones	Control of design (drawings)
		Insulation - sound absorbant. Porous materials prefered over insulating boards	Control of design (drawings)
	Resistance to outdoor noise - design guidelines	Structural breaks - staggered stud system prefered over conventional single stud wall	Control of design (drawings)
		Interior finishing - double gypsum board system, or gypsum board on resilient channels preffered over single gypsum board attached directly to the studs.	Control of design (drawings)
	Resistance to outdoor noise - design guidelines	Windows - type: larger airspace between glass panes prefered over small ones	Control of design (drawings)
		Windows - openings: fixed windows prefered over openable ones	Control of design (drawings)
		Roof assembly - insulated attics prefered over cathedral type roofs	Control of design (drawings)
	Aircraft noise sound insulation	Indoor sound level vs. frequency	Scenario comparison by IBANA-Calc software, against control sample house.
		A-weighted indoor sound level vs. frequency	Scenario comparison by IBANA-Calc software, against control sample house.
		Transmission loss vs. frequency	Scenario comparison by IBANA-Calc software, against control sample house.
		Source NEF-Leq24 calibrated sound level vs. frequency	Scenario comparison by IBANA-Calc software, against control sample house.

<table>
<tr><th>FUNCTIONAL REQUIREMENT</th><th>OPERATIVE (PERFORMANCE) REQUIREMENT</th><th>CRITERION</th><th>EVALUATION (VERIFICATION) METHOD</th></tr>
<tr><td>**Fire control of building envelope**</td><td>Spatial separation of buildings (NHC)</td><td>If limiting distance[60] < 1.2 m, the exposing building face[61] must have fire rating min 45 min.
If limiting distance < 0.6 m, the exposing face must have a noncombustible cladding.</td><td>Control of design (drawings)</td></tr>
<tr><td>**Fire control of building envelope**</td><td>Location of skylights</td><td>No skylights within a hor. distance of 5 m of the windows in the exposed wall from adjoining roof of a separate unsprinkeled *fire compartment* in the same *building*</td><td>Control of design (drawings)</td></tr>
<tr><td>**Fire control of building envelope**</td><td>Maximum percentage area of unprotected openings in exterior walls</td><td>See table 6.3.2.1.A. of National Housing Code of Canada 1998</td><td>Control of design (drawings)</td></tr>
<tr><td>**Fire control of building envelope**</td><td>Minimum construction requirements for exposing faces</td><td><table>
<tr><th>% openings</th><th>fire rating</th><th>construction req.</th><th>cladding req.</th></tr>
<tr><td>0-10</td><td>1 h</td><td>non-comb</td><td>non-comb.</td></tr>
<tr><td>11-25</td><td>1 h</td><td>comb./non-comb</td><td>non-comb.</td></tr>
<tr><td>26-<100</td><td>45 min</td><td>comb./non-comb</td><td>comb./non-comb</td></tr>
</table></td><td>Control of design (drawings)</td></tr>
</table>

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[60] Limiting distance: id the distance from an exposing building face to a property line, or to an imaginary line between two buildings*(NHC,1995)*;

[61] The exposing building face: is the exterior wall of a house that can expose another building to fire. It is an area bounded by the building width, the building grade and the uppermost ceiling *(NHC,1995)*

Execution & Installation phase

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component	≤ 0.02 L/s per m^2 @ 75 Pa	ASTM E1677-95(2000) Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls Inspection if installed by design specifications
	Air leakage of windows	≤ 0.77 L/s per m' of sash crack[62] (≤ 2.79 m^3/h per m' = A1)	Inspection if installed by design specifications
	Air leakage of doors - sliding doors and non-weather stripped doors	≤ 2.5 L/s per m^2 of door area @75 Pa[63]	Inspection if installed by design specifications
	Air leakage of doors - all other doors	≤ 17 L/s per m' of sash crack[64]	Inspection if installed by design specifications
Moisture management performance	Moisture content of structural lumber at the time of installation	<19% (NBC)	Inspection and control of installation at the plant; Inspection and control of installation on site

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[62] Quebec Energy Code
[63] ibid
[64] ibid.

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Water vapor permeability of the assembly	Mandatory vapour barrier installed on the warm side of insulation, with initial permeance < 45 ng/(Pa·s·m^2) or < 15 ng/(Pa·s·m^2), if sheathing or cladding on the exterior side have low permeance.[65]	ASTM E1643-98 Standard Practice for Installation of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs
	Dryability of the assembly: allowing trapped moisture to escape: setting the levels of water vapor permeance for layers	Mandatory vapour barrier installed on the warm side of insulation, with initial permeance < 45 ng/(Pa·s·m^2) or < 15 ng/(Pa·s·m^2), if sheathing or cladding on the exterior side have low permeance.[66]	Inspection at the plant; Inspection on site
Moisture management performance	Drainage of precipitation and surface runoff	Surface grading:	Inspection at the plant; Inspection on site
		Building external drains	Inspection at the plant; Inspection on site
		Impermeable cap over backfill	Inspection at the plant; Inspection on site

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[65] (National Housing Code of Canada 1998)
[66] (National Housing Code of Canada 1998)

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Drainage of precipitation and surface runoff	Waterproofing barriers / Membranes:	Inspection at the plant; Inspection on site
		Subgrade drainage system (drainage pipes)	Inspection at the plant; Inspection on site
		Control joints	Inspection at the plant; Inspection on site
	Limiting intrusion of precipitation (roofs)	Roof planes sloped away from building	Inspection at the plant; Inspection on site
		Roof planes sloped more than 1:6 (NBC)	Inspection at the plant; Inspection on site
		Roof valleys sloped away from the building	Inspection at the plant; Inspection on site
		Flat roof planes sloped minimum 2%	Inspection at the plant; Inspection on site
Moisture management performance	Limiting intrusion of precipitation (roofs)	Flat roof valleys sloped more than 0.5%[67]	Inspection at the plant; Inspection on site
		Flashings and additional sealing for all penetrations through water shedding roof membranes	Inspection at the plant; Inspection on site
	Limiting intrusion of precipitation : reducing deposition on exterior walls	The size of roof overhangs	Inspection at the plant; Inspection on site
		Gutters at all sloped roof perimeters	Inspection at the plant; Inspection on site
		Design size of rainwater downspouts	Inspection at the plant; Inspection on site

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[67] NHC does not have requirement. This is from DIN code

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Limiting intrusion of precipitation : reducing deposition on exterior walls	Balconies, terraces and decks sloped away from exterior walls	Inspection at the plant; Inspection on site
		Flashing and sealing of balconies thresholds	Inspection at the plant; Inspection on site
		Flashing and sealing of junctions of exterior walls with large horizontal surfaces (decks, balconies, roofs)	Inspection at the plant; Inspection on site
		Window sills sloped away from the window	Inspection at the plant; Inspection on site
		Drip on window sills	Inspection at the plant; Inspection on site
Moisture management performance	Limiting intrusion of precipitation: reducing deposition on exterior walls	Drip on copings	Inspection at the plant; Inspection on site
	Rain water penetration management	Drainage space behind cladding: air space of min. 1 in	Inspection at the plant; Inspection on site
		Drainage plane	Inspection at the plant; Inspection on site
		Flashings	Inspection at the plant; Inspection on site
		Weep holes	Inspection at the plant; Inspection on site
	Rain water penetration management-watertightness rating of installed windows	Minimum rating B2	Inspection at the plant; Inspection on site

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
	Rain water penetration management-watertightness rating of installed sliding patio doors	Minimum rating B2	Inspection at the plant; Inspection on site
Moisture management performance	Capillary suction - control below grade	3/4 in layer of crushed stone below basement slab	Inspection at the plant; Inspection on site
		capillary break over the top of the footing, placed prior to construction of perimeter foundation walls	Inspection at the plant; Inspection on site
		dampproofing the exterior surface of basement walls	Inspection at the plant; Inspection on site
		capillary break between the sill plate and the top of foundation wall	Inspection at the plant; Inspection on site
	Capillary suction - control above grade	capillary break in porous cladding materials (e.g. horizontal wood siding)	Inspection at the plant; Inspection on site
Thermal performance - steady state	Thermal resistance of opaque parts of the envelope (as built values)	Roof: RSI 5.3 Above grade walls: 3.4 Bellow grade walls: 2.2 Floors above non heated space: 4.7 Basement floor: 0.0 Crawl space floor: 0[68] Slab-on-grade with embedded pipes 1.6 Slab -on-grade without pipes 1.2	Inspection and control of installation at the plant; Inspection and control of installation on site

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[68] Quebec Energy Code Values

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
		Installation of insulation according to following standards	ASTM C1320-99 Standard Practice for Installation of Mineral Fiber Batt and Blanket Thermal Insulation for Light Frame Construction ASTM C1015-99 Standard Practice for Installation of Cellulosic and Mineral Fiber Loose-Fill Thermal Insulation[69] Inspection and control of installation at the plant; Inspection and control of installation on site
Thermal performance - steady state	Thermal resistance of installed windows	RSI = 0.35 m^2 C/W[70]	Inspection and control of installation at the plant; Inspection and control of installation on site
	Thermal resistance of installed doors	RSI = 0.70 m^2 C/W[71]	Inspection and control of installation at the plant; Inspection and control of installation on site
Energy performance	Energy rating of installed windows	E3	Inspection at the plant; Inspection on site
	Energy rating of installed sliding patio doors	E3	Inspection at the plant; Inspection on site
Structural stability of building envelope	Wind load resistance of windows and sliding glass doors	C2	Inspection at the plant; Inspection on site

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[69] There is 2002 edition; it yet needs to be obtained.
[70] Quebec Energy Code Values
[71] Quebec Energy Code Values

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Structural stability of building envelope	Resistance to horizontal loads - seismic		
Fire control of building envelope	Spatial separation of buildings (NHC)	If limiting distance[72] < 1.2 m, the exposing building face[73] must have fire rating min 45 min. If limiting distance < 0.6 m, the exposing face must have a noncombustible cladding.	Inspection at the plant; Inspection on site
	Location of skylights	No skylights within a hor. distance of 5 m of the windows in the exposed wall from adjoining roof of a separate unsprinkeled *fire compartment* in the same *building*	Inspection at the plant; Inspection on site
	Maximum percentage area of unprotected openings in exterior walls	See table 6.3.2.1.A. of National Housing Code of Canada 1998	Inspection at the plant; Inspection on site

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[72] Limiting distance: id the distance from an exposing building face to a property line, or to an imaginary line between two buildings*(NHC,1995)*;

[73] The exposing building face: is the exterior wall of a house that can expose another building to fire. It is an area bounded by the building width, the building grade and the uppermost ceiling *(NHC,1995)*

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION				EVALUATION (VERIFICATION) METHOD
Fire control of building envelope	Minimum construction requirements for exposing faces	% openings	fire rating	construction required	cladding required	Inspection at the plant; Inspection on site
		0-10	1 h	noncomb	noncomb	
		11-25	1 h	comb. or noncomb	noncomb	
		26-<100	45 min	comb. or noncomb	comb. or noncomb	
Quality workmanship	Quality management system					CMHC's Quality by design manual (based on ISO 9001: 1994)
Quality workmanship	Plant production stage - Build for quality	Same check-list to be followed				Control of workmanship in scheduled manner ISO 12491:1997 Statistical methods for quality control of building materials and components
Quality workmanship	Assembly on site - During the assembly process	Site assembly check-list to be developed				Control of workmanship in scheduled manner

Laboratory tests

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Air tightness	Air permeance of the opaque parts of building envelope	≤ 0.02 L/s per m^2 @ 75 Pa	CMHC / AIR-INS Inc. Test Method for Determining the Air Permeance of Building Materials at Various Pressure Differentials (25 - 100 Pa) (1988); IRC test: A test method to determine air flow resistance of exterior membranes and sheathings by M. Bomberg and M. K. Kumaran *(still to be found);*
Air tightness	Air leakage of windows	≤ 0.77 L/s per m' of sash crack @ 75 Pa A1[74] Division 5, point 67 of Quebec Energy Code - Regulation respecting energy conservation in new buildings, 1992	ASTM E283-91 (Reapproved 1999) Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors Under Specified Pressure Differences Across the Specimen. ASTM E1424-91 (Reapproved 2000) Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen CAN/CSA-A440-M90 Windows

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[74]

Rating	L/s per m' crack	m^3/h per m'
A1	≤ 0.77	≤ 2.79
A2	≤ 0.46	≤ 1.65
A3	≤ 0.15	≤ 0.55
Fixed	≤ 0.07	≤ 0.25

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Air tightness	Air leakage of doors	≤ 2.5 L/s per m^2 of door area @ 75 Pa (for sliding glass door and non whether stripped doors); ≤ 17 L/s per m' of door crack @ 75 Pa (for all other door)[75]	ASTM E283-91 (Reapproved 1999) Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors Under Specified Pressure Differences Across the Specimen ASTM E1424-91 (Reapproved 2000) Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen
Moisture management performance	Initial (construction) moisture content of structural lumber	<19% at the time of installation[76]	D4442-92(1997)e1 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials
Moisture management performance	Water vapor permeability of the opaque parts of building envelopes	Mandatory vapour barrier installed on the warm side of insulation, with initial permeance < 45 ng/(Pa·s·m^2) or < 15 ng/(Pa·s·m^2), if sheathing or cladding on the exterior side have low permeance.[77]	ASTM E96-00e1 Standard Test Methods for Water Vapor Transmission of Materials

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[75] Division 5, point 68 of Quebec Energy Code - Regulation respecting energy conservation in new buildings, 1992

[76] National Housing Code of Canada 1998, 1.4.2.5

[77] National Housing Code of Canada 1998

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Moisture management performance	Precipitation penetration and leakage of exterior walls above ground	Not allowed to penetrate into a back-wall (part of the wall behind cladding and air-space)	ASTM E 514-90 (Reapproved 1996) Standard Test Method for Water Penetration and Leakage Through Masonry *DIN EN 12865 Hygrothermal performance of building components and building elements - Determination of the resistance of external wall systems to driving rain under pulsating air pressure; English version of DIN EN 12865 (FOREIGN STANDARD)*[78]
	Precipitation penetration and leakage of roofs	No water is allowed to penetrate into the assembly	NT BUILD 421 (App. 1993-05) Roofs: Watertightness Under Pulsating Air Pressure
	Precipitation penetration and leakage of windows and sliding glass doors	Minimum rating B2	ASTM E331-96 Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference; ASTM E547-00 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference NT BUILD 116 (App. 1980-03) Windows, Window-doors, External Doors, Facades: Pulsating Air Pressure Test;

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[78] The document specifies a general method for testing the watertightness of external walls under pulsating air pressure in order to provide a defined watertightness of a wall element including joints so as to limit water penetration to an acceptable level.

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Thermal performance	Thermal resistance of opaque parts of the envelope	Roof: RSI 5.3 Above grade walls: 3.4 Bellow grade walls: 2.2 Floors above non heated space: 4.7 Basement floor: 0.0 Crawl space floor: 0.0 Slab-on-grade with embedded pipes 1.6 Slab -on-grade without pipes 1.2[79]	ASTM C1363-97 Standard Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus; ASTM C1373-01 Standard Practice for Determination of Thermal Resistance of Attic Insulation Systems Under Simulated Winter Conditions ASTM C1303-00 Standard Test Method for Estimating the Long-Term Change in the Thermal Resistance of Unfaced Rigid Closed Cell Plastic Foams by Slicing and Scaling Under Controlled Laboratory Conditions ASTM C687-96 Standard Practice for Determination of Thermal Resistance of Loose-Fill Building Insulation ASTM C1045-01 Standard Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions; *(based upon test data)* *DIN 52611-1 Determination of thermal resistance of building elements; laboratory method (FOREIGN STANDARD)*[80]
Thermal performance	Thermal resistance of windows	Low-E double-glazed with argon filled space and insulated spacers RSI = 0.35	ASTM C1199-00 Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using hot box Methods
	Thermal resistance of doors	Doors: RSI -= 0.7	

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[79] Quebec Energy Code Values

[80] The standard describes the determination of the thermal resistance and the thermal transmission coefficient of structural components.

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Structural stability of building envelope	Structural lumber: flexure		ASTM D198-02 Standard test methods of static tests of lumber in structural sizes
	Structural lumber: Compression parallel to grain (short column, no lateral support, l/r<17)		ASTM D198-02 Standard test methods of static tests of lumber in structural sizes
	Structural lumber: Compression parallel to grain (crushing strength of laterally supported long member, effective l'/r'<17)		ASTM D198-02 Standard test methods of static tests of lumber in structural sizes
	Structural lumber: Tension parallel to grain		ASTM D198-02 Standard test methods of static tests of lumber in structural sizes
Structural stability of building envelope	Structural lumber: Torsion		ASTM D198-02 Standard test methods of static tests of lumber in structural sizes
	Structural lumber: Shear modulus		ASTM D198-02 Standard test methods of static tests of lumber in structural sizes
	Wall constructions and panels: Compressive load		ASTM E72-02 Standard test Methods of Conducting Strength Tests of Panels for Building Construction ASTM E1803-99 Standard Test Methods for Determining Structural Capacities of Insulated Panels
	Wall constructions and panels: Tensile load		ASTM E72-02 Standard test Methods of Conducting Strength Tests of Panels for Building Construction ASTM E1803-99 Standard Test Methods for Determining Structural Capacities of Insulated Panels

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Structural stability of building envelope	Wall constructions and panels: Transverse load - specimen horizontal		ASTM E72-02 Standard test Methods of Conducting Strength Tests of Panels for Building Construction ASTM E1803-99 Standard Test Methods for Determining Structural Capacities of Insulated Panels
	Wall constructions and panels: Transverse load - specimen vertical		ASTM E72-02 Standard test Methods of Conducting Strength Tests of Panels for Building Construction ASTM E1803-99 Standard Test Methods for Determining Structural Capacities of Insulated Panels
	Wall constructions and panels: Concentrated load		ASTM E72-02 Standard test Methods of Conducting Strength Tests of Panels for Building Construction ASTM E1803-99 Standard Test Methods for Determining Structural Capacities of Insulated Panels
	Wall constructions and panels: Racking load (dry materials)		
	Wall constructions and panels: Racking load (wet materials)		ASTM E72-02 Standard test Methods of Conducting Strength Tests of Panels for Building Construction ASTM E1803-99 Standard Test Methods for Determining Structural Capacities of Insulated Panels
	Shear capacity of framed wall supported on rigid foundation		ASTM E564-00e1 Standard Practice for Static Load Test for Shear Resistance of Framed Walls for Buildings
	Relative resistance to impact loading		ASTM E695-79(1997)e1 Standard Method for Measuring Relative Resistance of Wall, Floor, and Roof Construction to Impact Loading

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Acoustic performance of building envelope[81]	Sound Transmission Class (STC) of building enclosure	No requirements for residential buildings[82]	ASTM E90-02 Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements[83] ASTM E1332-90(1998) Standard Classification for Determination of Outdoor-Indoor Transmission Class;
Fire response of building envelope	Time to flashover[84]	No requirements for residential buildings[85]	ASTM E603-01 Standard Guide for Room Fire Experiments[86] Also: Draft Under Development: ASTM WK305 Test Method for Room Fire Test of Wall and Ceiling Materials and Assemblies
Service life of the building envelope	Structural component of building envelope	TBD:	ASTM E632 – 82 (Reapproved 1996) Developing Accelerated Tests to Aid Prediction of the Service Life of Building Materials and Components;

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[81] National Housing Code (NHC) does not address the transmission of outside noises, impact sounds or vibration.

[82] National Housing Code (NHC) - no requirements

[83] This test is intended for partitions and floors, but it probably can be adapted to simulate indoor-outdoor conditions, because it is done in the chamber, similar to cold/warm chamber.

[84] Flashover - the rapid transition to a state of total surface involvement in a fire of combustible materials within an enclosure. *(ASTM E 176, 1999)*

[85] National Housing Code (NHC) - no requirements

[86] Full scale test to determine fire response of building materials and assemblies under specified fire exposure (could be adapted for specific use).

FUNCTIONAL REQUIREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Service life of the building envelope	Insulation	TBD:	ASTM E632 – 82 (Reapproved 1996) Developing Accelerated Tests to Aid Prediction of the Service Life of Building Materials and Components; NT BUILD 495 (App. 2000-11) Building Materials and Components in the Vertical Position: Exposure to Accelerated Climatic Strains[87] NT BUILD 434 (App. 1995-05) Roofing Membrane Underlay (Insulation Material): Ageing Due to Increased Humidity and Heat
	Interior finishes	TBD:	ASTM E632 – 82 (Reapproved 1996) Developing Accelerated Tests to Aid Prediction of the Service Life of Building Materials and Components;
	Exterior finishes	TBD:	ASTM E632 – 82 (Reapproved 1996) Developing Accelerated Tests to Aid Prediction of the Service Life of Building Materials and Components; NT BUILD 495 (App. 2000-11) Building Materials and Components in the Vertical Position: Exposure to Accelerated Climatic Strains
	Windows	TBD:	ASTM E632 – 82 (Reapproved 1996) Developing Accelerated Tests to Aid Prediction of the Service Life of Building Materials and Components;

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[87] To be adapted: not to take into account UV exposure, but only heat, water and frost.

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Service life of the building envelope	Doors	TBD:	ASTM E632 – 82 (Reapproved 1996) Developing Accelerated Tests to Aid Prediction of the Service Life of Building Materials and Components;
Quality materials	Mandatory use of kiln dried wood	<19% M.C. (NBC)	I D4442-92(1997)e1 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials

Field test

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Air tightness	Air leakage of the finished houses[88]	< 0.7 cm^2/m^2 or <1.5 ACH at 50 Pa (R2000) or $1.0 < X < 2.5$ ACH at 50 Pa (Novoclimat)	Measuring: CAN/CGSB 149.10-M86 Determination of the Air-tightness of Building Envelopes by the Fan Depressurization Method[89] ASTM E779 - 99 Standard test Method for Determining Air Leakage Rate by Fan Pressurization ANSI/ASHRAE Standard 119-1988 Air Leakage Performance for Detached Single-Family Residential Buildings

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[88] Measured before interior finish is installed; for closed panels: to be added

[89] It is a method for the determination of the airtightness of building envelopes. It is not a method for determining the actual air leakage which occurs through a building envelope under the influence of wind and buoyancy pressures or the operation of heating and ventilation systems. The

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Air tightness	Air leakage of the finished houses	Detecting the points of air leakage	ASTM E1186-98 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Retarder Systems By infrared method: ASTM C 1060 - 90 (Reapproved 1997) Standard Practice for Thermographic Inspection of Insulation Installation in Envelope Cavities of Frame Buildings[90] ISO 6781-1983: Thermal Insulation - Qualitative Detection of Thermal Irregularities in Building Envelopes - Infrared Method
Thermal performance - steady state	Detection of thermal irregularities in building envelopes (qualitative)	The existence of thermal irregularities in building envelopes	Measuring by infrared camera: CAN/CGSB 149-GP-2MP Manual for Thermographic Analysis of Building Enclosures;[91] ASTM C 1060 - 90 (Reapproved 1997) Standard Practice for Thermographic Inspection of Insulation Installation in Envelope Cavities of Frame Buildings[92] ISO 6781-1983: Thermal Insulation - Qualitative Detection of Thermal Irregularities in Building Envelopes - Infrared Method

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method is applicable to small detached buildings (especially houses) but with appropriate modifications, it can also be used for other buildings or parts of buildings.

