the ATHENA™
Sustainable Materials Institute

LIFE CYCLE ANALYSIS OF BRICK AND MORTAR PRODUCTS

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PREFACE

This report was commissioned as part of a continuing program to expand the knowledge base of the ATHENA™ Sustainable Materials Institute, a not-for-profit organization dedicated to helping the building community meet the environmental challenges of the future.

Our ultimate goal is to foster sustainability by encouraging building designs which will minimize life cycle environmental impacts. To achieve that goal the Institute is developing ATHENA™, a systems model for assessing the relative life cycle environmental implications of alternative building or assembly designs. Intended for use by building designers, researchers and policy analysts, ATHENA™ is a decision support tool which compliments and augments other decision support tools like costing models. It provides a wealth of information to help users understand the environmental implications of different material mixes or other design changes in all or part of a building.

Two of the Institute's key objectives are to:

1. increase public awareness of the environmental impacts of buildings and the built environment; and

2. provide information and tools to help put the environment on a footing with cost and other traditional design criteria.

To help achieve these objectives and to ensure transparency of our research and data development process, we make all of our reports available to Institute members and model users.

Institute studies and publications fall into two general categories: investigative or exploratory studies intended to further general understanding of life cycle assessment as it applies to building materials and buildings; and individual life cycle inventory studies which deal with specific industries, product groups or building life cycles stages. All studies in this latter category are firmly grounded on the principles and practices of life cycle assessment (LCA), and follow our published Research Guidelines which define boundary or scope conditions and ensure equal treatment of all building materials and products in terms of assumptions, research decisions, estimating methods and other aspects of the work.

The integration of all inventory data is a primary function of ATHENA™ itself and we therefore caution that individual industry life cycle study reports may not be entirely stand-alone documents in the sense that they tell the whole story about an individual set of products. ATHENA™ also generates various composite measures that can be best described as environmental impact indicators, a step toward the ultimate LCA goal of developing true measures of impacts on human and ecosystem health.

ACKNOWLEDGMENTS

We would like to acknowledge the essential support provided by all of the ATHENA™ Institute's members. As an incorporated not-for-profit organization, the Institute offers memberships to individuals, companies, governments or other organizations, with the membership fees helping fund the Institute's core research program. We are especially grateful for the generous additional support provided by our founding members, Forintek Canada Corp. and Natural Resources Canada, and by the US Department of Energy. Without that support we could not maintain the costly data and model work required to meet our objectives.

The life cycle study described in this report was carried out by VENTA, GLASER & ASSOCIATES under Forintek Canada Corp. Contract. The author gratefully acknowledges their support. Special thanks go to the managers of the ATHENA™ Project, Wayne Trusty of Wayne B. Trusty & Associates Limited and Jamie Meil of JKM Associates for their enthusiasm and guidance. We wish to thank all the major brick companies in Canada - Canada Brick, Brampton Brick, Shaw Brick and I.XL Industries Ltd. - for their trust and cooperation in providing the necessary data input. Thanks are especially extended to the following individuals for their valuable contributions:

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CONTENTS

ATHENA™ PROJECT

A LIFE CYCLE ANALYSIS OF BRICK AND MORTAR PRODUCTS

1.0 INTRODUCTION

This report presents cradle to gate life cycle inventory estimates for masonry - brick and associated mortar - products, and explains how the estimates were developed. The work was commissioned by the ATHENA™ project as part of the continuing series of life cycle studies being done to support the ATHENA™ environmental decision support tool described in the Preface.

ATHENA™ relies on life cycle inventory databases, termed unit factors, which include estimates of raw material, energy and water inputs as well as atmospheric emissions, liquid effluents and solid wastes outputs per unit of product. The estimates encompass production activities from raw materials extraction (e.g. clay quarrying) through product manufacturing, including related transportation. We have also provided estimates of typical or average transportation modes and distances for the distribution of finished products from relevant manufacturing facilities to the six regions covered by the computer model.

The estimates presented in this report were developed by Venta, Glaser & Associates with the assistance and cooperation of the Brick Institute of America, National Concrete Masonry Association and their member companies.

1.1 RESEARCH GUIDELINES

To ensure consistent and compatible approaches for all Life Cycle Analyses, all estimates have to be prepared in accordance with a set of research guidelines first issued in October, 1992 and subsequently revised as needs dictate. This research protocol defined information requirements and procedures for the study, such as the following:

- the specific building products;
- the content of general and detailed industry descriptions;
- the specific energy forms, emissions and effluents of potential interest;
- the treatment of secondary building components and assemblies;
- preferred data types and sources (e.g. actual industry data and data from process studies);
- the analysis scope, including system boundaries and limits and the level of detail of the analysis;
- geographic divisions;

- transportation factors to be included when estimating transportation energy use; and
- a set of standard conventions for dealing with such aspects as non-domestic production, process feedstocks, in-plant recycling and multiple products.

In addition, the research guidelines provide a set of conversion factors and tables of standard factors for calculating energy contents and emissions by fuel type.

The analysis limits established for the project in the guidelines are similar to a Level II analysis for energy studies as determined by the International Federation of Institutes of Advanced Studies. These limits typically capture about 90% to 95% of the full impacts of an industry.

The life cycle analysis framework and other Institute's studies are discussed in detail in other Institute's publications, especially in the Summary Report, Phases II and III. That document includes the most recent (1997) version of the Research Guidelines and we have not, in this report, duplicated that material by explaining the rationale for all steps in the research and calculation process. For example, the Research Guidelines require that empty backhauls be included when calculating transportation energy use in certain circumstances. Our calculations therefore show the addition of such backhaul mileages without explaining why backhauls should be included. We have, however, provided full explanations wherever our calculations do not conform to the guidelines because of data limitations or for other reasons.

1.2 STUDY STRUCTURE

The systems model requires Life Cycle Inventory (LCI) data for the following specific types of masonry products:

- clay brick,
- calcium silicate brick,
- concrete brick, and
- brick cement mortar.

Brick and mortar are essential building materials for the Canadian residential, commercial, industrial and institutional building industries, and we had to fully analyze the brick and associated industries before developing unit factors for these products. Based on their raw materials and manufacturing technologies, two "families" of brick products are analyzed: clay-based bricks and concrete brick. That fact dictated how our study was structured.

Unit factor estimates for the Canadian brick industry were developed and are expressed in terms of material inputs or waste outputs per unit of product. Similar estimates were then developed for the cement-based mortar required to apply and finish brick-based walls. These two sets of factors have to be combined in the ATHENA™ computer model to develop the desired estimates for a specific design application.

The analysis procedures and calculations are described in detail in the relevant sections of this report. The key point at this stage is that the study was structured as two separate, but obviously related, analysis streams — one for brick and one for the cement mortar.

1.3 REPORT STRUCTURE

The arrangement of this report basically parallels the study structure. Section 2 of the report provides the background information regarding the industry within the framework of the Canadian economy. It discusses in some detail the industry structure, manufacturing processes, types of bricks and mortars manufactured and used in Canada. The fact that at least two types of bricks, clay- and concrete-based are produced and used, affects the discussion of the manufacturing processes. Section 2 also introduces the major aspects of the industry with respect to energy consumption and environment, and highlights some of the achievements in this area. Sections 3 through 7 deal with various aspects of raw material balances, energy consumption and environmental issues of brick and mortar production.

As indicated below, the basic progression in each part involves an overview section followed by a series of sections dealing with each of the environmental impact areas (e.g. raw material use, energy use, emissions, etc.) Results are presented to show regional variations and, as necessary, by production stage (e.g. resource extraction, raw materials transportation, and manufacturing) and finished products transportation modes and distances.

The following regional breakdown was used for the concrete brick:

- West (British Columbia);
- Prairies (Alberta and Saskatchewan);
- Central (Manitoba and Ontario); and
- East (Quebec and Atlantic Provinces).

In the case of clay brick, there is only a limited number producers in Canada, with the overwhelming proportion of brick (over 70%) produced in the central region. Therefore, to retain the confidentiality of the information and take into consideration the fact that essentially the same modern brick manufacturing process is used by all the participants, the energy and emissions estimates are based on a typical "model" Canadian clay brick operation. Information for this model was provided by all four of Canada's major brick producers. Their data was then consolidated by an independent reviewer selected by members of the industry. Only the distances for the finished product shipments to the market were regionalized.

The report is organized as follows:

Section 2	presents an overview profile of the brick industry in Canada, including a description of the different production processes, the industry structure in geographic, process and capacity terms, and the general nature of resource and energy use, emissions and other wastes for both the brick and the cement mortar materials.
Section 3	details raw material use by the brick and cement mortar industries on a regional basis, and discusses raw material transportation requirements.
Section 4	describes the brick and mortar energy use analysis and presents the results, with sub-divisions by region and by stage of production.
Section 5	deals with atmospheric emissions associated with brick and mortar production on a regional basis by production stage, including the analysis method and results.
Section 6	focuses on liquid effluents associated with production of brick and mortar products.
Section 7	deals with solid wastes generated by production of brick and mortar.

2.0 MASONRY INDUSTRY - AN OVERVIEW

This section provides an overview of the masonry - brick and mortar - products industry in Canada. It provides basic information on the structure, size, production volumes and geographical distribution of the industry, and its position within the framework of the Canadian minerals as well as construction industries. As the Canadian and U.S. brick and cement/concrete industries are generally integrated, some U.S. data are also included, especially in cases where similar Canadian information is lacking or inadequate.

The basic manufacturing processes for the production of clay brick, concrete brick and cement mortar, are shown and described. Related energy use and efficiency issues, as well as emissions, effluents and waste outputs are also briefly discussed as an introduction to a more detailed description of these aspects and the development of the appropriate unit factors in subsequent sections.

2.1 INDUSTRY STRUCTURE

2.1.1 Clay Brick

The clays are a complex group of materials that consist of several mineral commodities, each having somewhat different mineralogy, geological occurrence, technology and applications. They are all natural, earthy, fine-grained minerals of secondary origin and composed of an alumino silicate structure with additional iron, alkalis and alkaline earth elements.[1] Clay is an abundant raw material with a wide variety of uses and properties. To the brick industry, common clays and shales are of primary interest. Common clays are sufficiently plastic to permit ready molding and when fired, they vitrify below 1100°C. Other types of clays include kaolinitic clays, such as ball clay, fire (refractory) clays, stoneware clay and kaolinite, as well as a number of specialty clays, including bentonite, Fuller's earth and attapulgite. In 1994, the annual clays production represented about $114-million, with more than $76-million accounted for by Ontario.[7]

Shale is a sedimentary rock, composed chiefly of clay minerals, which has been laminated and hardened while buried under other sediments. Suitable common clays and shales are used in the manufacture of structural clay products such as clay brick (50%), structural and drain tiles, as well as lightweight aggregate (14%) and portland cement (27%).[4] Common clay and shales are found in all parts of Canada.

Clays and shales are used in a myriad of products. The last year that the Canadian Minerals Yearbook reported on them was 1992.[1] Some draft more up-to-date data were obtained directly from Natural Resources Canada.[2] These statistics, however, provide primarily consumption of china clay, ball clay, fire clay and bentonite. Consumption of common clay and shale that constitute the type of clay used in brick production is not listed in the Yearbook data.

U.S. data shed some light on quarrying and use of common clays and shales, that in most aspects is valid for Canada as well. Most of the producers quarry common clay and shale for their own use; less than 10% of total output is sold.[4-6] The average value for common clay and shale produced in the USA was US$5.48 per tonne (1994). The economic radius for shipment of clay / shale is usually 320 kilometres or less. The high cost of transport promoted the development of local ownership companies, or in the case of a large firm, the ownership and operation of several strategically located pits and associated fabricating plants. Common clay is used most frequently in the manufacture of heavy clay products, including:

- structural clay products, such as building brick, flue linings, sewer pipe, drain tile, structural tile, and terra cotta;
- portland cement clinker; and
- lightweight aggregate.

In the U.S., 1994 domestic sales and use of common clay and shale was 25.9-million tonnes valued at US$142 million. Approximately 14.3-million tonnes of clays (55%) were used in the manufacture of structural clay products. Common and face brick accounted for 93% of this total. The Bureau of Census reported shipments of building and face brick to be 7.20 billion bricks valued at US$1.10 billion (1995). It is estimated that for 1995 common clay and shale production was about 29.7-million tonnes.

Table 2.1 shows the clay mining and brick manufacturing operations, and their locations.

Over the years, there has been significant consolidation in the Canadian brick industry, as in North America generally, with further and further concentration of ownership among a few large companies. Prior to WWII, there were over 3,000 brick manufacturers and over 4,500 brick plants in the U.S.A. In 1996, there were only 93 manufacturers operating 204 plants there. At the same time, the industry capacity in units has remained relatively constant.[13]

The North American brick industry is fairly integrated, with Canadian producers participating in a major way in brick production in the U.S. as well. A Canadian based company, the Jannock's Brick Group, is one of North America's largest manufacturers of clay brick with operations not only in southern Ontario and Quebec, but also in Texas, North and South Carolina, Mississippi, Michigan and Kentucky.[14]

The "Clay Brick Association of Canada" suspended its operation, it has no staff or office, although it still legally exists. Its former members maintain an informal contact and affiliation with the "Brick Institute of America." The four main Canadian clay brick producers agreed to cooperate and to provide a consolidated summary of the required information for the ATHENA™ study through a third party acting as an independent assessor.

TABLE 2.1: CLAY MINING AND BRICK PRODUCTS MANUFACTURING OPERATIONS, 1996

Company	Location	Products	Raw Material	Size
Nova Scotia				
The Shaw Group Ltd.	Lantz	brick, block & tile	common clay, ball clay	E
Quebec				
St. Lawrence Brick (Division of Jannock Ltd.)	Laprairie	building brick	shale	C
Ontario				
Brampton Brick Ltd.	Brampton	building brick	shale	C
Canada Brick Ltd. (Division of Jannock Ltd.)		building brick	shale	E
Burlington plant	Burlington			
Ottawa plant	Ottawa			
Streetsville plant	Streetsville			
Cooksville plant *	Streetsville			
Hamilton Brick Ltd.	Hamilton	building bricks	shale	B
Manitoba				
I.XL Industries Ltd. Red River Brick & Tile Division*	Lockport	brick & tile	common clay	E
Alberta				
I.XL Industries Ltd.				
Medicine Hat Brick & Tile Division	Medicine Hat	brick, block, flue liners	common clay	D
Northwest Brick & Tile Division*	Edmonton	building brick	common clay	B
Redcliff Pressed Brick Division	Redcliff	facing & fire brick	common clay	B
British Columbia				
Clayburn Industries Ltd.	Abbotsford	refractory brick, mortar	imported ball clay	D
Sumas Clay Products Ltd.	Sumas	brick, drain tile & flue lining	common clay	C

Size keys: (A) up to 25 employees, (B) 25-49 employees, (C) 50-99 employees, (D) 100-199 employees, (E) 200-499 employees, (F) 500-999 employees, (G) over 1000 employees.
Source: Adapted from Ref. (1, 2)
Notes: * plant not in operation

In 1997 the four majors, I.XL Industries Ltd., Canada Brick Ltd, Brampton Brick Ltd. and the Shaw Group Ltd. have operated a total of 27 lines in 13 plant locations. Their total plant capacity is 541,000,000 units (based on the “Ontario” brick - 213x102x60 mm [LxWxH]). The 1996 capacity utilization was 80%.[28]

2.1.2 Calcium Silicate Brick

Calcium silicate, or sand-lime, masonry units are made by mixing lime and sand with a sufficient amount of water to permit the mixture to be molded under high pressure. The resulting "green" units are subjected to high pressure steam in an autoclave which promotes a reaction between the lime and silica to form hydrated calcium silicates similar to those formed when water and portland cement react.[24]

Worldwide more than 30 billion calcium silicate bricks are produced annually, mainly in Europe, the Middle East, East Asia, Australia and Mexico. The first sand-lime brick plant in the U.S. was built in 1901, and by 1927 more than 320 million bricks were being produced each year at more than 50 plants. In 1986, only one American producer, Grays Ferris Brick Co., N.J., remained.[25] Market dominance of clay brick coupled with poor product quality is considered to be the reason for the decline of the U.S. calcium silicate industry.

There is one producer of calcium silicate (sand lime) brick in Canada, Arriscraft Corporation in Cambridge, Ontario. The units are produced for architectural application, including structural components and vertical thin-wall exterior or interior masonry skins. The units are said to have high compressive strength and tolerate severe weathering.[24]

2.1.3 Concrete Brick

Concrete masonry units (CMUs) are made from various aggregates, cementitious binder - usually portland cement, and water. The most common CMU, concrete block, was covered in detail in another ATHENA™ study, "Building Materials in the Context of Sustainable Development: Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates for Cement and Structural Concrete Products".[15]

While standard concrete block represents the majority of CMU production, other products, such as architectural units, concrete pavers, segmental retaining walls, concrete brick and specialty products are also made. In the U.S., nationally, standard block constitutes 51.7% of the total production, while concrete brick only 4.4%.

In Canada, there are 96 CMU manufacturing facilities covering all regions of the country. Concrete masonry combined with precast/prestressed concrete products, accounts for only 5% of Canadian cement consumption.[16] It can be safely assumed that only some of the CMU producers manufacture concrete masonry brick.

The interests of the Canadian concrete masonry industry are represented by the Canadian Concrete Masonry Products Association (CCMPA). In the U.S.A., the National Concrete Masonry Association (NCMA) has a similar mandate.

2.1.4 Cement Mortar

Mortars are bonding materials that integrate a brick, clay or concrete, into a masonry wall, binding the masonry units into a single element. Mortar must be strong, durable, and capable of keeping the wall intact. Mortar also must help to create a water resistant barrier.[11] The basic mortar ingredients include portland cement, hydrated lime, sand and water. Masonry cement may be used in place of a portland cement/lime combination. Cement mortar was discussed in detail in the Cement and Structural Concrete Products Report,[15] and it will be reviewed here only briefly in the context of clay/concrete brick use.

2.2 CLAY BRICK MANUFACTURING

Brick manufacturing still follows the basic steps of centuries past. Technological advancements over the years, however, have made the modern brick plant substantially more efficient and have also improved the overall quality of the products. A more complete knowledge of raw materials and their properties, better control of firing, improved kiln designs and more advanced mechanization have all resulted in the development of a modern, progressive industry.

2.2.1 Raw Materials

While clay is one of the most abundant mineral materials on earth, clay for production of brick must possess some specific properties and characteristics. To satisfy modern production requirements, clays must have plasticity which permits them to be shaped or molded when mixed with water, and they must have sufficient wet and air-dry tensile strength to maintain their shape after forming. Finally, when subjected to rising temperatures, the clay particles must fuse together.[8]

Clays used in brick manufacturing occur in three principal forms, all of which have similar chemical compositions but different physical characteristics. **Surface clays**, found near the earth surface, may be the upthrusts of older deposits or of more recent, sedimentary formation. **Shales** are clays that have been subjected to high pressures until they have hardened almost to the form of soft rock. **Fire clays** are usually found at deeper levels than other clays, they contain fewer impurities than either surface clays or shales, have more uniform chemical and physical properties, and have refractory qualities.

2.2.2 Manufacturing Process

Although individual manufacturing plants may vary somewhat from the basic brick manufacturing process in order to accommodate their particular raw materials and methods of operation, the principles are fairly uniform. The basic technology consists of mixing of ground clay with water, forming of bricks into the desired shape and size, and drying and firing. The Brick Institute of America subdivides the brick manufacturing procedure into six general phases:[8]

- winning and storage of raw materials;
- preparing of raw materials;
- forming units;
- drying;
- firing and cooling; and
- drawing and storing of finished products.

The basic manufacturing steps are depicted in Figure 2.1 and summarized below:

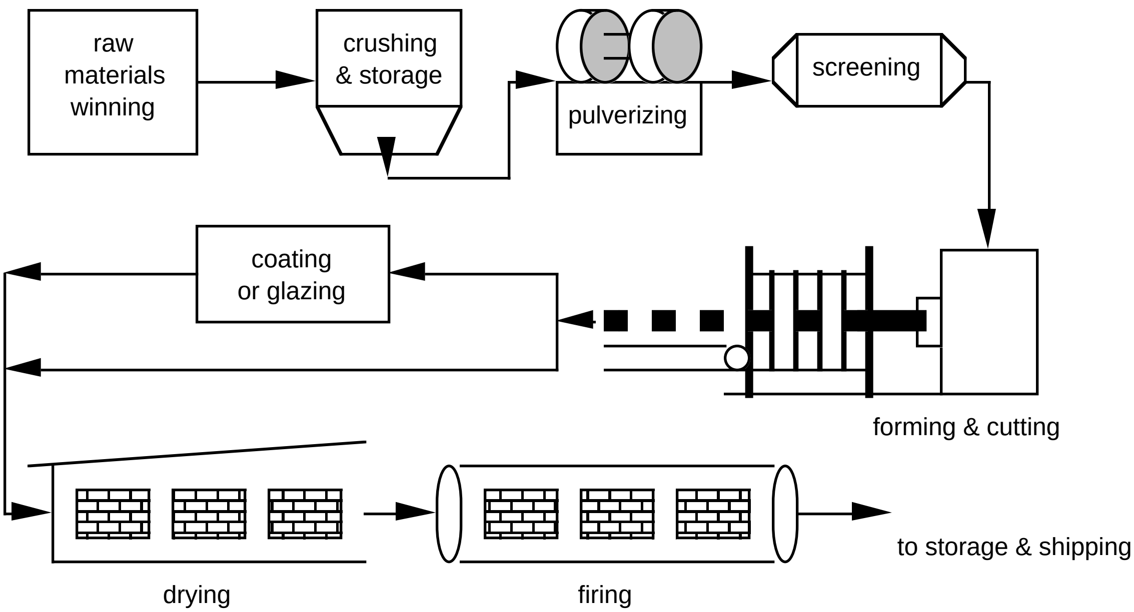

Fig. 2.1 Flow diagram of a clay brick plant (adapted from Refs. 8).

2.2.3 Extraction

The clay industry uses the term "winning" for clay mining (quarrying). To *win* originally meant to *obtain*. Surface clays, shales and some fire clays are mined in open pits with power equipment such as power shovels, front-end loaders, backhoes and scraper-loaders; some fire clays are taken from underground mines. The clay or shale mixtures are then transported to plant storage areas.

It is a common practice to store enough raw materials for several days' operations, thus insuring continuous operation regardless of weather conditions. Normally, the manufacturer mixes clays from different locations in the pit and, often, from more than one source. Blending produces more uniform raw materials, helps to control colour and permits some control over raw materials' suitability for manufacturing a given type of brick.

2.2.4 Preparation

The clay is delivered to a crusher, which breaks up the larger pieces with steel knives and removes stones. It is then discharged onto circular pans, where it is ground to a fine powder by large grinding wheels, weighing 4 to 8 tonnes each. Some clays require very little preparation, while others require extensive grinding. Most plants then screen the clay, passing it through inclined vibrating screens to control particle sizes.

2.2.5 Forming

After the clay is ground, it is tempered in a pug mill. Tempering is the first step in the forming process. Water is added to the ground clay in the mixing chamber of the pug mill whose revolving shafts mix (temper) the raw materials. Tempering reduces the clay to a homogeneous plastic mass and produces the desired consistency for brick forming. Bricks can be formed by a soft-mud, stiff-mud, or dry-press processes.

In the **Stiff-Mud Process**, clay is mixed with only sufficient water to produce plasticity, usually from 12 to 15 percent by weight. After thorough mixing, i.e. “pugging”, the tempered clay goes through a de-airing chamber in which a vacuum of 375 to 725 mm of mercury is maintained. De-aerating removes air holes and bubbles, giving the clay increased workability and plasticity, thus resulting in greater strength. Next, clay is extruded through a die to produce a column of clay in which two dimensions of the final unit are determined. The column then passes through an automatic cutter to make the final dimension of the brick unit. Cutter-wire spacing and die sizes must be carefully calculated to compensate for normal shrinkage during wet stages through drying and firing. As the clay column leaves the die, textures or surface coatings / glazes may be applied.

The **Soft-Mud Process** is particularly suitable for clays which contain too much natural water to be extruded by the stiff-mud process. It consists of mixing clays so that they contain 20 to 30 percent water and then forming the units in molds. To prevent clay from sticking, the molds are lubricated with either sand or water. When sand is used, the brick are “sand-struck”; if water is used, they are “water-struck” brick. Brick may be produced in this manner by a machine or by hand process.