[90] ANSI/ASHRAE Standard 101-1981 Application of Infrared Sensing Devices to the Assessment of Building Heat Loss Characteristics - (Withdrawn 89/06 because ASTM standard is preferred) *Source www.ashrae.org*

[91] It is a manual, not a Standard

[92] ANSI/ASHRAE Standard 101-1981 Application of Infrared Sensing Devices to the Assessment of Building Heat Loss Characteristics - (Withdrawn 89/06 because ASTM standard is preferred) *Source www.ashrae.org*

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Thermal performance - steady state	Thermal resistance of opaque parts of the envelope (as built) - quantitative	Roof: RSI 5.3 Above grade walls: 3.4 Bellow grade walls: 2.2 Floors above non heated space: 4.7 Basement floor: 0.0 Crawl space floor: 0[93] Slab-on-grade with embedded pipes 1.6 Slab -on-grade without pipes 1.2	Measuring: ASTM C1046-95 (re 2001): Standard Practice for In-Situ Measurement of Heat Flux and Temperature on Building Envelope Components
Moisture management performance	Rain water penetration management	Not allowed to penetrate into a backwall	ASTM E1105-96 Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Static Air Pressure Difference;
Moisture management performance	Moisture content of wood components of building envelope	Mandatory use of kiln dried wood: <19% at the time of installation National Housing Code of Canada 1998, 1.4.2.5	NT BUILD 420 (Approved 1993-05) Building materials, wood: Moisture Content *(measured in building in use)*
Acoustic performance of building envelope[94]	Sound Transmission Class (STC) of building enclosure	NHC - no requirements Check for others (JUS)	ASTM E966-02 Standard Guide for Field Measurements of Airborne Sound Insulation of Building Facades and Facade Elements;

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[93] Quebec Energy Code Values

[94] National Housing Code (NHC) does not address the transmission of outside noises, impact sounds or vibration.

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Acoustic performance of building envelope	Sound Transmission Loss coefficient ranks for openings on exterior walls	Rank 3: .≥ 25 dB Rank 2: ≥ 20 dB Rank 1 : -------- (HQAL)	ASTM E966-02 Standard Guide for Field Measurements of Airborne Sound Insulation of Building Facades and Facade Elements; NT ACOU 102 (App.1999-06) Building Elements - Façade Elements and Facades: Field Measurement of Airborne Sound Insulation - Loudspeaker Method Using MLS (Maximum Length Sequence) Noise Signals ISO 140-5:1998 Acoustics -- Measurement of sound insulation in buildings and of building elements -- Part 5: Field measurements of airborne sound insulation of facade elements and facades
Quality workmanship	Final test - Upon completion, to test for air-leakage	<1.5; 1.5 - 4; 4 - 6; 6 - 8; > 8	CAN/CGSB 149.10-M86 Determination of the Air-tightness of Building Envelopes by the Fan Depressurization Method ASTM E779 - 99 Standard test Method for Determining Air Leakage Rate by Fan Pressurization

Occupancy

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION		EVALUATION (VERIFICATION) METHOD
Moisture management performance	Indoor RH levels[95]	T_{out} (C)	Recommended maximum indoor RH at T_{in} of 21°C	Calibrated hygrometer
		-29	20%	
		-24	25%	
		-18	30%	
		-12	35%	
		-7	40%	
Moisture management performance	Moisture content of wood components of building envelope	Mandatory use of kiln dried wood: <19% at the time of installation National Housing Code of Canada 1998, 1.4.2.5		NT BUILD 420 (Approved 1993-05) Building materials, wood: Moisture Content *(measured in building in use)*
Energy performance	Heating / cooling energy[96]	Annual Energy Target = Q_s+Q_w[97]		ANSI/ASHRAE Standard 105-1984 Standard Method of Measuring and Expressing Building Energy Performance
Maintenance	Short term, several times a year	CMHC Homeowners' manual		Checking gutters and downspouts and cleaning if needed
Maintenance	Short term, several times a year	CMHC Homeowners' manual		Inspecting basement or crawl space for signs of seepage/leakage
		CMHC Homeowners' manual		Ensuring good slopes away from foundation walls
		CMHC Homeowners' manual		Cleaning windows, screens and hardware

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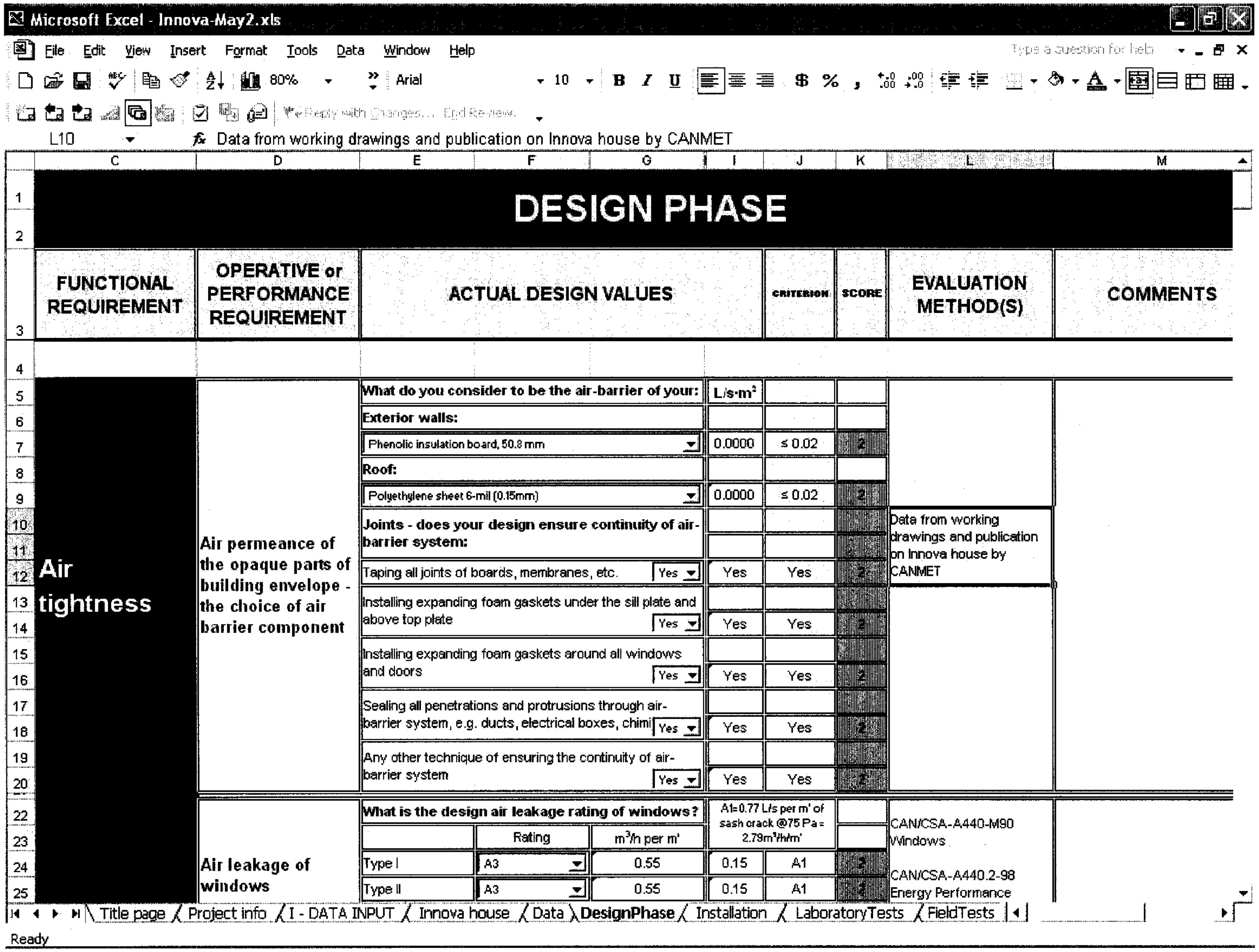
[95] Controlling indoor RH levels (as a source of moisture) - Home manual values

[96] Annual heating energy consumption - depends on building envelope. Hot water consumption is not included here

[97] Q_s: space heating energy consumption target; Q_w: domestic hot water energy consumption target. R2000 values. To be calculated for each individual house, depending on its size, position, location and local water mains temperature.

FUNCTIONAL REQUREMENT	OPERATIVE (PERFORMANCE) REQUIREMENT	CRITERION	EVALUATION (VERIFICATION) METHOD
Maintenance	Short term, several times a year	CMHC Homeowners' manual	Airing out damp basement on dry days or using dehumidifier
		CMHC Homeowners' manual	Checking exterior finishes
		CMHC Homeowners' manual	Checking exterior wood for deterioration
		CMHC Homeowners' manual	Checking caulking and weather-stripping, including around entry door between garage and house
		CMHC Homeowners' manual	Cleaning leaves out of eavesttoughts
		CMHC Homeowners' manual	Checking roofing and flashing for signs of wear or damage
	Medium term: annually	CMHC Homeowners' manual	Check attics for signs of moisture
	Long term (2 to 5 years)	CMHC Homeowners' manual	Recaulk if necessary

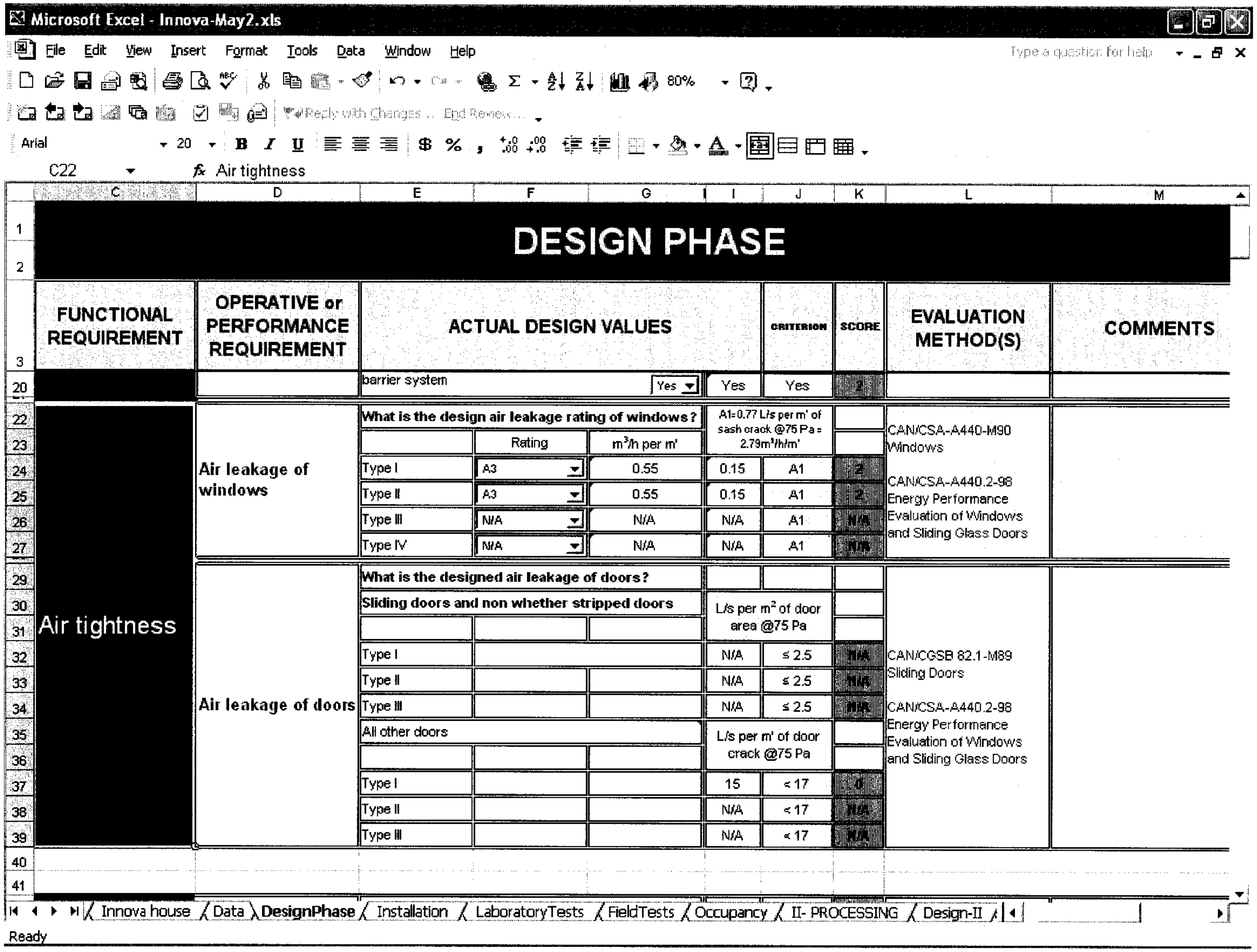
APPENDIX B: BEPAT TOOL – USER INTERFACE



L10 Data from working drawings and publication on Innova house by CANMET

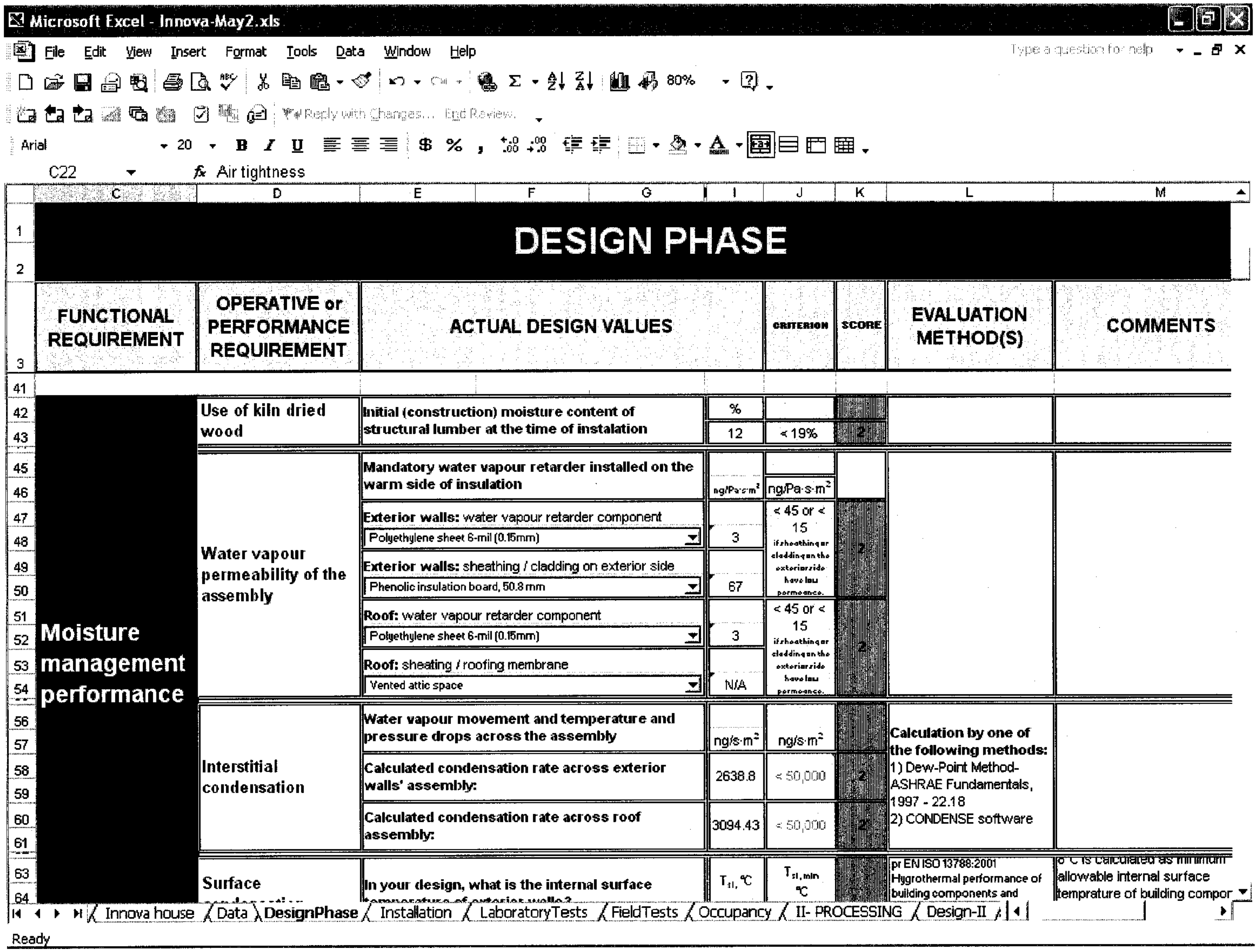
DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES				CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component	**What do you consider to be the air-barrier of your:**			L/s·m²				
		Exterior walls:							
		Phenolic insulation board, 50.8 mm ▾			0.0000	≤ 0.02	2		
		Roof:							
		Polyethylene sheet 6-mil (0.15mm) ▾			0.0000	≤ 0.02	2		
		Joints - does your design ensure continuity of air-barrier system:						Data from working drawings and publication on Innova house by CANMET	
		Taping all joints of boards, membranes, etc. Yes ▾			Yes	Yes	2		
		Installing expanding foam gaskets under the sill plate and above top plate Yes ▾			Yes	Yes	2		
		Installing expanding foam gaskets around all windows and doors Yes ▾			Yes	Yes	2		
		Sealing all penetrations and protrusions through air-barrier system, e.g. ducts, electrical boxes, chimi Yes ▾			Yes	Yes	2		
		Any other technique of ensuring the continuity of air-barrier system Yes ▾			Yes	Yes	2		
	Air leakage of windows	**What is the design air leakage rating of windows?**			A1=0.77 L/s per m' of sash crack @75 Pa = 2.79m³/h/m'			CAN/CSA-A440-M90 Windows	
			Rating	m³/h per m'					
		Type I	A3 ▾	0.55	0.15	A1	2	CAN/CSA-A440.2-98 Energy Performance	
		Type II	A3 ▾	0.55	0.15	A1	2		



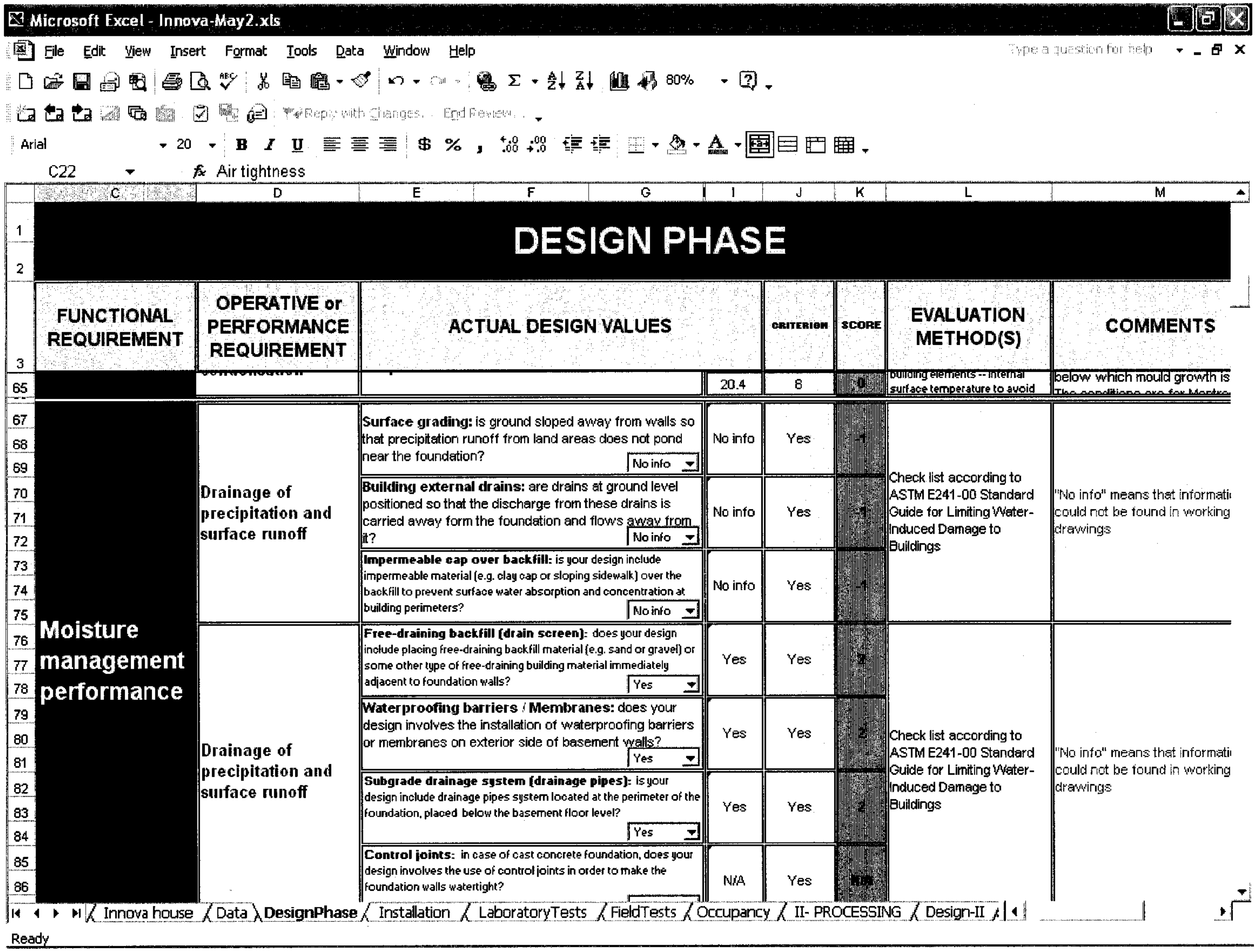
DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES				CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
		barrier system		Yes	Yes	Yes	2		
Air tightness	Air leakage of windows	What is the design air leakage rating of windows?			A1=0.77 L/s per m' of sash crack @75 Pa = 2.79m³/h/m'			CAN/CSA-A440-M90 Windows CAN/CSA-A440.2-98 Energy Performance Evaluation of Windows and Sliding Glass Doors	
			Rating	m³/h per m'					
		Type I	A3	0.55	0.15	A1	2		
		Type II	A3	0.55	0.15	A1	2		
		Type III	N/A	N/A	N/A	A1	N/A		
		Type IV	N/A	N/A	N/A	A1	N/A		
	Air leakage of doors	What is the designed air leakage of doors?						CAN/CGSB 82.1-M89 Sliding Doors CAN/CSA-A440.2-98 Energy Performance Evaluation of Windows and Sliding Glass Doors	
		Sliding doors and non whether stripped doors			L/s per m² of door area @75 Pa				
		Type I			N/A	≤ 2.5	N/A		
		Type II			N/A	≤ 2.5	N/A		
		Type III			N/A	≤ 2.5	N/A		
		All other doors			L/s per m' of door crack @75 Pa				
		Type I			15	< 17	0		
		Type II			N/A	< 17	N/A		
		Type III			N/A	< 17	N/A		



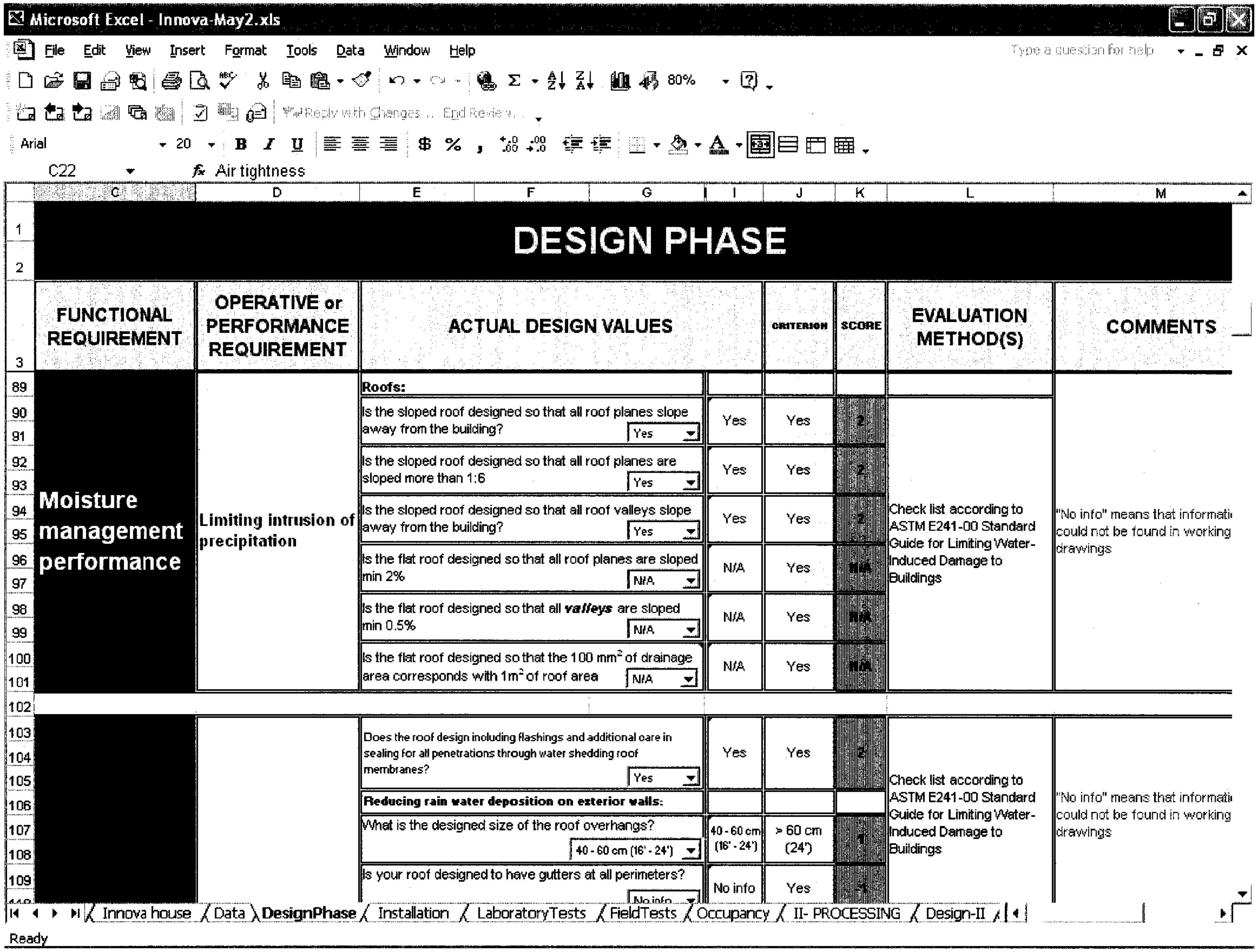
DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES		CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
Moisture management performance	**Use of kiln dried wood**	**Initial (construction) moisture content of structural lumber at the time of instalation**	% 12	< 19%	2		
	Water vapour permeability of the assembly	**Mandatory water vapour retarder installed on the warm side of insulation**	ng/Pa·s·m²	ng/Pa·s·m²			
		Exterior walls: water vapour retarder component Polyethylene sheet 6-mil (0.15mm)	3	< 45 or < 15 if sheathing or cladding on the exterior side have low permeance.	2		
		Exterior walls: sheathing / cladding on exterior side Phenolic insulation board, 50.8 mm	67				
		Roof: water vapour retarder component Polyethylene sheet 6-mil (0.15mm)	3	< 45 or < 15 if sheathing or cladding on the exterior side have low permeance.	2		
		Roof: sheating / roofing membrane Vented attic space	N/A				
	Interstitial condensation	**Water vapour movement and temperature and pressure drops across the assembly**	ng/s·m²	ng/s·m²		**Calculation by one of the following methods:** 1) Dew-Point Method- ASHRAE Fundamentals, 1997 - 22.18 2) CONDENSE software	
		Calculated condensation rate across exterior walls' assembly:	2638.8	< 50,000	2		
		Calculated condensation rate across roof assembly:	3094.43	< 50,000	2		
	Surface	**In your design, what is the internal surface**	T_{si}, °C	$T_{si,min}$ °C		pr EN ISO 13788:2001 Hygrothermal performance of building components and	C is calculated as minimum allowable internal surface temprature of building compor



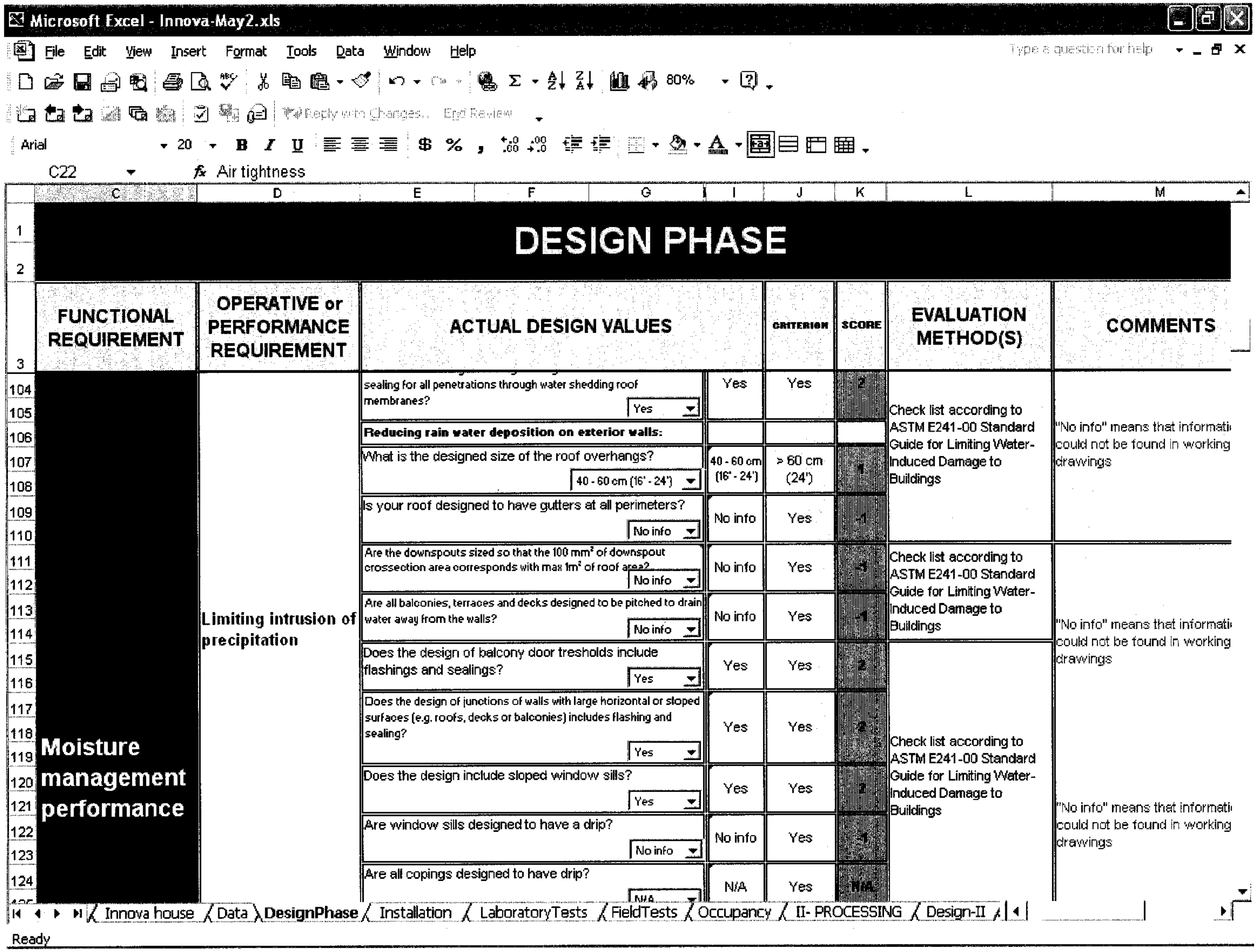
DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES		CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
			20.4	8	0	building elements -- internal surface temperature to avoid	below which mould growth is
Moisture management performance	Drainage of precipitation and surface runoff	**Surface grading:** is ground sloped away from walls so that precipitation runoff from land areas does not pond near the foundation? No info	No info	Yes	-1	Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
		Building external drains: are drains at ground level positioned so that the discharge from these drains is carried away form the foundation and flows away from it? No info	No info	Yes	-1		
		Impermeable cap over backfill: is your design include impermeable material (e.g. clay cap or sloping sidewalk) over the backfill to prevent surface water absorption and concentration at building perimeters? No info	No info	Yes	-1		
	Drainage of precipitation and surface runoff	**Free-draining backfill (drain screen):** does your design include placing free-draining backfill material (e.g. sand or gravel) or some other type of free-draining building material immediately adjacent to foundation walls? Yes	Yes	Yes	2	Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
		Waterproofing barriers / Membranes: does your design involves the installation of waterproofing barriers or membranes on exterior side of basement walls? Yes	Yes	Yes	2		
		Subgrade drainage system (drainage pipes): is your design include drainage pipes system located at the perimeter of the foundation, placed below the basement floor level? Yes	Yes	Yes	2		
		Control joints: in case of cast concrete foundation, does your design involves the use of control joints in order to make the foundation walls watertight?	N/A	Yes	N/A		



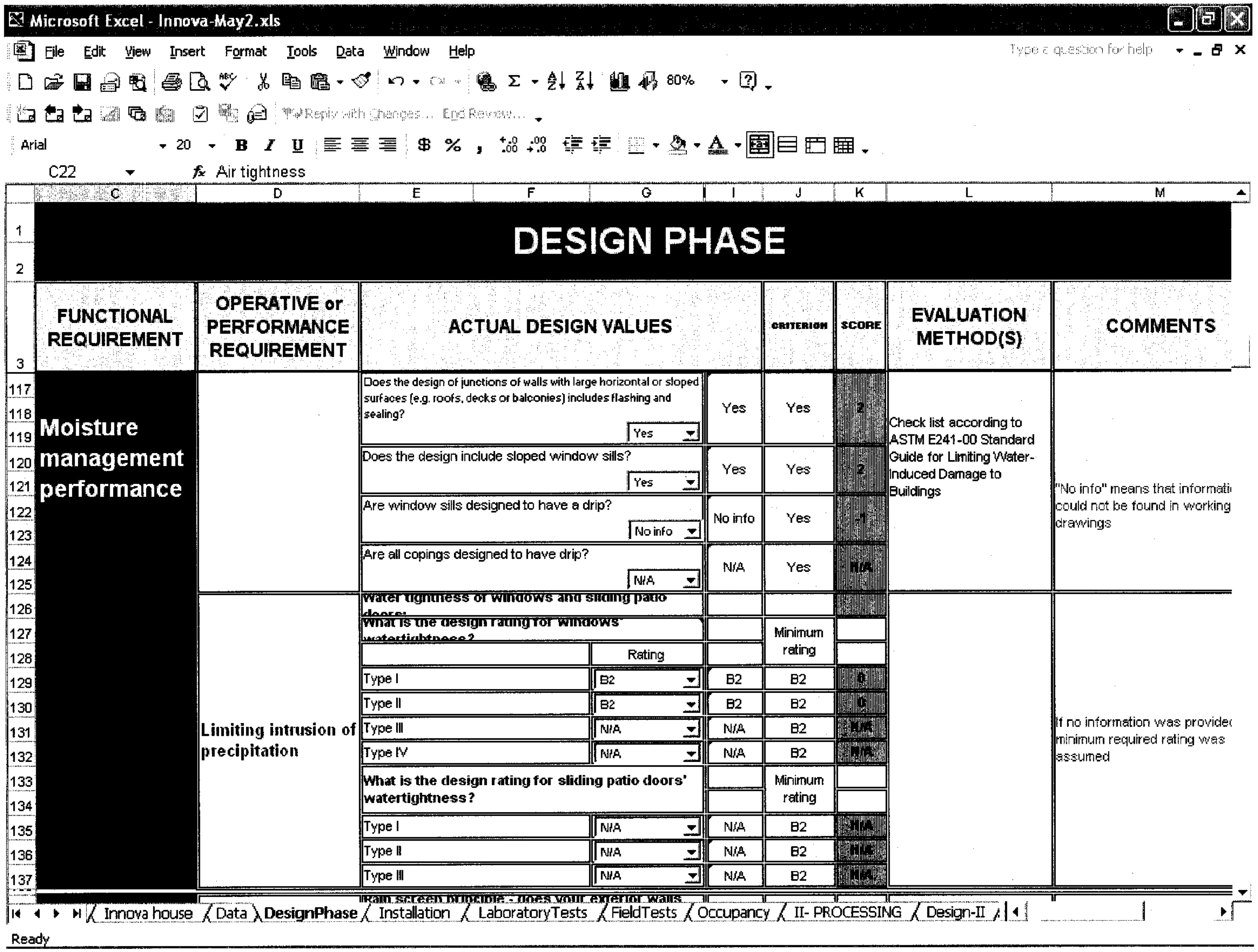
DESIGN PHASE

	FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES			CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
89	Moisture management performance	Limiting intrusion of precipitation	**Roofs:**					Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
90–91			Is the sloped roof designed so that all roof planes slope away from the building?	Yes	Yes	Yes	2		
92–93			Is the sloped roof designed so that all roof planes are sloped more than 1:6	Yes	Yes	Yes	2		
94–95			Is the sloped roof designed so that all roof valleys slope away from the building?	Yes	Yes	Yes	2		
96–97			Is the flat roof designed so that all roof planes are sloped min 2%	N/A	N/A	Yes	N/A		
98–99			Is the flat roof designed so that all ***valleys*** are sloped min 0.5%	N/A	N/A	Yes	N/A		
100–101			Is the flat roof designed so that the 100 mm^2 of drainage area corresponds with 1m^2 of roof area	N/A	N/A	Yes	N/A		
102									
103–105			Does the roof design including flashings and additional care in sealing for all penetrations through water shedding roof membranes?	Yes	Yes	Yes	2	Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
106			**Reducing rain water deposition on exterior walls:**						
107–108			What is the designed size of the roof overhangs?	40 - 60 cm (16' - 24')	40 - 60 cm (16' - 24')	> 60 cm (24')	1		
109			Is your roof designed to have gutters at all perimeters?	No info	No info	Yes	-1		



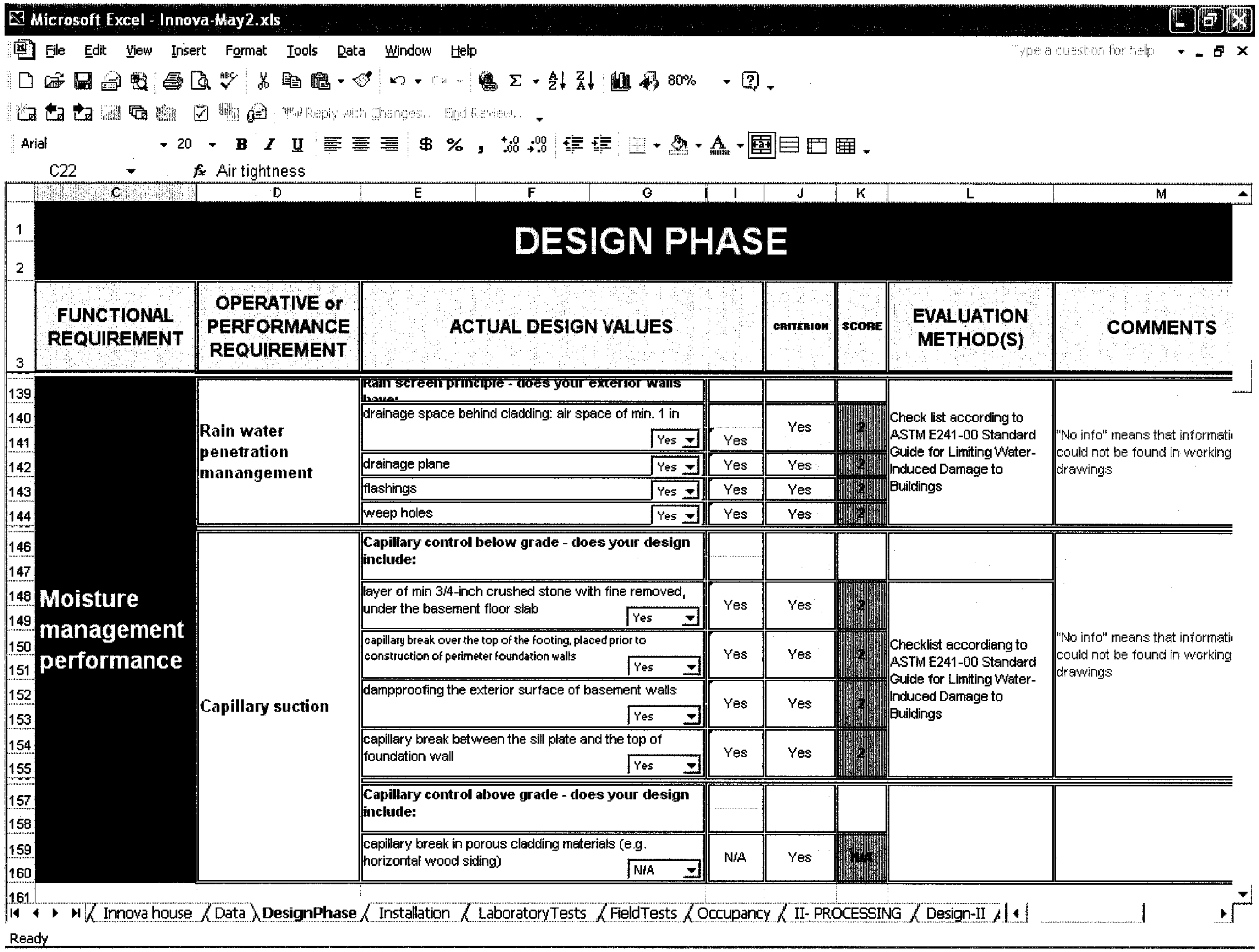
DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES		CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
Moisture management performance	Limiting intrusion of precipitation	sealing for all penetrations through water shedding roof membranes? Yes	Yes	Yes	2	Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
		Reducing rain water deposition on exterior walls:					
		What is the designed size of the roof overhangs? 40 - 60 cm (16' - 24')	40 - 60 cm (16' - 24')	> 60 cm (24')	1		
		Is your roof designed to have gutters at all perimeters? No info	No info	Yes	-1		
		Are the downspouts sized so that the 100 mm² of downspout crossection area corresponds with max 1m² of roof area? No info	No info	Yes	-1	Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
		Are all balconies, terraces and decks designed to be pitched to drain water away from the walls? No info	No info	Yes	-1		
		Does the design of balcony door tresholds include flashings and sealings? Yes	Yes	Yes	2	Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
		Does the design of junctions of walls with large horizontal or sloped surfaces (e.g. roofs, decks or balconies) includes flashing and sealing? Yes	Yes	Yes	2		
		Does the design include sloped window sills? Yes	Yes	Yes	2		
		Are window sills designed to have a drip? No info	No info	Yes	-1		
		Are all copings designed to have drip? N/A	N/A	Yes	N/A		