The **Dry-Press Process** is particularly adaptable for clays of very low plasticity. Clay is mixed with a minimum of water (up to 10 percent), then formed in steel molds under pressures from about 3.5 to 10.5 MPa using mechanical rams.

Based on a survey of its membership, the Brick Institute of America reports that 94% of the brick shipped was produced by extrusion (stiff-mud process), 5% by machine molding (soft-mud process), and the remainder by dry pressing or hand molding.[27]

2.2.6 Drying

When wet bricks come from the brick-making molding or cutting machine, they contain from 7 to 30% moisture, depending on the forming process used. Before the firing process begins, most of this water is evaporated. Wet bricks may be stacked in open sheds for a period of 1 to 6 weeks for drying. However, most brick is now dried in mechanical dryers under controlled conditions of heat, moisture, and air velocity. Drying times, which vary with drying temperatures (about 40°C to 200°C) and different clays, are usually from 2 to 4 days. Although heat may be generated specifically for dryer chambers, it is more commonly supplied as exhaust heat from firing kilns. In all cases, heat and humidity must be carefully regulated to avoid excessive cracking of the brick.

2.2.7 Firing and Cooling

Firing is one of the more specialized steps in the manufacture of brick, requiring from 40 to 150 hours, depending upon kiln type and other variables. Most bricks are now burned (fired) in kilns having permanent enclosures, with heat (flame) directed straight into the kiln. Clay bricks are fired, usually with natural gas, although propane, oil, sawdust, coal or combinations of these fuels can also be used, at temperatures of about 1100 to 1200°C. The temperature range used in brick firing is high enough to generate both fuel and thermal NO_X emissions, with a very substantial portion of the emissions in the non-attainment areas.

The heat may be furnished through grates under bricks piled in arches as in older types of kilns. These kilns are called up-draft kilns. If the heat enters near the top of the kiln and passes down through the piled brick and out through openings in the floor to chimneys, the kiln is called a down-draft kiln. The kilns may be either intermittent (periodic, batch) or continuous. A periodic kiln is one that is loaded, fired, allowed to cool and unloaded, after which the same processes are repeated. The continuous tunnel kilns are now widely used. The tunnel kiln consists of either a straight or a curved tunnel, with several zones in which heat is carefully controlled. Firing may be divided into the following six stages, associated with different temperature ranges and the steps of the firing process, with the actual temperatures being determined by the particular clay or shale used:

- "water-smoking" (evaporation of free water) < 205°C
- dehydration 150°C – 980°C
- oxidation 540°C – 980°C
- vitrification 870°C – 1320°C
- flashing
- cooling

Bricks are loaded onto special cars and pushed through the various sections of the tunnel kiln at a pre-determined schedule. The tunnel kiln operates continuously, is very efficient and produces a more uniform product. A modern tunnel kiln can produce 40 to 80 million bricks a year, in contrast to older periodic kilns which produced perhaps 2 million bricks in a batch process. Of course, the modern manufacturing processes require a substantial capital investment.

Clays are unlike metals in that they soften slowly and melt or fuse gradually when subjected to rising temperatures. It is this property of clay, its fusibility, which causes it to become hard, solid and of relatively low absorption when properly fired. Fusing takes place in three stages:

1) incipient fusion, that point when the clay particles become sufficiently soft that the mass sticks together;
2) vitrification, when there is extensive fluxing and the mass becomes tight, solid and non-absorbent; and
3) viscous fusion, the point at which the clay mass breaks down and tends to become molten.

The key to the firing process is to control the temperature in the kiln so that incipient fusion and partial vitrification are complete but viscous fusion is avoided. The rate of temperature change must be carefully controlled, depending on raw materials, as well as the units being produced. Kilns are normally equipped with recording pyrometers and other temperature sensors to provide a constant check on the firing process. After the temperature has reached the maximum and is maintained for a prescribed time, the cooling process begins. Two to three days are required for proper cooling in periodic kilns, but in tunnel kilns the cooling period seldom exceeds 2 days. Because the rate of cooling has a direct effect on colour and because excessively rapid cooling will cause cracking and checking of the ware, cooling is an important stage in the firing process.

2.2.8 Drawing

Drawing is the process of unloading a kiln after cooling. It is at this stage that units are sorted, graded, packaged and taken to a storage yard or loaded for delivery. The majority of bricks today are packaged in self-contained, steel-strapped cubes, which can be broken down into individual strapped packages for ease of handling on the job site. The packages and cubes are formed in such a manner as to provide openings for handling by fork lifts. Most of the brick is shipped by truck, although some is transported by rail as well.

Brick manufacturing is a mature, fine tuned technology. In recent years, the Canadian producers have been improving their manufacturing facilities, largely to replace obsolete equipment and reduce energy consumption. As well, there were some new, state-of-the-art brick plants commissioned and opened in the late 1980s. The primary factors behind the efficiency and production costs of different plants is their location (proximity to the source of clay vs. markets), vertical integration (clay/shale quarry, brick production line/kiln), and, of course, the size and the speed of the production lines.

2.2.9 Types and Shipments of Clay Brick

The industry has developed and is producing a range of different bricks for different applications. CAN/CSA National Standards cover various types of brick and specify their composition and special properties. In the U.S.A. the brick products are covered by ASTM standards. With the demise of the Clay Brick Association of Canada, no data regarding the breakdown of brick production by type is available. From the Brick Institute of America (BIA) detailed information regarding the situation in the U.S. is available[18], and in the absence of similar Canadian data we will assume that these are indicative of the breakdown of the Canadian market.

Face brick (i.e. brick made for facing purposes) made from selected clays to produce desired colour and often treated to produce surface texture, accounted for the majority of shipments in 1995 at 95.8% of the total. Building brick, formerly called common brick, not specially treated for texture or colour represented another 1.6%, while thin brick units and paving brick accounted for the remaining 0.1 and 2.5%, respectively.

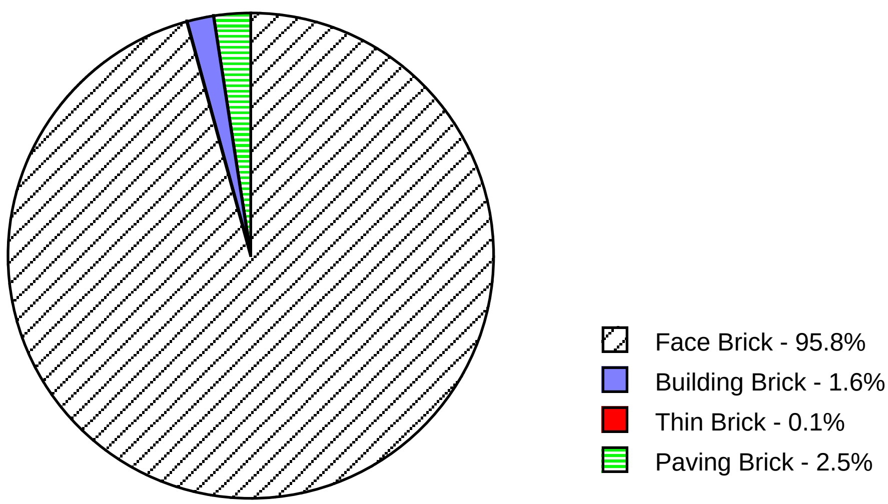

Fig. 2.2 Clay brick shipments by product type, 1995 (Source: BIA[18]).

Bricks are produced in a wide variety of sizes. To indicate relative popularity of various sizes, Table 2.2 shows the BIA's U.S. statistics for 1995 shipments of various types of units expressed both in actual units shipped and their Standard Brick Equivalent (S.B.E.). Modular brick was the most prevalent type, accounting for 37.5 % of all S.B.E. brick shipped, followed by Standard brick at 19.4 S.B.E.[18]

Shipments through dealer/distributors account for 63.6 % of the total, while direct sales represent 36.4 %. Among direct sales shipments, residential is the predominant end use, accounting for 76.4 % of the total. This is followed by non-residential building uses (12.5 %) and non-building uses (11.1 %). Similarly, the majority of the dealer/distributors sales are for the residential market (68.4 %), followed by non-residential use (29.1 %) and non-building applications (2.5%), as shown in Table 2.3.[18]

TABLE 2.2: TYPES OF CLAY BRICKS SHIPPED IN THE U.S.A., 1995[18]

Type of Unit	*Dimensions in Inches (inclusive sizes)*			*Actual Units Shipped (1000)*	*% of Total*	*S.B.E. Conversion Factor*	*S.B.E. Shipped (1000)*	*% of Total*
	Thickness	Height	Length					
Modular	3-1/2–3-5/8	2-1/4	7-1/2–7-5/8	2,219,784	41.4	1.00	2,219,784	37.5
Standard	3-1/2–3-3/4	2-1/4	8	1,149,291	21.4	1.00	1,149,291	19.4
King	2-3/4–3	2-5/8–2-3/4	9-5/8–9-3/4	619,956	11.6	1.35	836,964	14.1
Engineer standard	3-1/2–3-3/4	2-3/4–2-13/16	8	432,402	8.1	1.20	518,882	8.8
Queen	2-3/4–3	2-3/4	8	84,375	1.6	1.10	135,000	2.3
Other sizes	various dimensions			278,992	5.2	-	298,080	5.0
2-1/2" brick	3-1/2–3-3/4	2-1/2	8	19,776	0.4	1.10	21,754	0.4
Paver full thickness	2-1/4	3-5/8–4	7-5/8–8	89,920	1.7	1.20	107,904	1.8
Engineer modular	3-1/2–3-5/8	2-3/4–2-13/16	7-1/2–7-5/8	310,998	5.8	1.20	373,198	6.3
Paver half thickness	1–1-5/8	3-5/8–4	7-5/8–8	35,688	0.7	1.10	39,257	0.7
Roman	3-1/2–3-5/8	1-1/2–1-5/8	11-1/2–11-5/8	1,970	<0.1	1.00	1,970	<0.1
Thin brick wall	3/8–1/2	2-1/4	7-5/8–8	12,072	0.2	0.20	483	<0.1
Utility	3-1/2–3-5/8	3-1/2–3-5/8	11-1/2–11-5/8	86,301	1.6	2.20	189,845	3.2
Norman	3-1/2–3-5/8	2-1/4	11-1/2–11-5/8	10,106	0.2	1.45	14,654	0.2
Other types & sizes	various dimensions			9,163	~0.1	-	16,815	~0.2
TOTAL				5,360,794	100.0	-	5,923,881	100.0

TABLE 2.3: SHIPMENTS OF CLAY BRICKS BY END USE (U.S.A., 1995)[18]

	Percent of Total Shipments	*Percent of Direct Sales Shipments*	*Percent of Dealer / Distributor Sales Shipments*
Residential	74.5	76.4	68.4
Single family	*70.4*	*73.7*	*59.8*
Multi family	*4.1*	*2.7*	*8.6*
Non-residential	16.4	12.5	29.1
Commercial	*10.1*	*7.6*	*18.3*
Industrial	*0.8*	*0.5*	*1.8*
Institutional	*5.6*	*4.5*	*9.0*
Non-building	9.1	11.1	2.5
TOTAL	100.0	100.0	100.0

2.3 CALCIUM SILICATE BRICK MANUFACTURING

The calcium silicate (sand-lime) brick manufacturing process is shown in Fig. 2.3, and briefly discussed below:

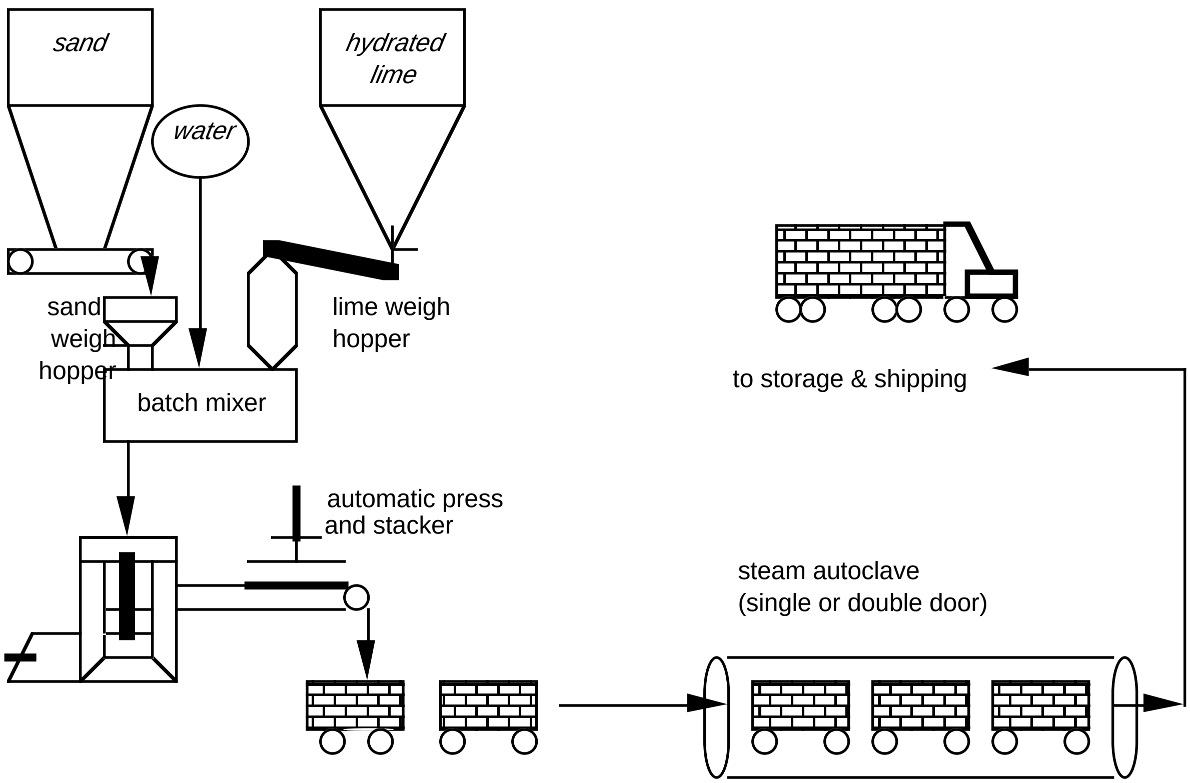

Fig. 2.3 Flow diagram of a calcium silicate brick plant.[25]

2.3.1 Raw Materials and Manufacturing Process

Clean, high grade sand is mixed intimately with 5 to 8% high calcium hydrated lime [$Ca\ (OH)_2$] in a wet state. If quick lime [CaO] is used, it is hydrated (slaked) first, i.e. it is reacted with water to form hydrated lime.

The resulting plastic mixture is molded into bricks and then autoclaved under pressure in an atmosphere of steam for 3 to 8 hours, depending on the pressure–temperature levels. Under these conditions, lime reacts with silica to form complex hydro di-calcium silicates, similar to those formed when water and portland cement react, that act as the cementing material and provide high dimensional stability. Improved modern production techniques can develop strengths exceeding portland cement-based products. Finished brick is pearl-gray in appearance. The grading and use of sand-lime brick are similar to those of burned clay brick.[24, 25]

2.4 CONCRETE BRICK MANUFACTURING

The concrete masonry manufacturing process is schematically shown in Fig. 2.4, and its main steps are discussed below:

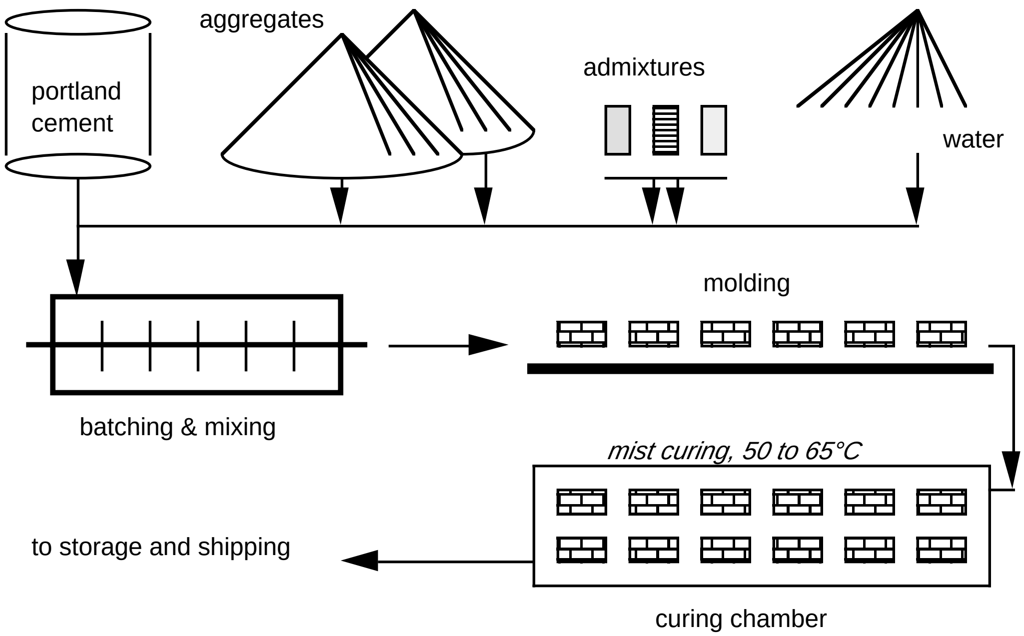

Fig. 2.4 Flow diagram of a concrete brick plant.

2.4.1 Raw Materials

Concrete brick is made of portland cement (PC) and suitable aggregates. Production of these two main components of concrete masonry was discussed in detail in the ATHENA™ Cement and Structural Concrete study.[15] PC is shipped to the concrete masonry unit (CMU) manufacturer most often by truck, as is fly ash, sometimes used as a supplementary cementing material. The cementitious materials are pumped into silos for storage at the CMU manufacturing plant, and from there fed to the concrete mixer.

Aggregates are usually locally available and in abundant supply. While natural aggregates from local quarries and pits are normally used as the main aggregate in concrete masonry production, lightweight aggregates such as expanded shale or clay and pumice might also be used. The aggregates are stockpiled at the CMU manufacturing site. Electric powered conveying systems transport the aggregates to the concrete mixer. Most mixers have a capacity of 1.5 to 3 m^3.

2.4.2 Mixing and Forming

Concrete brick (and other CMUs) are produced by molding a zero slump concrete into the desired shape and curing the product. Unlike most concrete products, zero slump concrete is not a wet mix. The amount of water used to manufacture concrete brick is seldom more than 5 percent by weight. As the stockpiled aggregate often contains up to 60 percent of the required water, the actual amount of water added is proportionally reduced. Typically, 100 kg of water is added per m^3 of concrete. Zero slump concrete mixes use water efficiently.[17, 26]

The concrete mix is fed into a mold and vibrated. The consolidation by vibration not only minimizes the required water, but also minimizes the required cementitious materials. The quantity of cementitious materials is usually between 6 to 12 percent by weight of the aggregate. This is about 160 to 225 kg of cement per m^3 of concrete. The moist mix minimizes dust and related environmental impact. Pigments and other additives, such as soaps and stearates, may be used in the manufacture of architectural concrete masonry units. When used, the combined quantity of all additives is usually about 2.5 to 3 percent by weight of cement. This is approximately 4 to 8 kg per m^3 of concrete.

The concrete bricks are formed on steel pallets. The pallets are placed on racks and moved to curing chambers. Most racks are automated and electrically powered. In older manufacturing facilities, or on specialty lines, the racks are usually moved with fork lifts.

2.4.3 Curing and Drawing

The curing processes vary from low temperature mist cures to high pressure steam (180°C) or autoclave curing. Most concrete masonry units produced today are produced using low temperature, 50 to 65°C, mist curing. Fossil fuels are used to fire boilers to heat the curing water. Other than the energy for curing the brick, electricity is used to power conveying systems for the ingredients, mixers and the concrete masonry molding machine.[17]

During the manufacturing process, any product that is damaged prior to curing is returned to the mixer. There are no waste products generated from this stage of the production process. Cured product that is not usable may be crushed and used as aggregate.

The concrete bricks are generally packaged in cubes, in the same manner as clay bricks. Banding with metal straps is common. Cubed product is moved to storage areas and to trucks by fork lifts.

2.4.4 CMU Types and Shipments

As already indicated, concrete bricks represent only a small fraction of the total concrete masonry produced and sold.

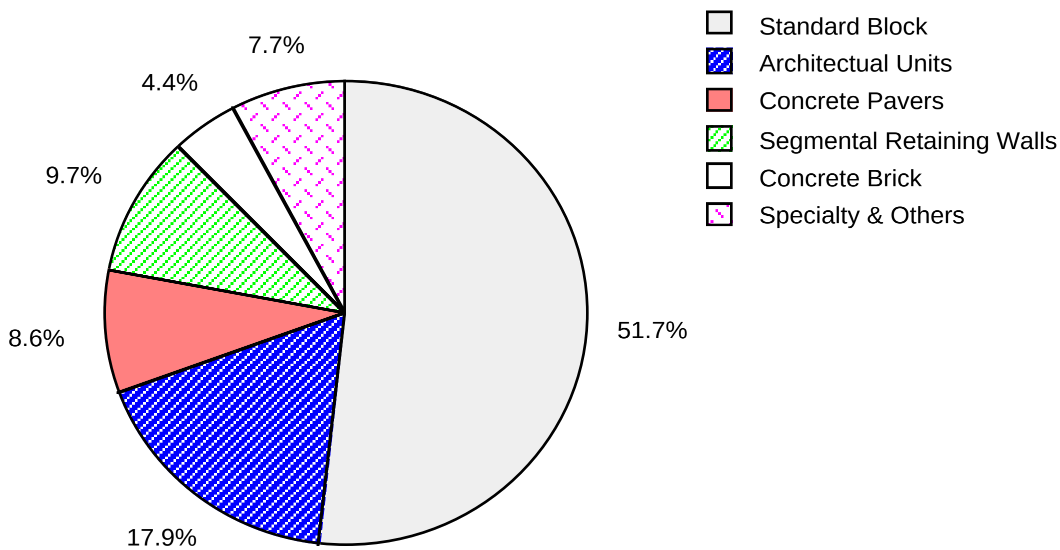

Fig. 2.6 Sales mix of concrete masonry units (U.S.A.), 1995[19]

In contrast with clay brick, the majority of CMUs are used in non-residential applications, with only about 28 % of the total units, including all types of block, concrete brick and concrete pavers, used in the residential market.

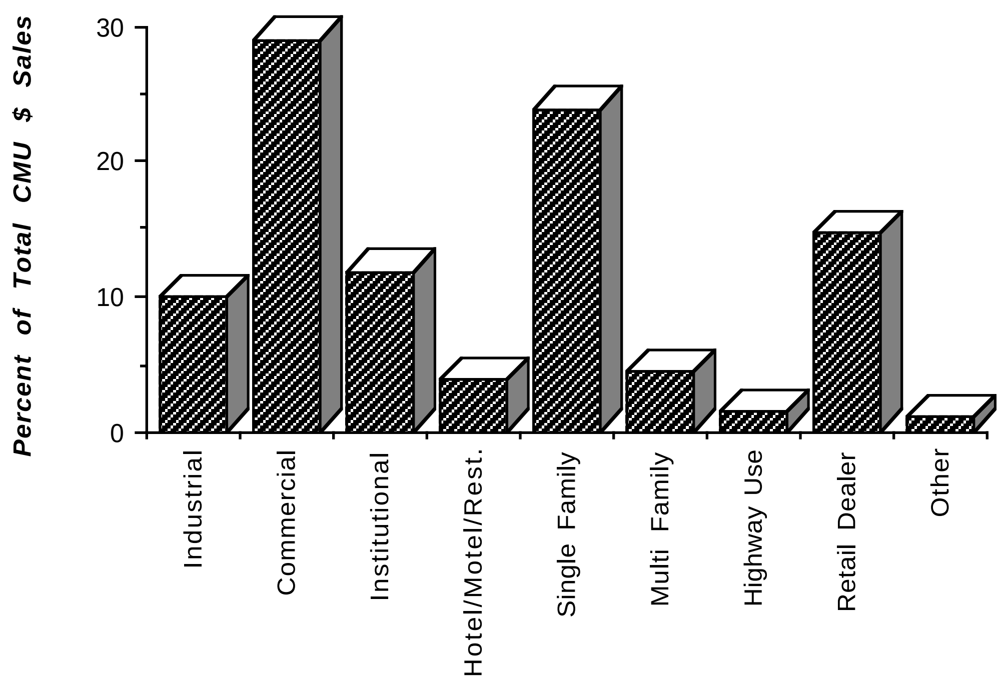

Fig. 2.7 Market distribution of concrete masonry units (U.S.A.), 1995[19]

2.5 CEMENT MORTARS

2.5.1 Cement Mortars Manufacturing

Mortars consist of cementitious materials, sand and water. For cement production we refer back to the earlier ATHENA™ study on the Cement and Structural Concrete Products Study.[15]

Cementitious mortar may be premixed and shipped to the project, ready for use, but this is not a common practice. Normally, mortar is manufactured at the construction site. Site batching of mortar usually involves a diesel powered mechanical mixer.

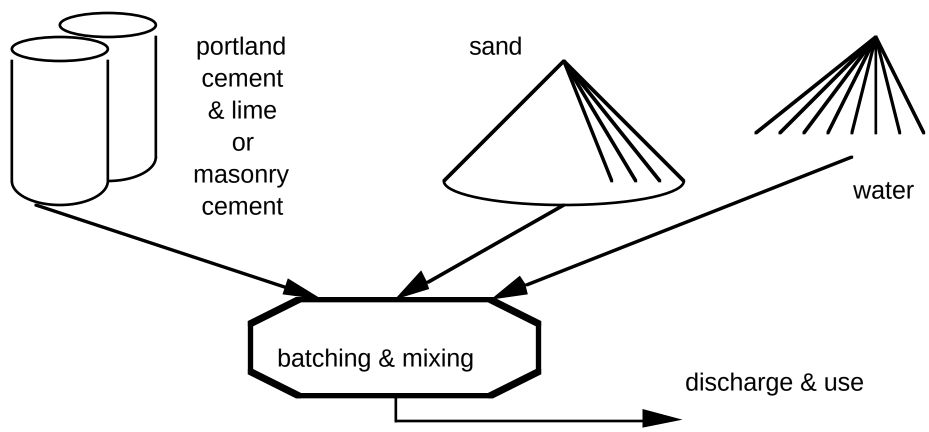

Fig. 2.8 Flow diagram of cement mortar production.

2.5.2 Types of Cement Mortars Produced

The general types of mortar according to specifications are as follows:

- Type S: This is high-strength mortar suitable for general use and recommended specifically for reinforced brick masonry and plain masonry below grade.
- Type N: This is a medium-strength mortar suitable for general use in exposed masonry above grade.

Proportioning of the main ingredients – portland or masonry cements, hydrated lime, sand and water – determines mortar type and performance.

2.6 MASONRY INDUSTRY, ENERGY AND ENVIRONMENT

Like any industry, brick and mortar manufacturing uses energy resources and emits some pollutants to the atmosphere. It also generates some liquid effluents and solid wastes. At the same time, brick is perhaps one of the more environmentally friendly building products because:

- processing temperatures are relatively low, and
- clay, the primary component of fired brick, is one of the most abundant raw materials

2.6.1 Energy Use and Efficiency

In Canada, the principal fuel used in the manufacturing of clay brick today is natural gas, although in the U.S. the industry began a return to other fuels due to gas shortages in the early 1970's. The mix of fuels there shifted from 95% natural gas in 1970 to 65.9 % today. The principal solid fuel in use is sawdust (10.8%) followed closely by powdered coal (9.6%). Then comes fuel oil (7.8%) and propane (6.0%). The principal stand-by fuels are propane and fuel oil.[9]

2.6.2 Atmospheric Emissions

Atmospheric emissions - CO_2, SO_2, NO_x, CH_4, VOC, CO and particulates (PM) - are generated in all steps of the clay brick manufacturing process, mainly due to the use of energy in raw materials transportation, in the manufacturing stages (primarily from kiln fuel combustion), as well as in transportation of the finished ware. Temperatures in clay brick kilns are high enough to produce also some thermal NO_x, in addition to fuel NO_x. Because most of the Canadian manufacturers use natural gas as the main kiln fuel, emissions have been reduced, especially in comparison to the past, when coal and oil were the predominant fuels.

The primary sources of PM emissions are the kiln and raw materials grinding and screening operations. Other sources of PM emissions include sawdust dryers used by plants with sawdust-fired kilns, coal crushing systems used by plants with coal-fired kilns, and fugitive dust sources such as roads and storage piles.[10]

Certain additional pollutants originating from the raw materials themselves may be emitted from the brick kiln. These include fluorine (40 to 205 ppm in stack gases), present as hydrogen fluoride and a small amount of chlorine (0.7 to 4 ppm in stack gases), as well as SO_x and CO_2.[23] Fluorine and chlorine are present in brick raw materials. As the green bricks reach temperatures of 500° to 600°C, hydrogen fluoride and chloride are formed. Because F and Cl content in clays and shales is highly variable, emissions of their compounds vary considerably depending on the raw materials used.[10] The environmental effects of fluorine and chlorine include acid precipitation and possible resulting acidification of surface waters as well as tree and crop damage. The brick industry is currently involved in monitoring fluoride emissions and developing ways to eliminate them.[21]

Recent draft emission factor documentation prepared for U.S. EPA AP-42[10], covering surveys of available data on emissions associated with clay brick production, will be discussed in more detail in Section 5. Emissions associated with concrete brick and cement mortar production, mainly due to use of portland cement, will be estimated in a similar manner as in the ATHENA™ Cement and Concrete study for concrete block and cement mortar.[15]

BIA's 1995 Manufacturing Report[9] notes that 35% of surveyed plants reported the use of one or more pollution control measures. Of these, 30% use the bag house method to control particulate emissions, 4.2% use wet or dry scrubbers, and 0.7% of plants use a dust collector.[9]

2.6.3 Liquid Effluent

As in other mining operations, quarrying of clays in open pits results in some runoff and polluted waste water. It is usually contained by the nature of the operation. What waste water runoff there is, usually comes from roadways or from plant storage areas and is contained by collection and settling ponds where necessary.[27] Some waste water is also generated in the cleaning of concrete masonry and cement mortar manufacturing equipment.

2.6.4 Solid Waste

Extraction of clay, in contrast to many other quarrying and mining operations, generates very little waste, as clay is usually used in its entirety in the manufacturing process, without any separation of impurities, refining or smelting. There is essentially no waste when clay brick is manufactured. For every pound of clay, nearly one pound of brick is produced with only slight moisture and mineral loss.[20]

Solid waste generated in cement and concrete masonry production were discussed in the ATHENA™ Cement and Concrete study.[15] Excess cement mortar is usually buried at construction sites or disposed of in landfills.

2.6.5 Recycling

Recycled clay brick from construction demolition sites is popular in residential construction for decorative use. In some areas, "antique" brick brings a higher price than new brick. If new brick does not meet a manufacturer's standard, it can be easily recycled through an inexpensive crushing process. Crushed brick chips can be used as landscape material or reground to manufacture new, quality brick.

The durability of structures constructed with brick and mortar averts the need for producing replacement materials, avoiding the accompanying depletion of resources.

Recently, in some operations, sewage sludge is mixed with normal brick-making materials to produce clay brick with no decrease in material properties.[22] Also contaminated soils can be combined with clay to yield a quality brick, with the waste completely and safely encapsulated with no leaching of the contaminants. To prepare contaminated soil for brick making, it is fired at temperatures exceeding 930°C for 12 hours. Such high temperatures burn out or encapsulate the wastes and prevent them from escaping from the bricks. Materials containing various petroleum products, hydraulic fluids, transmission fluids, lubricating oils, naphthalene and mineral oils and spirits are recycled in this brick-making process. By recycling the contaminated materials into brick, this process saves the increasingly scarce space in landfill sites.[20]

Waste wood (saw dust) is frequently used as a source of energy in clay brick kiln firing in the U.S.A., but not in Canada. A range of waste derived fuels is utilized by the cement industry in production of portland cement, the principal raw material of concrete brick and cement mortar.

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3.0 RAW MATERIAL REQUIREMENTS AND TRANSPORTATION

This section provides a brief overview of raw material requirements for various types of bricks and cement mortar production in Canada. The section also provides an overview of transportation distances and typical modes used to move raw materials to the brick plants. These transportation data were used to develop corresponding energy estimates presented in Section 4.0.

Typical data on actual raw material requirements, transportation distances and modes for the brick industries was provided to VG&A by the respective industries and verified by published information. The bulk of the Canadian clay brick production is concentrated in the hands of only three or four large producers, each one of them being active, usually, in only one of the regions. It is therefore not possible to provide all of the manufacturing data on a regional basis and at the same time protect the confidentiality of the information. Instead, the Canadian clay brick industry provided information for a "typical brick operation". Since most Canadian clay bricks are produced using essentially the same raw materials, extrusion (stiff mud) forming process and modern continuous tunnel kilns, we do not feel this approach unduly compromised our study. Transportation information is regionalized, as are the data for production of concrete brick.

In comparison, the concrete masonry units (CMU) industry is rather fragmented. The Holderbank study lists six (6) concrete block plants on the West Coast, ten (10) on the Prairies (including Manitoba), sixty one (61) in Ontario and nineteen (19) in the East.[5] (As the process is essentially the same, we assume that any concrete block operation can produce concrete bricks as well.) The last type of masonry bricks used in Canada, the sand-lime (calcium silicate) bricks, are currently produced by only one operation in Ontario. They are, however, distributed all over the country.

3.1 Raw Material Requirements

Brick and cement mortar formulations are essentially identical from one region of the country to another. Raw materials used, such as clay, cement, sand and aggregates are abundantly available. The differences between raw materials used from one producer to another are insignificant. Portland cement is an exception, as the raw materials mix, kiln fuels used and the process technology itself varies across different regions of Canada.[1] Regional variations will be introduced in later sections of the report to take into account the differences in energy use and other unit factors in cement production.

Generally, as indicated in Section 2, clay brick formulations consist of 82% to 85% clay, around 12% to 15% water, and small amounts of additives (each one of them less than 2%), on a mass basis.[2] Calcium silicate brick formulation consists of 85% sand, 6% lime and 9% water,[3] and concrete brick about 10% portland cement, 25% fine aggregate, 60% coarse aggregate and 5% water.[1,4,6]

Cement mortar is assumed to be made with a portland cement/fine aggregate ratio of 1:3 by volume (94:240 by weight) and a water/cement ratio of 0.5 to 0.7. (Cement mortars often have some lime content to improve plasticity. However, the differences between unit factor estimates for a lime mortar and one made only with portland cement would be minimal and we have, therefore, developed estimates for only the portland cement version.) Cement mortar joint application of a 10 mm (3/8″) thickness is assumed.

Traditionally, clay and calcium silicate brick formulations and raw materials consumption are given in kilograms per tonne of finished ware. (Alternately, these can also be given in grams per brick, which, of course, varies depending on the size of brick selected. The third possible consumption units, often used in the field by the masonry trade, are expressed per square meter.) In the concrete industry, for either concrete brick or cement mortar, formulas in kilograms per cubic meter are more common.

TABLE 3.1
BRICK AND MORTAR GENERIC FORMULATIONS / AVERAGE RAW MATERIALS USE

	Clay brick (kg/tonne of finished ware)	Calcium silicate brick (kg/tonne of finished ware)	Concrete brick (kg/m^3)	Cement mortar (kg/m^3)
Clay / shale	1000	-	-	-
Portland cement	-	-	217	307
Lime	-	60	-	-
Coarse aggregate	-	-	583	-
Fine aggregate (sand)	-	940	1361	785
Water	135	90	69	185
TOTAL	1135	1090	2230	1277

Small amounts of additives might be used in production of various brick products. None of the individual additives, however, reach the 2% limit recommended as a cut-off level in the ATHENA™ project Research Guidelines, and therefore their specific energy and emissions estimates were not developed.

3.2 Raw Materials Transportation

3.2.1 Clay Brick

The raw materials used in the manufacture of clay bricks include surface clays and shales which are mined in open pits. Some brick works have on-site quarrying operations (within 1/2 km), while others bring in raw materials by truck. In Canada 2/3 of the facilities have clay pits on the plant site, using front end loaders and trucks to move the raw materials from the pit to the preparation area, while the remaining 1/3 of the plants truck their clay or shale in, usually from a 10 to 25 km radius. A fraction of the clay supplies comes from some outlying areas as far as 75 km away.[7]

Based on the information provided by the Canadian clay brick producers, we estimated 9.22 km as an average weighted distance for our typical plant. Trucking is the only mode of transportation used in the industry (diesel fuel), and no backhaul is assumed for the raw materials transport. Therefore the clay / shale transportation distances for the energy and emissions estimates is doubled to 18.44 km.

3.2.2 Calcium Silicate Brick

Both principal raw materials, lime and sand, used in production of calcium silicate brick in the Cambridge, ON plant that is the sole producer of these bricks in Canada are locally available. Lime is produced in the Beachville - Ingersoll area, 65 km away, and transported from there to the brick plant by truck (diesel fuel). We assume no backhaul, therefore the lime transportation requirement for the subsequent energy and emissions estimates is doubled to 130 km.

Fine aggregate (sand), that constitutes by far the largest portion of the sand-lime brick composition, is a plentifully available raw material. There are sources close to the Cambridge plant, and although we have no hard information about its transportation distances and modes, we believe that an average of 15 kilometres by truck is a reasonable assumption. Doubling this distance to account for empty backhauls results in assumed truck transportation requirements of 30 kilometres for fine aggregates.

3.2.3 Concrete Brick and Cement Mortar

Cement
Transportation of cement to concrete plants / market distribution centres in each of the six cities is included in the total cement energy estimates from Part I of the cement and structural concrete study.[1] It is shown here again for the completeness of this study.

Based on the information about transportation distances and modes provided by the Canadian cement plants and the Research Guidelines requirement that finished product transportation data should be provided in kilometres by mode of transport for average haul distances to Halifax, Montreal, Toronto, Winnipeg, Calgary and Vancouver from the relevant production points, weighted average transportation distances and transportation energy were estimated.

We assumed the same finished cement percentage breakdown modes as for other structural concrete products, i.e.:

- West Coast region plants serve Vancouver by truck;
- Prairie region plants serve Calgary by truck and Winnipeg by rail;
- Central Region plants serve Toronto by truck if within 200 kilometres or off Lake Ontario and by ship if on Lake Ontario and beyond 200 kilometres;
- Quebec plants serve Montreal 75% by truck and 25% by rail; and
- Nova Scotia plants serve Halifax by truck and Newfoundland plants serve Halifax by ship.

The weighted average transportation distances by mode shown in Table 3.2.1 were then developed using the distances of each plant from the designated cities and assuming an empty backhaul (i.e. the actual distances were doubled in all cases). The empty backhaul assumption is consistent with the fact that most finished cement moves to markets in specialized bulk transporters, with only a relatively small percent bagged before shipment. Our ultimate focus is on cement used to make concrete masonry bricks. Virtually all of that cement moves in bulk form.

TABLE 3.2.1
WEIGHTED AVERAGE TRANSPORTATION DISTANCES AND MODES FOR FINISHED CEMENT (KILOMETRES PER TONNE)

		DISTANCE BY MODE		
REGION		Truck	Rail	Ship
West Coast				
	Vancouver	114.39		
Prairie				
	Calgary	316.46		
	Winnipeg		2620.00	
Central				
	Toronto	97.15		136.35
East				
	Montreal	182.06	60.69	
	Halifax	184.80		303.60

We should make clear that the averages in Table 3.2.1 only reflect where cement is produced and how it is moved. They do not reflect cement consumption levels in any of the cities. This table can be interpreted by thinking in terms of the embodied final transportation mileage in a representative or average tonne of cement landed in any one of the six cities. For example, it says that an average tonne of cement in Montreal embodies 182.06 truck kilometres plus 60.69 rail kilometres of finished product transportation.

Aggregates
As noted earlier, the concrete masonry industry is widely dispersed with a large number of plants in every region. Coarse and fine aggregate sources are also plentiful across the country and most concrete plants can therefore locate relatively close to sources of the two raw materials. Therefore, although we have no hard information about raw material transportation distances and modes, we believe the following assumptions are reasonable.

For coarse aggregates, we have assumed an average haul distance by truck of 10 kilometres for all plants in all regions. For fine aggregates, we have assumed an average of 15 kilometres by truck for all plants in all regions. Doubling these distances to account for empty backhauls results in assumed truck transportation requirements of 20 kilometres for coarse and 30 kilometres for fine aggregates.

References

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6. S.S. Szoke, "Environmental Impact of Concrete Masonry Construction", National Concrete Masonry Association (NCMA), Herndon, VA.
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4.0 ENERGY USE

This section presents our estimates of energy use for the clay, concrete and sand-lime bricks products listed previously. The estimates include energy required to extract, process and transport the raw materials and energy required to manufacture the products.

The boundary for this analysis is the plant gate of the brick production facility. Energy associated with the transportation of finished masonry products from the plant gate to regional centres is being estimated as part of the building construction component of the ATHENA™ Sustainable Materials Project, however this study provides a separate estimate of kilometres by mode of transport to cover the final transportation of products from the plant gate(s) to the regional centres. All estimates are expressed in giga joules per unit of finished product (i.e. GJ per m^3, per tonne or per 1000 bricks of specified size).

4.1. Clay Brick

Energy is consumed in all major steps of the clay brick manufacturing process, in clay winning and transportation, clay preparation, brick forming, drying and firing, and drawing and shipping. Typically, most of the total energy usage at brickworks occurs at the kiln for firing and drying purposes.[11] In Canada, since WWII, the entire brick industry with the exception of plants in Atlantic Canada, built their kilns (and converted the older ones) to natural gas. We assume light oil is being used in the Nova Scotia brickworks. Electricity is used in all the steps of the manufacturing process for fans, conveyers, and more specifically, in the preparation (crushing, milling, and mixing) and forming of the brick. In older operations it used to represent only about 4 to 8% of the total energy consumption.[11-14] With the advent of modern, highly automated plants similar to those used in Canada, however, the electricity consumption is substantially higher. Diesel fuel is the source of energy for the quarrying and hauling of the clay, both in the pit and in the plant.

4.1.1 Clay Winning (Extraction) and Transportation

The results of the Canadian brick producers survey,[10] indicate a diesel fuel consumption of 1.14 litres per tonne of clay that is extracted and handled at the quarry site. Taking the diesel fuel energy content of 38.68 MJ/L (as per Research Guidelines) into consideration, the energy embodied in quarried clay can thus be estimated to be 0.0441 GJ/tonne. Typically, the quarried clay contains about 10 to 18% moisture - let us assume the average of 14%. Therefore, 1.14 tonnes of moist, quarried clay has to be used to produce 1 tonne of finished ware, and on a dry basis **0.0503 GJ/tonne** of brick is used in the clay extraction step.

As noted in Section 3.2.1, it is assumed that raw materials (clay or shale) are trucked an average weighted distance of 9.22 km. As there is no backhaul transportation, this distance is doubled to 18.44 km. Taking the mode of transport (diesel-powered truck at 1.18 MJ/tonne.km energy consumption) into consideration, we estimated the energy embodied in the raw materials transportation from the quarry to the brick operation to be **0.0248 GJ/tonne** of brick.

4.1.2 Clay Brick Processing

Fuel Energy

There are many factors affecting the energy consumption in the clay brick manufacturing process. Kiln fuel usage depends on the firing temperature and heat time cycle, the type and condition of the kiln, its efficiency, mode of operation, type of finished product, and type of and carbon content of the raw materials. That is the reason for the rather wide range of thermal energy consumption given in literature. The "Brick and Tile Making Handbook",[12] for example, cites a range of 1.47 to 3.57 GJ/tonne for total drying and firing energy requirements. It is narrowed down to 1.68 to 2.10 GJ/tonne for common brick and to 2.39 to 2.65 GJ/tonne for engineering or facing brick. For a tunnel kiln, used by all Canadian brick producers, it suggests a specific fuel consumption of 1.30 to 2.52 GJ/tonne. The same source gives a specific heat requirement for drying in a tunnel drier of 3.36 to 4.20 GJ/tonne of evaporated water. Of course, an appropriate linkage between the kiln and the dryer can save 20% to 35% of the gross heat input.

The results of the Canadian brick industry survey[10] indicate an average fuel energy consumption for a typical brickworks plant of **2.559 GJ/tonne** of finished ware. This is an average, representative value provided by the industry, and as such we will use it in further calculations and estimates. At the same time, it should be noted that for a modern, state-of-the-art Canadian plant, fuel consumption as low as 1.768 GJ/tonne of brick is achievable, while some older, smaller operations could have fuel consumption as high as 3.798 GJ/tonne of ware.

We were interested how the above Canadian fuel consumption value of 2.559 GJ/tonne of finished ware compares with other, albeit very limited information in literature. Dr. Frederic of the Ceramic Center of Clemson University[15] offers a figure of 1000 BTU/lb of fired clay for drying and firing in a gas-fired kiln. This translates to 2.652 GJ/tonne of finished ware, when use of 1.14 tonnes of moist clay is considered to be needed for a tonne of finished brick, a number very comparable to that provided by the Canadian industry.

Electrical Power Usage

Electrical power is used mainly in the preparation and forming of green ware, as well as for conveyance of the green brick and kiln cars. Depending on the type of forming process and equipment used, the total electrical energy consumption in brickworks can vary. Some references give a typical range of 0.108 to 0.180 GJ/tonne of bricks.[12] Modern brick plants, however, due to the high degree of automation coupled with the prevalent use of the stiff mud forming process in North America, tend to use substantially more power than older operations.

Typical electrical power consumption offered by the Canadian clay brick manufacturers survey[10] is 1000 kWh/1000 brick. Considering the density of 1436 kg/m^3 for Ontario brick,[16] electrical power consumption due to brick processing of **1.9232 GJ/tonne** of brick can be arrived at. This is somewhat higher than expected, however, it was verified by the industry.

In Plant Energy Use
In addition to the kiln fuel used for drying and firing of brick and the electrical power that is used mainly in brick preparation and forming, some diesel fuel is used for various moving equipment. The survey[10] gives a consumption of 0.71 litres per tonne of brick, which represents about **0.0275 GJ/tonne** energy input.

4.1.3 Detailed Energy Estimates - Clay Brick Production

From the individual energy consumption estimates for the raw materials extraction, their transportation and brick processing obtained in the above sections, the total combined energy embodied in clay brick is presented below by process step and energy form.

TABLE 4.1.1
ENERGY USAGE IN CLAY BRICK PRODUCTION BY PROCESS STEP

	GJ/tonne of finished brick	***GJ/m³ of finished brick***
Raw Materials Extraction	0.0503	0.0722
Raw Materials Transport	0.0248	0.0356
drying / firing	*2.5586*	*3.6741*
preparation / forming / conveyance	*1.9232*	*2.7617*
in plant fuel	*0.0275*	*0.0395*
Brick Processing Subtotal	4.5093	6.4754
TOTAL	4.5844	6.5832

The total energy requirement of 4.5844 GJ/tonne for the Canadian clay brick industry corresponds rather well with the limited data in literature, such as 4.68 GJ/tonne for the production of facing brick in tunnel kilns in Britain, or 4.03 GJ/tonne for the average US building brick, both numbers reported by the comprehensive UK Building Brick Industry energy audit report.[11]

Clay bricks are made in many different sizes and dimensional configurations. The eight typical and most common Canadian bricks, their dimensions, volumes, and number of bricks needed per m^2 of single wythe application are shown in Table 4.1.2. It is assumed that the density of all these bricks is essentially the same, i.e. that the the number of cores and their size varies proportionally with the overall dimensions of the bricks. The embodied energy for all eight types of bricks, expressed per 1000 bricks, is shown in Table 4.1.3.

Finally, in Table 4.1.4, we show energy associated with the clay brick production by energy form. The only difference from our “typical” Canadian brick plants is found in operations in Atlantic Canada. While all other Canadian kilns use natural gas as fuel, the Nova Scotia brickworks use light oil for drying and firing as natural gas is not available there.