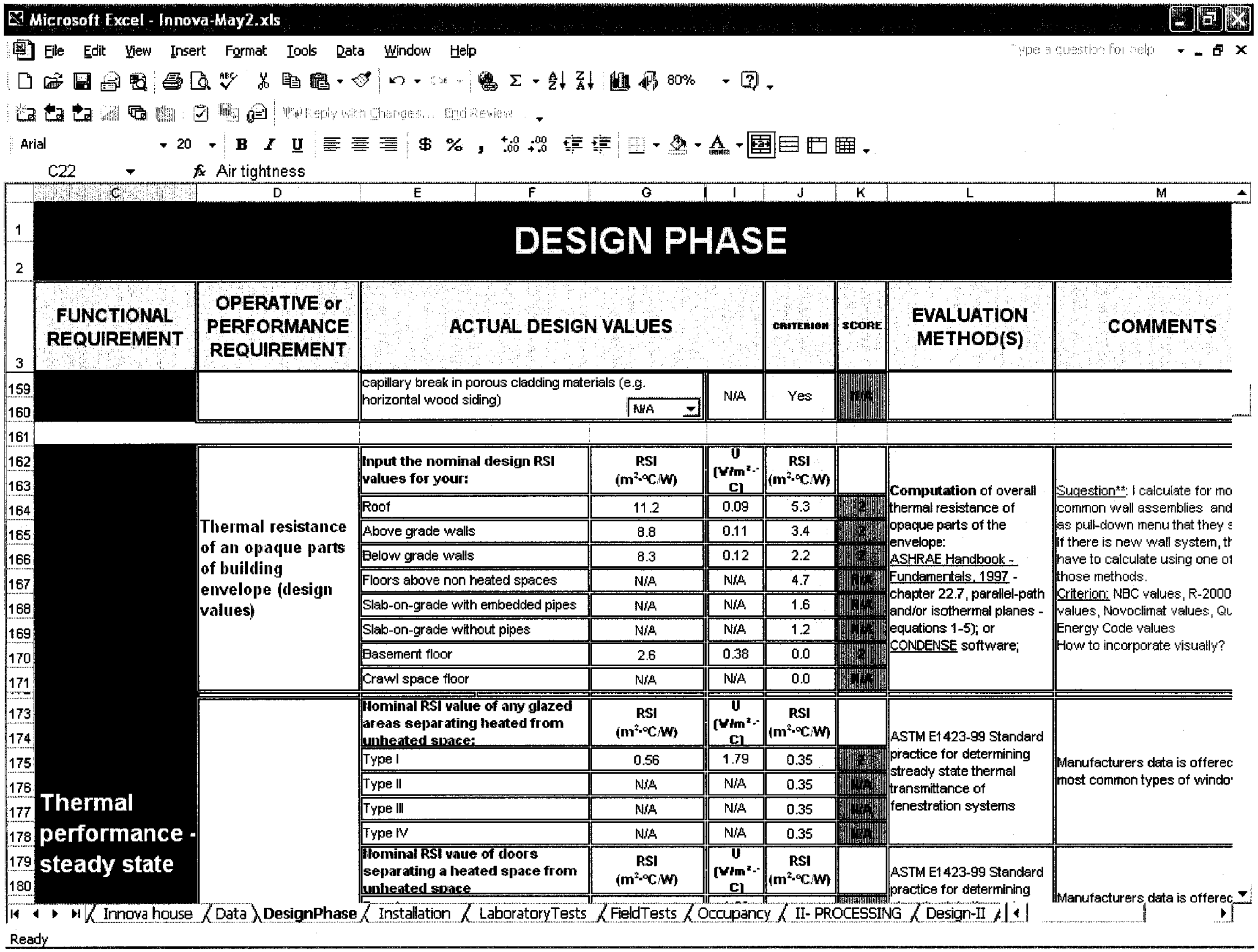
DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES			CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
Moisture management performance		Does the design of junctions of walls with large horizontal or sloped surfaces (e.g. roofs, decks or balconies) includes flashing and sealing?	Yes	Yes	Yes	2	Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
		Does the design include sloped window sills?	Yes	Yes	Yes	2		
		Are window sills designed to have a drip?	No info	No info	Yes	-1		
		Are all copings designed to have drip?	N/A	N/A	Yes	N/A		
	Limiting intrusion of precipitation	Water tightness of windows and sliding patio doors:						If no information was provided minimum required rating was assumed
		What is the design rating for windows' watertightness?			Minimum rating			
			Rating					
		Type I	B2	B2	B2	0		
		Type II	B2	B2	B2	0		
		Type III	N/A	N/A	B2	N/A		
		Type IV	N/A	N/A	B2	N/A		
		What is the design rating for sliding patio doors' watertightness?			Minimum rating			
		Type I	N/A	N/A	B2	N/A		
		Type II	N/A	N/A	B2	N/A		
		Type III	N/A	N/A	B2	N/A		
		Rain screen principle - does your exterior walls						



DESIGN PHASE

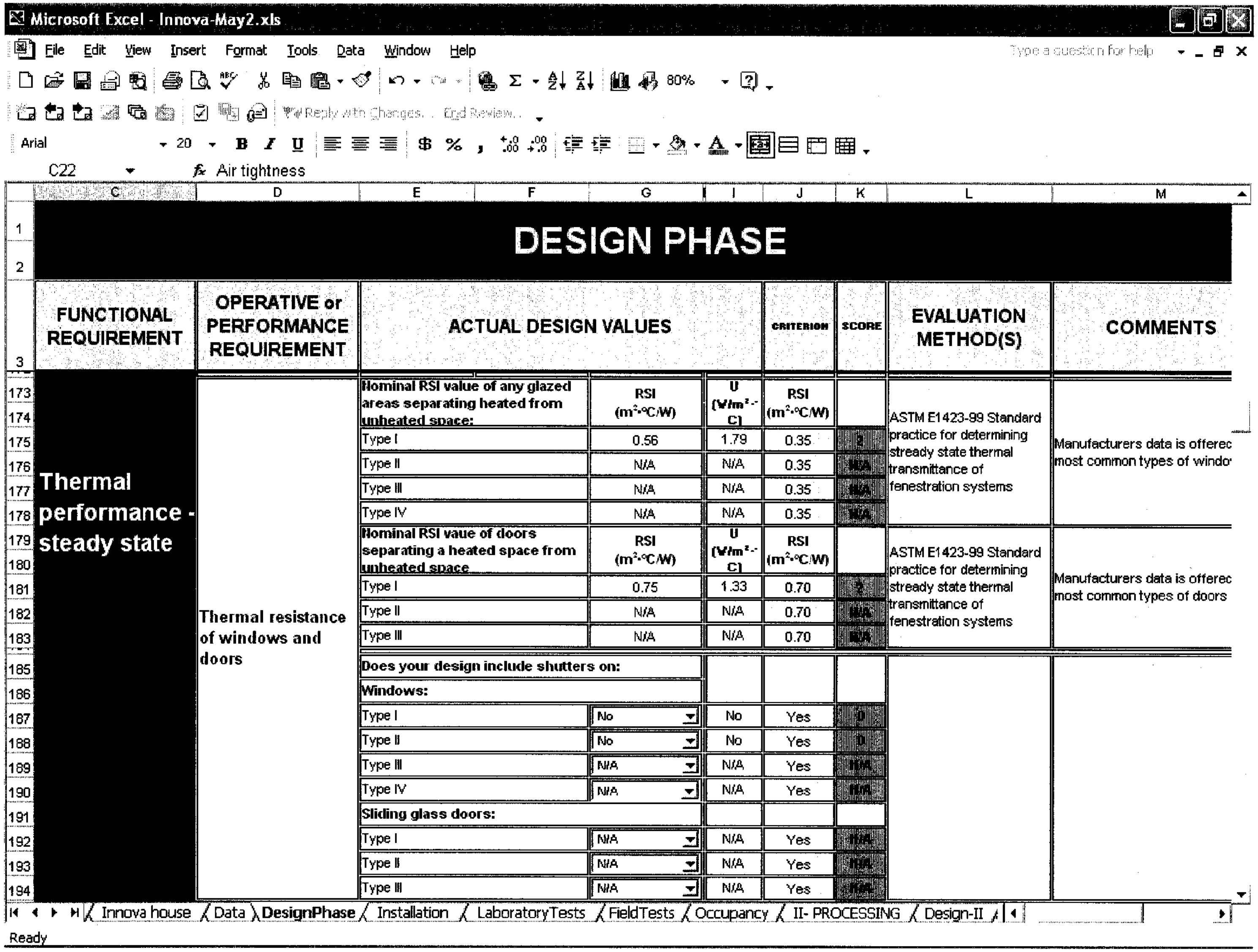
FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES			CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
Moisture management performance	**Rain water penetration manangement**	**Rain screen principle - does your exterior walls have:**						
		drainage space behind cladding: air space of min. 1 in	Yes	Yes	Yes	2	Check list according to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
		drainage plane	Yes	Yes	Yes	2		
		flashings	Yes	Yes	Yes	2		
		weep holes	Yes	Yes	Yes	2		
	Capillary suction	**Capillary control below grade - does your design include:**						
		layer of min 3/4-inch crushed stone with fine removed, under the basement floor slab	Yes	Yes	Yes	2	Checklist accordiang to ASTM E241-00 Standard Guide for Limiting Water-Induced Damage to Buildings	"No info" means that informati could not be found in working drawings
		capillary break over the top of the footing, placed prior to construction of perimeter foundation walls	Yes	Yes	Yes	2		
		dampproofing the exterior surface of basement walls	Yes	Yes	Yes	2		
		capillary break between the sill plate and the top of foundation wall	Yes	Yes	Yes	2		
		Capillary control above grade - does your design include:						
		capillary break in porous cladding materials (e.g. horizontal wood siding)	N/A	N/A	Yes	N/A		



C22 fx Air tightness

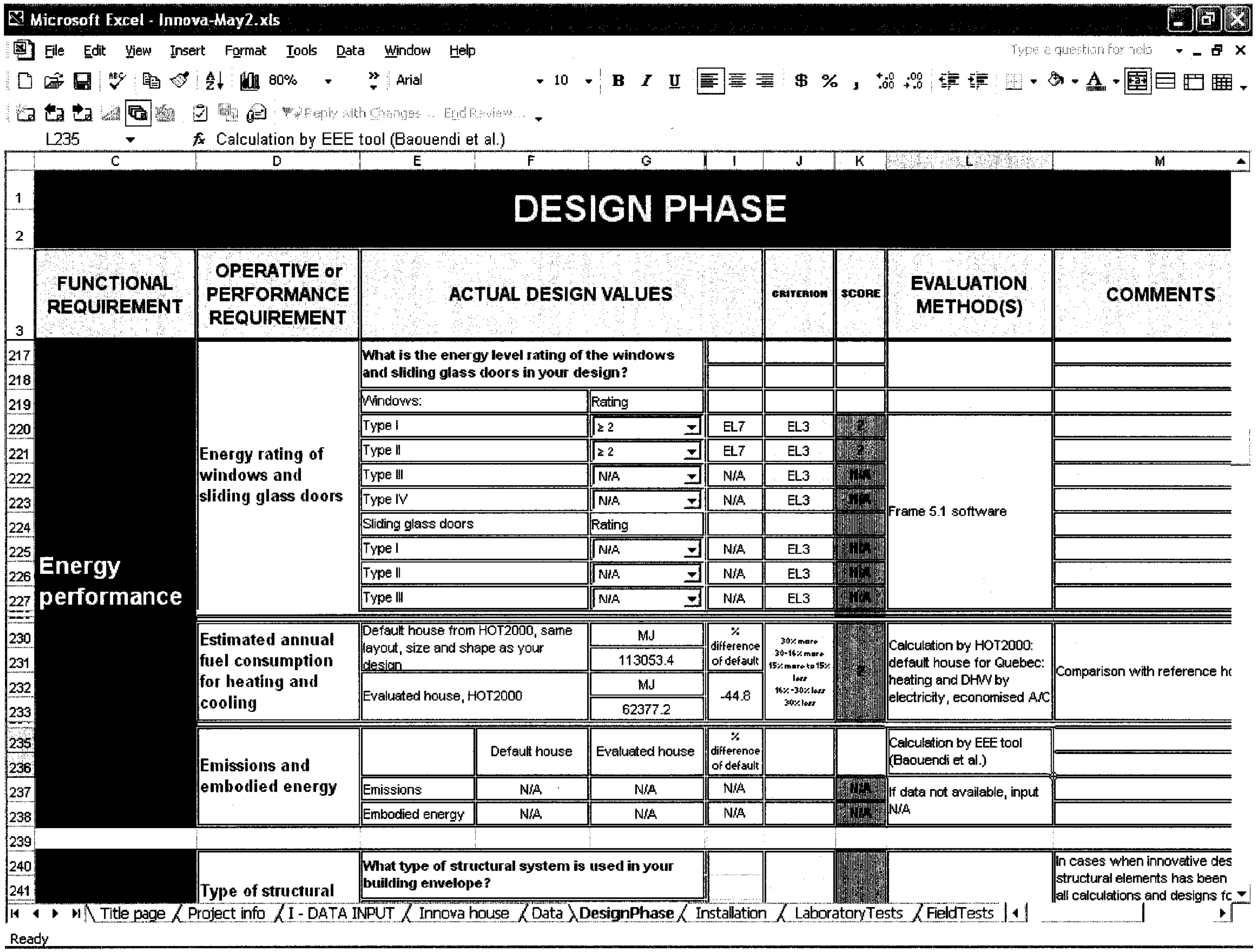
DESIGN PHASE

	C	D	E	F	G	I	J	K	L	M
3	FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES				CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
159			capillary break in porous cladding materials (e.g. horizontal wood siding)		N/A	N/A	Yes	N/A		
160										
161										
162	Thermal performance - steady state	Thermal resistance of an opaque parts of building envelope (design values)	**Input the nominal design RSI values for your:**		**RSI** (m²·°C/W)	**U** (W/m²·C)	**RSI** (m²·°C/W)		**Computation** of overall thermal resistance of opaque parts of the envelope: ASHRAE Handbook - Fundamentals, 1997 - chapter 22.7, parallel-path and/or isothermal planes - equations 1-5); or CONDENSE software;	Sugestion**: I calculate for mo common wall assemblies and as pull-down menu that they s If there is new wall system, th have to calculate using one of those methods. Criterion: NBC values, R-2000 values, Novoclimat values, Qu Energy Code values How to incorporate visually?
164			Roof		11.2	0.09	5.3	2		
165			Above grade walls		8.8	0.11	3.4	2		
166			Below grade walls		8.3	0.12	2.2	2		
167			Floors above non heated spaces		N/A	N/A	4.7	N/A		
168			Slab-on-grade with embedded pipes		N/A	N/A	1.6	N/A		
169			Slab-on-grade without pipes		N/A	N/A	1.2	N/A		
170			Basement floor		2.6	0.38	0.0	2		
171			Crawl space floor		N/A	N/A	0.0	N/A		
173			**Nominal RSI value of any glazed areas separating heated from unheated space:**		**RSI** (m²·°C/W)	**U** (W/m²·C)	**RSI** (m²·°C/W)		ASTM E1423-99 Standard practice for determining stready state thermal transmittance of fenestration systems	Manufacturers data is offerec most common types of windo
175			Type I		0.56	1.79	0.35	2		
176			Type II		N/A	N/A	0.35	N/A		
177			Type III		N/A	N/A	0.35	N/A		
178			Type IV		N/A	N/A	0.35	N/A		
179			**Nominal RSI vaue of doors separating a heated space from unheated space**		**RSI** (m²·°C/W)	**U** (W/m²·C)	**RSI** (m²·°C/W)		ASTM E1423-99 Standard practice for determining	Manufacturers data is offerec



DESIGN PHASE

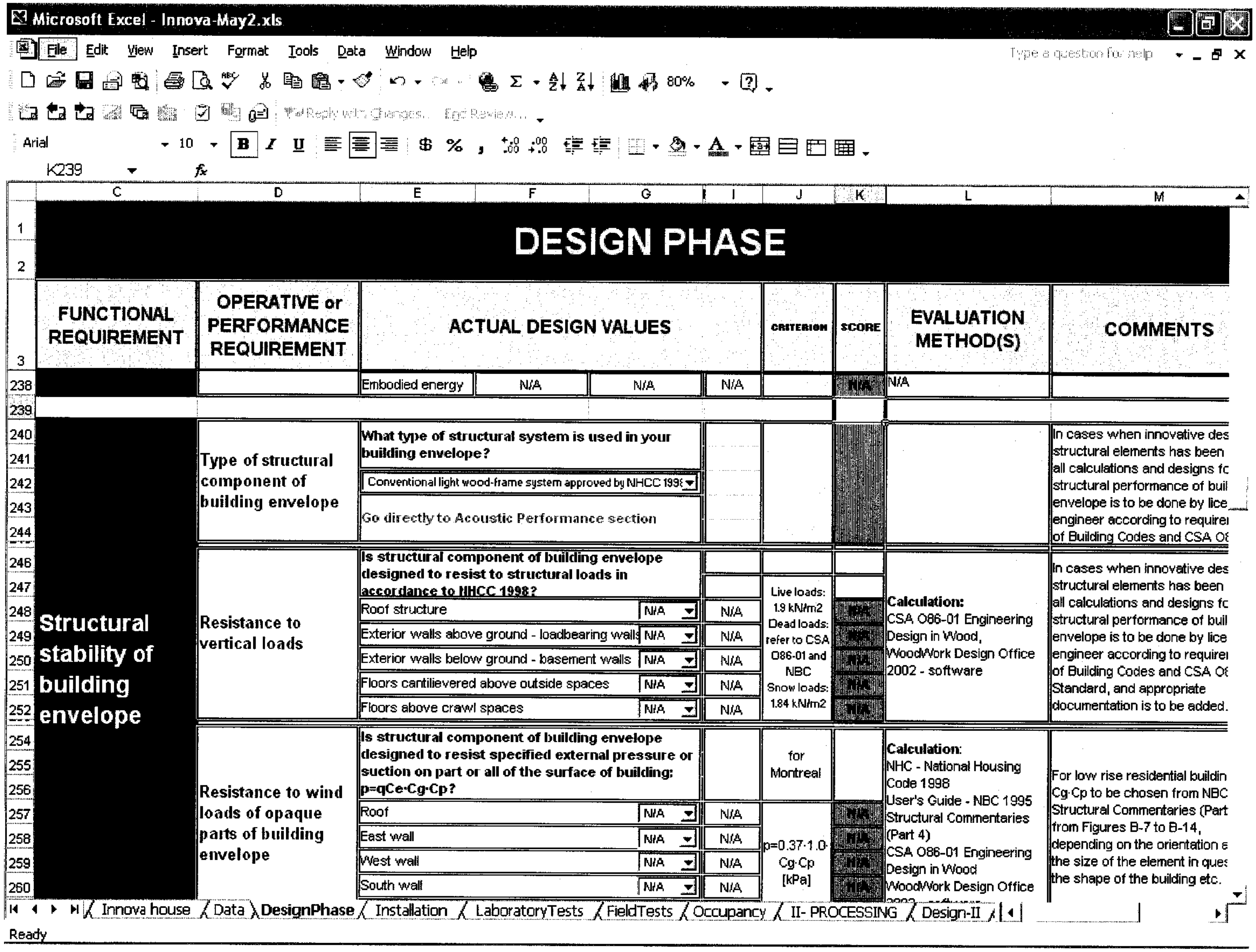
	FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES			CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
173	Thermal performance - steady state	Thermal resistance of windows and doors	**Nominal RSI value of any glazed areas separating heated from unheated space:**	RSI (m²·°C/W)	U (W/m²·C)	RSI (m²·°C/W)		ASTM E1423-99 Standard practice for determining stready state thermal transmittance of fenestration systems	Manufacturers data is offerec most common types of windo
174									
175			Type I	0.56	1.79	0.35	2		
176			Type II	N/A	N/A	0.35	N/A		
177			Type III	N/A	N/A	0.35	N/A		
178			Type IV	N/A	N/A	0.35	N/A		
179			**Nominal RSI vaue of doors separating a heated space from unheated space**	RSI (m²·°C/W)	U (W/m²·C)	RSI (m²·°C/W)		ASTM E1423-99 Standard practice for determining stready state thermal transmittance of fenestration systems	Manufacturers data is offerec most common types of doors
180									
181			Type I	0.75	1.33	0.70	2		
182			Type II	N/A	N/A	0.70	N/A		
183			Type III	N/A	N/A	0.70	N/A		
185			**Does your design include shutters on:**						
186			**Windows:**						
187			Type I	No	No	Yes	0		
188			Type II	No	No	Yes	0		
189			Type III	N/A	N/A	Yes	N/A		
190			Type IV	N/A	N/A	Yes	N/A		
191			**Sliding glass doors:**						
192			Type I	N/A	N/A	Yes	N/A		
193			Type II	N/A	N/A	Yes	N/A		
194			Type III	N/A	N/A	Yes	N/A		



L235 Calculation by EEE tool (Baouendi et al.)

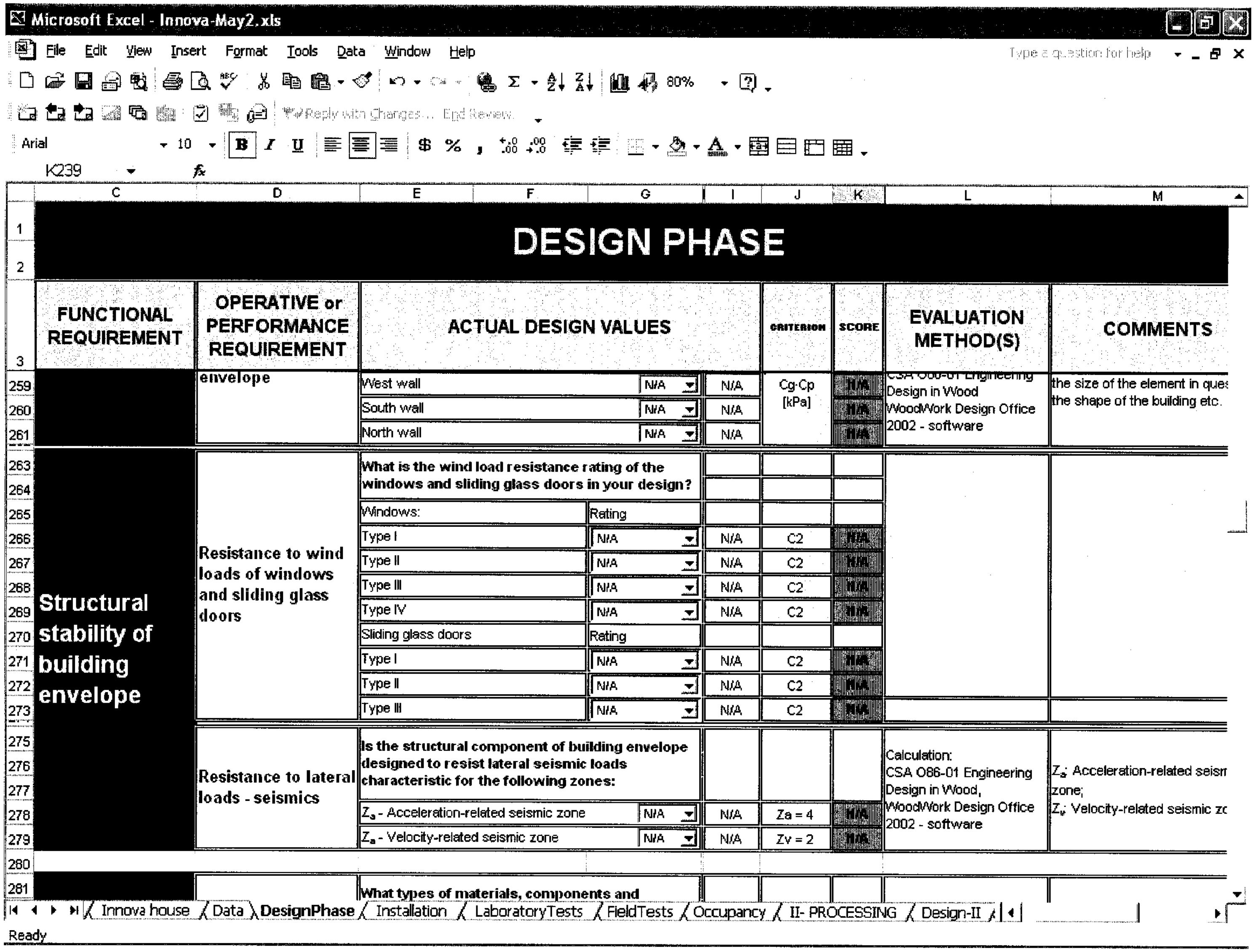
DESIGN PHASE

	FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES				CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
217 218	Energy performance	Energy rating of windows and sliding glass doors	**What is the energy level rating of the windows and sliding glass doors in your design?**							
219			Windows:		Rating					
220			Type I		≥ 2	EL7	EL3	2	Frame 5.1 software	
221			Type II		≥ 2	EL7	EL3	2		
222			Type III		N/A	N/A	EL3	N/A		
223			Type IV		N/A	N/A	EL3	N/A		
224			Sliding glass doors		Rating					
225			Type I		N/A	N/A	EL3	N/A		
226			Type II		N/A	N/A	EL3	N/A		
227			Type III		N/A	N/A	EL3	N/A		
230 231		Estimated annual fuel consumption for heating and cooling	Default house from HOT2000, same layout, size and shape as your design		MJ 113053.4	% difference of default	30% more 30-16% more 15% more to 15% less 16%-30% less 30% less	2	Calculation by HOT2000: default house for Quebec: heating and DHW by electricity, economised A/C	Comparison with reference h
232 233			Evaluated house, HOT2000		MJ 62377.2	-44.8				
235 236		Emissions and embodied energy		Default house	Evaluated house	% difference of default			Calculation by EEE tool (Baouendi et al.)	
237			Emissions	N/A	N/A	N/A		N/A	If data not available, input N/A	
238			Embodied energy	N/A	N/A	N/A		N/A		
239										
240 241		Type of structural	**What type of structural system is used in your building envelope?**							In cases when innovative des structural elements has been all calculations and designs fc