TABLE 4.1.2
PARAMETERS OF TYPICAL CANADIAN CLAY BRICKS

	L [mm]	W [mm]	H [mm]	V [m^3]	bricks per m^2
Ontario	213	102	60	0.0013036	64.5
Metric Modular	190	90	57	0.0009747	75.0
CSR	230	90	70	0.0014490	52.0
MAX	257	90	79	0.0018273	42.0
Metric Closure	190	90	90	0.0015390	50.0
Metric Jumbo	290	90	90	0.0023490	33.0
Engineer Norman	290	90	70	0.0018270	42.0
Metric Norman	290	90	57	0.0014877	49.8

TABLE 4.1.3
ENERGY USAGE IN TYPICAL CLAY BRICK PRODUCTS BY PROCESS STEP

	GJ/1000 bricks			
	Ontario	**Metric Modular**	**CSR**	**MAX**
Raw Materials Extraction	0.0942	0.0704	0.1047	0.1320
Raw Materials Transport	0.0464	0.0347	0.0516	0.0651
drying / firing	*4.7895*	*3.5812*	*5.3238*	*6.7137*
preparation / forming / conveyance	*3.6001*	*2.6918*	*4.0017*	*5.0464*
in plant fuel	*0.0515*	*0.0385*	*0.0572*	*0.0722*
Brick Processing Subtotal	8.4410	6.3115	9.3828	11.8322
TOTAL	8.5816	6.4166	9.5391	12.0293
	Metric Closure	**Metric Jumbo**	**Engineer Norman**	**Metric Norman**
Raw Materials Extraction	0.1112	0.1697	0.1320	0.1075
Raw Materials Transport	0.0548	0.0837	0.0651	0.0530
drying / firing	*5.6545*	*8.6306*	*6.7127*	*5.4660*
preparation / forming / conveyance	*4.2503*	*6.4873*	*5.0457*	*4.1086*
in plant fuel	*0.0608*	*0.0928*	*0.0721*	*0.0587*
Brick Processing Subtotal	9.9656	15.2106	11.8305	9.6334
TOTAL	10.1315	15.4639	12.0275	9.7938

TABLE 4.1.4
ENERGY USAGE IN CLAY BRICK PRODUCTION BY ENERGY FORM

	Vancouver, Calgary, Winnipeg, Toronto & Montreal		Halifax	
	GJ/tonne of finished brick	GJ/m^3 of finished brick	GJ/tonne of finished brick	GJ/m^3 of finished brick
nat. gas	2.5586	3.6741	0.0000	0.0000
light oil	0.0000	0.0000	2.5586	3.6741
diesel road	0.1026	0.1473	0.1026	0.1473
electricity	1.9232	2.7617	1.9232	2.7617
TOTAL	4.5844	6.5832	4.5844	6.5832

4.1.4 Finished Clay Brick Transport

The last energy use category covers the transportation of finished brick from brickworks to the market. Again, the survey of the Canadian brick producers[10] provided the basic information about transportation distances, modes and geographical market distribution.

All clay brick products are shipped to the job sites or distribution points by truck, there is no rail or marine transport involved. In Eastern Canada specialized boom trucks are often used, resulting in no backhaul. Truck shipment of clay brick to and around Western Canada is handled by independent haulers, with 90% backhaul.[17]

Based on the information received, we made the following assumption regarding servicing of the six metropolitan areas - Vancouver, Calgary, Winnipeg, Toronto, Montreal and Halifax - from the relevant production operations:

- Vancouver is served 50-50% from Alberta and the USA
- Calgary is served 100% from the plant in Alberta;
- Winnipeg is served 50% from Alberta, 25% from Ontario and 25% from the USA;
- Toronto is served 100% from the Ontario-based plants;
- Montreal is supplied 90% form the local facility, 10% from Ontario; and
- Halifax is supplied 100% from local operations.

Based on the above assumptions, weighted average transportation distances were then developed using the distances of each plant from the designated cities. These were multiplied by appropriate factors to account for backhaul volumes in different geographical areas (Table 4.1.5).

From these distances, using the appropriate mode of transport factor (1.18 MJ/tonne-km for truck transportation), the ATHENA™ computer model calculates the energy consumption associated with the finished ware transportation from the brickworks gate to the market.

TABLE 4.1.5
WEIGHTED AVERAGE TRANSPORTATION DISTANCES FOR FINISHED CLAY BRICK

	Average Distances [km]
Vancouver	1540
Calgary	313
Winnipeg	1329
Toronto	80
Montreal	116
Halifax	74
Truck transport factor [MJ/tonne-km]	1.18

notes: appropriate backhaul factors included in the distances
diesel truck is the only mode of transport used by the industry

4.2. Calcium Silicate Brick

Energy associated with the production of calcium silicate brick comes from three major inputs - production of lime, including limestone extraction and transport, lime manufacturing involving limestone crushing and pyroprocessing, and finally transportation of the finished lime to the user.

4.2.1 Lime Production

There are many similarities between production of cement and lime, however, while cement energy estimates have been available from an earlier Athena study[1], for lime we had to develop such data specifically for this project. To estimate energy use in limestone extraction, we have assumed all energy use is in the form of diesel fuel (road) as specified in the Project Research Guidelines. Further, we have assumed that limestone is extracted from open pit mining and that it takes 0.027 GJ to extract one tonne of limestone.[4] In subsequent calculations, we had to take into account the fact that 1.785 tonnes of limestone is needed to produce one tonne of lime, therefore energy due to the extraction of raw materials (limestone) is 0.04820 GJ/tonne of lime.

In the case of particular lime operations supplying the clacium silicate brick plant under consideration here, limestone processing and lime production is conducted on sites adjacent to the open mining pit, and we assume that limestone is moved from the quarry to the plant by electricity-powered conveyors for an average distance of 1 km:

0.00194 GJ/tonne.km x 1.785 tonne of limestone/tonne of lime = 0.00346 GJ/tonne of lime

In lime processing, limestone is first crushed and reduced to appropriate size, then calcined, most often in rotary kilns, and finished lime crushed and pulverized to the desired fineness. Similarly as in the cement study[1], for primary and secondary limestone crushing as well as for lime crushing and pulverizing, we used energy use factors from the Gardner model.[5]

For the energy consumption associated with the pyro-processing, as a part of Environment Canada's project on Lime Kilns NO_X Control Technologies[8], we had an opportunity to develop a detailed confidential survey of energy usage of Canadian lime producers. Weighted average energy use from this survey of 6.47 GJ/tonne of lime, taking the type of kiln and fuel into consideration, is used here. As for electrical power consumption associated with the kiln operation, an average figure of 0.12078 GJ/tonne of lime was taken.[9]

Finally, energy associated with the finished lime transport from the lime plant to the brick producer was estimated. As noted in Section 3.2.2, it is assumed that lime is trucked, with no backhaul transportation, a distance of 65 km. Taking the mode of transport (diesel-powered truck at 1.18 MJ/tonne.km energy consumption), we estimated the energy embodied in the finished lime transportation to be 0.1534 GJ/tonne of lime.

The above numbers are summarized in Table 4.2.1:

TABLE 4.2.1
LIME PRODUCTION [GJ/TONNE] - ONTARIO

	Raw Materials Extraction	Raw Materials Transport	Production			Finished Lime Transport	Total
			crushing	pyro-processing	total		
diesel road	0.04820				0.00000	0.15340	0.20160
natural gas				6.47000	6.47000		6.47000
electricity		0.00346	0.06863	0.12078	0.18941		0.19288
total	0.04820	0.00346	0.06863	6.59078	6.65941	0.15340	6.86447

4.2.2 Sand Production

The manner in which the energy associated with production of fine aggregate (sand) was developed was described in detail in Section 11.1 of the Cement and Structural Concrete Report[1], and it is further reviewed in this report in Section 4.3.1 on concrete brick aggregate extraction, processing and transportation. For clarity, here (Table 4.2.2) we just summarize the same data.

TABLE 4.2.2
SAND PRODUCTION [GJ/TONNE]

	Extraction	Processing	Transportation	Total
diesel road	0.02700		0.03540	0.06240
electricity		0.03240		0.03240
total	0.02700	0.03240	0.03540	0.09480

4.2.3 Calcium Silicate Brick Processing

There are no energy consumption data regarding the sand-lime brick processing available. However, as the process of sand-lime brick forming, curing and drawing is very similar to that of concrete brick, we feel that the process energy consumption figures developed in the Holderbank report[2] for concrete masonry units and given in the Table 4.2.3 below are applicable here as well.

TABLE 4.2.3
SAND-LIME BRICK PROCESSING [GJ/TONNE]

diesel road	0.12700
natural gas	0.47300
electricity	0.06400
total	0.66400

4.2.4 Detailed Energy Estimates - Sand-Lime Brick Production

Combining the above estimates for energy embodied per tonne of lime and sand, the consumption of these two basic raw materials in the sand-lime brick formula (Table 3.1), and the energy associated with the brick processing itself, average energy use in sand-lime brick production was arrived at. It is summarized in Tables 4.2.4 to 4.2.6 by its main constituents, by raw materials and process stage and energy form, respectively. All data are expressed in three different ways; in GJ per tonne of bricks, in GJ per m^3 of bricks, as well as in GJ per 1000 bricks of the three most common sand-lime brick types CB25, ES26 and VB31.

TABLE 4.2.4
COMMON CANADIAN SAND-LIME BRICKS

Type	Dimensions W x H x L [mm]	Number of units per m^3 of concrete mix
Colonial - CB25	92 x 67 x 324	500
Executive - ES26	89 x 70 x 230	698
Vintage - VB31	89 x 79 x 257	553

Note: All sand lime bricks are :solid”, no “cored” bricks are manufactured

TABLE 4.2.5
AVERAGE ENERGY USE IN SAND-LIME BRICK PRODUCTION
BY MAIN CONSTITUENTS

Design	***tonne of RM /tonne of brick***	***GJ/tonne of brick***	***GJ/m^3***	***GJ/1000 bricks***		
				CB25	***ES26***	***VB31***
Lime	0.06000	0.41187	0.85010	1.69776	1.21810	1.53610
Sand	0.94000	0.08911	0.18393	0.36733	0.26355	0.33235
Water	0.09000	0.00000	0.00000	0.00000	0.00000	0.00000
Sub-Ttl (Material)	1.09000	0.50098	1.03402	2.06509	1.48165	1.86845
Process energy		0.66400	1.37050	2.73707	1.96378	2.47644
Total		***1.16498***	***2.40452***	***4.80215***	***3.44544***	***4.34489***

TABLE 4.2.6
AVERAGE ENERGY USE IN SAND-LIME BRICK PRODUCTION
BY RAW MATERIAL & PROCESS STAGE

	energy source	***GJ/tonne of brick***	***GJ/m^3***	***GJ/1000 bricks***		
				CB25	***ES26***	***VB31***
Lime RM extraction	diesel RD	0.00289	0.00597	0.01192	0.00855	0.01078
Lime RM transport	electricity	0.00021	0.00043	0.00086	0.00061	0.00077
Lime processing	nat. gas	0.38820	0.80124	1.60019	1.14810	1.44782
	electricity	0.01136	0.02346	0.04685	0.03361	0.04239
	subttl	0.39956	0.82470	1.64704	1.18172	1.49021
Lime transport	diesel RD	0.00920	0.01900	0.03794	0.02722	0.03433
Lime ttl		0.41187	0.85010	1.69776	1.21810	1.53610
Sand extraction	diesel RD	0.02538	0.05238	0.10462	0.07506	0.09466
Sand processing	electricity	0.03046	0.06286	0.12554	0.09007	0.11359
Sand transport	diesel RD	0.03328	0.06868	0.13717	0.09841	0.12411
Sand ttl		0.08911	0.18393	0.36733	0.26355	0.33235
Brick processing	diesel RD	0.12700	0.26213	0.52351	0.37560	0.47366
	nat. gas	0.47300	0.97627	1.94975	1.39890	1.76409
	electricity	0.06400	0.13210	0.26381	0.18928	0.23869
	subttl	0.66400	1.37050	2.73707	1.96378	2.47644
RM Extraction subttl		0.02827	0.05835	0.11654	0.08361	0.10544
RM Processing subttl		0.43002	0.88756	1.77258	1.27179	1.60380
RM Transport subttl		0.04269	0.08811	0.17596	0.12625	0.15921
Brick Processing		0.66400	1.37050	2.73707	1.96378	2.47644
Total		***1.16498***	***2.40452***	***4.80215***	***3.44544***	***4.34489***

TABLE 4.2.7
AVERAGE ENERGY USE IN SAND-LIME BRICK PRODUCTION BY ENERGY FORM

Energy Form	GJ/tonne of brick	GJ/m^3	GJ/1000 bricks		
			CB25	ES26	VB31
Natural Gas	0.86120	1.77752	3.54994	2.54700	3.21191
Diesel Road	0.19775	0.40816	0.81515	0.58485	0.73753
Electricity	0.10603	0.21884	0.43706	0.31358	0.39544
	1.16498	**2.40452**	**4.80215**	**3.44544**	**4.34489**

4.2.5 Finished Sand-Lime Brick Transport

The last energy use category covers the transportation of finished sand-lime brick from its manufacturing facility about 80 km west of Toronto to the distribution centres. It is obvious that the bulk of the sand-lime bricks are used in the heavily populated areas of southern and south-western Ontario, nevertheless, according to the manufacturer's information, their bricks are shipped to the distributors and available across the whole country.

As far as the finished product transportation data, mode of transport and average haul distances to Vancouver, Calgary, Winnipeg, Toronto, Montreal and Halifax are concerned, we assumed the following:

- Vancouver, Calgary, Winnipeg and Halifax are all served by independent carriers, by truck; 90% backhaul is assumed,
- Toronto is supplied by truck, mainly by specialized brick loading/unloading vehicles, and therefore only 20% backhaul is involved, and
- Montreal is also served by truck, 50% by the same type of specialized truck, 50% by conventional carriers, resulting in 50% backhaul.

The transportation distances by mode are shown for the six designated cities in Table 4.2.8. The backhaul assumptions are already reflected in the distance figures presented there.

TABLE 4.2.8
TRANSPORTATION DISTANCES BY MODE FOR SAND-LIME BRICK (KM)

	Distances & Transport Mode
	Truck
Vancouver	3915
Calgary	3060
Winnipeg	1865
Toronto	144
Montreal	945
Halifax	1970
Transport factors [MJ/tonne-km]	1.18

note: appropriate backhaul factors included in the distances

4.3. Concrete Brick

4.3.1 Aggregate Extraction, Processing and Transportation

We have assumed the same per tonne energy breakdown for the extraction and processing of raw materials (fine and coarse aggregates) as for other concrete products considered in an earlier ATHENA™ study of cement and structural concrete.[1] As in that study, we also assumed the same per tonne energy breakdown for all regions.

For coarse aggregates, the energy requirements by fuel type for raw material extraction and processing are as follows:

Extraction[4]	Diesel - Road	0.0270 GJ/t
Processing[5]	Electricity	0.0108 GJ/t
Total		0.0378 GJ/t

The same sources provide the following estimates for fine aggregates, assuming fine aggregate production involves quarrying and crushing:

Extraction[4]	Diesel - Road	0.0270 GJ/t
Processing[5]	Electricity	0.0324 GJ/t
Total		0.0594 GJ/t

Using the distance estimates from Section 3.2.3 and the diesel (road) combustion energy factor of 1.18 MJ per tonne-kilometre yields the following estimates of raw material transportation energy.

Coarse Aggregates Transportation	0.0236 GJ/t
Fine Aggregates Transportation	0.0354 GJ/t

Raw materials requirements in kg/m^3, as given in Section 3.1, were multiplied by energy per tonne factor estimates shown above. Following are the basic calculations for estimating energy use by activity stage.

Aggregates Extraction and Processing

Raw Material	kg/m^3 of concrete	x	GJ/1000 kg	=	GJ/m^3 of concrete
Coarse Aggregate	583		0.0378		0.02204
Fine Aggregate	1361		0.0594		0.08084
			Total		0.10288

Aggregates Transportation

Raw Material	kg/m^3 of concrete	x	GJ/1000 kg	=	GJ/m^3 of concrete
Coarse Aggregate	583		0.0236		0.01376
Fine Aggregate	1361		0.0354		0.04818
			Total		0.06194

4.3.2 Cement Manufacturing and Transportation

Weighted average energy embodied in a tonne of finished cement production by region, by process stage and energy form, was obtained from the ATHENA™ Cement and Concrete study[1] (Section 4.4), and the relevant tables 4.3.1 and 4.3.2 are shown here only for completion and transparency.

TABLE 4.3.1
WEIGHTED AVERAGE ENERGY USE IN CEMENT PRODUCTION BY PROCESS STAGE (GJ/TONNE OF FINISHED CEMENT)

	PROCESS STAGE				
REGION	Raw Material Extraction	Raw Material Transportation	Manufacturing	Cement Transportation	TOTAL
West Coast					
Vancouver	0.04464	0.09041	4.68889	0.13498	4.95892
Prairie					
Calgary	0.04455	0.22543	4.30586	0.37342	4.94926
Winnipeg	0.04455	0.22543	4.30586	1.28380	5.85964
Central					
Toronto	0.04451	0.06829	4.44557	0.13100	4.68937
East					
Montreal	0.04417	0.02365	5.52673	0.24457	5.83912
Halifax	0.04417	0.02365	5.52673	0.25449	5.84904

TABLE 4.3.2
WEIGHTED AVERAGE ENERGY USE IN CEMENT PRODUCTION BY ENERGY FORM
(GJ/TONNE OF FINISHED CEMENT)

	ENERGY FORM									
REGION	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	**TOTAL**
West Coast										
Vancouver	0.187	0.001	0.082	2.303	1.463	0.155	0.196	0.00	0.571	4.959
Prairie										
Calgary	0.454	0.188	0.00	3.666	0.00	0.00	0.00	0.00	0.640	4.949
Winnipeg	0.081	1.472	0.00	3.666	0.00	0.00	0.00	0.00	0.640	5.860
Central										
Toronto	0.188	0.006	0.048	0.582	2.269	0.081	0.631	0.266	0.619	4.689
East										
Montreal	0.274	0.030	0.008	0.774	1.663	0.848	1.187	0.469	0.586	5.839
Halifax	0.277	0.00	0.044	0.774	1.663	0.848	1.187	0.469	0.586	5.849

Note: Totals may not add due to rounding.

As was done for other concrete products reported in the cement and concrete study[1], the cement energy is included at the manufacturing stage.

As was the case for the aggregates in Section 4.3.1, cement requirements in kg/m^3 of concrete mix, as given in Section 3.1, were multiplied by energy per tonne factor estimates given above.

4.3.3 Concrete Brick Processing

In the estimate of the manufacturing energy requirements per tonne of concrete masonry mix, data from the Holderbank study were used.[2]

	GJ/t
Electricity	0.0640
Natural Gas	0.4730
Diesel Fuel	0.1270
Total	0.6640

Since we assume the same manufacturing energy estimates for all six cities, this introduces a slight error in our estimates of energy use by fuel type for Halifax where natural gas is not available. As a consequence, our later estimates of atmospheric emissions for Halifax are slightly understated.

4.3.4 Detailed Energy Estimates - Concrete Brick Production

From the above data for energy required per tonne of cement and aggregates production and the raw materials average use in generic concrete brick formula (Table 3.1), as well as energy associated with concrete brick processing, energy embodied in 1 m^3 of concrete brick, both by process stage and fuel type, was derived (Tables 4.3.3 and 4.3.4).

TABLE 4.3.3
ENERGY USE IN CONCRETE MASONRY BRICK PRODUCTION BY PROCESS STAGE (GJ/M^3)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Aggregate Extraction & Processing	0.10288	0.10288	0.10288	0.10288	0.10288	0.10288
Aggregate Transport	0.06194	0.06194	0.06194	0.06194	0.06194	0.06194
Manufacturing						
Cement Manufacturing	1.07609	1.07395	1.27160	1.01755	1.26719	1.26929
Concrete Processing	1.48072	1.48072	1.48072	1.48072	1.48072	1.48072
Subtotal Manufacturing	2.55681	2.55467	2.75232	2.49827	2.74791	2.75001
TOTAL	**2.72163**	**2.71949**	**2.91714**	**2.66308**	**2.91273**	**2.91483**

TABLE 4.3.4
ENERGY USE IN CONCRETE BLOCK PRODUCTION BY FUEL TYPE (GJ/M^3)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Natural Gas	1.55450	1.85042	1.85042	1.18107	1.22282	1.22282
Coal	0.31754	0.00000	0.00000	0.49231	0.36087	0.36087
Oil	0.03374	0.00000	0.00000	0.01758	0.18402	0.18402
Coke	0.04260	0.00000	0.00000	0.13684	0.25758	0.25758
Waste	0.00000	0.00000	0.00000	0.05778	0.10183	0.10183
Diesel Road	0.43822	0.49615	0.41521	0.43843	0.45709	0.45775
Diesel Rail	0.00012	0.04090	0.31948	0.00121	0.00645	0.00000
H.F.Oil	0.01780	0.00000	0.00000	0.01041	0.00172	0.00963
Electricity	0.31713	0.33203	0.33203	0.32745	0.32033	0.32033
TOTAL	**2.72163**	**2.71949**	**2.91714**	**2.66308**	**2.91273**	**2.91483**

CSA standard A165.2-94 for Concrete Brick Masonry Units[3] gives dimensions for two types of standard Canadian modular units of 100x67x200 mm and 100x100x200 mm. Both of these standard units can be produced either as solid (non-cored) or cored units, where the net volume of cores cannot be more than 15% of the gross volume of the unit. Thus we have derived energy consumption for four types of standard Canadian concrete bricks called here A1, A2, B1 and B2 (Table 4.3.5), by dividing the GJ/m^3 energy estimates in Tables 4.3.3 and 4.3.4 by the appropriate number of bricks produced from 1 m^3 of concrete mix.

TABLE 4.3.5
CANADIAN CONCRETE BRICK MASONRY UNITS
(CSA A165.2-94)

Type	Modular dimensions W x H x L [mm]	Basic or manufactured dimensions W x H x L [mm]	Solid [S] or Cored [C]	Number of units per m^3 of concrete mix
A1	100 x 67 x 200	90 x 57 x 190	S	1026
A2	100 x 67 x 200	90 x 57 x 190	C	1180
B1	100 x 100 x 200	90 x 90 x 190	S	650
B2	100 x 100 x 200	90 x 90 x 190	C	747

Energy consumption associated with the production of standard Canadian concrete bricks and expressed per 1000 of A1, A2, B1 and B2 bricks, by both the process stage and by the fuel type, is shown in Tables 4.3.6 to 4.3.13.

TABLE 4.3.6
ENERGY USE IN CONCRETE A1 (100 X 67 X 200 MM SOLID)
MASONRY BRICK PRODUCTION BY PROCESS STAGE (GJ/1000 BRICKS)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Aggregate Extraction & Processing	0.10027	0.10027	0.10027	0.10027	0.10027	0.10027
Aggregate Transport	0.06037	0.06037	0.06037	0.06037	0.06037	0.06037
Manufacturing						
Cement Manufacturing	1.04882	1.04674	1.23937	0.99176	1.23507	1.23712
Concrete Processing	1.44320	1.44320	1.44320	1.44320	1.44320	1.44320
Subtotal Manufacturing	2.49202	2.48994	2.68257	2.43496	2.67827	2.68032
TOTAL	**2.65266**	**2.65058**	**2.84321**	**2.59560**	**2.83891**	**2.84096**

TABLE 4.3.7
ENERGY USE IN CONCRETE A1 (100 X 67 X 200 MM SOLID)
MASONRY BRICK PRODUCTION BY FUEL TYPE (GJ/1000 BRICKS)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Natural Gas	1.51511	1.80352	1.80352	1.15114	1.19184	1.19184
Coal	0.30949	0.00000	0.00000	0.47983	0.35173	0.35173
Oil	0.03288	0.00000	0.00000	0.01713	0.17935	0.17935
Coke	0.04152	0.00000	0.00000	0.13337	0.25105	0.25105
Waste	0.00000	0.00000	0.00000	0.05631	0.09925	0.09925
Diesel Road	0.42711	0.48358	0.40469	0.42732	0.44551	0.44615
Diesel Rail	0.00012	0.03986	0.31138	0.00118	0.00629	0.00000
H.F.Oil	0.01735	0.00000	0.00000	0.01015	0.00168	0.00938
Electricity	0.30909	0.32361	0.32361	0.31916	0.31221	0.31221
TOTAL	**2.65266**	**2.65058**	**2.84321**	**2.59560**	**2.83891**	**2.84096**

TABLE 4.3.8
ENERGY USE IN CONCRETE A2 (100 X 67 X 200 MM CORED)
MASONRY BRICK PRODUCTION BY PROCESS STAGE (GJ/1000 BRICKS)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Aggregate Extraction & Processing	0.08719	0.08719	0.08719	0.08719	0.08719	0.08719
Aggregate Transport	0.05249	0.05249	0.05249	0.05249	0.05249	0.05249
Manufacturing						
Cement Manufacturing	0.91194	0.91013	1.07763	0.86233	1.07389	1.07567
Concrete Processing	1.25485	1.25485	1.25485	1.25485	1.25485	1.25485
Subtotal Manufacturing	2.16679	2.16498	2.33247	2.11717	2.32873	2.33052
TOTAL	**2.30646**	**2.30466**	**2.47215**	**2.25685**	**2.46841**	**2.47019**

TABLE 4.3.9
ENERGY USE IN CONCRETE A2 (100 X 67 X 200 MM CORED)
MASONRY BRICK PRODUCTION BY FUEL TYPE (GJ/1000 BRICKS)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Natural Gas	1.31737	1.56815	1.56815	1.00091	1.03629	1.03629
Coal	0.26910	0.00000	0.00000	0.41721	0.30582	0.30582
Oil	0.02859	0.00000	0.00000	0.01490	0.15595	0.15595
Coke	0.03610	0.00000	0.00000	0.11597	0.21829	0.21829
Waste	0.00000	0.00000	0.00000	0.04896	0.08630	0.08630
Diesel Road	0.37137	0.42047	0.35188	0.37155	0.38737	0.38792
Diesel Rail	0.00010	0.03466	0.27075	0.00102	0.00547	0.00000
H.F.Oil	0.01508	0.00000	0.00000	0.00883	0.00146	0.00816
Electricity	0.26875	0.28138	0.28138	0.27750	0.27146	0.27146
TOTAL	**2.30646**	**2.30466**	**2.47215**	**2.25685**	**2.46841**	**2.47019**

TABLE 4.3.10
ENERGY USE IN CONCRETE B1 (100 X 100 X 200 MM SOLID)
MASONRY BRICK PRODUCTION BY PROCESS STAGE (GJ/1000 BRICKS)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Aggregate Extraction & Processing	0.15828	0.15828	0.15828	0.15828	0.15828	0.15828
Aggregate Transport	0.09529	0.09529	0.09529	0.09529	0.09529	0.09529
Manufacturing						
Cement Manufacturing	1.65552	1.65224	1.95630	1.56545	1.94952	1.95275
Concrete Processing	2.27803	2.27803	2.27803	2.27803	2.27803	2.27803
Subtotal Manufacturing	3.93355	3.93027	4.23434	3.84348	4.22755	4.23078
TOTAL	**4.18712**	**4.18384**	**4.48790**	**4.09705**	**4.48112**	**4.48435**

TABLE 4.3.11
ENERGY USE IN CONCRETE B1 (100 X 100 X 200 MM SOLID)
MASONRY BRICK PRODUCTION BY FUEL TYPE (GJ/1000 BRICKS)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Natural Gas	2.39154	2.84679	2.84679	1.81703	1.88127	1.88127
Coal	0.48852	0.00000	0.00000	0.75740	0.55519	0.55519
Oil	0.05190	0.00000	0.00000	0.02705	0.28310	0.28310
Coke	0.06554	0.00000	0.00000	0.21052	0.39628	0.39628
Waste	0.00000	0.00000	0.00000	0.08889	0.15667	0.15667
Diesel Road	0.67418	0.76331	0.63879	0.67451	0.70322	0.70422
Diesel Rail	0.00018	0.06292	0.49151	0.00186	0.00993	0.00000
H.F.Oil	0.02738	0.00000	0.00000	0.01602	0.00265	0.01481
Electricity	0.48789	0.51081	0.51081	0.50377	0.49281	0.49281
TOTAL	**4.18712**	**4.18384**	**4.48790**	**4.09705**	**4.48112**	**4.48435**

TABLE 4.3.12
ENERGY USE IN CONCRETE B2 (100 X 100 X 200 MM CORED)
MASONRY BRICK PRODUCTION BY PROCESS STAGE (GJ/1000 BRICKS)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Aggregate Extraction & Processing	0.13773	0.13773	0.13773	0.13773	0.13773	0.13773
Aggregate Transport	0.08292	0.08292	0.08292	0.08292	0.08292	0.08292
Manufacturing						
Cement Manufacturing	1.44055	1.43769	1.70227	1.36218	1.69637	1.69918
Concrete Processing	1.98222	1.98222	1.98222	1.98222	1.98222	1.98222
Subtotal Manufacturing	3.42277	3.41991	3.68450	3.34440	3.67859	3.68140
TOTAL	**3.64341**	**3.64055**	**3.90514**	**3.56504**	**3.89923**	**3.90205**

TABLE 4.3.13
ENERGY USE IN CONCRETE B2 (100 X 100 X 200 MM CORED)
MASONRY BRICK PRODUCTION BY FUEL TYPE (GJ/1000 BRICKS)

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Natural Gas	2.08099	2.47713	2.47713	1.58109	1.63698	1.63698
Coal	0.42508	0.00000	0.00000	0.65905	0.48309	0.48309
Oil	0.04516	0.00000	0.00000	0.02353	0.24634	0.24634
Coke	0.05703	0.00000	0.00000	0.18319	0.34482	0.34482
Waste	0.00000	0.00000	0.00000	0.07735	0.13632	0.13632
Diesel Road	0.58663	0.66420	0.55584	0.58692	0.61191	0.61278
Diesel Rail	0.00016	0.05475	0.42768	0.00162	0.00864	0.00000
H.F.Oil	0.02382	0.00000	0.00000	0.01394	0.00231	0.01289
Electricity	0.42453	0.44448	0.44448	0.43836	0.42882	0.42882
TOTAL	**3.64341**	**3.64055**	**3.90514**	**3.56504**	**3.89923**	**3.90205**

4.3.5 Finished Concrete Brick Transport

There are a large number of concrete production facilities spread across Canada. While the ready mixed concrete represents the largest segment of the concrete industry, concrete masonry and precast/prestressed concrete products are the second largest consumer of cement.[2] These operations are usually close to the metropolitan areas, where the bulk of their products are used in construction.

Even when no detailed information is available concerning the modes of transport, based on our experience we believe that it is largely correct to make an assumption that in all six cities under consideration - Vancouver, Calgary, Winnipeg, Toronto, Montreal and Halifax - concrete brick is made locally and delivered by truck from a distance of not more than 50 km. Further, we assume that 50% of the concrete brick is delivered by specialized brick loading/unloading trucks with no backhaul, the other 50% by the regular carriers with 20% backhaul, resulting in an average backhaul of 10%.

This low backhaul number results in adjusted shipping distance for concrete brick, all by truck, of 95 kilometres.

4.4 CEMENT MORTAR

The full set of energy estimates for cement mortar is included in this report for completeness, as are associated emissions and other unit factors, even though cement mortar is typically made from the raw materials at a construction site and should therefore logically be treated as a construction stage activity. Detailed discussion of how these estimates were developed is contained in Section 11.4 of the Cement and Structural Concrete Report.[1]

Following are the calculations for energy to produce cement mortar, by activity stage.

4.4.1 Aggregate Extraction, Processing and Transportation

Raw Material Extraction & Processing	***kg/m^3 of mortar***	***x***	***GJ/1000 kg***	***=***	***GJ/m^3 of mortar***
Fine Aggregate	785		0.0594		0.04663

Raw Material Transportation	***kg/m^3 of mortar***	***x***	***GJ/1000 kg***	***=***	***GJ/m^3 of mortar***
Fine Aggregate	785		0.0354		0.02779

4.4.2 Cement Production and Transportation

Weighted average energy embodied in a tonne of finished cement production by region, by process stage and energy form, was obtained from the ATHENA™ Cement and Concrete study[1] (Section 4.4). In this study, the appropriate tables are shown in the Concrete Brick energy section, in Tables 4.3.1 and 4.3.2.

4.4.3 Cement Mortar Processing (Mixing)

The manufacturing stage simply involves mixing the fine aggregate, cement and water. We have assumed a 3 cubic foot (0.085 m^3) mixer driven by a 3/4 HP electric motor, with a mix time of 10 minutes.[6] The following calculations yield the estimate of total electrical energy use per m^3 of mortar.[7]

3/4 HP = 560 W
0.560 kWh x 3.6 MJ/kWh = 2.016 MJ
= 0.336 MJ/mix
= 3.95 MJ/m^3

4.4.4 Cement Mortar - Energy Consumption Summary

Tables 4.4.1 and 4.4.2 show the cement mortar energy requirements by activity stage and by fuel type, with cement included at the manufacturing stage.

TABLE 4.4.1
ENERGY USE IN CEMENT MORTAR PRODUCTION BY PROCESS STAGE
(GJ/M³)

	PROCESS STAGE					
	Raw Material	Raw Material	Manufacturing			
REGION	Extraction	Transport	Cement	Processing	Sub-Total	TOTAL
West Coast						
Vancouver	0.04663	0.02779	1.52239	0.00395	1.52634	**1.60076**
Prairie						
Calgary	0.04663	0.02779	1.51937	0.00395	1.52332	**1.59774**
Winnipeg	0.04663	0.02779	1.79899	0.00395	1.80294	**1.87736**
Central						
Toronto	0.04663	0.02779	1.43957	0.00395	1.44352	**1.51794**
East						
Montreal	0.04663	0.02779	1.79275	0.00395	1.79670	**1.87112**
Halifax	0.04663	0.02779	1.79572	0.00395	1.79967	**1.87409**

Note: The raw material is fine aggregate; extraction includes processing.

TABLE 4.4.2
ENERGY USE IN CEMENT MORTAR PRODUCTION BY FUEL TYPE
(GJ/M^3)

REGION	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	TOTAL
West Coast										
Vancouver	0.1064	0.0002	0.0252	0.7070	0.4492	0.0477	0.0603	0.0000	0.2048	***1.6008***
Prairie										
Calgary	0.1884	0.0579	0.0000	1.1256	0.0000	0.0000	0.0000	0.0000	0.2259	***1.5977***
Winnipeg	0.0739	0.4520	0.0000	1.1256	0.0000	0.0000	0.0000	0.0000	0.2259	***1.8774***
Central										
Toronto	0.1067	0.0017	0.0147	0.1787	0.6965	0.0249	0.1936	0.0817	0.2194	***1.5179***
East										
Montreal	0.1331	0.0091	0.0024	0.2377	0.5105	0.2603	0.3644	0.1441	0.2094	***1.8711***
Halifax	0.1340	0.0000	0.0136	0.2377	0.5105	0.2603	0.3644	0.1441	0.2094	***1.8741***

Note: Totals may not add due to rounding.

The standard cement mortar bed is about 10 mm (3/8") thick. The volume of cement mortar needed for an application of 1000 bricks in a single wythe can be easily estimated. For example, for 1000 “A” type (100 x 67 x 200 mm) concrete masonry bricks, assuming 20% mortar waste:

1000 x (100x200 + 100x67) x 10 mm x 1.2 / 10^9 = **0.3204 m^3/1000 of “A” bricks**

Similarly mortar needs can be calculated for “B” type (100 X 100 x 200 mm) concrete masonry bricks, as well as for double wythe applications:

TABLE 4.4.3
CEMENT MORTAR USE BY TYPE OF CONCRETE MASONRY BRICK AND SINGLE / DOUBLE WYTHE APPLICATION [M^3/1000 BRICKS]

Brick	Mortar Volume Single wythe	Mortar Volume Double wythe
“A” brick	0.3204	0.4008
“B” brick	0.3600	0.4800

For sand-lime and clay bricks of the most standard and common sizes, similar calculations can be made:

TABLE 4.4.4
CEMENT MORTAR USE BY TYPE OF SAND-LIME BRICK AND SINGLE / DOUBLE WYTHE APPLICATION [M^3/1000 BRICKS]

Brick	Mortar Volume	
	Single wythe	Double wythe
"CB25" brick	0.5031	0.6574
"ES26" brick	0.3802	0.4954
"VB31" brick	0.4229	0.5655

TABLE 4.4.5
CEMENT MORTAR USE BY TYPE OF CLAY BRICK AND SINGLE / DOUBLE WYTHE APPLICATION [M^3/1000 BRICKS]

Brick	Mortar Volume	
	Single wythe	Double wythe
Ontario	0.3938	0.4875
Metric Modular	0.3204	0.4008
CSR	0.3840	0.4992
MAX	0.4272	0.5698
Metric Closure	0.3600	0.4800
Metric Jumbo	0.4800	0.6600
Engineer Norman	0.4560	0.6000
Metric Norman	0.4404	0.5610

These volume factors from Tables 4.4.3 to 4.4.5 can be used to estimate the embodied energy in GJ/1000 concrete masonry, sand-lime or clay bricks by multiplying energy used in the cement mortar production in GJ/m^3 from Tables 4.4.1 and 4.4.2 above. (It should be noted that sand-lime and clay brick is seldom built as a double wythe wall in Canada. If a solid masonry wall is to be built, then the back-up would be most probably concrete block.)

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5.0 ATMOSPHERIC EMISSIONS

This section addresses atmospheric emissions associated with the production of clay, sand-lime and concrete bricks, as well as for the cement mortar, in all their processing stages, from the extraction and transportation of raw materials through manufacturing.

Like any energy-burning production process, brick masonry production, regardless of the type or method of production of its constituent raw materials, generates common air pollutants including carbon dioxide (CO_2), sulfur oxides (SO_x) — primarily sulfur dioxide (SO_2) — nitrogen oxides (NO_x), volatile organic compounds (VOC), methane (CH_4), and carbon monoxide (CO) as well as total particulate matter (TPM). These energy-related emissions are termed “fuel emissions”.

A specific issue concerning the clay brick industry is the fact that during the clay brick firing, because of the presence of slight amounts of fluorine (0.01 to 0.1%)[11] and chlorine impurities in clay, hydrogen fluoride and hydrochloric acid gases are released and emitted into the atmosphere with the waste gases. This phenomena is discussed in more detail in Section 5.2.

On the other hand, the specific characteristics of cements, the basic raw materials of concrete masonry bricks and of cement mortar, and the nature of high temperature cement manufacturing, result in additional process emission. There is a significant “calcination CO_2” release due to the decomposition of limestone in the manufacturing of cement, as well as “thermal” and “prompt” NO_x, usually outweighing the “fuel” NO_x. These aspects were discussed in detail in the ATHENA™ cement and concrete study.[1] Similarly lime production, used in manufacturing of calcium silicate bricks, releases additional calcination CO_2 and thermal NO_x, as discussed in Section 5.3.

As in the energy section of the report, all results are presented in terms of weighted averages.

5.1 APPROACH

For the concrete masonry units, lime-silica bricks and cement mortar, with the exception of those related to electricity, energy-related atmospheric emission estimates were developed using the energy estimates by process stage from Section 4 and energy emission factors as given in the *Research Guidelines*. Where some values were missing in the *Research Guidelines*, the original sources were consulted.[2] Energy emission factors used throughout this work are summarized in Table 5.1.1.

For the clay brick, we departed from the above approach, as a fairly comprehensive set of actual, measured emissions was recently compiled from a number of trials and tests at a variety of brickworks in the USA by Midwest Research Institute[9] for the U.S. EPA in anticipation of bringing the relevant section of AP-42 on “Brick and Structural Clay Manufacturing”[10] up-to-date. As the clay brick processing in Canada and the U.S.A. is essentially the same (stiff mud extrusion forming and tunnel kiln firing), and because we could use actual data as opposed to calculated estimates, we felt that this method provides better, more accurate information.

Emissions related to the generation and use of electricity in the production of any and all of the brick products are not included in the tables that follow in this section. These emissions are calculated separately within the ATHENA™ Model for all of the products under consideration. The estimates of electricity use in brick and mortar production presented in this report will be translated in the model into the mix of primary energy forms used to generate the electricity for the relevant regional electrical systems. Corresponding atmospheric emissions will then be added to the other emissions estimated in this study.

TABLE 5.1.1
ENERGY EMISSION FACTORS (KG/GJ)

	CO_2	SO_2	NO_x	VOC	CH_4	CO
Natural gas	49.700	0.0002	0.0590	0.00120	0.00130	0.01500
Diesel road	70.700	0.1020	0.8070	0.08690	0.02170	0.44300
Diesel rail	70.700	0.1020	1.4000	0.07000	0.00780	0.05700
H.F. oil marine	74.000	0.4500	0.2000	0.36000	0.04000	0.00740
H.F. oil industr.	74.000	0.8375	0.1600	0.00290	0.00082	0.01440
L.F.oil	73.100	0.1228	0.0620	0.00060	0.00016	0.01550
Coal - W. Coast	94.300	0.4400	0.2500	0.00150	0.00054	0.09300
Coal - Prairie	94.300	0.4400	0.2500	0.00150	0.00054	0.09300
Coal - Central	87.600	0.8360	0.2500	0.00150	0.00054	0.09300
Coal - East	85.333	1.7278	0.2500	0.00150	0.00054	0.09300
Coke	86.000	1.1500	0.2400	0.00140	0.00051	0.08800
Waste	67.500	-	0.1200	0.00120	0.00110	-
Electricity	-	-	-	-	-	-

5.2 Clay Brick

Apart from the usual emissions found in most of the manufacturing processes (CO_2, SO_2, NO_x, VOC, CH_4, CO and particulates), the clay brick manufacturing process also releases small amounts of fluorides, which are considered to be harmful pollutants. Factors that may affect emissions include raw material composition and moisture content, kiln fuel type, kiln operating parameters, and plant design.[9]

The primary sources of PM emissions are the raw materials winning (extraction), grinding and screening, and the kiln operation. Other sources of PM emissions include sawdust dryers used by plants with sawdust-fired kilns, and coal crushing systems used by plants with coal-fired kilns. Both of these latter types are used in the U.S.A., but not in Canada.

Combustion by-products are emitted from kiln fuel combustion. Facilities using fuels with higher sulfur content, such as the east coast plants that use light fuel oil as its principal fuel instead of natural gas, have higher SO_2 emissions. Brick dryers heated with waste heat from the cooling section of the kiln are not usually a source of combustion products, unless supplementary sources of heat are used, because kilns are designed to prevent the kiln gases from entering the cooling section of the kiln.

Organic compounds, including methane and VOCs, are emitted from both brick dryers and kilns. Such emissions from brick dryers are primarily a result of volatilization of the lubricating oil that is typically applied to the formed material during extrusion. It may also result from volatilization of organic matter in the raw material. Further organic emissions from the raw materials and from the kiln fuel are released during kiln firing.[9]

Hydrogen fluoride and other fluoride compounds are emitted from the kilns as a result of the release of the fluorine impurities contained in the raw materials. Fluorine is present in clays and shales in the range of 0.01 to 0.1%. As the green bricks reach temperatures of 500 to 600°C, the fluorine in the raw materials forms hydrogen fluoride (HF) and other fluorine compounds. Much of the fluorine is released as HF. Because fluorine content in clays and shales is highly variable, emissions of HF and other fluoride compounds vary considerably depending on the raw materials used.[9]

Fluorine pollution can be harmful to vegetation. The extent of the hazards depends on the F^- concentration of the waste gases, but also on other factors, such as the plant species, their health, the water economy of the soil, the depth of the plant roots, the direction of the wind and inclement weather conditions. The critical threshold for animals and human beings is well over the concentrations occurring in the environment of brick plants.[11] The clay brick industry has recognized the environmental concerns regarding the HF pollution, and is addressing these.[11,12] Changes in firing, additives to the clay, or ultimately flue gas cleaning are all considered as possible solutions. Control efficiencies of 95% or higher have been reported at one plant using dry scrubbers with limestone as a sorption medium to control HF emissions.[10]

5.2.1 Clay Winning (Extraction) and Transportation

Table 5.2.1 summarizes atmospheric emissions due to winning clay and shales in the open pits and their transportation to the manufacturing plants . They were obtained by multiplying the energy associated with the extraction and transportation of the raw materials from Table 4.1.1 by appropriate energy emission factors for diesel road fuel from Table 5.1.1. For example, CO_2 emissions for the raw material extraction was arrived at by multiplying the extraction energy content of 0.0503 GJ/tonne of the finished product by the 70.7 kg/GJ emission factor to obtain 3.556 kg CO_2 emissions per tonne of finished brick.

For the particulate emissions associated with mining and rock quarrying in an open pit, an emission factor of 0.51 kg/tonne is normally used,[3] however, as the quarried clay contains usually between 12 and 18% moisture, the resulting dusting due to its mining is substantially suppressed. It has been estimated that wetting of the rock, gravel or sand reduces particulate emissions by 70 to 95%.[13] For the purpose of this study, we selected an 80% wet suppression. The particulate matter emissions (PM) were then estimated as 1.14 tonnes of clay (required to produce 1 tonne of finished brick) multiplied by a 0.51 kg/tonne emission factor multiplied by a 0.2 wet suppression factor.

TABLE 5.2.1
ATMOSPHERIC EMISSIONS DUE TO EXTRACTION AND TRANSPORTATION OF RAW MATERIALS

		raw materials extraction	raw materials transport
CO_2	kg/tonne	3.556	1.753
SO_2	g/tonne	5.131	2.530
NO_x	g/tonne	40.592	20.014
CH_4	g/tonne	1.092	0.538
VOC	g/tonne	4.371	2.155
CO	g/tonne	22.283	10.986
PM	g/tonne	116.280	-

5.2.2 Processing

It has been noted in the introduction to this section that in developing the atmospheric emissions for the clay brick manufacturing we utilized the compilation of measured emissions from a recent MRI report[9] prepared for the U.S. EPA, provided to us by the courtesy of the Brick Institute of America.

MRI developed emission factors for brick manufacturing operations (grinding rooms, brick dryers and natural gas-, coal-, and sawdust-fired kilns) using data from 22 test reports and 1 summary report. The MRI data, and additional information from the 1986 AP-42 section[10] were reviewed for validity of test methodologies used. The specific data sets are discussed in detail and summarized in the MRI report. We have selected the appropriate emission factors for the operations using natural gas-fired kilns, as those represent 90 – 95% of the Canadian facilities.

The MRI report differentiates between various categories of particulate matter, between PM and respirable PM-10, as well as between filterable and condensible inorganic and organic PM. For a completeness we show all the respective fractions, as well as the total PM and PM-10. As far as the organic emissions are concerned, MRI reports total organic compounds (TOCs) emissions (as propane) and separately methane/ethane emissions. The VOCs are obtained as a difference between TOCs and CH_4 emissions.

The factors for arsenic, antimony, beryllium, cadmium, chromium, cobalt, lead, mercury, manganese, nickel, phosphorus, and selenium emissions as well as for speciated volatile and semivolatile compounds from brick kilns were also developed in the MRI study. They are too small to be significant, and we are not showing them in our report.

TABLE 5.2.2
PROCESSING ATMOSPHERIC EMISSIONS — CLAY BRICK (NATURAL GAS-FIRED KILN) BY PROCESS STEP

		grinding room	kiln	dryer	in-plant fuel use	subtotal processing
CO_2	kg/tonne		225.000		1.944	226.944
SO_2	g/tonne		250.000		2.805	252.805
NO_x	g/tonne		205.000		22.193	227.193
TOC	g/tonne		35.000	42.500		77.500
CH_4	g/tonne		20.500	14.000	0.597	35.097
VOC	g/tonne		14.500	28.500	2.390	45.390
CO	g/tonne		700.000		12.183	712.183
Filterable PM	*g/tonne*	*14.250*	*140.000*			154.250
Filterable PM-10	*g/tonne*	*1.311*	*105.000*			106.311
Condensible Inorganic PM	*g/tonne*		*265.000*			265.000
Condensible Organic PM	*g/tonne*		*55.000*			55.000
total PM	g/tonne	14.250	460.000			474.250
total PM-10	g/tonne	1.311	425.000			426.311
HF	g/tonne		190.000			190.000
HCl	g/tonne		105.000			105.000

Interestingly, the MRI study addresses only natural gas-, coal-, and sawdust-fired kilns. While this also covers the overwhelming majority of Canadian operations, no numbers are presented for oil-fired kiln used in Atlantic Canada. (According to BIA[14], in 1994 oil was the primary fuel in only 7.8% of the U.S. operations. For Canada, this number is, probably, even lower.) To estimate the emissions from the oil-fired kilns, we have multiplied the natural gas-fired kiln processing emissions from Table 5.2.2 by the ratio of light oil emission factors / natural gas emission factors from Table 5.1.1. The major difference between the oil-and natural gas-fired kilns is in the SO_2 emissions. While for the gas-fired kilns these are measured in g/tonne, for the oil-fired ones they are shown in kg/tonne.