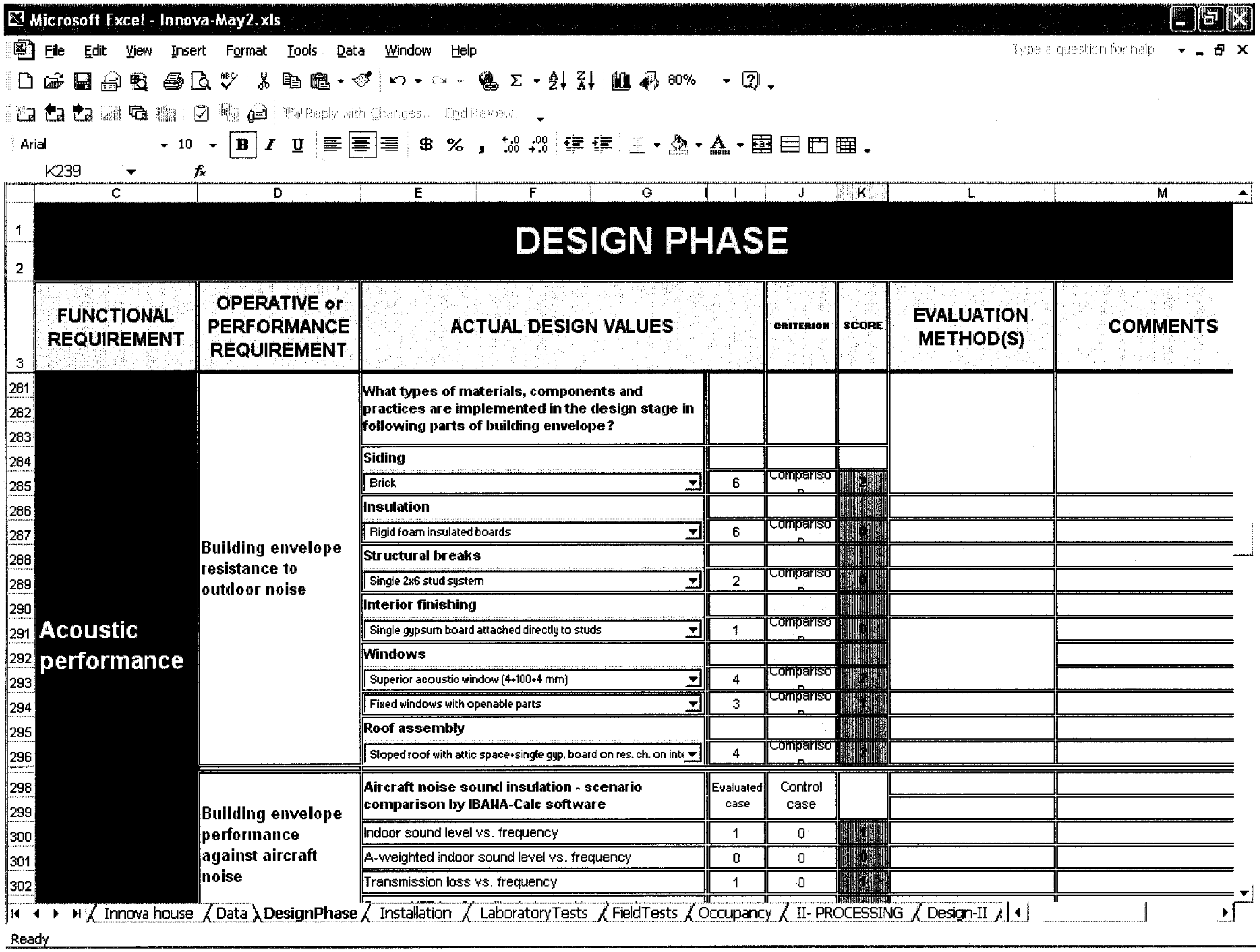
DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES				CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
		Embodied energy	N/A	N/A	N/A		N/A	N/A	
Structural stability of building envelope	**Type of structural component of building envelope**	**What type of structural system is used in your building envelope?** Conventional light wood-frame system approved by NHCC 199 Go directly to Acoustic Performance section							In cases when innovative des structural elements has been all calculations and designs fc structural performance of buil envelope is to be done by lice engineer according to requirei of Building Codes and CSA O8
	Resistance to vertical loads	**Is structural component of building envelope designed to resist to structural loads in accordance to NHCC 1998?**				Live loads: 1.9 kN/m2 Dead loads: refer to CSA O86-01 and NBC Snow loads: 1.84 kN/m2		**Calculation:** CSA O86-01 Engineering Design in Wood, WoodWork Design Office 2002 - software	In cases when innovative des structural elements has been all calculations and designs fc structural performance of buil envelope is to be done by lice engineer according to requirei of Building Codes and CSA O8 Standard, and appropriate documentation is to be added.
		Roof structure		N/A	N/A		N/A		
		Exterior walls above ground - loadbearing walls		N/A	N/A		N/A		
		Exterior walls below ground - basement walls		N/A	N/A		N/A		
		Floors cantilievered above outside spaces		N/A	N/A		N/A		
		Floors above crawl spaces		N/A	N/A		N/A		
	Resistance to wind loads of opaque parts of building envelope	**Is structural component of building envelope designed to resist specified external pressure or suction on part or all of the surface of building: p=qCe·Cg·Cp?**				for Montreal		**Calculation:** NHC - National Housing Code 1998 User's Guide - NBC 1995 Structural Commentaries (Part 4) CSA O86-01 Engineering Design in Wood WoodWork Design Office 2002 - software	For low rise residential buildin Cg·Cp to be chosen from NBC Structural Commentaries (Part from Figures B-7 to B-14, depending on the orientation a the size of the element in ques the shape of the building etc.
		Roof		N/A	N/A	p=0.37·1.0·Cg·Cp [kPa]	N/A		
		East wall		N/A	N/A		N/A		
		West wall		N/A	N/A		N/A		
		South wall		N/A	N/A		N/A		



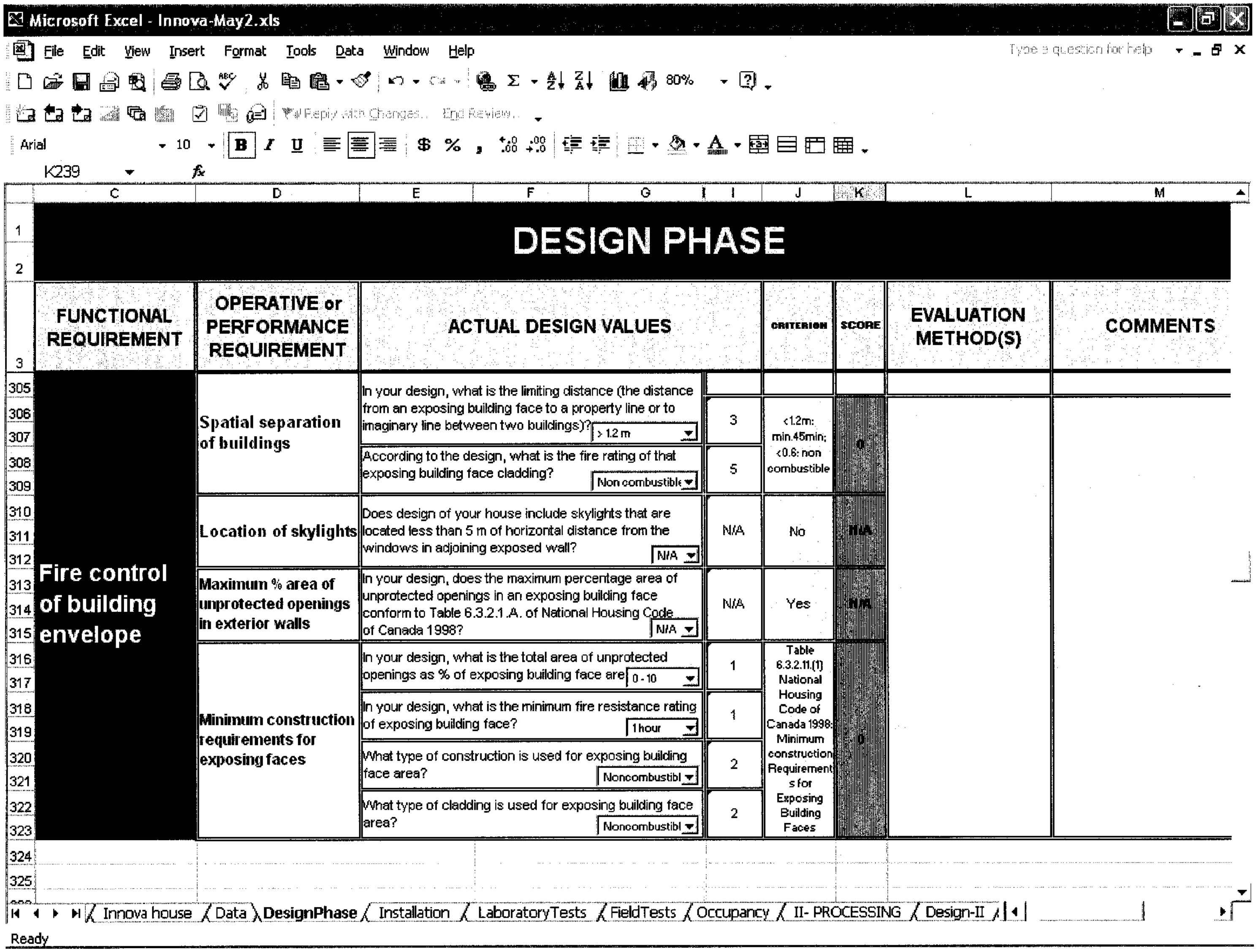
DESIGN PHASE

	FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES			CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
259		envelope	West wall	N/A	N/A	Cg·Cp [kPa]	N/A	CSA O86-01 Engineering Design in Wood WoodWork Design Office 2002 - software	the size of the element in que the shape of the building etc.
260			South wall	N/A	N/A		N/A		
261			North wall	N/A	N/A		N/A		
263	Structural stability of building envelope	Resistance to wind loads of windows and sliding glass doors	**What is the wind load resistance rating of the windows and sliding glass doors in your design?**						
265			Windows:	Rating					
266			Type I	N/A	N/A	C2	N/A		
267			Type II	N/A	N/A	C2	N/A		
268			Type III	N/A	N/A	C2	N/A		
269			Type IV	N/A	N/A	C2	N/A		
270			Sliding glass doors	Rating					
271			Type I	N/A	N/A	C2	N/A		
272			Type II	N/A	N/A	C2	N/A		
273			Type III	N/A	N/A	C2	N/A		
275		Resistance to lateral loads - seismics	**Is the structural component of building envelope designed to resist lateral seismic loads characteristic for the following zones:**					Calculation: CSA O86-01 Engineering Design in Wood, WoodWork Design Office 2002 - software	Z_a: Acceleration-related seism zone; Z_v: Velocity-related seismic zo
278			Z_a - Acceleration-related seismic zone	N/A	N/A	Za = 4	N/A		
279			Z_a - Velocity-related seismic zone	N/A	N/A	Zv = 2	N/A		
280									
281			**What types of materials, components and**						



DESIGN PHASE

3	FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES		CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
281–283	**Acoustic performance**	**Building envelope resistance to outdoor noise**	**What types of materials, components and practices are implemented in the design stage in following parts of building envelope?**					
284			**Siding**					
285			Brick	6	Compariso	2		
286			**Insulation**					
287			Rigid foam insulated boards	6	Compariso	0		
288			**Structural breaks**					
289			Single 2x6 stud system	2	Compariso	0		
290			**Interior finishing**					
291			Single gypsum board attached directly to studs	1	Compariso	0		
292			**Windows**					
293			Superior acoustic window (4+100+4 mm)	4	Compariso	2		
294			Fixed windows with openable parts	3	Compariso	1		
295			**Roof assembly**					
296			Sloped roof with attic space+single gyp. board on res. ch. on int	4	Compariso	2		
298–299		**Building envelope performance against aircraft noise**	**Aircraft noise sound insulation - scenario comparison by IBANA-Calc software**	Evaluated case	Control case			
300			Indoor sound level vs. frequency	1	0	1		
301			A-weighted indoor sound level vs. frequency	0	0	0		
302			Transmission loss vs. frequency	1	0	1		



DESIGN PHASE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL DESIGN VALUES		CRITERION	SCORE	EVALUATION METHOD(S)	COMMENTS
Fire control of building envelope	**Spatial separation of buildings**	In your design, what is the limiting distance (the distance from an exposing building face to a property line or to imaginary line between two buildings)? > 1.2 m	3	<1.2m: min.45min; <0.6: non combustible	0		
		According to the design, what is the fire rating of that exposing building face cladding? Non combustible	5				
	Location of skylights	Does design of your house include skylights that are located less than 5 m of horizontal distance from the windows in adjoining exposed wall? N/A	N/A	No	N/A		
	Maximum % area of unprotected openings in exterior walls	In your design, does the maximum percentage area of unprotected openings in an exposing building face conform to Table 6.3.2.1.A. of National Housing Code of Canada 1998? N/A	N/A	Yes	N/A		
	Minimum construction requirements for exposing faces	In your design, what is the total area of unprotected openings as % of exposing building face are 0 - 10	1	Table 6.3.2.11.(1) National Housing Code of Canada 1998: Minimum construction Requirements for Exposing Building Faces	0		
		In your design, what is the minimum fire resistance rating of exposing building face? 1hour	1				
		What type of construction is used for exposing building face area? Noncombustibl	2				
		What type of cladding is used for exposing building face area? Noncombustibl	2				

APPENDIX C: BEPAT – INTRODUCTORY PAGES

TITLE PAGE

Authors

Developed by: M. Horvat, M. Arch, Ph.D. Candidate,

Concept and supervision provided by: P. Fazio, Ph.D., P.Eng.(Que.), P.Eng.(Ont.), FCSCE, FASCE, Professor, Building Envelope Performance Laboratories,

Centre for Building Studies, Department of Building, Civil and Environmental Engineering, CONCORDIA UNIVERSITY, 1455 boul. de Maisonneuve West, Montreal, QC, H3G 1M8, CANADA

Disclaimer

BEPAT - Building Envelope Performance Assessment Tool is presently under development as a part of the requirements of Ph.D. thesis at the department of Building, Civil and Environmental Engineering, Faculty of Engineering and Computer Science, Concordia University, Montreal, Quebec. At this point, it is not intended for commercial use in any form. Results obtained in this evaluation are for informational purpose only and do not override the requirements of National Building Code of Canada. Questions and comments can be directed to the author Miljana Horvat at mhorvat@ryerson.ca.

Intended use

BEPAT tool is intended to be used for overall performance evaluation of light-frame building envelopes that are used in residential and small commercial buildings, both site-built and prefabricated.

This tool is intended to be used by professionals: architects, building envelope designers, home builders and producers of factory-made houses in Canada for a voluntary examination of existing designs as well as exploration and verification of new designs.

Description

BEPAT tool evaluates the envelope on following functional requirements: air tightness, moisture management performance, thermal performance, energy performance, structural stability, acoustic performance and fire control of building envelope. Quality control in design and workmanship is included in the evaluation process through fulfillment of certain operative requirements.

This tool covers the assessment of the envelope from the design stage to the execution and installation phase. It also includes full-scale laboratory tests if necessary, in cases of innovative designs and new building systems, as well as field tests that are done upon completion of the building.

Developed in Microsoft Excel, BEPAT tool performs some internal calculations. However, in some cases it uses data generated by other models, calculation methods and computer programs, such as HOT2000, Condense, EEE, IBANA etc. BEPAT utilize that data by comparing it to benchmark values, and performs scoring and weighting according to the level of priority of certain operative requirement over the others.

The criteria for evaluation are based on Montreal's climatic, technical and social environment. However, this tool is envisioned to represent a framework for developing similar protocols and assessment tools for examining performance of building envelopes under different parameters, priorities, technologies and building traditions that exist in various regions and countries.

Data entry

In order to simplify the data entry process for the user, whenever it was possible, the "pull-down" menus are employed with multiple choices of values, from which the user can make a selection. Similarly, the questions are posed in a way that user can select "yes", "no" or "N/A" (for Not applicable) as an answer.

Some fields, though, have to be filled manually, usually with numerical values - results obtained from calculations and computer models mentioned earlier.

In case the certain operative requirements have no application or relevancy in certain cases, user should just leave them blank, and these fields will not be incorporated in final calculation.

Scoring system

For each instance, the assigned points reflect in what level evaluated performance correspond with its criterion. The points assigned usually range from -2, -1, 0, +1, +2, where:

0 points represents that requirement meets the local building code,

+1 and + 2 that requirement exceeds it in comparable levels, and

-1 and -2 that it performs below expectations, again, comparably.

For example, in case of air leakage, 0 points would be assigned for measured air leakage of 4-6 ACH at 50 Pa (average for new houses nowadays), +1 point for leakage from 1.5 to 4 ACH and +2 points for air leakage of less than 1.5 ACH at 50 Pa (R-2000 value). Accordingly, -1 points would be assigned for air leakage from 6 to 8, and - 2 points for more than 8 ACH at 50 Pa.

Weighting system

The weighting system is developed to reflect priorities among the parameters, which is able to be changed with relevance to users' needs. For example, within the moisture management performance section, not all requirements carry the same importance. E.g. out of total 100% for moisture management performance, the existence of rain screen can carry 30% of weight, continuous air barrier 15%, capillary break barriers 15%, vapour barrier 10%, waterproofing of basement walls against ground water 15%, condensation within assembly 15%, etc.

Microsoft Excel will automatically calculate points from scoring section multiplied with their according weight (percentage). Total score will represent the level of performance of wood frame building envelope. The threshold score (A) will be set; everything below will indicate that performance is not satisfactory. Scores that exceed will reflect different categories of performance: e.g. B - C points represents good performance, D to E points - very good, and F to G - excellent performance.

PROJECT INFORMATION

Client – building owner

- Name
- Address, telephone & fax number, web-site
- Contact person: name, title, telephone, e-mail

Assessed building

- Name
- Location
- Type (e.g.: detached, semi-detached, townhouse, multi-unit apartment building);
- Structure (e.g.: wood-frame, steel-frame, structural insulated panels - SIPs, concrete, insulated concrete formworks – ICFs, other);
- System (e.g.: conventionally site built, kit house, panellised, modular, other).

Design

- Company name;
- Address, telephone & fax number, web-site;
- Contact person: name, title, telephone, e-mail.

Builder / manufacturer

- Company name;
- Address, telephone & fax number, web-site;
- Contact person: name, title, telephone, e-mail.

Assessor

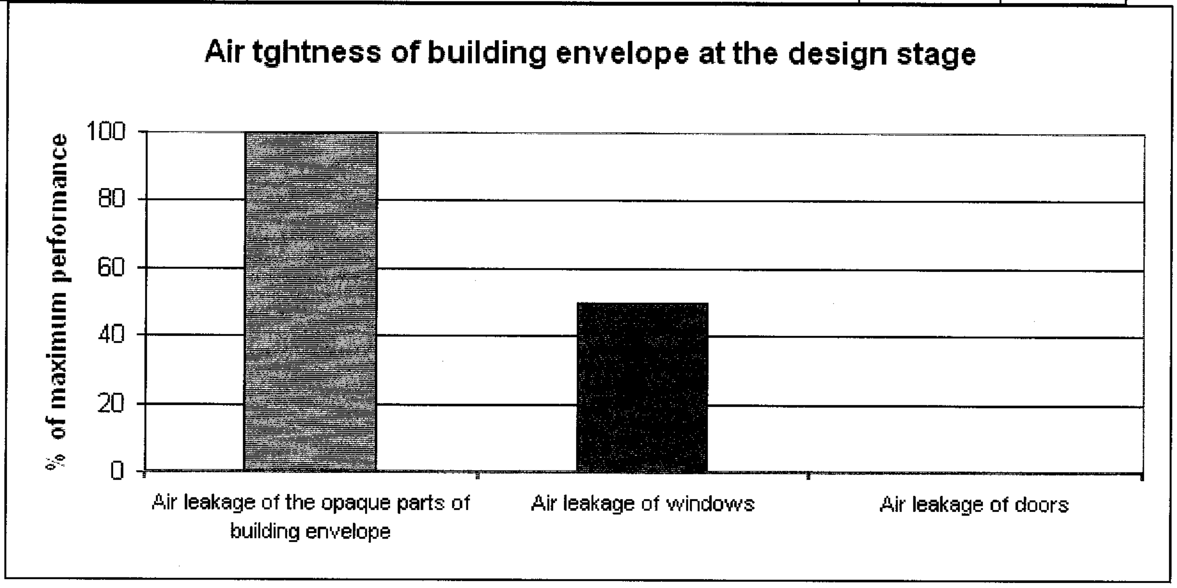
- Company name;
- Address, telephone & fax number, web-site;
- Contact person: name, title, telephone, e-mail.