TABLE 5.2.3
PROCESSING ATMOSPHERIC EMISSIONS — CLAY BRICK
(LIGHT OIL-FIRED KILN) BY PROCESS STEP

		grinding room	kiln	dryer	in-plant fuel use	subtotal processing
CO_2	kg/tonne		330.936		1.944	332.880
SO_2	kg/tonne		153.502		0.003	153.505
NO_x	g/tonne		215.424		22.193	237.616
TOC	g/tonne		35.000	42.500		77.500
CH_4	g/tonne		2.523	14.000	0.597	17.120
VOC	g/tonne		7.250	28.500	2.390	38.140
CO	g/tonne		723.333		12.183	735.516
Filterable PM	*g/tonne*	*14.250*	*140.000*			*154.250*
Filterable PM-10	*g/tonne*	*1.311*	*105.000*			*106.311*
Condensible Inorganic PM	*g/tonne*		*265.000*			*265.000*
Condensible Organic PM	*g/tonne*		*55.000*			*55.000*
total PM	g/tonne	14.250	460.000			474.250
total PM-10	g/tonne	1.311	425.000			426.311
HF	g/tonne		190.000			190.000
HCl	g/tonne		105.000			105.000

5.2.3 Summary of Atmospheric Emissions for Clay Brick

The emissions developed for clay brick raw materials extraction, their transportation to the brickworks, and processing into the finished product, are summarized in Tables 5.2.4 and 5.2.5. Results are shown per tonne of finished ware. In Table 5.2.6 the clay brick emissions are expresed in kilograms or grams (as appropriate) per m^3 of finished bricks.

Since the masonry trade is often dealing in units of 1000 bricks, in Tables 5.2.7 – 5.2.14 the atmospheric emissions associated with the production of clay bricks are shown per 1000 units of eight popular Canadian bricks, as shown in Table 4.1.2.

TABLE 5.2.4
PROCESSING EMISSIONS BY PROCESS STEP (NATURAL GAS-FIRED KILN)

		raw materials extraction	raw materials transport	subtotal processing	TOTAL
CO_2	kg/tonne	3.556	1.753	226.944	232.254
SO_2	g/tonne	5.131	2.530	252.805	260.465
NO_x	g/tonne	40.592	20.014	227.193	287.798
TOC	g/tonne			77.500	77.500
CH_4	g/tonne	1.092	0.538	35.097	36.726
VOC	g/tonne	4.371	2.155	45.390	51.916
CO	g/tonne	22.283	10.986	712.183	745.452
Filterable PM	*g/tonne*			*154.250*	*154.250*
Filterable PM-10	*g/tonne*			*106.311*	*106.311*
Condensible Inorganic PM	*g/tonne*			*265.000*	*265.000*
Condensible Organic PM	*g/tonne*			*55.000*	*55.000*
total PM	g/tonne	116.280		474.250	590.530
total PM-10	g/tonne			426.311	426.311
HF	g/tonne			190.000	190.000
HCl	g/tonne			105.000	105.000

TABLE 5.2.5
PROCESSING EMISSIONS BY PROCESS STEP (LIGHT OIL-FIRED KILN)

		raw materials extraction	raw materials transport	subtotal processing	TOTAL
CO_2	kg/tonne	3.556	1.753	332.880	338.189
SO_2	kg/tonne	0.005	0.003	153.505	153.513
NO_x	g/tonne	40.592	20.014	237.616	298.222
TOC	g/tonne			77.500	77.500
CH_4	g/tonne	1.092	0.538	17.120	18.749
VOC	g/tonne	4.371	2.155	38.140	44.666
CO	g/tonne	22.283	10.986	735.516	768.785
Filterable PM	*g/tonne*			*154.250*	*154.250*
Filterable PM-10	*g/tonne*			*106.311*	*106.311*
Condensible Inorganic PM	*g/tonne*			*265.000*	*265.000*
Condensible Organic PM	*g/tonne*			*55.000*	*55.000*
total PM	g/tonne	116.280		474.250	590.530
total PM-10	g/tonne			426.311	426.311
HF	g/tonne			190.000	190.000
HCl	g/tonne			105.000	105.000

TABLE 5.2.6
CLAY BRICK ATMOSPHERIC EMISSIONS BY PROCESS STEP [PER M^3]

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg/m^3	5.107	2.518	325.892	333.516
SO_2	g/m^3	7.368	3.633	363.028	374.028
NO_x	g/m^3	58.290	28.740	326.248	413.278
TOC	g/m^3	0.000	0.000	111.290	111.290
CH_4	g/m^3	1.567	0.773	50.399	52.739
VOC	g/m^3	6.277	3.095	65.180	74.551
CO	g/m^3	31.998	15.776	1022.694	1070.469
Filterable PM	*g/m^3*	*0.000*	*0.000*	*221.503*	*221.503*
Filterable PM-10	*g/m^3*	*0.000*	*0.000*	*152.663*	*152.663*
Condensible Inorganic PM	*g/m^3*	*0.000*	*0.000*	*380.540*	*380.540*
Condensible Organic PM	*g/m^3*	*0.000*	*0.000*	*78.980*	*78.980*
total PM	g/m^3	166.978	0.000	681.023	848.001
total PM-10	g/m^3	0.000	0.000	612.183	612.183
HF	g/m^3	0.000	0.000	272.840	272.840
HCl	g/m^3	0.000	0.000	150.780	150.780
Light Oil-Fired Kiln					
CO_2	kg/m^3	5.107	2.518	478.015	485.640
SO_2	kg/m^3	0.007	0.004	220.433	220.445
NO_x	g/m^3	58.290	28.740	341.217	428.247
TOC	g/m^3	0.000	0.000	111.290	111.290
CH_4	g/m^3	1.567	0.773	24.584	26.924
VOC	g/m^3	6.277	3.095	54.769	64.140
CO	g/m^3	31.998	15.776	1056.201	1103.975
Filterable PM	*g/m^3*	*0.000*	*0.000*	*221.503*	*221.503*
Filterable PM-10	*g/m^3*	*0.000*	*0.000*	*152.663*	*152.663*
Condensible Inorganic PM	*g/m^3*	*0.000*	*0.000*	*380.540*	*380.540*
Condensible Organic PM	*g/m^3*	*0.000*	*0.000*	*78.980*	*78.980*
total PM	g/m^3	166.978	0.000	681.023	848.001
total PM-10	g/m^3	0.000	0.000	612.183	612.183
HF	g/m^3	0.000	0.000	272.840	272.840
HCl	g/m^3	0.000	0.000	150.780	150.780

TABLE 5.2.7
CLAY BRICK ATMOSPHERIC EMISSIONSBY PROCESS STEP
PER 1000 ONTARIO BRICKS

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg	6.657	3.282	424.820	434.759
SO_2	g	9.604	4.735	473.229	487.568
NO_x	g	75.985	37.464	425.284	538.733
TOC	g	0.000	0.000	145.073	145.073
CH_4	g	2.043	1.007	65.698	68.749
VOC	g	8.182	4.034	84.966	97.182
CO	g	41.712	20.566	1333.143	1395.420
Filterable PM	*g*	*0.000*	*0.000*	*288.742*	*288.742*
Filterable PM-10	*g*	*0.000*	*0.000*	*199.005*	*199.005*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*496.057*	*496.057*
Condensible Organic PM	*g*	*0.000*	*0.000*	*102.955*	*102.955*
total PM	g	217.666	0.000	887.754	1105.420
total PM-10	g	0.000	0.000	798.017	798.017
HF	g	0.000	0.000	355.663	355.663
HCl	g	0.000	0.000	196.551	196.551
Light Oil-Fired Kiln					
CO_2	kg	6.657	3.282	623.122	633.061
SO_2	kg	0.009	0.006	287.348	287.363
NO_x	g	75.985	37.464	444.797	558.245
TOC	g	0.000	0.000	145.073	145.073
CH_4	g	2.043	1.007	32.047	35.097
VOC	g	8.182	4.034	71.394	83.611
CO	g	41.712	20.566	1376.821	1439.098
Filterable PM	*g*	*0.000*	*0.000*	*288.742*	*288.742*
Filterable PM-10	*g*	*0.000*	*0.000*	*199.005*	*199.005*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*496.057*	*496.057*
Condensible Organic PM	*g*	*0.000*	*0.000*	*102.955*	*102.955*
total PM	g	217.666	0.000	887.754	1105.420
total PM-10	g	0.000	0.000	798.017	798.017
HF	g	0.000	0.000	355.663	355.663
HCl	g	0.000	0.000	196.551	196.551

TABLE 5.2.8
CLAY BRICK ATMOSPHERIC EMISSIONSBY PROCESS STEP
PER 1000 METRIC MODULAR BRICKS

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg	4.978	2.454	317.647	325.079
SO_2	g	7.181	3.541	353.843	364.565
NO_x	g	56.816	28.012	317.994	402.822
TOC	g	0.000	0.000	108.474	108.474
CH_4	g	1.528	0.753	49.124	51.405
VOC	g	6.118	3.016	63.531	72.665
CO	g	31.189	15.377	996.820	1043.386
Filterable PM	*g*	*0.000*	*0.000*	*215.899*	*215.899*
Filterable PM-10	*g*	*0.000*	*0.000*	*148.800*	*148.800*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*370.912*	*370.912*
Condensible Organic PM	*g*	*0.000*	*0.000*	*76.982*	*76.982*
total PM	g	162.754	0.000	663.793	826.547
total PM-10	g	0.000	0.000	596.694	596.694
HF	g	0.000	0.000	265.937	265.937
HCl	g	0.000	0.000	146.965	146.965
Light Oil-Fired Kiln					
CO_2	kg	4.978	2.454	465.922	473.353
SO_2	kg	0.007	0.004	214.856	214.867
NO_x	g	56.816	28.012	332.584	417.412
TOC	g	0.000	0.000	108.474	108.474
CH_4	g	1.528	0.753	23.962	26.243
VOC	g	6.118	3.016	53.383	62.518
CO	g	31.189	15.377	1029.479	1076.045
Filterable PM	*g*	*0.000*	*0.000*	*215.899*	*215.899*
Filterable PM-10	*g*	*0.000*	*0.000*	*148.800*	*148.800*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*370.912*	*370.912*
Condensible Organic PM	*g*	*0.000*	*0.000*	*76.982*	*76.982*
total PM	g	162.754	0.000	663.793	826.547
total PM-10	g	0.000	0.000	596.694	596.694
HF	g	0.000	0.000	265.937	265.937
HCl	g	0.000	0.000	146.965	146.965

TABLE 5.2.9
CLAY BRICK ATMOSPHERIC EMISSIONSBY PROCESS STEP
PER 1000 CSR BRICKS

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg	7.400	3.648	472.217	483.265
SO_2	g	10.676	5.264	526.028	541.967
NO_x	g	84.463	41.644	472.734	598.840
TOC	g	0.000	0.000	161.259	161.259
CH_4	g	2.271	1.120	73.028	76.419
VOC	g	9.095	4.484	94.445	108.025
CO	g	46.365	22.860	1481.884	1551.109
Filterable PM	*g*	*0.000*	*0.000*	*320.958*	*320.958*
Filterable PM-10	*g*	*0.000*	*0.000*	*221.208*	*221.208*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*551.402*	*551.402*
Condensible Organic PM	*g*	*0.000*	*0.000*	*114.442*	*114.442*
total PM	g	241.951	0.000	986.802	1228.754
total PM-10	g	0.000	0.000	887.053	887.053
HF	g	0.000	0.000	395.345	395.345
HCl	g	0.000	0.000	218.480	218.480
Light Oil-Fired Kiln					
CO_2	kg	7.400	3.648	692.644	703.692
SO_2	kg	0.010	0.006	319.408	319.424
NO_x	g	84.463	41.644	494.423	620.529
TOC	g	0.000	0.000	161.259	161.259
CH_4	g	2.271	1.120	35.622	39.013
VOC	g	9.095	4.484	79.360	92.939
CO	g	46.365	22.860	1530.435	1599.660
Filterable PM	*g*	*0.000*	*0.000*	*320.958*	*320.958*
Filterable PM-10	*g*	*0.000*	*0.000*	*221.208*	*221.208*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*551.402*	*551.402*
Condensible Organic PM	*g*	*0.000*	*0.000*	*114.442*	*114.442*
total PM	g	241.951	0.000	986.802	1228.754
total PM-10	g	0.000	0.000	887.053	887.053
HF	g	0.000	0.000	395.345	395.345
HCl	g	0.000	0.000	218.480	218.480

TABLE 5.2.10
CLAY BRICK ATMOSPHERIC EMISSIONSBY PROCESS STEP
PER 1000 MAX BRICKS

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg	9.331	4.601	595.493	609.425
SO_2	g	13.462	6.638	663.350	683.450
NO_x	g	106.512	52.515	596.144	755.171
TOC	g	0.000	0.000	203.357	203.357
CH_4	g	2.864	1.412	92.092	96.369
VOC	g	11.470	5.655	119.101	136.225
CO	g	58.469	28.828	1868.738	1956.035
Filterable PM	*g*	*0.000*	*0.000*	*404.746*	*404.746*
Filterable PM-10	*g*	*0.000*	*0.000*	*278.956*	*278.956*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*695.349*	*695.349*
Condensible Organic PM	*g*	*0.000*	*0.000*	*144.318*	*144.318*
total PM	g	305.114	0.000	1244.413	1549.527
total PM-10	g	0.000	0.000	1118.623	1118.623
HF	g	0.000	0.000	498.552	498.552
HCl	g	0.000	0.000	275.516	275.516
Light Oil-Fired Kiln					
CO_2	kg	9.331	4.601	873.463	887.395
SO_2	kg	0.013	0.008	402.791	402.812
NO_x	g	106.512	52.515	623.495	782.522
TOC	g	0.000	0.000	203.357	203.357
CH_4	g	2.864	1.412	44.922	49.198
VOC	g	11.470	5.655	100.077	117.202
CO	g	58.469	28.828	1929.964	2017.261
Filterable PM	*g*	*0.000*	*0.000*	*404.746*	*404.746*
Filterable PM-10	*g*	*0.000*	*0.000*	*278.956*	*278.956*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*695.349*	*695.349*
Condensible Organic PM	*g*	*0.000*	*0.000*	*144.318*	*144.318*
total PM	g	305.114	0.000	1244.413	1549.527
total PM-10	g	0.000	0.000	1118.623	1118.623
HF	g	0.000	0.000	498.552	498.552
HCl	g	0.000	0.000	275.516	275.516

TABLE 5.2.11
CLAY BRICK ATMOSPHERIC EMISSIONSBY PROCESS STEP
PER 1000 METRIC CLOSURE BRICKS

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg	7.859	3.875	501.548	513.282
SO_2	g	11.339	5.590	558.700	575.629
NO_x	g	89.709	44.230	502.096	636.035
TOC	g	0.000	0.000	171.275	171.275
CH_4	g	2.412	1.189	77.564	81.166
VOC	g	9.660	4.763	100.312	114.734
CO	g	49.245	24.280	1573.926	1647.451
Filterable PM	*g*	*0.000*	*0.000*	*340.893*	*340.893*
Filterable PM-10	*g*	*0.000*	*0.000*	*234.948*	*234.948*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*585.651*	*585.651*
Condensible Organic PM	*g*	*0.000*	*0.000*	*121.550*	*121.550*
total PM	g	256.979	0.000	1048.094	1305.074
total PM-10	g	0.000	0.000	942.149	942.149
HF	g	0.000	0.000	419.901	419.901
HCl	g	0.000	0.000	232.050	232.050
Light Oil-Fired Kiln					
CO_2	kg	7.859	3.875	735.666	747.400
SO_2	kg	0.011	0.007	339.247	339.264
NO_x	g	89.709	44.230	525.133	659.072
TOC	g	0.000	0.000	171.275	171.275
CH_4	g	2.412	1.189	37.835	41.436
VOC	g	9.660	4.763	84.289	98.712
CO	g	49.245	24.280	1625.493	1699.018
Filterable PM	*g*	*0.000*	*0.000*	*340.893*	*340.893*
Filterable PM-10	*g*	*0.000*	*0.000*	*234.948*	*234.948*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*585.651*	*585.651*
Condensible Organic PM	*g*	*0.000*	*0.000*	*121.550*	*121.550*
total PM	g	256.979	0.000	1048.094	1305.074
total PM-10	g	0.000	0.000	942.149	942.149
HF	g	0.000	0.000	419.901	419.901
HCl	g	0.000	0.000	232.050	232.050

TABLE 5.2.12
CLAY BRICK ATMOSPHERIC EMISSIONSBY PROCESS STEP
PER 1000 METRIC JUMBO BRICKS

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg	11.996	5.914	765.520	783.430
SO_2	g	17.306	8.533	852.753	878.592
NO_x	g	136.924	67.509	766.358	970.791
TOC	g	0.000	0.000	261.420	261.420
CH_4	g	3.682	1.815	118.387	123.884
VOC	g	14.744	7.270	153.107	175.121
CO	g	75.164	37.059	2402.308	2514.531
Filterable PM	*g*	*0.000*	*0.000*	*520.311*	*520.311*
Filterable PM-10	*g*	*0.000*	*0.000*	*358.604*	*358.604*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*893.888*	*893.888*
Condensible Organic PM	*g*	*0.000*	*0.000*	*185.524*	*185.524*
total PM	g	392.232	0.000	1599.723	1991.955
total PM-10	g	0.000	0.000	1438.017	1438.017
HF	g	0.000	0.000	640.901	640.901
HCl	g	0.000	0.000	354.182	354.182
Light Oil-Fired Kiln					
CO_2	kg	11.996	5.914	1122.858	1140.768
SO_2	kg	0.017	0.010	517.798	517.825
NO_x	g	136.924	67.509	801.519	1005.951
TOC	g	0.000	0.000	261.420	261.420
CH_4	g	3.682	1.815	57.748	63.245
VOC	g	14.744	7.270	128.652	150.666
CO	g	75.164	37.059	2481.016	2593.238
Filterable PM	*g*	*0.000*	*0.000*	*520.311*	*520.311*
Filterable PM-10	*g*	*0.000*	*0.000*	*358.604*	*358.604*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*893.888*	*893.888*
Condensible Organic PM	*g*	*0.000*	*0.000*	*185.524*	*185.524*
total PM	g	392.232	0.000	1599.723	1991.955
total PM-10	g	0.000	0.000	1438.017	1438.017
HF	g	0.000	0.000	640.901	640.901
HCl	g	0.000	0.000	354.182	354.182

TABLE 5.2.13
CLAY BRICK ATMOSPHERIC EMISSIONSBY PROCESS STEP
PER 1000 ENGINEER NORMAN BRICKS

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg	9.330	4.600	595.405	609.335
SO_2	g	13.460	6.637	663.252	683.349
NO_x	g	106.496	52.507	596.056	755.059
TOC	g	0.000	0.000	203.327	203.327
CH_4	g	2.864	1.412	92.079	96.354
VOC	g	11.468	5.654	119.083	136.205
CO	g	58.461	28.824	1868.462	1955.746
Filterable PM	*g*	*0.000*	*0.000*	*404.686*	*404.686*
Filterable PM-10	*g*	*0.000*	*0.000*	*278.915*	*278.915*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*695.247*	*695.247*
Condensible Organic PM	*g*	*0.000*	*0.000*	*144.296*	*144.296*
total PM	g	305.069	0.000	1244.229	1549.298
total PM-10	g	0.000	0.000	1118.458	1118.458
HF	g	0.000	0.000	498.479	498.479
HCl	g	0.000	0.000	275.475	275.475
Light Oil-Fired Kiln					
CO_2	kg	9.330	4.600	873.334	887.264
SO_2	kg	0.013	0.008	402.731	402.752
NO_x	g	106.496	52.507	623.403	782.407
TOC	g	0.000	0.000	203.327	203.327
CH_4	g	2.864	1.412	44.915	49.191
VOC	g	11.468	5.654	100.062	117.184
CO	g	58.461	28.824	1929.679	2016.963
Filterable PM	*g*	*0.000*	*0.000*	*404.686*	*404.686*
Filterable PM-10	*g*	*0.000*	*0.000*	*278.915*	*278.915*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*695.247*	*695.247*
Condensible Organic PM	*g*	*0.000*	*0.000*	*144.296*	*144.296*
total PM	g	305.069	0.000	1244.229	1549.298
total PM-10	g	0.000	0.000	1118.458	1118.458
HF	g	0.000	0.000	498.479	498.479
HCl	g	0.000	0.000	275.475	275.475

TABLE 5.2.14
CLAY BRICK ATMOSPHERIC EMISSIONSBY PROCESS STEP
PER 1000 METRIC NORMAN BRICKS

		extraction	transport	processing	TOTAL
Natural Gas-Fired Kiln					
CO_2	kg	7.597	3.746	484.829	496.172
SO_2	g	10.961	5.404	540.077	556.441
NO_x	g	86.718	42.756	485.360	614.834
TOC	g	0.000	0.000	165.566	165.566
CH_4	g	2.332	1.150	74.978	78.460
VOC	g	9.338	4.604	96.968	110.910
CO	g	47.604	23.471	1521.462	1592.536
Filterable PM	*g*	*0.000*	*0.000*	*329.530*	*329.530*
Filterable PM-10	*g*	*0.000*	*0.000*	*227.116*	*227.116*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*566.129*	*566.129*
Condensible Organic PM	*g*	*0.000*	*0.000*	*117.499*	*117.499*
total PM	g	248.413	0.000	1013.158	1261.571
total PM-10	g	0.000	0.000	910.744	910.744
HF	g	0.000	0.000	405.904	405.904
HCl	g	0.000	0.000	224.315	224.315
Light Oil-Fired Kiln					
CO_2	kg	7.597	3.746	711.144	722.487
SO_2	kg	0.011	0.006	327.938	327.956
NO_x	g	86.718	42.756	507.628	637.103
TOC	g	0.000	0.000	165.566	165.566
CH_4	g	2.332	1.150	36.574	40.055
VOC	g	9.338	4.604	81.479	95.422
CO	g	47.604	23.471	1571.310	1642.384
Filterable PM	*g*	*0.000*	*0.000*	*329.530*	*329.530*
Filterable PM-10	*g*	*0.000*	*0.000*	*227.116*	*227.116*
Condensible Inorganic PM	*g*	*0.000*	*0.000*	*566.129*	*566.129*
Condensible Organic PM	*g*	*0.000*	*0.000*	*117.499*	*117.499*
total PM	g	248.413	0.000	1013.158	1261.571
total PM-10	g	0.000	0.000	910.744	910.744
HF	g	0.000	0.000	405.904	405.904
HCl	g	0.000	0.000	224.315	224.315

5.3 Calcium Silicate Brick

5.3.1 Fuel Emissions

Emissions due to fossil fuel use in various processing steps of the sand-lime brick manufacturing production were estimated by applying energy emissions factors from Table 5.1 to average energy estimates developed in Section 4.2, and summarized there in Tables 4.2.5 through 4.2.7 by its constituents, by raw materials and process stage, and by energy form.

5.3.2 Calcination CO_2 and Thermal NO_X Emissions

In addition to the above fuel emissions, calcination CO_2 and thermal NO_x emissions due to the lime pyro-processing were taken into account:

- From the stoichiometry of limestone decomposition, it is given that 0.785 tonnes of CO_2 is generated per tonne of lime (CaO) produced (44.00995 g per mole of CO_2 / 56.0794 g per mole of CaO = 0.785 g of CO_2 / 1 g of CaO).

- There is an insufficient amount of reliable Canadian data concerning NO_x emissions from lime kilns available. The figure that we use in this report we derived by averaging the limited data from the confidential survey of the Canadian lime producers conducted for Environment Canada / CCME Lime Kiln NO_x Control study[5], EPA AP-42 data[6] and trade literature information.[7] This gives an average total of NO_x emissions of 1.20666 kg/tonne of lime produced. Multiplying this figure by 0.06 tonnes of lime required to produce a tonne of sand-lime bricks (from Table 3.1), an estimate of total NO_x emissions of 0.0724 kg per tonne of bricks was developed.

  Fuel NO_x was estimated using the fuel emission factors as discussed above (0.3882 GJ/tonne [from Table 4.2.6] multiplied by a natural gas emission factor of 0.059 kg NO_x/GJ = 0.0229 kg of fuel NOx/tonne of bricks). The thermal (process) NO_x was then calculated as the difference between the total and fuel NO_x. (Total NO_x 0.0724/tonne of bricks - fuel NO_x 0.0229/tonne of bricks = thermal NO_x 0.0495 kg/tonne of bricks.)