APPENDIX D: B-LEVEL (INTERMEDIATE) OUTPUT OF BEPAT

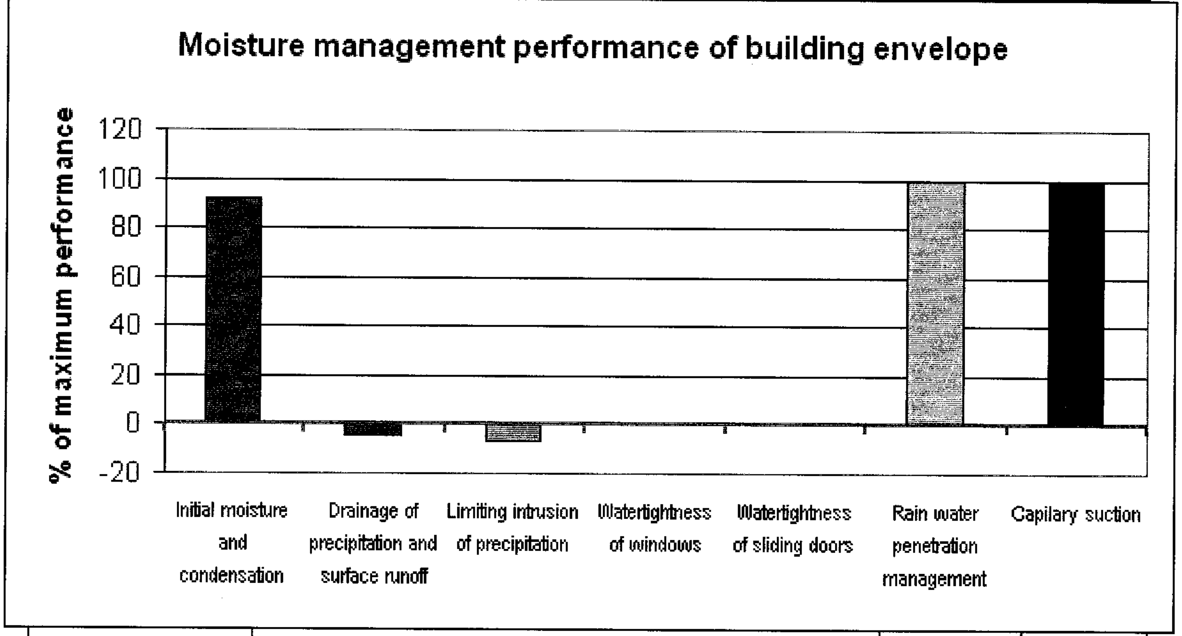
PROJECT INFORMATION

Client:	NRCan			Tel:	(613) 943-2260
	580 Booth Street	Ottawa	ON	Fax:	(613) 996-9909
Contact person:	Robin Sinha	Team Manager, Residential, ETPS/CETC/CETC-OTT/BET	K1A 0E4	E-mail:	Robin.Sinha@nrcan-rncan.gc.ca
Building:	Innova Advanced House				
	Detached house	Wood-frame	Site built		
N/A		Kanata	ON	N/A	
Builder/ Manufacturer:	Minto housing			Tel:	N/A
	N/A	Ottawa	ON	Fax:	N/A
Contact person:	N/A	N/A	N/A	E-mail:	N/A
Assessor:	Miljana Horvat		0		
	350 Victoria St.	Toronto	ON	Tel:	416-979-5000
Date of assessment:	14/06/2005			Fax:	416-979-5353
				E-mail:	mhorvat@ryerson.ca

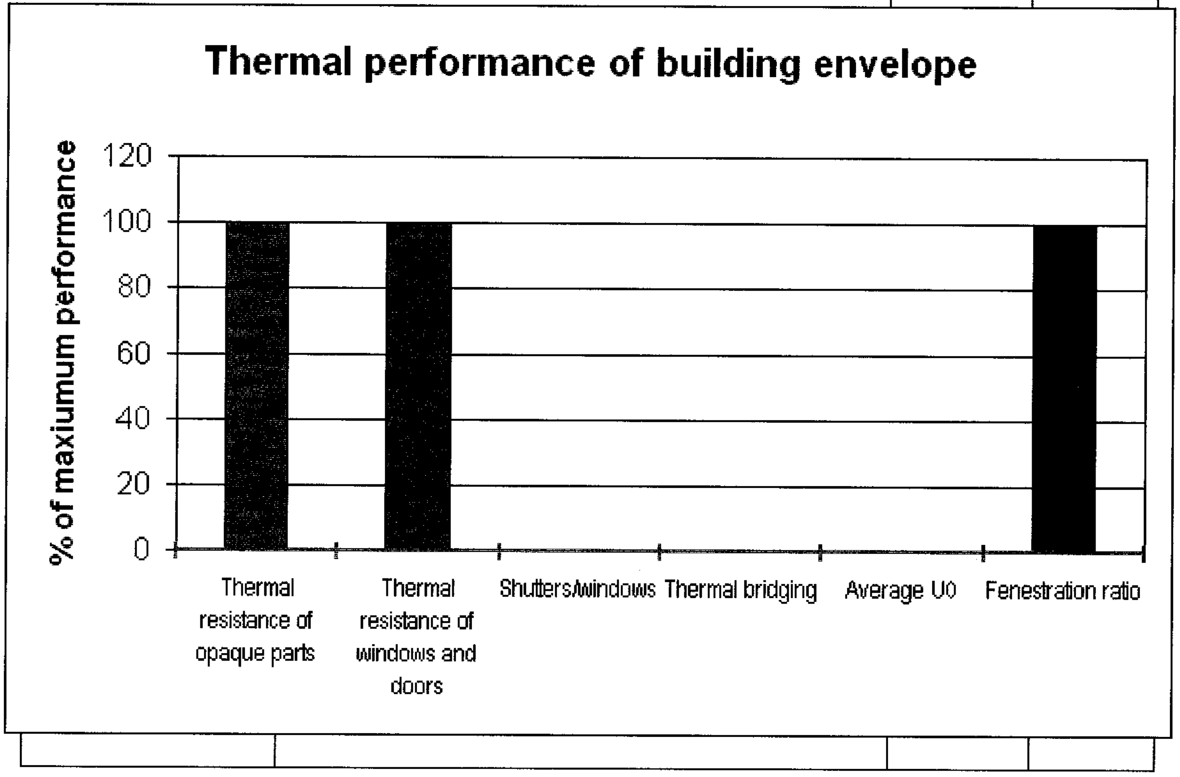
PERFORMANCE EVALUATION OUTPUT B - LEVEL (INTERMEDIATE)			
DESIGN STAGE			
Functional requirement	**Performance requirement**	**Sub-totals**	**%**
Air tightness performance	Air leakage of the opaque parts of building envelope	147.83	100
	Air leakage of windows	17.39	50
	Air leakage of doors	0.00	0


Air tghtness of building envelope at the design stage

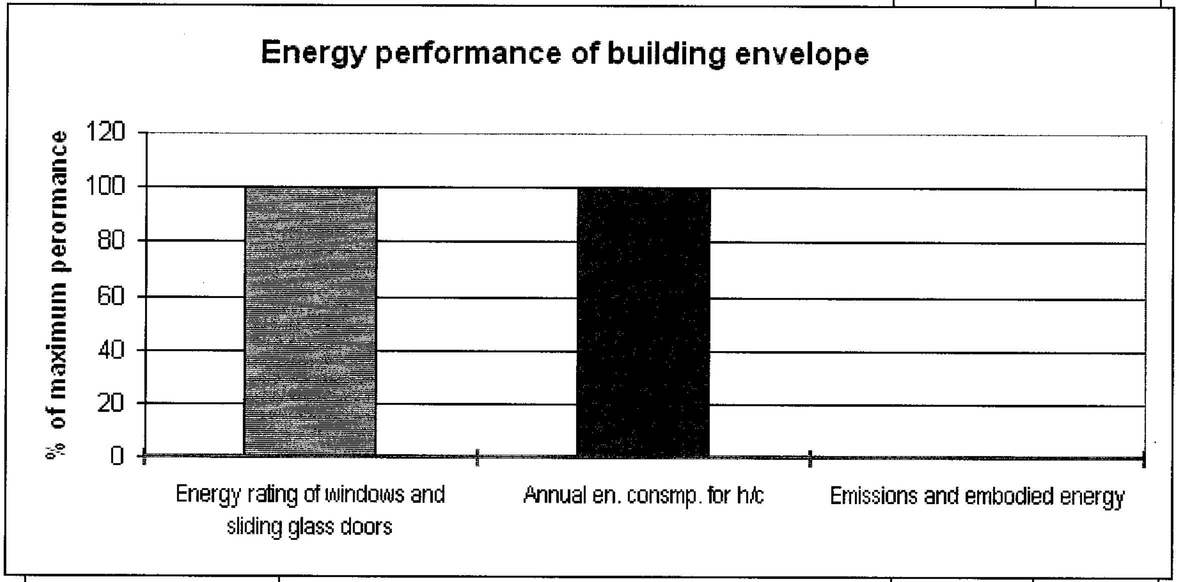
Functional requirement	**Performance requirement**	**Sub-totals**	**%**
Moisture management performance	Initial moisture and condensation	24.18	92
	Drainage of precipitation and surface runoff	-1.92	-4
	Limiting intrusion of precipitation	-5.22	-7
	Watertightness of windows	0.00	0
	Watertightness of sliding doors	0.00	0
	Rain water penetration management	28.57	100
	Capilarry suction	17.58	100



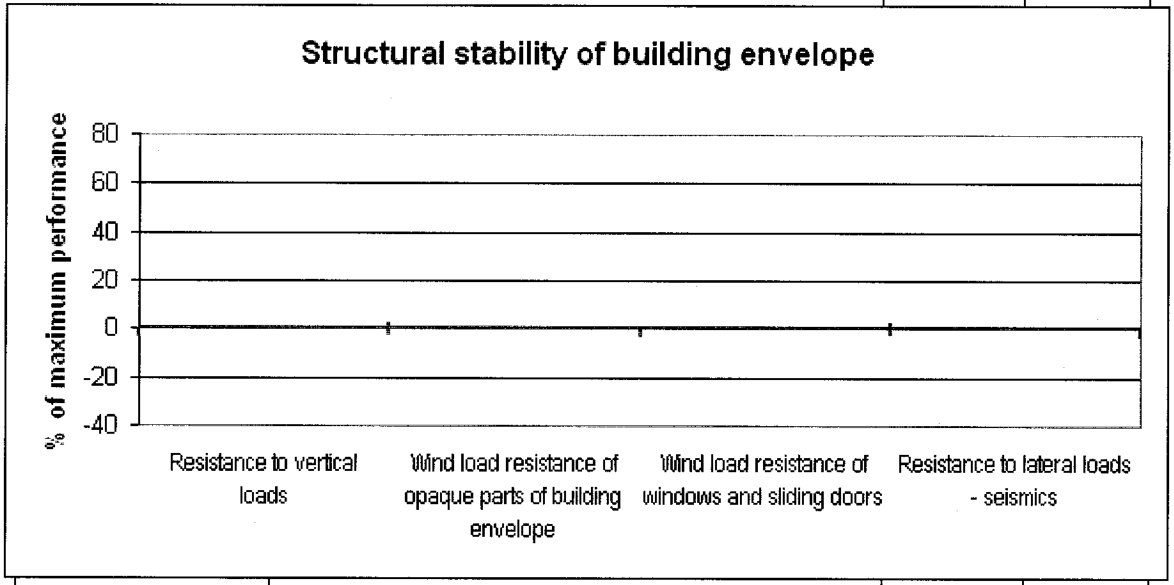
Functional requirement	Performance requirement	Sub-totals	%
Thermal performance of building envelope	Thermal resistance of opaque parts of building envelope (design values)	38.10	100
	Thermal resistance of windows and doors	57.14	100
	Shutters on windows and glass doors	0.00	0
	Thermal bridgeing	0.00	0
	Average U_0	0.00	0
	Fenestration ratio	200.00	100



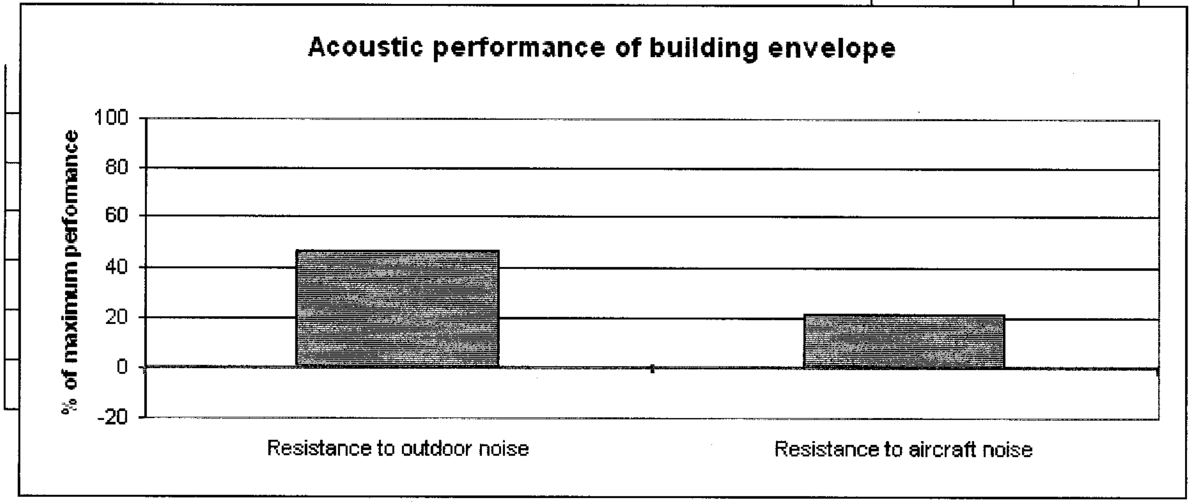
Functional requirement	**Performance requirement**	**Sub-totals**	**%**
Energy performance	Energy rating of windows and sliding glass doors	200.00	100
	Annual en. consmp. for h/c	200.00	100
	Emissions and embodied energy	0.00	0



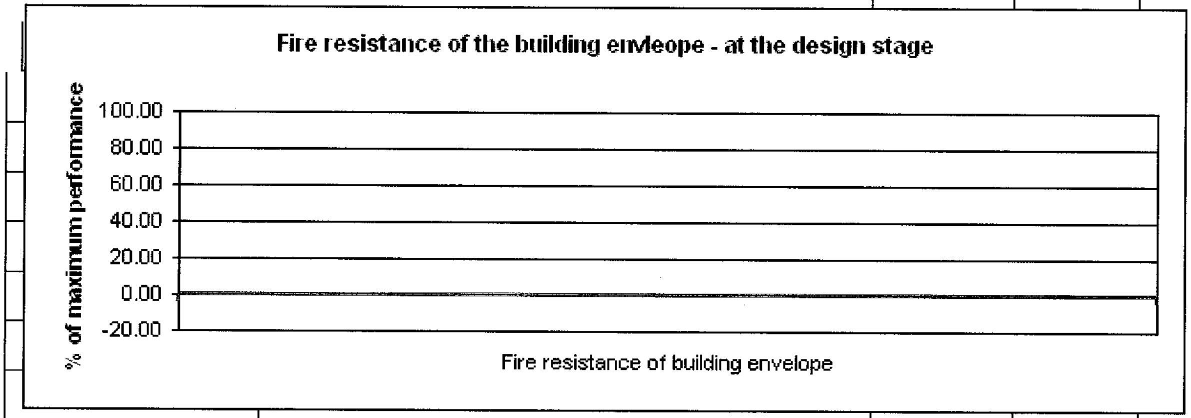
Functional requirement	Performance requirement	Sub-totals	%
Structural stability of building envelope	Resistance to vertical loads	0.00	0
	Wind load resistance of opaque parts of building envelope	0.00	0
	Wind load resistance of windows and sliding doors	0.00	0
	Resistance to lateral loads - seismics	0.00	0



Functional requirement	Performance requirement	Sub-totals	%
Acoustic performance	Resistance to outdoor noise	92.86	46
	Resistance to aircraft noise	42.86	21



Functional requirement	Performance requirement	Sub-totals	%
Fire resistance of building envelope	Building code requirements	0.00	0



APPENDIX E: BEPAT EVALUATION OUTPUT, 2ND RUN, INNOVA HOUSE, C-LEVEL DETAILED OUTPUT

PROJECT INFORMATION					
Client:	NRCan			Tel:	(613) 943-2260
	580 Booth Street	Ottawa	ON	Fax:	(613) 996-9909
Contact person:	Robin Sinha	Team Manager, Residential, ETPS/CETC/CETC-OTT/BET		E-mail:	Robin.Sinha@nrcan-rncan.gc.ca
Building:	Innova Advanced House				
	Detached house	Wood-frame	Site built		
Kanata		N/A	ON		
Builder/ Manufacturer	Minto housing			Tel:	N/A
	N/A	Ottawa	ON	Fax:	N/A
Contact person:	N/A	N/A		E-mail:	0
Assessor:	Miljana Horvat				
	Assistant Profesor	0		Tel:	416-979-5000, ext. 6512
Date of assessment:	14/06/2005			Fax:	416-979-5353
350 Victoria St.		Toronto	ON	E-mail:	mhorvat@ryerson.ca

PERFORMANCE EVALUATION OUTPUT
C - LEVEL (DETAILED)

DESIGN STAGE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL VALUES		SCORES (A)	◄	WEIGHT		RESULT (A x B)	SUBTOTAL	% exceeding the benchmark
						FACTOR	% (B)			
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component		$L/s \cdot m^2$							
		Exterior walls:	0.00	2		1	4.35	8.70	147.83	100
		Roof:	0.00	2		1	4.35	8.70		
		Joints:								
		boards and membranes	Yes	2		3	13.04	26.09		
		sillplate/top plate gaskets	Yes	2		3	13.04	26.09		
		windows and doors	Yes	2		4	17.39	34.78		
		penetrations	Yes	2		3	13.04	26.09		
		others	Yes	2		2	8.70	17.39		
	Air leakage of windows	Type I	0.15	2		2	8.70	17.39	34.78	100
		Type II	0.15	2		2	8.70	17.39		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
	Air leakage of doors	Sliding and non-whether stripped							0.00	0
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		All other doors								
		Type I	15	0		2	8.70	0.00		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
Moisture management	Use of kiln dried wood	Initial MC of lumber	12	2		3	3.16	6.32	23.16	92
	Water vapour permeability of	Exterior walls	3	2		2	2.11	4.21		

performance	the assembly	Sheathing	67							
		Roofs	3	2		2	2.11	4.21		
		Sheathing	N/A							
	Interstitial condensation	Calculated condensation rate across exterior walls' assembly:	2639	2		2	2.11	4.21		
		Calculated condensation rate across roof assembly:	3094	2		2	2.11	4.21		
	Surface condensation	Calculated internal surface temperature	20.4	0		1	1.05	0.00		
	Drainage of precipitation and surface runoff	Surface grading	No info	-1	◄	2	2.11	-2.11	27.37	65
		External drains	No info	-1	◄	2	2.11	-2.11		
		Impermeable backfill	No info	-1	◄	3	3.16	-3.16		
		Drain screen	Yes	2		5	5.26	10.53		
		Waterproof membrane	Yes	2		4	4.21	8.42	-7.37	-18
		Drainage pipes	Yes	2		4	4.21	8.42		
		Control joints	N/A	N/A		3	N/A	N/A		
Moisture management performance	Limiting intrusion of precipitation	Roofs:							52.63	66
		Planes sloped away	Yes	2		4	4.21	8.42		
		Sloped roof slope > 1:6	Yes	2		2	2.11	4.21		
		Valleys lead away	Yes	2		4	4.21	8.42		
		Flat roof slope >1:X	N/A	N/A		4	N/A	N/A		
		Flat roof valleys >1:Y	N/A	N/A		4	N/A	N/A		
		Required drainage area	N/A	N/A		5	N/A	N/A		
		Flashings for penetrations	Yes	2		4	4.21	8.42		
		Deposition on walls								
		Overhangs' size	40 - 60 cm	1		2	2.11	2.11		
		Gutters at roof edges	No info	-1	◄	2	2.11	-2.11	-12.63	-16
		Downspouts	No info	-1	◄	5	5.26	-5.26		
		Sloped balconies	No info	-1	◄	2	2.11	-2.11		
		Tresholds' flashings	Yes	2		4	4.21	8.42		
		Junctions' flashings	Yes	2		4	4.21	8.42		
		Sloped window sills	Yes	2		2	2.11	4.21		

		Sill drips	No info	-1	◄	3	3.16	-3.16		
		Coping drips	N/A	N/A		3	N/A	N/A		
		Watertightness of windows								
Moisture management performance	Rain water penetration management	Type I	B2	0		2	2.11	0.00	0.00	0.0
		Type II	B2	0		2	2.11	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Watertightness of sliding doors								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A	0.00	0
		Type III	N/A	N/A		2	N/A	N/A		
		Drainage space	Yes	2		3	3.16	6.32		
		Drainage plane	Yes	2		3	3.16	6.32	27.37	100
		Flashings	Yes	2		4	4.21	8.42		
		Weep holes	Yes	2		3	3.16	6.32		
		Under the slab	Yes	2		2	2.11	4.21		
	Capillary suction	Top of the footing	Yes	2		2	2.11	4.21	16.84	100
		Basement walls	Yes	2		2	2.11	4.21		
		Below sill plate	Yes	2		2	2.11	4.21		
		Porous cladding	N/A	N/A		2	N/A	N/A		
			RSI							
Thermal performance - steady state	Thermal resistance of an opaque parts of building envelope (design values)	Roof	11.2	2		1	4.17	8.33		
		Above grade walls	8.8	2		1	4.17	8.33	33.33	100
		Below grade walls	8.3	2		1	4.17	8.33		
		Floors above non heated spaces	N/A	N/A		1	N/A	N/A		
		Slab-on-grd w/pipes	N/A	N/A		1	N/A	N/A		
		Slab-on-grd no pipes	N/A	N/A		1	N/A	N/A		
		Basement floor	2.64	2		1	4.17	8.33		
		Crawl space floor	N/A	N/A		1	N/A	N/A		
		Windows, skylights:	RSI							
Thermal	Thermal resistance of	Type I	0.56	2		3	12.50	25.00	75.00	100

performance - steady state	windows and doors	Type II	0.56	2		3	12.50	25.00		
		Type III	N/A	N/A		3	N/A	N/A		
		Type IV	N/A	N/A		3	N/A	N/A		
		Sliding glass doors	RSI							
		Type I	0.75	2		3	12.50	25.00		
		Type II	N/A	N/A		3	N/A	N/A		
		Type III	N/A	N/A		3	N/A	N/A		
		Shutters for windows:								
		Type I	No	0		2	8.33	0.00		
		Type II	No	0		2	8.33	0.00	0.00	0
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Shutters for gl. doors								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
Thermal performance - steady state										
	Thermal bridging	% of studs in 1m' of wall	11.5	0		2	5.26	0.00	0.00	0
		$U_{average}$ of:								
	Average thermal transmittance of the building envelope - U_0	Walls above ground	0.00			1	4.17	0.00	0.00	0
		Walls below ground	0.00			1	4.17	0.00		
		Roof area	0.00			1	4.17	0.00		
		Floor area	0.00			1	4.17	0.00		
		Total U_0	0.00			1	4.17	0.00		
		North wall	4.80	2		1	16.67	33.33		
Transient thermal response	Ratio between fenestration vs. whole wall area (in elevation)	South wall	12.25	2		2	33.33	66.67	200.00	100
		East wall	3.23	2		1	16.67	33.33		
		West wall	2.50	2		2	33.33	66.67		