5.3.3 Particulate Emissions

Particulate emissions associated with the calcium silicate brick production come mainly from three sources: from raw materials extraction, from raw materials processing (primarily in kiln calcination of limestone to lime) and from brick processing itself.

a) For the raw materials extraction, the Nationwide Inventory[3] gives TPM (total particulate matter) emissions associated with quarrying of rock (limestone) in open pit mining as 0.51 kg/tonne. For the sand quarrying and processing, the same source provides TPM emissions of 0.05 kg/tonne.

b) TPM emissions due to the limestone processing are given by the sum of particulate emissions generated by limestone crushing, its processing in the natural gas-fired rotary kiln, and in its conveying and transfer. We used US EPA[6] factors to develop the limestone processing TPM estimate of 1.1943 kg per tonne of lime produced.

c) In the absence of any information regarding the particulate emissions due to sand-lime brick processing, considering the similarity between concrete brick and sand lime brick forming and curing processes, we assume the same TPM of 0.12 kg/m^3 (i.e. 0.0581 kg/tonne) for the sand-lime brick as for concrete batching.[3]

5.3.4 Emission Estimates for Sand-Lime Brick

Using the above noted numbers and underlying assumptions, estimates of air emissions associated with the calcium silicate brick production were calculated and are summarized in Tables 5.3.1 to 5.3.3 by energy form used, by process step and, in more detail, by raw materials used and process step. All are expressed in kilogram of emissions per tonne of brick produced.

TABLE 5.3.1
ATMOSPHERIC EMISSIONS DUE TO SAND-LIME BRICK PRODUCTION BY ENERGY FORM USED (KG/TONNE OF BRICK)

	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
fuel generated							
natural gas	42.80164	0.00017	0.05081	0.00103	0.00112	0.01292	
diesel road	13.98105	0.02017	0.15959	0.01718	0.00429	0.08760	
electricity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
process generated	47.10000		0.04950				0.20740
Total	***103.88269***	***0.02034***	***0.25989***	***0.01822***	***0.00541***	***0.10052***	***0.20740***

TABLE 5.3.2
ATMOSPHERIC EMISSIONS DUE TO SAND-LIME BRICK PRODUCTION BY PROCESS STEP (KG/TONNE OF BRICK)

	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
RM extraction	1.99881	0.00288	0.02282	0.00246	0.00061	0.01252	0.07760
RM processing	*19.29354*	*0.00008*	*0.02290*	*0.00047*	*0.00050*	*0.00582*	*0.07166*
calcination generated	*47.10000*		*0.04950*				
RM processing subttl	66.39354	0.00008	0.07240	0.00047	0.00050	0.00582	0.07166
RM transport	3.00334	0.00433	0.03428	0.00369	0.00092	0.01882	
brick processing	32.48700	0.01305	0.13040	0.01160	0.00337	0.06336	0.05814
Total	***103.88269***	***0.02034***	***0.25989***	***0.01822***	***0.00541***	***0.10052***	***0.20740***

TABLE 5.3.3
ATMOSPHERIC EMISSIONS DUE TO SAND-LIME BRICK PRODUCTION BY PROCESS STEP & RAW MATERIALS (KG/TONNE OF BRICK)

	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
limestone extraction	0.20444	0.00029	0.00233	0.00025	0.00006	0.00128	0.03060
limestone transport	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
lime processing	*19.29354*	*0.00008*	*0.02290*	*0.00047*	*0.00050*	*0.00582*	*0.07166*
calcination generated	*47.10000*		*0.04950*				
lime processing subttl	66.39354	0.00008	0.07240	0.00047	0.00050	0.00582	0.07166
lime transport	0.65072	0.00094	0.00743	0.00080	0.00020	0.00408	
lime subtotal	67.24871	0.00131	0.08216	0.00152	0.00077	0.01118	0.10226
sand extraction	1.79437	0.00259	0.02048	0.00221	0.00055	0.01124	0.04700
sand processing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
sand transport	2.35261	0.00339	0.02685	0.00289	0.00072	0.01474	
sand subtotal	4.14698	0.00598	0.04734	0.00510	0.00127	0.02598	0.04700
brick processing	32.48700	0.01305	0.13040	0.01160	0.00337	0.06336	0.05814
Total	***103.88269***	***0.02034***	***0.25989***	***0.01822***	***0.00541***	***0.10052***	***0.20740***

By multiplying the above estimates by the sand -lime brick average specific gravity[8] of 2064 kg/m^3 and brick dimensions from Table 4.2.4., emission data estimates can also be presented per 1000 of CB25, ES26 and VB31 bricks. (Tables 5.3.4 - 5.2.6)

TABLE 5.3.4
ATMOSPHERIC EMISSIONS — SAND-LIME BRICK [PER 1000 CB25 BRICKS]

	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
By Energy Source							
natural gas	176.43216	0.00071	0.20945	0.00426	0.00461	0.05325	0.00000
diesel road	57.63111	0.08315	0.65783	0.07084	0.01769	0.36111	0.00000
electricity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
process generated	194.15038	0.00000	0.20403	0.00000	0.00000	0.00000	0.85492
total	***428.21364***	***0.08386***	***1.07130***	***0.07510***	***0.02230***	***0.41436***	***0.85492***
By Process Step							
RM extraction	8.23927	0.01189	0.09405	0.01013	0.00253	0.05163	0.31987
RM processing	*79.52968*	*0.00032*	*0.09441*	*0.00192*	*0.00208*	*0.02400*	*0.29538*
calcination generated	*194.15038*	-	*0.20403*	-	-	-	-
RM processing subttl	273.68006	0.00000	0.29844	0.00000	0.00000	0.00000	0.29538
RM transport	12.38002	0.01786	0.14131	0.01522	0.00380	0.07757	0.00000
brick processing	133.91430	0.05379	0.53750	0.04783	0.01389	0.26116	0.23966
total	***428.21364***	***0.08386***	***1.07130***	***0.07510***	***0.02230***	***0.41436***	***0.85491***
By Constituents and Process Step							
limestone extraction	0.84273	0.00122	0.00962	0.00104	0.00026	0.00528	0.12614
limestone transport	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
lime processing	*79.52968*	*0.00032*	*0.09441*	*0.00192*	*0.00208*	*0.02400*	*0.29538*
calcination generated	*194.15038*	-	*0.20403*	-	-	-	-
lime processing subttl	273.68006	0.00032	0.29844	0.00192	0.00208	0.02400	0.29538
lime transport	2.68234	0.00387	0.03062	0.00330	0.00082	0.01681	0.00000
lime subtotal	277.20513	0.00541	0.33868	0.00625	0.00316	0.04609	0.42152
sand extraction	7.39654	0.01067	0.08443	0.00909	0.00227	0.04635	0.19374
sand processing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
sand transport	9.69768	0.01399	0.11069	0.01192	0.00298	0.06076	0.00000
sand subtotal	17.09422	0.02466	0.19512	0.02101	0.00525	0.10711	0.19374
brick processing	133.91430	0.05379	0.53750	0.04783	0.01389	0.26116	0.23966
total	***428.21364***	***0.08386***	***1.07130***	***0.07510***	***0.02230***	***0.41436***	***0.85491***

TABLE 5.3.5
ATMOSPHERIC EMISSIONS — SAND-LIME BRICK [PER 1000 ES26 BRICKS]

	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
By Energy Source							
natural gas	126.58609	0.00051	0.15027	0.00306	0.00331	0.03821	0.00000
diesel road	41.34902	0.05965	0.47198	0.05082	0.01269	0.25909	0.00000
electricity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
process generated	139.29851	0.00000	0.14639	0.00000	0.00000	0.00000	0.61339
total	***307.23362***	***0.06016***	***0.76863***	***0.05388***	***0.01600***	***0.29729***	***0.61339***
By Process Step							
RM extraction	5.91149	0.00853	0.06748	0.00727	0.00181	0.03704	0.22950
RM processing	*57.06075*	*0.00023*	*0.06774*	*0.00138*	*0.00149*	*0.01722*	*0.21193*
calcination generated	*139.29851*	-	*0.14639*	-	-	-	-
RM processing subttl	196.35927	0.00000	0.21412	0.00000	0.00000	0.00000	0.00000
RM transport	8.88238	0.01281	0.10139	0.01092	0.00273	0.05566	0.00000
brick processing	96.08048	0.03859	0.38565	0.03432	0.00997	0.18738	0.17195
total	***307.23362***	***0.06016***	***0.76863***	***0.05388***	***0.01600***	***0.29729***	***0.61338***
By Constituents and Process Step							
limestone extraction	0.60464	0.00087	0.00690	0.00074	0.00019	0.00379	0.09050
limestone transport	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
lime processing	*57.06075*	*0.00023*	*0.06774*	*0.00138*	*0.00149*	*0.01722*	*0.21193*
calcination generated	*139.29851*	-	*0.14639*	-	-	-	-
lime processing subttl	196.35927	0.00023	0.21412	0.00138	0.00149	0.01722	0.21193
lime transport	1.92452	0.00278	0.02197	0.00237	0.00059	0.01206	0.00000
lime subtotal	198.88842	0.00388	0.24299	0.00449	0.00227	0.03307	0.30243
sand extraction	5.30685	0.00766	0.06057	0.00652	0.00163	0.03325	0.13900
sand processing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
sand transport	6.95787	0.01004	0.07942	0.00855	0.00214	0.04360	0.00000
sand subtotal	12.26471	0.01769	0.13999	0.01508	0.00376	0.07685	0.00000
brick processing	96.08048	0.03859	0.38565	0.03432	0.00997	0.18738	0.17195
total	***307.23362***	***0.06016***	***0.76863***	***0.05388***	***0.01600***	***0.29729***	***0.61338***

TABLE 5.3.6
ATMOSPHERIC EMISSIONS — SAND-LIME BRICK [PER 1000 VB31 BRICKS]

	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
By Energy Form							
natural gas	159.63214	0.00064	0.18950	0.00385	0.00418	0.04818	0.00000
diesel road	52.14342	0.07523	0.59519	0.06409	0.01600	0.32673	0.00000
electricity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
process generated	175.66321	0.00000	0.18460	0.00000	0.00000	0.00000	0.77351
total	***387.43877***	***0.07587***	***0.96929***	***0.06795***	***0.02018***	***0.37490***	***0.77351***
By Process Step							
RM extraction	7.45472	0.01076	0.08509	0.00916	0.00229	0.04671	0.28942
RM processing	*71.95680*	*0.00029*	*0.08542*	*0.00174*	*0.00188*	*0.02172*	*0.26725*
calcination generated	*175.66321*	*-*	*0.18460*	*-*	*-*	*-*	*-*
RM processing subttl	247.62001	0.00000	0.27002	0.00000	0.00000	0.00000	0.00000
RM transport	11.20118	0.01616	0.12786	0.01377	0.00344	0.07019	0.00000
brick processing	121.16286	0.04867	0.48632	0.04328	0.01257	0.23629	0.21684
total	***387.43877***	***0.07587***	***0.96929***	***0.06795***	***0.02018***	***0.37490***	***0.77351***
By Constituents and Process Step							
limestone extraction	0.76249	0.00110	0.00870	0.00094	0.00023	0.00478	0.11413
limestone transport	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
lime processing	*71.95680*	*0.00029*	*0.08542*	*0.00174*	*0.00188*	*0.02172*	*0.26725*
calcination generated	*175.66321*	*-*	*0.18460*	*-*	*-*	*-*	*-*
lime processing subttl	247.62001	0.00029	0.27002	0.00174	0.00188	0.02172	0.26725
lime transport	2.42692	0.00350	0.02770	0.00298	0.00074	0.01521	0.00000
lime subtotal	250.80942	0.00489	0.30643	0.00566	0.00286	0.04170	0.38138
sand extraction	6.69223	0.00965	0.07639	0.00823	0.00205	0.04193	0.17529
sand processing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
sand transport	8.77426	0.01266	0.10015	0.01078	0.00269	0.05498	0.00000
sand subtotal	15.46649	0.02231	0.17654	0.01901	0.00475	0.09691	0.00000
brick processing	121.16286	0.04867	0.48632	0.04328	0.01257	0.23629	0.21684
total	***387.43877***	***0.07587***	***0.96929***	***0.06795***	***0.02018***	***0.37490***	***0.77351***

5.4 Concrete Brick

5.4.1 Aggregates

Non-particulate atmospheric emissions related to aggregate extraction, processing and transportation are a function of energy use. The estimates were developed in the ATHENA™ Cement and Concrete study[1], and are shown here only for completeness. They were estimated by applying the fuel-specific emission factors from Table 5.1 to energy use estimates for aggregate extraction, processing and transportation presented in Section 4.3. For example, the CO_2 emission estimate for the extraction of coarse aggregates is developed as a product of 0.027 GJ/t of diesel fuel use from Section 4.3 and the diesel road emission factor of 70.7 kg/t from Table 5.1. The resulting emission estimate is 1.9089 kg of CO_2 per tonne of aggregate.

The same per tonne energy breakdown is assumed for the extraction, processing and transportation of both fine and coarse aggregates in all of the regions and cities considered in the study. The atmospheric emission estimates for aggregate production and transportation are therefore the same for all regions and cities.

In the case of particulates, an uncontrolled total particulate matter (TPM) emission factor of 50 g/tonne for both coarse and fine aggregates was taken from Environment Canada.[3] This factor represents total emissions due to aggregate quarrying, crushing, screening, transportation and stockpiling. (The estimate is in agreement with the figure quoted in the AIA Environmental Resource Guide.[4])

Table 5.4.1 shows the resulting emission estimates for aggregate extraction and transportation. Processing emissions are not included in Table 5.4.1 because the energy used for processing is in the form of electricity and emissions related to electricity generation are being estimated within the ATHENA™ Model as explained earlier.

TABLE 5.4.1
ATMOSPHERIC EMISSIONS DUE TO FINE AND COARSE AGGREGATES

	CO_2 [kg/t]	SO_2 [g/t]	NO_X [g/t]	VOC [g/t]	CH_4 [g/t]	CO [g/t]	TPM [g/t]
Extraction							
Coarse Aggregate	1.9089	2.7540	21.7890	2.3463	0.5859	11.9610	
Fine Aggregate	1.9089	2.7540	21.7890	2.3463	0.5859	11.9610	
Transportation							
Coarse Aggregate	1.6685	2.4072	19.0452	2.0508	0.5121	10.4548	
Fine Aggregate	2.5028	3.6108	28.5678	3.0763	0.7682	15.6822	
Total							
Coarse Aggregate	3.5774	5.1612	40.8342	4.3971	1.0980	22.4158	50.0000
Fine Aggregate	4.4117	6.3648	50.3568	5.4226	1.3541	27.6432	50.0000

5.4.2 Cement

The atmospheric emissions associated with the production of cement were developed and discussed in detail in Section 5 of the ATHENA™ cement and concrete study[1]. These are summarized here in Table 5.4.2.

TABLE 5.4.2
ATMOSPHERIC EMISSIONS DUE TO CEMENT PRODUCTION BY REGION
(G/TONNE OF CEMENT)

Region	City	CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Raw Materials Extraction								
West Coast	Vancouver	3155.90	4.55	36.02	3.88	0.97	19.77	843.03
Prairies	Calgary	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
	Winnipeg	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
Central	Toronto	3146.97	4.54	35.92	3.87	0.97	19.72	840.99
East	Montreal	3122.92	4.51	35.65	3.84	0.96	19.57	834.20
	Halifax	3122.92	4.51	35.65	3.84	0.96	19.57	835.17
Raw Materials Transportation								
West Coast	Vancouver	6628.35	37.71	23.11	30.20	3.44	3.90	
Prairies	Calgary	15881.67	22.91	293.04	16.34	2.25	26.77	
	Winnipeg	15881.67	22.91	293.04	16.34	2.25	26.77	
Central	Toronto	4787.51	17.76	37.55	14.30	1.94	13.42	
East	Montreal	1616.61	5.06	13.33	4.12	0.63	6.51	
	Halifax	1616.61	5.06	13.33	4.12	0.63	6.51	
Manufacturing								
West Coast	Vancouver	779160.25	38.84	4447.38	5.68	4.01	188.15	483.06
Prairies	Calgary	680558.86	0.06	5422.31	4.40	4.77	52.71	938
	Winnipeg	680558.86	0.06	5422.31	4.40	4.77	52.71	938
Central	Toronto	804194.66	104.40	1661.74	5.54	2.66	273.95	340.32
East	Montreal	875240.59	192.04	2870.47	8.11	3.72	280.31	863.23
	Halifax	875240.59	192.04	2870.47	8.11	3.72	280.31	603
Finished Cement Transportation								
West Coast	Vancouver	9543.09	13.77	108.93	11.73	2.93	59.80	
Prairies	Calgary	26400.79	38.09	301.35	32.45	8.10	165.43	
	Winnipeg	90764.66	130.95	1797.32	89.87	10.01	73.18	
Central	Toronto	9315.69	19.06	95.79	15.85	3.14	50.91	
East	Montreal	17291.10	24.95	215.00	20.75	4.89	96.86	
	Halifax	18112.66	38.64	183.26	32.06	6.19	96.87	
Total Emissions due to Cement Production								
West Coast	Vancouver	798487.60	94.87	4615.45	51.50	11.35	271.62	1326.09
Prairies	Calgary	725991.01	65.60	6052.65	57.06	16.09	264.64	1779.50
	Winnipeg	790354.88	158.46	7548.62	114.47	18.00	172.39	1779.50
Central	Toronto	821444.83	145.75	1831.00	39.56	8.71	357.99	1181.31
East	Montreal	897271.21	226.55	3134.45	36.82	10.21	403.24	1697.43
	Halifax	898092.78	240.24	3102.71	48.13	11.50	403.25	1438.17

5.4.3 Emission Estimates for Concrete Masonry Brick

The atmospheric emissions estimates were developed for concrete masonry bricks in the same manner as in the Cement and Concrete study[1] for other concrete products, i.e.:

1. The component of total emissions that results from the direct use of energy at each process stage (i.e. aggregate extraction, aggregate transportation and concrete processing) was estimated by multiplying the energy use estimates by process stage and fuel type by the appropriate emission factors from Table 5.1. For each product, this component of emissions is the same for all cities because the product energy estimates were assumed to be the same for all cities.

2. The component of total emissions resulting from the use of cement was estimated by multiplying cement atmospheric emissions estimates for the relevant city by the cement content factor shown in Table 3.1.

For example, cement delivered in Vancouver embodies 271.62 grams of CO per tonne (from Table 5.4.2) and 217 kg of cement is used per m^3 of concrete brick mix (from Table 3.1). Therefore, CO emissions resulting from the use of cement in the production of concrete brick in Vancouver = 271.62 x .217 = 58.94 grams per m^3 of bricks.

3. The estimates from steps 1 and 2, above, were added to obtain the emission estimates by process stage and city, with the cement-related emissions added at the manufacturing stage as discussed in Section 4.3. The estimates for the concrete masonry brick vary by city because the cement-related emissions vary by city.

4. TPM estimates were developed in three steps.

  a) The TPM estimates from Table 5.4.1 for coarse and fine aggregates were adjusted to reflect the amount of aggregate in each product (e.g. 1.944 tonnes of fine plus coarse aggregate per m^3 of concrete brick mix (from Table 3.1) x 50 grams per tonne of TPM (from Table 5.4.1) = 97.2 grams of TPM per m^3 of concrete bricks. This component of the total TPM estimate was attributed to the raw material extraction and processing stage.

  b) An additional estimate of 120 grams of TPM per m^3 of concrete was taken from Environment Canada to cover releases during the concrete products manufacturing stage.[3] Our understanding of the estimates is that these TPM releases result from materials handling and mixing and that they do not vary significantly by product.

  c) The TPM estimates for cement (from Table 5.4.2) were factored to reflect the amount of cement in concrete brick as illustrated in point 2, above. This component of TPM varies by city. The estimates were added to the TPM component from Step 4 (b) to arrive at the total concrete brick manufacturing stage estimate of TPM for each city.

5. Finally, the emission estimates for concrete brick first derived in terms of m^3 of concrete can be converted to estimates per 1000 bricks of various types, as specified in Table 4.3.5 using the appropriate conversion factors as cited there.

The final estimates of atmospheric emissions for the concrete masonry brick are shown in Tables 5.4.3 (per m^3 of concrete) and 5.4.4 through 5.4.7 (per 1000 bricks) by process stage and city.

5.5 Atmospheric Emission - Cement Mortar

Atmospheric emissions for cement mortar are arrived at in a similar manner to that used for concrete masonry brick and other concrete products. The basic components of cement mortar, as shown in Table 3.1, are cement, fine aggregate (sand) and water. Cement mortars often have some lime content to improve plasticity, or use masonry cement instead of portland cement. However, the differences between unit factor estimates for a lime mortar and one made only with portland or masonry cement would be minimal and we have therefore developed estimates for only the portland cement version.

The atmospheric emission estimates associated with the production of cement mortar were developed in the ATHENATM Cement and Concrete study[1], and they are shown here as well in order to keep the relevant information together.

While these emissions are tabulated (Table 5.5.1) in grams per m^3 of cement mortar, if desired they can be multiplied by appropriate factors from Tables 4.4.3 to 4.4.5 for typical concrete masonry, sand-lime or clay bricks, to estimate atmospheric emissions associated with the cement mortar use expressed per 1000 bricks of the given size at the typical 10 mm (3/8") mortar bed thickness.