		Windows' en. level								
Energy performance	Energy rating of windows and sliding glass doors	Type I	EL7	2		2	50.00	100.00	200.00	100
		Type II	EL7	2		2	50.00	100.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Sliding door en. level								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
	Annual energy consumption for heating/cooling	Difference from default house	-44.8	2		1	100.00	200.00	200.00	100
		Emissions	N/A	N/A		1	N/A	N/A		
	Emissions and embodied energy	Embodied energy	N/A	N/A		1	N/A	N/A	0.00	0
		Roofs	N/A	N/A		1	N/A	N/A		
Structural stability of building envelope	Resistance to vertical loads	Exterior walls	N/A	N/A		1	N/A	N/A	0.00	0
		Basement walls	N/A	N/A		1	N/A	N/A		
		Cantilevered floors	N/A	N/A		1	N/A	N/A		
		Floors above crawl.sp	N/A	N/A		1	N/A	N/A		
		Roof	N/A	N/A		1	N/A	N/A		
	Wind load resistance of opaque parts of building envelope	East wall	N/A	N/A		1	N/A	N/A	0.00	0
		West wall	N/A	N/A		1	N/A	N/A		
		South wall	N/A	N/A		1	N/A	N/A		
		North wall	N/A	N/A		1	N/A	N/A		
Structural stability of building envelope		Windows						0.00		
	Wind load resistance of windows and sliding doors	Type I	N/A	N/A		1	N/A	N/A	0.00	0
		Type II	N/A	N/A		1	N/A	N/A		
		Type III	N/A	N/A		1	N/A	N/A		

		Type IV	N/A	N/A		1	N/A	N/A		
		Sliding glass doors								
		Type I	N/A	N/A		1	N/A	N/A		
		Type II	N/A	N/A		1	N/A	N/A		
		Type III	N/A	N/A		1	N/A	N/A		
		Za	N/A	N/A		2	N/A	N/A		
	Resistance to lateral loads - seismics	Zv	N/A	N/A		2	N/A	N/A	0.00	0
		Siding	6	2		1	7.14	14.29		
Acoustic performance	Resistance to outdoor noise	Insulation	6	0		2	14.29	0.00	92.86	46
		Structural breaks	2	0		3	21.43	0.00		
		Interior finishing	1	0		1	7.14	0.00		
		Windows - type	4	2		2	14.29	28.57		
		Windows - openning	3	1		3	21.43	21.43		
		Roofs	4	2		2	14.29	28.57		
		Indoor sound level	1	1		1	14.29	14.29		
	Resistance to aircraft noise	A-weighted in. s. l.	0	0		2	28.57	0.00	42.86	21
		Transmission loss	1	1		2	28.57	28.57		
		NEF Leq24	0	0		2	28.57	0.00		
		Limiting distance	3	0		1	50.00	0.00		
Fire control of building envelope	Spatial separation of buildings	fire rating of cladding	5						0.00	0
		< 5m from exposed w.	N/A	N/A		1	N/A	N/A		
	Location of skylights	Table 6.3.2.1.A of NHC1998	N/A	N/A		1	N/A	N/A		
	% area of unprot.openings	% openings in EBF	1	0		1	50.00	0.00		
	Minimum construction requirements for exposing faces	Min. fire rating	1							
		Type of construction	2							
		Type of cladding	2							

APPENDIX F: BEPAT EVALUATION RESULTS, 2ND RUN, REMAINING CASE STUDIES

NOVTEC HOUSE

PROJECT INFORMATION

Client:	NOVTEC house			Tel:	N/A
		Laval	QC	Fax:	N/A
Contact person:	Robin Sinha	project manager		E-mail:	N/A
Building:	NOVTEC house				
	Single family	EIFS	Site built		
		Laval	QC	Z7F 3G3	
Builder/ Manufacturer:	Q-housing			Tel:	(514) 222-222
	23 maple rd.	Montreal	QC	Fax:	(514) 333-3333
Contact person:	N/A	project manager	Z7F 3G3	E-mail:	hanks@lalala.com
Assessor:	M. Horvat		0		
	22 Clark	Montreal	QC	Tel:	(514) 111-1111
Date of assessment:				Fax:	(514) 444-4444
				E-mail:	N/A

PERFORMANCE EVALUATION OUTPUT
C - LEVEL (DETAILED)

DESIGN STAGE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL VALUES		SCORES (A)	◄	WEIGHT				% exceeding the benchmark
						FACTOR	% (B)	RESULT (A x B)	SUB TOTAL	
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component		$L/s\cdot m^2$							
		Exterior walls:	0.0000	2		1	4.76	9.52	142.86	100
		Roof:	0.0000	2		1	4.76	9.52		
		Joints:								
		boards and membranes	Yes	2		3	14.29	28.57		
		sillplate/top plate gaskets	Yes	2		3	14.29	28.57		

		windows and doors	Yes	2		4	19.05	38.10		
		penetrations	Yes	2		3	14.29	28.57		
		others	N/A	N/A		2	N/A	N/A		
	Air leakage of windows	Type I	0.15	2		2	9.52	19.05	38.10	100
		Type II	0.15	2		2	9.52	19.05		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
	Air leakage of doors	Sliding and non-whether stripped							0.00	0
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		All other doors								
		Type I	15	0		2	9.52	0.00		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
Moisture management performance	Use of kiln dried wood	Initial MC of lumber	12	2		3	3.13	6.25	-4.17	-17
	Water vapour permeability of the assembly	Exterior walls	40	-2	◀	2	2.08	-4.17		
		Sheathing	40							
		Roofs	3	2		2	2.08	4.17		
		Sheathing	N/A							
	Interstitial condensation	Calculated condensation rate across exterior walls' assembly:	10134	2		2	2.08	4.17		
		Calculated condensation rate across roof assembly:	19564	2		2	2.08	4.17		
	Surface condensation	Calculated internal surface temperature	20.3	0		1	1.04	0.00		
	Drainage of precipitation and surface runoff	Surface grading	No info	-1	◀	2	2.08	-2.08	-7.29	-18
		External drains	No info	-1	◀	2	2.08	-2.08		
		Impermeable backfill	No info	-1	◀	3	3.13	-3.13		
		Drain screen	Yes	2		5	5.21	10.42		
		Waterproof membrane	Yes	2		4	4.17	8.33	27.08	65
		Drainage pipes	Yes	2		4	4.17	8.33		
		Control joints	N/A	N/A		3	N/A	N/A		

Moisture management performance	Limiting intrusion of precipitation	Roofs:							-9.38	-12
		Planes sloped away	Yes	2		4	4.17	8.33		
		Sloped roof slope > 1:6	Yes	2		2	2.08	4.17		
		Valleys lead away	Yes	2		4	4.17	8.33		
		Flat roof slope >1:X	N/A	N/A		4	N/A	N/A		
		Flat roof valleys >1:Y	N/A	N/A		4	N/A	N/A		
		Required drainage area	N/A	N/A		5	N/A	N/A		
						2	2.08	0.00		
		Flashings for penetrations	Yes	2		4	4.17	8.33		
		Deposition on walls								
		Overhangs' size	> 60 cm (>24')	2		2	2.08	4.17	18.75	24
		Gutters at roof edges	No	-2	◀	2	2.08	-4.17		
		Downspouts				5	5.21	0.00		
		Sloped balconies	N/A	N/A		2	N/A	N/A		
		Tresholds' flashings	N/A	N/A		4	N/A	N/A		
		Junctions' flashings	Yes	2		4	4.17	8.33		
		Sloped window sills	No info	-1	◀	2	2.08	-2.08		
		Sill drips	No info	-1	◀	3	3.13	-3.13		
		Coping drips	Yes	2		3	3.13	6.25		
Moisture management performance	Rain water penetration management	Watertightness of windows								
		Type I	B2	0		2	2.08	0.00	0.00	0.0
		Type II	B2	0		2	2.08	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Watertightness of sliding doors								
		Type I	B2	0		2	2.08	0.00	0.00	0
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		Drainage space	No	-2	◀	3	3.13	-6.25	-12.50	-46
		Drainage plane	Yes	2		3	3.13	6.25		
		Flashings	Yes	2		4	4.17	8.33	14.58	54
		Weep holes	No	-2	◀	3	3.13	-6.25		

	Capillary suction	Under the slab	Yes	2		2	2.08	4.17	16.67	100
		Top of the footing	Yes	2		2	2.08	4.17		
		Basement walls	Yes	2		2	2.08	4.17		
		Below sill plate	Yes	2		2	2.08	4.17	16.67	100
		Porous cladding	N/A	N/A		2	N/A	N/A		
Thermal performance	Thermal resistance of an opaque parts of building envelope (design values)		RSI							
		Roof	9.4	2		1	4.35	8.70	26.09	100
		Above grade walls	5.5	2		1	4.35	8.70		
		Below grade walls	N/A	N/A		1	N/A	N/A		
		Floors above non heated spaces	N/A	N/A		1	N/A	N/A		
		Slab-on-grd w/pipes	2.2	2		1	4.35	8.70		
		Slab-on-grd no pipes	N/A	N/A		1	N/A	N/A		
		Basement floor	N/A	N/A		1	N/A	N/A		
		Crawl space floor	N/A	N/A		1	N/A	N/A		
	Thermal resistance of windows and doors	Windows, skylights:	RSI						78.26	100
		Type I	0.46	2		3	13.04	26.09		
		Type II	0.49	2		3	13.04	26.09		
		Type III	N/A	N/A		3	N/A	N/A		
		Type IV	N/A	N/A		3	N/A	N/A		
		Sliding glass doors	RSI							
		Type I	1.14	2		3	13.04	26.09		
		Type II	N/A	N/A		3	N/A	N/A		
		Type III	N/A	N/A		3	N/A	N/A		
		Shutters for windows:								
		Type I	No	0		2	8.70	0.00	0.00	0
		Type II	No	0		2	8.70	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Shutters for gl. doors								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		

		Type III	N/A	N/A		2	N/A	N/A		
Thermal performance										
	Thermal bridging	% of studs in 1m' of wall	N/A	0		2	5.26	0.00 0.00	0.00	0
	Average thermal transmittance of the building envelope - U_0	$U_{average}$ of:							0.00	0
		Walls above ground	N/A			1	4.35	0.00		
		Walls below ground	N/A			1	4.35	0.00		
		Roof area	N/A			1	4.35	0.00		
		Floor area	N/A			1	4.35	0.00		
		Total U_0	N/A			1	4.35	0.00		
	Ratio between fenestration vs. whole wall area (in elevation)	North wall	30.78	2		2	40.00	80.00	-40.00	-20
		South wall	50.97	-2	◀	1	20.00	-40.00		
		East wall	18.17	2		1	20.00	40.00		
		West wall	12.97	2		1	20.00	40.00		
Energy performance	Energy rating of windows and sliding glass doors	Windows' en. level							100.00	50
		Type I	EL4	1		2	50.00	50.00		
		Type II	EL4	1		2	50.00	50.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Sliding door en. level								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
	Annual energy consumption for heating/cooling	Difference from default house	-42.0	2		1	100.00 0.00 0.00	200.00	200.00	100
	Emissions and embodied energy	Emissions	N/A	N/A		1	N/A	N/A	0.00	0
		Embodied energy	N/A	N/A		1	N/A	N/A		
Structural stability of building envelope	Resistance to vertical loads	Roofs	N/A	N/A		1	N/A	N/A	0.00	0
		Exterior walls	N/A	N/A		1	N/A	N/A		
		Basement walls	N/A	N/A		1	N/A	N/A		

		Cantilevered floors	N/A	N/A		1	N/A	N/A		
		Floors above crawl.sp	N/A	N/A		1	N/A	N/A		
	Wind load resistance of opaque parts of building envelope	Roof	N/A	N/A		1	N/A	N/A	0.00	0
		East wall	N/A	N/A		1	N/A	N/A		
		West wall	N/A	N/A		1	N/A	N/A		
		South wall	N/A	N/A		1	N/A	N/A		
		North wall	N/A	N/A		1	N/A	N/A		
Structural stability of building envelope										
	Wind load resistance of windows and sliding doors	Windows							0.00	0
		Type I	N/A	N/A		1	N/A	N/A		
		Type II	N/A	N/A		1	N/A	N/A		
		Type III	N/A	N/A		1	N/A	N/A		
		Type IV	N/A	N/A		1	N/A	N/A		
		Sliding glass doors								
		Type I	N/A	N/A		1	N/A	N/A		
		Type II	N/A	N/A		1	N/A	N/A		
		Type III	N/A	N/A		1	N/A	N/A		
	Resistance to lateral loads - seismics	Za	N/A	N/A		2	N/A	N/A	0.00	0
		Zv	N/A	N/A		2	N/A	N/A		
Acoustic performan ce	Resistance to outdoor noise	Siding	4	1		1	7.14	7.14	35.71	18
		Insulation	4	2		2	14.29	28.57		
		Structural breaks	2	0		3	21.43	0.00		
		Interior finishing	1	0		1	7.14	0.00		
		Windows - type	2	0		2	14.29	0.00		
		Windows - openning	2	0		3	21.43	0.00		
		Roofs	1	0		2	14.29	0.00		
	Resistance to aircraft noise	Indoor sound level	1	1		1	14.29	14.29	14.29	7
		A-weighted in. s. I.	0	0		2	28.57	0.00		
		Transmission loss	0	0		2	28.57	0.00		
		NEF Leq24	0	0		2	28.57	0.00		
Fire control of building envelope	Spatial separation of buildings	Limiting distance	3	0		1	50.00	0.00	0.00	0
		fire rating of cladding	5							

	Location of skylights	< 5m from exposed w.	N/A	N/A		1	N/A	N/A		
	% area of unprot.openings	Table 6.3.2.1.A of NHC1998	N/A	N/A		1	N/A	N/A		
	Minimum construction requirements for exposing faces	% openings in EBF	1	0		1	50.00	0.00		
		Min. fire rating	1							
		Type of construction	2							
		Type of cladding	2							

M-THERMO HOUSE

PROJECT INFORMATION

Client:	CONFIDENTIAL			Tel:		
			QC	Fax:		
Contact person:				E-mail:		
Building:	M-THERMO HOUSE					
	SINGLE FAMILY	Wood frame	Modular			
Builder/ Manufacturer:	CONFIDENTIAL					
Contact person:						
Assessor:	M. Horvat		0			
	22 Clark	Montreal	QC	Tel:	(514) 111-1111	
Date of assessment:	38182			Fax:	(514) 444-4444	
				E-mail:		

PERFORMANCE EVALUATION OUTPUT
C - LEVEL (DETAILED)

DESIGN STAGE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL VALUES		SCORES (A)	◄	WEIGHT		RESULT (A x B)	SUB TOTAL	% exceeding the bench mark
						FACTOR	% (B)			
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component		$L/s \cdot m^2$							
		Exterior walls:	0.00	2		1	4.00	8.00	136.00	100
		Roof:	0.00	2		1	4.00	8.00		
		Joints:								
		boards and membranes	Yes	2		3	12.00	24.00		
		sillplate/top plate gaskets	Yes	2		3	12.00	24.00		
		windows and doors	Yes	2		4	16.00	32.00		
		penetrations	Yes	2		3	12.00	24.00		

		others	Yes	2		2	8.00	16.00		
	Air leakage of windows	Type I	0.46	1		2	8.00	8.00	16.00	50
		Type II	0.46	1		2	8.00	8.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
	Air leakage of doors	Sliding and non-whether stripped							16.00	50
		Type I	1.9	1		2	8.00	8.00		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		All other doors								
		Type I	12	1		2	8.00	8.00		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
Moisture management performance	Use of kiln dried wood	Initial MC of lumber	15	0		3	3.33	0.00	17.78	67
	Water vapour permeability of the assembly	Exterior walls	2.9	2		2	2.22	4.44		
		Sheathing	120							
		Roofs	3	2		2	2.22	4.44		
		Sheathing	N/A							
	Interstitial condensation	Calculated condensation rate across exterior walls' assembly:	2031.8	2		2	2.22	4.44		
		Calculated condensation rate across roof assembly:	1476.4	2		2	2.22	4.44		
	Surface condensation	Calculated internal surface temperature	20.4	0		1	1.11	0.00		
	Drainage of precipitation and surface runoff	Surface grading	No info	-1	◄	2	2.22	-2.22	-7.78	-18
		External drains	No info	-1	◄	2	2.22	-2.22		
		Impermeable backfill	No info	-1	◄	3	3.33	-3.33		
		Drain screen	Yes	2		5	5.56	11.11		
		Waterproof membrane	Yes	2		4	4.44	8.89	28.89	65
		Drainage pipes	Yes	2		4	4.44	8.89		
		Control joints	N/A	N/A		3	N/A	N/A		
Moisture management performance	Limiting intrusion of precipitation	Roofs:							-7.78	-11
		Planes sloped away	Yes	2		4	4.44	8.89		

		Sloped roof slope > 1:6	Yes	2		2	2.22	4.44		
		Valleys lead away	Yes	2		4	4.44	8.89		
		Flat roof slope >1:X	N/A	N/A		4	N/A	N/A		
		Flat roof valleys >1:Y	N/A	N/A		4	N/A	N/A		
		Required drainage area	N/A	N/A		5	N/A	N/A		
		Flashings for penetrations	Yes	2		4	4.44	8.89		
		Deposition on walls							28.89	39
		Overhangs' size	40 - 60 cm (16' - 24')	1		2	2.22	2.22		
		Gutters at roof edges	No	-2	◄	2	2.22	-4.44		
		Downspouts	N/A	N/A		5	N/A	N/A		
		Sloped balconies	Yes	2		2	2.22	4.44		
		Tresholds' flashings	Yes	2		4	4.44	8.89		
		Junctions' flashings	Yes	2		4	4.44	8.89		
		Sloped window sills	Yes	2		2	2.22	4.44		
		Sill drips	No info	-1	◄	3	3.33	-3.33		
		Coping drips	N/A	N/A		3	N/A	N/A		
Moisture management performance	Rain water penetration management	Watertightness of windows								
		Type I	B3	1		2	2.22	2.22	4.44	50
		Type II	B3	1		2	2.22	2.22		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Watertightness of sliding doors								
		Type I	N/A	N/A		2	N/A	N/A	0.00	0
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		Drainage space	Yes	2		3	3.33	6.67	28.89	100
		Drainage plane	Yes	2		3	3.33	6.67		
		Flashings	Yes	2		4	4.44	8.89	28.89	100
		Weep holes	Yes	2		3	3.33	6.67		
	Capillary suction	Under the slab	Yes	2		2	2.22	4.44	17.78	100
		Top of the footing	Yes	2		2	2.22	4.44		

		Basement walls	Yes	2		2	2.22	4.44		
		Below sill plate	Yes	2		2	2.22	4.44	17.78	100
		Porous cladding	N/A	N/A		2	N/A	N/A		
Thermal performance	Thermal resistance of an opaque parts of building envelope (design values)		RSI							
		Roof	10.7	2		1	4.76	9.52	28.57	75
		Above grade walls	7.62	2		1	4.76	9.52		
		Below grade walls	2.8	2		1	4.76	9.52		
		Floors above non heated spaces	N/A	N/A		1	N/A	N/A		
		Slab-on-grd w/pipes	N/A	N/A		1	N/A	N/A		
		Slab-on-grd no pipes	N/A	N/A		1	N/A	N/A		
		Basement floor	0	0		1	4.76	0.00		
		Crawl space floor	N/A	N/A		1	N/A	N/A		
Thermal performance	Thermal resistance of windows and doors	Windows, skylights:	RSI							
		Type I	0.56	2		3	14.29	28.57	28.57	50
		Type II	N/A	N/A		3	N/A	N/A		
		Type III	N/A	N/A		3	N/A	N/A		
		Type IV	N/A	N/A		3	N/A	N/A		
		Sliding glass doors	RSI							
		Type I	0.7	0		3	14.29	0.00		
		Type II	N/A	N/A		3	N/A	N/A		
		Type III	N/A	N/A		3	N/A	N/A		
		Shutters for windows:								
		Type I	No	0		2	9.52	0.00	0.00	0
		Type II	No	0		2	9.52	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Shutters for gl. doors								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
	Thermal bridging	% of studs in 1m' of wall	N/A	0		2	5.26	0.00	0.00	0

	Average thermal transmittance of the building envelope - U_0	$U_{average}$ of:							0.00	0
		Walls above ground	N/A			1	4.76	0.00		
		Walls below ground	N/A			1	4.76	0.00		
		Roof area	N/A			1	4.76	0.00		
		Floor area	N/A			1	4.76	0.00		
		Total U_0	N/A			1	4.76	0.00		
	Ratio between fenestration vs. whole wall area (in elevation)	North wall	14.04	2		1	16.67	33.33	200.00	100
		South wall	17.71	2		2	33.33	66.67		
		East wall	20.16	2		1	16.67	33.33		
		West wall	11.79	2		2	33.33	66.67		
Energy performance	Energy rating of windows and sliding glass doors	Windows' en. level							200.00	100
		Type I	EL7	2		2	50.00	100.00		
		Type II	EL7	2		2	50.00	100.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Sliding door en. level								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
	Annual energy consumption for heating/cooling	Difference from default house	-43.5	2		1	100.00	200.00	200.00	100
	Emissions and embodied energy	Emissions	N/A	N/A		1	N/A	N/A	0.00	0
		Embodied energy	N/A	N/A		1	N/A	N/A		
Structural stability of building envelope	Resistance to vertical loads	Roofs	N/A	N/A		1	N/A	N/A	0.00	0
		Exterior walls	N/A	N/A		1	N/A	N/A		
		Basement walls	N/A	N/A		1	N/A	N/A		
		Cantilevered floors	N/A	N/A		1	N/A	N/A		
		Floors above crawl.sp	N/A	N/A		1	N/A	N/A		
	Wind load resistance of opaque parts of building envelope	Roof	N/A	N/A		1	N/A	N/A	0.00	0
		East wall	N/A	N/A		1	N/A	N/A		
		West wall	N/A	N/A		1	N/A	N/A		
		South wall	N/A	N/A		1	N/A	N/A		

		North wall	N/A	N/A		1	N/A	N/A		
	Wind load resistance of windows and sliding doors	Windows						0.00	0.00	0
		Type I	C2	0		1	50.00	0.00		
		Type II	C2	0		1	50.00	0.00		
		Type III	N/A	N/A		1	N/A	N/A		
		Type IV	N/A	N/A		1	N/A	N/A		
		Sliding glass doors								
		Type I	N/A	N/A		1	N/A	N/A		
		Type II	N/A	N/A		1	N/A	N/A		
		Type III	N/A	N/A		1	N/A	N/A		
	Resistance to lateral loads - seismics	Za	N/A	N/A		2	N/A	N/A	0.00	0
		Zv	N/A	N/A		2	N/A	N/A		
Acoustic performance	Resistance to outdoor noise	Siding	3	0		1	7.14	0.00	78.57	39
		Insulation	5	2		2	14.29	28.57		
		Structural breaks	2	0		3	21.43	0.00		
		Interior finishing	1	0		1	7.14	0.00		
		Windows - type	4	2		2	14.29	28.57		
		Windows - openning	3	1		3	21.43	21.43		
		Roofs	1	0		2	14.29	0.00		
	Resistance to aircraft noise	Indoor sound level	1	1		1	14.29	14.29	42.86	21
		A-weighted in. s. l.	0	0		2	28.57	0.00		
		Transmission loss	1	1		2	28.57	28.57		
		NEF Leq24	0	0		2	28.57	0.00		
Fire control of building envelope	Spatial separation of buildings	Limiting distance	3	0		1	50.00	0.00	0.00	0
		fire rating of cladding	5							
	Location of skylights	< 5m from exposed w.	N/A	N/A		1	N/A	N/A		
	% area of unprot.openings	Table 6.3.2.1.A of NHC1998	N/A	N/A		1	N/A	N/A		
	Minimum construction requirements for exposing faces	% openings in EBF	1	0		1	50.00	0.00		
		Min. fire rating	1							
		Type of construction	2							
		Type of cladding	2							

A-NOVOCLIMAT HOUSE

PROJECT INFORMATION						
Client:	CONFIDENTIAL					
Contact person:						
Building:	A-NOVOCLIMAT					
	SINGLE FAMILY	WOOD-FRAME	MODULR			
Builder/ Manufacturer:	CONFIDENTIAL					
Contact person:						
Assessor:	M. HORVAT		0			
	22 Clark	Montreal	QC	Tel:	(514) 111-1111	
Date of assessment:	38182			Fax:	(514) 444-4444	
				E-mail:		

PERFORMANCE EVALUATION OUTPUT
C - LEVEL (DETAILED)

DESIGN STAGE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL VALUES		SCORES (A)	◄	WEIGHT		RESULT (A x B)	SUB TOTAL	% exceeding the benchmark
						FACTOR	% (B)			
Air tightness	Air permeance of the opaque parts of building envelope - the choice of air barrier component		L/s·m^2							
		Exterior walls:	0.00	2		1	4.35	8.70	104.35	80
		Roof:	0.00	2		1	4.35	8.70		
		Joints:								

		boards and membranes	Yes	2		3	13.04	26.09		
		sillplate/top plate gaskets	No	0		3	13.04	0.00		
		windows and doors	Yes	2		4	17.39	34.78		
		penetrations	Yes	2		3	13.04	26.09		
		others	N/A	N/A		2	N/A	N/A		
	Air leakage of windows	Type I	0.77	0		2	8.70	0.00	0.00	0
		Type II	0.77	0		2	8.70	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
	Air leakage of doors	Sliding and non-whether stripped							8.70	25
		Type I	2.1	1		2	8.70	8.70		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		All other doors								
		Type I	15	0		2	8.70	0.00		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
Moisture management performance	Use of kiln dried wood	Initial MC of lumber	18	0		3	3.03	0.00	12.12	50
	Water vapour permeability of the assembly	Exterior walls	0	2		2	2.02	4.04		
		Sheathing	44							
		Roofs	15	0		2	2.02	0.00		
		Sheathing	N/A							
	Interstitial condensation	Calculated condensation rate across exterior walls' assembly:	1414.5	2		2	2.02	4.04		
		Calculated condensation rate across roof assembly:	7466.4	2		2	2.02	4.04		
	Surface condensation	Calculated internal surface temperature	20.06	0		1	1.01	0.00		
	Drainage of precipitation and surface runoff	Surface grading	Yes	2		2	2.02	4.04	-2.02	-5
		External drains	No info	-1	◄	2	2.02	-2.02		
		Impermeable backfill	Yes	2		3	3.03	6.06		
		Drain screen	Yes	2		5	5.05	10.10		

		Waterproof membrane	Yes	2		4	4.04	8.08	36.36	90
		Drainage pipes	Yes	2		4	4.04	8.08		
		Control joints	N/A	N/A		3	N/A	N/A		
Moisture management performance	Limiting intrusion of precipitation	Roofs:							-6.06	-8
		Planes sloped away	Yes	2		4	4.04	8.08		
		Sloped roof slope > 1:6	Yes	2		2	2.02	4.04		
		Valleys lead away	Yes	2		4	4.04	8.08		
		Flat roof slope >1:X	N/A	N/A		4	N/A	N/A		
		Flat roof valleys >1:Y	N/A	N/A		4	N/A	N/A		
		Required drainage area	N/A	N/A		5	N/A	N/A		
						2	2.02	0.00		
		Flashings for penetrations	Yes	2		4	4.04	8.08		
		Deposition on walls							56.57	70
		Overhangs' size	40 - 60 cm (16' - 24')	1		2	2.02	2.02		
		Gutters at roof edges	No	-2	◄	2	2.02	-4.04		
		Downspouts				5	5.05	0.00		
		Sloped balconies	No info	-1	◄	2	2.02	-2.02		
		Tresholds' flashings	Yes	2		4	4.04	8.08		
		Junctions' flashings	Yes	2		4	4.04	8.08		
		Sloped window sills	Yes	2		2	2.02	4.04		
		Sill drips	Yes	2		3	3.03	6.06		
		Coping drips	N/A	N/A		3	N/A	N/A		
Moisture management performance	Rain water penetration management	Watertightness of windows								
		Type I	B2	0		2	2.02	0.00	0.00	0.0
		Type II	B2	0		2	2.02	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Watertightness of sliding doors								
		Type I	B2	0		2	2.02	0.00	0.00	0
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		Drainage space	No	-2	◄	3	3.03	-6.06	-6.06	-23

		Drainage plane	Yes	2		3	3.03	6.06		
		Flashings	Yes	2		4	4.04	8.08	20.2	77
		Weep holes	Yes	2		3	3.03	6.06		
	Capillary suction	Under the slab	Yes	2		2	2.02	4.04	-4.04	-25
		Top of the footing	No info	-1	◄	2	2.02	-2.02		
		Basement walls	Yes	2		2	2.02	4.04	8.08	50
		Below sill plate	No info	-1	◄	2	2.02	-2.02		
		Porous cladding	N/A	N/A		2	N/A	N/A		
Thermal performance	Thermal resistance of an opaque parts of building envelope (design values)		RSI							
		Roof	7.9	2		1	4.76	9.52	38.10	100
		Above grade walls	5.6	2		1	4.76	9.52		
		Below grade walls	3.7	2		1	4.76	9.52		
		Floors above non heated spaces	N/A	N/A		1	N/A	N/A		
		Slab-on-grd w/pipes	N/A	N/A		1	N/A	N/A		
		Slab-on-grd no pipes	N/A	N/A		1	N/A	N/A		
		Basement floor	1.32	2		1	4.76	9.52		
		Crawl space floor	N/A	N/A		1	N/A	N/A		
Thermal performance	Thermal resistance of windows and doors	Windows, skylights:	RSI						28.57	50
		Type I	0.36	1		3	14.29	14.29		
		Type II	0.36	1		3	14.29	14.29		
		Type III	N/A	N/A		3	N/A	N/A		
		Type IV	N/A	N/A		3	N/A	N/A		
		Sliding glass doors	RSI							
		Type I	N/A	N/A		3	N/A	N/A		
		Type II	N/A	N/A		3	N/A	N/A		
		Type III	N/A	N/A		3	N/A	N/A		
		Shutters for windows:								
		Type I	No	0		2	9.52	0.00	0.00	0
		Type II	No	0		2	9.52	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		

		Shutters for gl. doors								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
Thermal performance										
	Thermal bridging	% of studs in 1m' of wall	11.5	0		2	5.26	0.00	0.00	0
	Average thermal transmittance of the building envelope - U_0	$U_{average}$ of:							0.00	0
		Walls above ground	0.00			1	4.76	0.00		
		Walls below ground	0.00			1	4.76	0.00		
		Roof area	0.00			1	4.76	0.00		
		Floor area	0.00			1	4.76	0.00		
		Total U_0	0.00			1	4.76	0.00		
	Ratio between fenestration vs. whole wall area (in elevation)	North wall	0.00	2		1	25.00	50.00	200	100
		South wall	26.68	2		1	25.00	50.00		
		East wall	31.23	2		1	25.00	50.00		
		West wall	17.07	2		1	25.00	50.00		
Energy performance	Energy rating of windows and sliding glass doors	Windows' en. level							100.00	50
		Type I	EL4	1		2	50.00	50.00		
		Type II	EL4	1		2	50.00	50.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Sliding door en. level								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
	Annual energy consumption for heating/cooling	Difference from default house	-26.6	1		1	100.00	100.00	100.00	50
	Emissions and embodied energy	Emissions	N/A	N/A		1	N/A	N/A	0.00	0

		Embodied energy	N/A	N/A		1	N/A	N/A		
Structural stability of building envelope	Resistance to vertical loads	Roofs	N/A	N/A		1	N/A	N/A	0.00	0
		Exterior walls	N/A	N/A		1	N/A	N/A		
		Basement walls	N/A	N/A		1	N/A	N/A		
		Cantilevered floors	N/A	N/A		1	N/A	N/A		
		Floors above crawl.sp	N/A	N/A		1	N/A	N/A		
	Wind load resistance of opaque parts of building envelope	Roof	N/A	N/A		1	N/A	N/A	0.00	0
		East wall	N/A	N/A		1	N/A	N/A		
		West wall	N/A	N/A		1	N/A	N/A		
		South wall	N/A	N/A		1	N/A	N/A		
		North wall	N/A	N/A		1	N/A	N/A		
Structural stability of building envelope										
	Wind load resistance of windows and sliding doors	Windows							0.00	0
		Type I	C2	0		1	50.00	0.00		
		Type II	C2	0		1	50.00	0.00		
		Type III	N/A	N/A		1	N/A	N/A		
		Type IV	N/A	N/A		1	N/A	N/A		
		Sliding glass doors								
		Type I	N/A	N/A		1	N/A	N/A		
		Type II	N/A	N/A		1	N/A	N/A		
		Type III	N/A	N/A		1	N/A	N/A		
	Resistance to lateral loads - seismics	Za	N/A	N/A		2	N/A	N/A	0.00	0
		Zv	N/A	N/A		2	N/A	N/A		
Acoustic performance	Resistance to outdoor noise	Siding	3	0		1	7.14	0.00	28.57	14
		Insulation	4	2		2	14.29	28.57		
		Structural breaks	2	0		3	21.43	0.00		
		Interior finishing	1	0		1	7.14	0.00		
		Windows - type	2	0		2	14.29	0.00		
		Windows - openning	2	0		3	21.43	0.00		
		Roofs	1	0		2	14.29	0.00		

	Resistance to aircraft noise	Indoor sound level	1	1		1	14.29	14.29	14.29	7
		A-weighted in. s. l.	0	0		2	28.57	0.00		
		Transmission loss	0	0		2	28.57	0.00		
		NEF Leq24	0	0		2	28.57	0.00		
Fire control of building envelope	Spatial separation of buildings	Limiting distance	3	0		1	50.00	0.00	0.00	0
		fire rating of cladding	5							
	Location of skylights	< 5m from exposed w.	N/A	N/A		1	N/A	N/A		
	% area of unprot.openings	Table 6.3.2.1.A of NHC1998	N/A	N/A		1	N/A	N/A		
	Minimum construction requirements for exposing faces	% openings in EBF	1	0		1	50.00	0.00		
		Min. fire rating	1							
		Type of construction	2							
		Type of cladding	2							

A-STANDARD

PROJECT INFORMATION					
Client:	CONFIDENTIAL				
Contact person:					
Building:	A-STANDARD				
	SINGLE FAMILY	WOOD-FRAME	MODULAR	.	
Builder/ Manufacturer:	CONFIDENTIAL				
Assessor:	M. HORVAT		0		
	22 Clark	Montreal	QC	Tel:	(514) 111-1111
Date of assessment:	38182			Fax:	(514) 444-4444
				E-mail:	

PERFORMANCE EVALUATION OUTPUT
C - LEVEL (DETAILED)
DESIGN STAGE

FUNCTIONAL REQUIREMENT	OPERATIVE or PERFORMANCE REQUIREMENT	ACTUAL VALUES	SCORES (A)		◄	WEIGHT		RESULT (A x B)	SUB TOTAL	% exceeding the benchmark
						FACTOR	% (B)			
Air tightness			L/s·m²							
	Air permeance of the opaque parts of building envelope - the choice of air barrier component	Exterior walls:	0.0108	0		1	4.76	0.00	104.76	73
		Roof:	0.0000	2		1	4.76	9.52		
		Joints:								
		boards and membranes	Yes	2		3	14.29	28.57		
		sillplate/top plate gaskets	No	0		3	14.29	0.00		
		windows and doors	Yes	2		4	19.05	38.10		
		penetrations	Yes	2		3	14.29	28.57		
		others	N/A	N/A		2	N/A	N/A		
	Air leakage of windows	Type I	0.77	0		2	9.52	0.00	0.00	0
		Type II	0.77	0		2	9.52	0.00		
		Type III	N/A	N/A		2	N/A	N/A		

		Type IV	N/A	N/A		2	N/A	N/A		
	Air leakage of doors	Sliding and non-whether stripped							0.00	0
		Type I	N/A	N/A		2	N/A	N/A	0.00	0
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		All other doors							0.00	0
		Type I	15	0		2	9.52	0.00		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
Moisture management performance	Use of kiln dried wood	Initial MC of lumber	18	0		3	3.03	0.00	8.08	33
	Water vapour permeability of the assembly	Exterior walls	15	0		2	2.02	0.00		
		Sheathing	40							
		Roofs	15	0		2	2.02	0.00		
		Sheathing	N/A							
	Interstitial condensation	Calculated condensation rate across exterior walls' assembly:	8117.71	2		2	2.02	4.04		
		Calculated condensation rate across roof assembly:	10949.4	2		2	2.02	4.04		
	Surface condensation	Calculated internal surface temperature	19.9	0		1	1.01	0.00		
	Drainage of precipitation and surface runoff	Surface grading	No info	-1	◄	2	2.02	-2.02	-7.07	-18
		External drains	No info	-1	◄	2	2.02	-2.02		
		Impermeable backfill	No info	-1	◄	3	3.03	-3.03		
		Drain screen	Yes	2		5	5.05	10.10		
		Waterproof membrane	Yes	2		4	4.04	8.08	26.26	65
		Drainage pipes	Yes	2		4	4.04	8.08		
		Control joints	N/A	N/A		3	N/A	N/A		
Moisture management performance	Limiting intrusion of precipitation	Roofs:							-15.15	-19
		Planes sloped away	Yes	2		4	4.04	8.08		
		Sloped roof slope > 1:6	Yes	2		2	2.02	4.04		
		Valleys lead away	Yes	2		4	4.04	8.08		
		Flat roof slope >1:X	N/A	N/A		4	N/A	N/A		

		Flat roof valleys >1:Y	N/A	N/A		4	N/A	N/A		
		Required drainage area	N/A	N/A		5	N/A	N/A		
						2	2.02	0.00		
		Flashings for penetrations	Yes	2		4	4.04	8.08		
		Deposition on walls								
		Overhangs' size	40 - 60 cm (16' - 24')	1		2	2.02	2.02	10.10	13
		Gutters at roof edges	No	-2	◄	2	2.02	-4.04		
		Downspouts				5	5.05	0.00		
		Sloped balconies	No info	-1	◄	2	2.02	-2.02		
		Tresholds' flashings	No info	-1	◄	4	4.04	-4.04		
		Junctions' flashings	Yes	2		4	4.04	8.08		
		Sloped window sills	No info	-1	◄	2	2.02	-2.02		
		Sill drips	No info	-1	◄	3	3.03	-3.03		
		Coping drips	N/A	N/A		3	N/A	N/A		
Moisture management performance	Rain water penetration management	Watertightness of windows								
		Type I	B2	0		2	2.02	0.00	0.00	0.0
		Type II	B2	0		2	2.02	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Watertightness of sliding doors								
		Type I	B2	0		2	2.02	0.00	0.00	0
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
		Drainage space	Yes	2		3	3.03	6.06	26.26	100
		Drainage plane	Yes	2		3	3.03	6.06		
		Flashings	Yes	2		4	4.04	8.08	26.26	100
		Weep holes	Yes	2		3	3.03	6.06		
	Capillary suction	Under the slab	Yes	2		2	2.02	4.04	-4.04	-25
		Top of the footing	No info	-1	◄	2	2.02	-2.02		
		Basement walls	Yes	2		2	2.02	4.04		
		Below sill plate	No info	-1	◄	2	2.02	-2.02	8.08	50
		Porous cladding	N/A	N/A		2	N/A	N/A		

Thermal performance	Thermal resistance of an opaque parts of building envelope (design values)		RSI							
		Roof	7.5	2		1	4.17	8.33	25.00	75
		Above grade walls	4.9	2		1	4.17	8.33		
		Below grade walls	2.8	2		1	4.17	8.33		
		Floors above non heated spaces	N/A	N/A		1	N/A	N/A		
		Slab-on-grd w/pipes	N/A	N/A		1	N/A	N/A		
		Slab-on-grd no pipes	N/A	N/A		1	N/A	N/A		
		Basement floor	0	0		1	4.17	0.00		
		Crawl space floor	N/A	N/A		1	N/A	N/A		
Thermal performance	Thermal resistance of windows and doors	Windows, skylights:	RSI						12.50	17
		Type I	0.35	0		3	12.50	0.00		
		Type II	0.35	0		3	12.50	0.00		
		Type III	N/A	N/A		3	N/A	N/A		
		Type IV	N/A	N/A		3	N/A	N/A		
		Sliding glass doors	RSI							
		Type I	0.8	1		3	12.50	12.50		
		Type II	N/A	N/A		3	N/A	N/A		
		Type III	N/A	N/A		3	N/A	N/A		
		Shutters for windows:								
		Type I	No	0		2	8.33	0.00	0.00	0
		Type II	No	0		2	8.33	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Shutters for gl. doors								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
	Thermal bridging	% of studs in 1m' of wall	11.5	0		2	5.26	0.00	0.00	0
	Average thermal transmittance of the building envelope - U_0	$U_{average}$ of:							0.00	0
		Walls above ground	N/A			1	4.17	0.00		

		Walls below ground	N/A			1	4.17	0.00		
		Roof area	N/A			1	4.17	0.00		
		Floor area	N/A			1	4.17	0.00		
		Total U_0	N/A			1	4.17	0.00		
	Ratio between fenestration vs. whole wall area (in elevation)	North wall	7.20	2		2	40.00	80.00	200.00	100
		South wall	1.25	2		1	20.00	40.00		
		East wall	20.31	2		1	20.00	40.00		
		West wall	38.61	2		1	20.00	40.00		
Energy performance	Energy rating of windows and sliding glass doors	Windows' en. level							0.00	0
		Type I	EL3	0		2	50.00	0.00		
		Type II	EL3	0		2	50.00	0.00		
		Type III	N/A	N/A		2	N/A	N/A		
		Type IV	N/A	N/A		2	N/A	N/A		
		Sliding door en. level								
		Type I	N/A	N/A		2	N/A	N/A		
		Type II	N/A	N/A		2	N/A	N/A		
		Type III	N/A	N/A		2	N/A	N/A		
	Annual energy consumption for heating/cooling	Difference from default house	-7.2	0		1	100.00	0.00	0.00	0
	Emissions and embodied energy	Emissions	N/A	N/A		1	N/A	N/A	0.00	0
		Embodied energy	N/A	N/A		1	N/A	N/A		
Structural stability of building envelope	Resistance to vertical loads	Roofs	N/A	N/A		1	N/A	N/A	0.00	0
		Exterior walls	N/A	N/A		1	N/A	N/A		
		Basement walls	N/A	N/A		1	N/A	N/A		
		Cantilevered floors	N/A	N/A		1	N/A	N/A		
		Floors above crawl.sp	N/A	N/A		1	N/A	N/A		
	Wind load resistance of opaque parts of building envelope	Roof	N/A	N/A		1	N/A	N/A	0.00	0
		East wall	N/A	N/A		1	N/A	N/A		
		West wall	N/A	N/A		1	N/A	N/A		
		South wall	N/A	N/A		1	N/A	N/A		
		North wall	N/A	N/A		1	N/A	N/A		

Structural stability of building envelope	Wind load resistance of windows and sliding doors	Windows							0.00	0
		Type I	N/A	N/A		1	N/A	N/A		
		Type II	N/A	N/A		1	N/A	N/A		
		Type III	N/A	N/A		1	N/A	N/A		
		Type IV	N/A	N/A		1	N/A	N/A		
		Sliding glass doors								
		Type I	N/A	N/A		1	N/A	N/A		
		Type II	N/A	N/A		1	N/A	N/A		
		Type III	N/A	N/A		1	N/A	N/A		
	Resistance to lateral loads - seismics	Za	N/A	N/A		2	N/A	N/A	0.00	0
		Zv	N/A	N/A		2	N/A	N/A		
Acoustic performance	Resistance to outdoor noise	Siding	3	0		1	7.14	0.00	28.57	14
		Insulation	4	2		2	14.29	28.57		
		Structural breaks	2	0		3	21.43	0.00		
		Interior finishing	1	0		1	7.14	0.00		
		Windows - type	2	0		2	14.29	0.00		
		Windows - openning	2	0		3	21.43	0.00		
		Roofs	1	0		2	14.29	0.00		
	Resistance to aircraft noise	Indoor sound level	1	1		1	14.29	14.29	14.29	7
		A-weighted in. s. l.	0	0		2	28.57	0.00		
		Transmission loss	0	0		2	28.57	0.00		
		NEF Leq24	0	0		2	28.57	0.00		
Fire control of building envelope	Spatial separation of buildings	Limiting distance	3	0		1	50.00	0.00	0.00	0
		fire rating of cladding	5							
	Location of skylights	< 5m from exposed w.	N/A	N/A		1	N/A	N/A		
	% area of unprot.openings	Table 6.3.2.1.A of NHC1998	N/A	N/A		1	N/A	N/A		
	Minimum construction requirements for exposing faces	% openings in EBF	1	0		1	50.00	0.00		
		Min. fire rating	1							
		Type of construction	2							
		Type of cladding	2							