TABLE 5.4.3
CONCRETE BRICK EMISSIONS [GRAMS/M^3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Aggregates Extraction								
West Coast	Vancouver	3710.90	5.35	42.36	4.56	1.14	23.25	97.20
Prairie	Calgary	3710.90	5.35	42.36	4.56	1.14	23.25	97.20
	Winnipeg	3710.90	5.35	42.36	4.56	1.14	23.25	97.20
Central	Toronto	3710.90	5.35	42.36	4.56	1.14	23.25	97.20
East	Montreal	3710.90	5.35	42.36	4.56	1.14	23.25	97.20
	Halifax	3710.90	5.35	42.36	4.56	1.14	23.25	97.20
Aggregates Transportation								
West Coast	Vancouver	4379.03	6.32	49.98	5.38	1.34	27.44	0.00
Prairie	Calgary	4379.03	6.32	49.98	5.38	1.34	27.44	0.00
	Winnipeg	4379.03	6.32	49.98	5.38	1.34	27.44	0.00
Central	Toronto	4379.03	6.32	49.98	5.38	1.34	27.44	0.00
East	Montreal	4379.03	6.32	49.98	5.38	1.34	27.44	0.00
	Halifax	4379.03	6.32	49.98	5.38	1.34	27.44	0.00
Concrete Production								
West Coast	Vancouver	72446.01	29.10	290.78	25.88	7.52	141.28	120.00
Prairie	Calgary	72446.01	29.10	290.78	25.88	7.52	141.28	120.00
	Winnipeg	72446.01	29.10	290.78	25.88	7.52	141.28	120.00
Central	Toronto	72446.01	29.10	290.78	25.88	7.52	141.28	120.00
East	Montreal	72446.01	29.10	290.78	25.88	7.52	141.28	120.00
	Halifax	97128.10	158.42	293.95	25.24	6.31	141.81	120.00
Cement								
West Coast	Vancouver	173271.81	20.59	1001.55	11.17	2.46	58.94	287.76
Prairie	Calgary	157540.05	14.24	1313.43	12.38	3.49	57.43	386.15
	Winnipeg	171507.01	34.39	1638.05	24.84	3.91	37.41	386.15
Central	Toronto	178253.53	31.63	397.33	8.58	1.89	77.68	256.34
East	Montreal	194707.85	49.16	680.18	7.99	2.22	87.50	368.34
	Halifax	194886.13	52.13	673.29	10.45	2.50	87.51	312.08
Processing Sub-total								
West Coast	Vancouver	245717.82	49.69	1292.33	37.05	9.98	200.23	407.76
Prairie	Calgary	229986.06	43.33	1604.21	38.26	11.01	198.71	506.15
	Winnipeg	243953.02	63.48	1928.83	50.72	11.42	178.69	506.15
Central	Toronto	250699.54	60.73	688.11	34.46	9.41	218.97	376.34
East	Montreal	267153.86	78.26	970.96	33.87	9.73	228.79	488.34
	Halifax	292014.23	210.55	967.23	35.69	8.81	229.32	432.08
Total								
West Coast	Vancouver	253807.75	61.36	1384.68	46.99	12.46	250.92	504.96
Prairie	Calgary	238075.99	55.01	1696.55	48.20	13.49	249.40	603.35
	Winnipeg	252042.95	75.16	2021.18	60.66	13.91	229.38	603.35
Central	Toronto	258789.47	72.40	780.45	44.40	11.89	269.66	473.54
East	Montreal	275243.80	89.93	1063.30	43.81	12.21	279.48	585.54
	Halifax	300104.16	222.22	1059.58	45.63	11.29	280.01	529.28

TABLE 5.4.4
CONCRETE BRICK EMISSIONS [GRAMS/1000 A1 BRICKS]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Aggregate Extraction								
West Coast	Vancouver	3616.86	5.22	41.28	4.45	1.11	22.66	94.74
Prairie	Calgary	3616.86	5.22	41.28	4.45	1.11	22.66	94.74
	Winnipeg	3616.86	5.22	41.28	4.45	1.11	22.66	94.74
Central	Toronto	3616.86	5.22	41.28	4.45	1.11	22.66	94.74
East	Montreal	3616.86	5.22	41.28	4.45	1.11	22.66	94.74
	Halifax	3616.86	5.22	41.28	4.45	1.11	22.66	94.74
Aggregate Transportation								
West Coast	Vancouver	4268.06	6.16	48.72	5.25	1.31	26.74	0.00
Prairie	Calgary	4268.06	6.16	48.72	5.25	1.31	26.74	0.00
	Winnipeg	4268.06	6.16	48.72	5.25	1.31	26.74	0.00
Central	Toronto	4268.06	6.16	48.72	5.25	1.31	26.74	0.00
East	Montreal	4268.06	6.16	48.72	5.25	1.31	26.74	0.00
	Halifax	4268.06	6.16	48.72	5.25	1.31	26.74	0.00
Concrete Processing								
West Coast	Vancouver	70610.15	28.36	283.41	25.22	7.33	137.70	116.96
Prairie	Calgary	70610.15	28.36	283.41	25.22	7.33	137.70	116.96
	Winnipeg	70610.15	28.36	283.41	25.22	7.33	137.70	116.96
Central	Toronto	70610.15	28.36	283.41	25.22	7.33	137.70	116.96
East	Montreal	70610.15	28.36	283.41	25.22	7.33	137.70	116.96
	Halifax	94666.76	154.40	286.50	24.60	6.15	138.22	116.96
Cement								
West Coast	Vancouver	168880.90	20.07	976.17	10.89	2.40	57.45	280.47
Prairie	Calgary	153547.81	13.88	1280.14	12.07	3.40	55.97	376.37
	Winnipeg	167160.83	33.51	1596.54	24.21	3.81	36.46	376.37
Central	Toronto	173736.38	30.83	387.26	8.37	1.84	75.72	249.85
East	Montreal	189773.74	47.92	662.94	7.79	2.16	85.29	359.01
	Halifax	189947.50	50.81	656.23	10.18	2.43	85.29	304.17
Processing Sub-total								
West Coast	Vancouver	239491.05	48.43	1259.59	36.11	9.73	195.15	397.43
Prairie	Calgary	224157.95	42.24	1563.56	37.29	10.73	193.68	493.33
	Winnipeg	237770.97	61.88	1879.96	49.43	11.13	174.16	493.33
Central	Toronto	244346.53	59.19	670.67	33.59	9.17	213.42	366.81
East	Montreal	260383.88	76.28	946.35	33.01	9.49	222.99	475.97
	Halifax	284614.26	205.21	942.72	34.78	8.59	223.51	421.13
Total								
West Coast	Vancouver	247375.98	59.80	1349.59	45.80	12.15	244.56	492.17
Prairie	Calgary	232042.88	53.61	1653.56	46.98	13.15	243.08	588.06
	Winnipeg	245655.90	73.25	1969.96	59.12	13.55	223.57	588.06
Central	Toronto	252231.45	70.56	760.67	43.28	11.59	262.82	461.54
East	Montreal	268268.81	87.65	1036.36	42.70	11.91	272.40	570.70
	Halifax	292499.18	216.59	1032.73	44.48	11.01	272.91	515.87

TABLE 5.4.5
CONCRETE BRICK EMISSIONS [GRAMS/1000 A2 BRICKS]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Aggregates Extraction								
West Coast	Vancouver	3144.83	4.54	35.90	3.87	0.97	19.71	82.37
Prairie	Calgary	3144.83	4.54	35.90	3.87	0.97	19.71	82.37
	Winnipeg	3144.83	4.54	35.90	3.87	0.97	19.71	82.37
Central	Toronto	3144.83	4.54	35.90	3.87	0.97	19.71	82.37
East	Montreal	3144.83	4.54	35.90	3.87	0.97	19.71	82.37
	Halifax	3144.83	4.54	35.90	3.87	0.97	19.71	82.37
Aggregates Transportation								
West Coast	Vancouver	3711.04	5.35	42.36	4.56	1.14	23.25	0.00
Prairie	Calgary	3711.04	5.35	42.36	4.56	1.14	23.25	0.00
	Winnipeg	3711.04	5.35	42.36	4.56	1.14	23.25	0.00
Central	Toronto	3711.04	5.35	42.36	4.56	1.14	23.25	0.00
East	Montreal	3711.04	5.35	42.36	4.56	1.14	23.25	0.00
	Halifax	3711.04	5.35	42.36	4.56	1.14	23.25	0.00
Concrete Production								
West Coast	Vancouver	61394.92	24.66	246.43	21.93	6.37	119.73	101.69
Prairie	Calgary	61394.92	24.66	246.43	21.93	6.37	119.73	101.69
	Winnipeg	61394.92	24.66	246.43	21.93	6.37	119.73	101.69
Central	Toronto	61394.92	24.66	246.43	21.93	6.37	119.73	101.69
East	Montreal	61394.92	24.66	246.43	21.93	6.37	119.73	101.69
	Halifax	82311.95	134.25	249.11	21.39	5.35	120.18	101.69
Cement								
West Coast	Vancouver	146840.52	17.45	848.77	9.47	2.09	49.95	243.87
Prairie	Calgary	133508.52	12.06	1113.07	10.49	2.96	48.67	327.25
	Winnipeg	145344.92	29.14	1388.18	21.05	3.31	31.70	327.25
Central	Toronto	151062.31	26.80	336.72	7.27	1.60	65.83	217.24
East	Montreal	165006.66	41.66	576.42	6.77	1.88	74.16	312.15
	Halifax	165157.74	44.18	570.58	8.85	2.12	74.16	264.48
Processing Sub-total								
West Coast	Vancouver	208235.44	42.11	1095.20	31.40	8.46	169.68	345.56
Prairie	Calgary	194903.44	36.72	1359.50	32.42	9.33	168.40	428.94
	Winnipeg	206739.85	53.80	1634.61	42.98	9.68	151.43	428.94
Central	Toronto	212457.24	51.46	583.14	29.20	7.97	185.57	318.94
East	Montreal	226401.58	66.32	822.85	28.70	8.25	193.89	413.85
	Halifax	247469.69	178.43	819.69	30.24	7.47	194.34	366.17
Total								
West Coast	Vancouver	215091.31	52.00	1173.45	39.83	10.56	212.64	427.93
Prairie	Calgary	201759.32	46.62	1437.75	40.85	11.43	211.36	511.31
	Winnipeg	213595.72	63.69	1712.86	51.41	11.79	194.39	511.31
Central	Toronto	219313.11	61.35	661.40	37.63	10.08	228.52	401.31
East	Montreal	233257.45	76.21	901.10	37.13	10.35	236.85	496.22
	Halifax	254325.56	188.32	897.95	38.67	9.57	237.29	448.54

TABLE 5.4.6
CONCRETE BRICK EMISSIONS [GRAMS/1000 B1 BRICKS]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Aggregates Extraction								
West Coast	Vancouver	5709.08	8.24	65.17	7.02	1.75	35.77	149.54
Prairie	Calgary	5709.08	8.24	65.17	7.02	1.75	35.77	149.54
	Winnipeg	5709.08	8.24	65.17	7.02	1.75	35.77	149.54
Central	Toronto	5709.08	8.24	65.17	7.02	1.75	35.77	149.54
East	Montreal	5709.08	8.24	65.17	7.02	1.75	35.77	149.54
	Halifax	5709.08	8.24	65.17	7.02	1.75	35.77	149.54
Aggregates Transportation								
West Coast	Vancouver	6736.97	9.72	76.90	8.28	2.07	42.21	0.00
Prairie	Calgary	6736.97	9.72	76.90	8.28	2.07	42.21	0.00
	Winnipeg	6736.97	9.72	76.90	8.28	2.07	42.21	0.00
Central	Toronto	6736.97	9.72	76.90	8.28	2.07	42.21	0.00
East	Montreal	6736.97	9.72	76.90	8.28	2.07	42.21	0.00
	Halifax	6736.97	9.72	76.90	8.28	2.07	42.21	0.00
Concrete Production								
West Coast	Vancouver	111455.40	44.77	447.36	39.81	11.56	217.36	184.62
Prairie	Calgary	111455.40	44.77	447.36	39.81	11.56	217.36	184.62
	Winnipeg	111455.40	44.77	447.36	39.81	11.56	217.36	184.62
Central	Toronto	111455.40	44.77	447.36	39.81	11.56	217.36	184.62
East	Montreal	111455.40	44.77	447.36	39.81	11.56	217.36	184.62
	Halifax	149427.84	243.72	452.23	38.84	9.71	218.17	184.62
Cement								
West Coast	Vancouver	266572.01	31.67	1540.85	17.19	3.79	90.68	442.71
Prairie	Calgary	242369.31	21.90	2020.65	19.05	5.37	88.35	594.08
	Winnipeg	263856.94	52.90	2520.08	38.22	6.01	57.55	594.08
Central	Toronto	274236.20	48.66	611.27	13.21	2.91	119.51	394.38
East	Montreal	299550.54	75.63	1046.42	12.29	3.41	134.62	566.68
	Halifax	299824.82	80.20	1035.83	16.07	3.84	134.62	480.13
Processing Sub-total								
West Coast	Vancouver	378027.41	76.44	1988.21	57.00	15.35	308.04	627.33
Prairie	Calgary	353824.71	66.67	2468.01	58.86	16.94	305.71	778.69
	Winnipeg	375312.34	97.67	2967.44	78.03	17.57	274.91	778.69
Central	Toronto	385691.60	93.43	1058.63	53.02	14.47	336.87	578.99
East	Montreal	411005.94	120.40	1493.78	52.10	14.97	351.98	751.30
	Halifax	449252.66	323.92	1488.05	54.91	13.55	352.79	664.74
Total								
West Coast	Vancouver	390473.46	94.39	2130.27	72.30	19.17	386.03	776.86
Prairie	Calgary	366270.76	84.62	2610.08	74.16	20.76	383.70	928.23
	Winnipeg	387758.39	115.62	3109.50	93.32	21.39	352.90	928.23
Central	Toronto	398137.65	111.38	1200.70	68.31	18.29	414.86	728.53
East	Montreal	423451.99	138.36	1635.85	67.40	18.79	429.97	900.83
	Halifax	461698.71	341.88	1630.12	70.20	17.37	430.78	814.28

TABLE 5.4.7
CONCRETE BRICK EMISSIONS [GRAMS/1000 B2 BRICKS]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Aggregates Extraction								
West Coast	Vancouver	4967.74	7.17	56.70	6.11	1.52	31.13	130.12
Prairie	Calgary	4967.74	7.17	56.70	6.11	1.52	31.13	130.12
	Winnipeg	4967.74	7.17	56.70	6.11	1.52	31.13	130.12
Central	Toronto	4967.74	7.17	56.70	6.11	1.52	31.13	130.12
East	Montreal	4967.74	7.17	56.70	6.11	1.52	31.13	130.12
	Halifax	4967.74	7.17	56.70	6.11	1.52	31.13	130.12
Aggregates Transportation								
West Coast	Vancouver	5862.16	8.46	66.91	7.21	1.80	36.73	0.00
Prairie	Calgary	5862.16	8.46	66.91	7.21	1.80	36.73	0.00
	Winnipeg	5862.16	8.46	66.91	7.21	1.80	36.73	0.00
Central	Toronto	5862.16	8.46	66.91	7.21	1.80	36.73	0.00
East	Montreal	5862.16	8.46	66.91	7.21	1.80	36.73	0.00
	Halifax	5862.16	8.46	66.91	7.21	1.80	36.73	0.00
Concrete Production								
West Coast	Vancouver	96982.61	38.95	389.27	34.64	10.06	189.14	160.64
Prairie	Calgary	96982.61	38.95	389.27	34.64	10.06	189.14	160.64
	Winnipeg	96982.61	38.95	389.27	34.64	10.06	189.14	160.64
Central	Toronto	96982.61	38.95	389.27	34.64	10.06	189.14	160.64
East	Montreal	96982.61	38.95	389.27	34.64	10.06	189.14	160.64
	Halifax	130024.22	212.07	393.50	33.79	8.45	189.84	160.64
Cement								
West Coast	Vancouver	231956.91	27.56	1340.77	14.96	3.30	78.90	385.22
Prairie	Calgary	210896.99	19.06	1758.27	16.57	4.67	76.88	516.94
	Winnipeg	229594.39	46.03	2192.84	33.25	5.23	50.08	516.94
Central	Toronto	238625.87	42.34	531.90	11.49	2.53	103.99	343.17
East	Montreal	260653.08	65.81	910.54	10.70	2.97	117.14	493.10
	Halifax	260891.74	69.79	901.32	13.98	3.34	117.14	417.78
Processing Sub-total								
West Coast	Vancouver	328939.52	66.51	1730.03	49.60	13.36	268.04	545.87
Prairie	Calgary	307879.60	58.01	2147.53	51.22	14.74	266.01	677.58
	Winnipeg	326577.00	84.99	2582.11	67.89	15.29	239.21	677.58
Central	Toronto	335608.48	81.29	921.16	46.13	12.59	293.13	503.81
East	Montreal	357635.69	104.77	1299.81	45.34	13.03	306.28	653.74
	Halifax	390915.97	281.86	1294.83	47.78	11.79	306.98	578.42
Total								
West Coast	Vancouver	339769.41	82.14	1853.65	62.91	16.68	335.90	675.99
Prairie	Calgary	318709.49	73.64	2271.15	64.53	18.06	333.87	807.70
	Winnipeg	337406.90	100.61	2705.72	81.21	18.62	307.07	807.70
Central	Toronto	346438.38	96.92	1044.78	59.44	15.92	360.99	633.93
East	Montreal	368465.59	120.39	1423.43	58.65	16.35	374.13	783.86
	Halifax	401745.86	297.48	1418.44	61.09	15.12	374.84	708.54

TABLE 5.5.1
ATMOSPHERIC EMISSIONS DUE TO CEMENT MORTAR PRODUCTION
(GRAMS/M³)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Aggregate Extraction								
West Coast	Vancouver	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Prairie	Calgary	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
	Winnipeg	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Central	Toronto	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
East	Montreal	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
	Halifax	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Aggregate Transportation								
West Coast	Vancouver	1964.68	2.83	22.43	2.41	0.60	12.31	0.00
Prairie	Calgary	1964.68	2.83	22.43	2.41	0.60	12.31	0.00
	Winnipeg	1964.68	2.83	22.43	2.41	0.60	12.31	0.00
Central	Toronto	1964.68	2.83	22.43	2.41	0.60	12.31	0.00
East	Montreal	1964.68	2.83	22.43	2.41	0.60	12.31	0.00
	Halifax	1964.68	2.83	22.43	2.41	0.60	12.31	0.00
Concrete Processing								
West Coast	Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Prairie	Calgary	0.00	0.00	0.00	0.00	0.00	0.00	120.00
	Winnipeg	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Central	Toronto	0.00	0.00	0.00	0.00	0.00	0.00	120.00
East	Montreal	0.00	0.00	0.00	0.00	0.00	0.00	120.00
	Halifax	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Cement Production								
West Coast	Vancouver	245135.69	29.13	1416.94	15.81	3.49	83.39	407.11
Prairie	Calgary	222879.24	20.14	1858.16	17.52	4.94	81.24	546.31
	Winnipeg	242638.95	48.65	2317.43	35.14	5.53	52.92	546.31
Central	Toronto	252183.56	44.75	562.12	12.14	2.67	109.90	362.66
East	Montreal	275462.26	69.55	962.28	11.30	3.13	123.80	521.11
	Halifax	275714.48	73.75	952.53	14.78	3.53	123.80	441.52
Processing Sub-total								
West Coast	Vancouver	245135.69	29.13	1416.94	15.81	3.49	83.39	527.11
Prairie	Calgary	222879.24	20.14	1858.16	17.52	4.94	81.24	666.31
	Winnipeg	242638.95	48.65	2317.43	35.14	5.53	52.92	666.31
Central	Toronto	252183.56	44.75	562.12	12.14	2.67	109.90	482.66
East	Montreal	275462.26	69.55	962.28	11.30	3.13	123.80	641.11
	Halifax	275714.48	73.75	952.53	14.78	3.53	123.80	561.52
TOTAL								
West Coast	Vancouver	248598.86	34.12	1456.47	20.07	4.55	105.09	566.36
Prairie	Calgary	226342.41	25.14	1897.69	21.77	6.00	102.94	705.56
	Winnipeg	246102.12	53.64	2356.96	39.40	6.59	74.62	705.56
Central	Toronto	255646.73	49.74	601.65	16.40	3.74	131.60	521.91
East	Montreal	278925.43	74.55	1001.81	15.56	4.20	145.50	680.36
	Halifax	279177.65	78.75	992.06	19.03	4.59	145.50	600.77

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6.0 EMISSIONS TO WATER

This section addresses effluent associated with brick production. Water is one of the basic components of any brick material, making the raw brick mix plastic and enabling brick formation. It constitutes about 12 to 14% by volume of the clay brick mix, 8% of the sand-lime brick raw materials, about 3% by weight of the concrete brick mix, and 14.5% by weight of the cement mortar. In the extraction of the brick raw materials, the mining and quarrying of clays, shales, limestone and aggregates, large volumes of water are generated. Water therefore plays a direct role in the production of all bricks considered in this study.

6.1 Clay Brick

We were not able to find any information or references in the literature regarding liquid effluents associated with clay brick operations. The brick manufacturing process itself generates hardly any process effluent. The results of the industry survey[6] indicate that Canadian brick plants operate a closed loop water system, and that they recycle their process water. Brick operations, however, do use some water to clean equipment and yards. In addition, rainwater washes away clay dust into containment areas. This “brickyard effluent” is treated in settling ponds. Whereas the sediment from the bottom of the ponds is usually landfilled (see Section 7.1), water is recycled.

While only limited data on water usage and effluent associated with the clay brick production came from the industry, we were able to obtain some detailed monitoring data concerning Ontario brick plants from the Environmental Monitoring and Reporting Branch of the Ontario Ministry of the Environment (MOE) from their MISA program.[5] The MOE MISA provides only the total effluent monitoring information, it does not differentiate between the individual processing steps of the production. Most of the data is from large integrated operations, including both the extraction of the raw materials and the actual brick production. As, according to the industry, most of the process water is recycled back into the production, we assume that the effluent is generated mainly in the winning and preparation of the clay / shale. The quarrying of clays or shales generates regular and often fairly substantial volumes of “quarry effluent”. Sudden storms can also create “stormwater effluent” at quarries. MOE MISA data generated in the early 1990s is providing the total flows and pollutants concentrations as well as daily and annual effluent loadings.

In the absence of more detailed information from various brick operations across the country, and considering the fact that the overwhelming portion of the industry is concentrated in Ontario, we will use the MOE data as representative of clay brick industry for all regions.

Effluent flow rates vary in the range of 250 to 1080 m^3 per day, with the average flow for different operations usually in the range of 500 to 700 m^3 per day. In Table 6.1.1 average pH, conductivity and concentration of various pollutants in milligrams per liter of effluent are shown, as is their average annual loading. From the brick production volume the effluent load in grams per tonne, per m^3 and per 1000 Ontario bricks was estimated. Tables 6.1.2 and 6.1.3 show average effluent loadings for eight types of typical Canadian bricks.

TABLE 6.1.1
AVERAGE EFFLUENT FROM CLAY BRICK PRODUCTION

pH	7.83				
conductance @ 25C [µS/cm]	1717				
	concentration	***annual loading***	***effluent load***		
	mg/L	kg/year	g/tonne of bricks	g/m^3 of bricks	g/1000 Ontario bricks
total suspended solids	258.4890	58164.7930	214.67201	308.26901	401.85948
dissolved organic compounds (DOC)	3.6500	951.7375	4.23679	6.08403	7.93115
ammonium	0.9350	135.7754	0.60442	0.86795	1.13146
phenolics	0.0019	0.2187	0.00114	0.00163	0.00213
cyanide	0.0013	0.3495	0.00156	0.00223	0.00291
sulfur compounds	105.0800	35680.5750	158.83705	228.09000	297.33812
iron	11.4000	1342.1050	5.97457	8.57948	11.18421
non-ferrous metals					
aluminum	11.5000	1381.5250	6.15005	8.83147	11.51271
copper	0.0090	1.2556	0.00559	0.00803	0.01046
zinc	0.1035	13.5798	0.06045	0.08681	0.11317

TABLE 6.1.2
AVERAGE EFFLUENT ASSOCIATED WITH CLAY BRICK PRODUCTION

	Ontario	***Metric Modular***	***CSR***	***MAX***
volume [m^3/1000 bricks]	1.3036	0.9747	1.4490	1.8273
pH	7.83			
conductance @ 25C [µS/cm]	1717			
	[g/1000 brick]			
total suspended solids	401.85948	300.46980	446.68182	563.29995
dissolved organic compounds (DOC)	7.93115	5.93011	8.81576	11.11735
ammonium	1.13146	0.84599	1.25766	1.58601
phenolics	0.00213	0.00159	0.00237	0.00298
cyanide	0.00291	0.00218	0.00324	0.00408
sulfur compounds	297.33812	222.31932	330.50241	416.78886
iron	11.18421	8.36242	12.43166	15.67728
non-ferrous metals				
aluminum	11.51271	8.60804	12.79680	16.13775
copper	0.01046	0.00782	0.01163	0.01467
zinc	0.11317	0.08461	0.12579	0.15863

TABLE 6.1.3
AVERAGE EFFLUENT ASSOCIATED WITH CLAY BRICK PRODUCTION

	Metric Closure	Metric Jumbo	Engineer Norman	Metric Norman
volume [m3/1000 bricks]	1.5390	2.3490	1.8270	1.4877
pH	7.83			
conductance @ 25C [µS/cm]	1717			
	[g/1000 brick]			
total suspended solids	474.42600	724.12209	563.20747	458.61180
dissolved organic compounds (DOC)	9.36333	14.29139	11.11553	9.05122
ammonium	1.33578	2.03882	1.58575	1.29125
phenolics	0.00251	0.00383	0.00298	0.00243
cyanide	0.00344	0.00525	0.00408	0.00332
sulfur compounds	351.03051	535.78341	416.72043	339.32950
iron	13.20382	20.15320	15.67471	12.76369
non-ferrous metals				
aluminum	13.59164	20.74513	16.13510	13.13858
copper	0.01235	0.01885	0.01466	0.01194
zinc	0.13360	0.20392	0.15860	0.12915

6.2 Calcium Silicate Brick

In comparison with many other building materials, calcium silicate brick uses relatively little water in its production. The overall water management in the sand-lime brick industry as well as effluent characteristics are rather similar to those of the concrete industry, discussed in detail in the ATHENA™ Cement and Concrete report[1] and reviewed in this study in Section 6.3. Considering the similarities of sand-lime brick and concrete masonry brick, both types of products using alkaline binders originating from decomposition of limestone, same type of aggregates and similar brick processing, it is not surprising.

Sand-lime brick raw materials extraction and processing is associated with effluent discharges. Mining or quarrying of gypsum rock generates regular and often fairly substantial volumes of “minewater” or “quarry effluent”. Sudden storms can also create “stormwater effluent” at quarries. In brick composition, water constitutes about 8% of the raw materials mix (Table 3.1). In addition, water is used in brick making operations for housekeeping and equipment clean up. While effluent discharges are perhaps negligible in comparison to the atmospheric emissions, they should not be ignored.

In our estimates, effluent from the following three sources were combined to estimate total effluent associated with sand-lime brick production:

- effluent from lime production;
- effluent from aggregate production; and
- effluent from brick manufacturing.

6.2.1 Lime Production

Detailed information regarding quarry water and stormwater from limestone quarries was obtained from the Water Resources Branch of the Ontario Ministry of Energy and Environment under its MISA program[2] for the Cement and Concrete study[1]. For the lime plants, as it was beyond the scope of this study to investigate the lime industry in detail, we assume that its effluent discharges are similar to those of the cement plants. Due to the similarities in water use of the two industries, we believe that any error is negligible.

6.2.2 Aggregate Production

Average aggregate quarry effluent data were developed on the basis of random sampling of a few quarries by the Water Resources Branch of the Ontario Ministry of Energy and Environment[3], as the Ministry does not normally monitor the aggregate industry. In addition to quarry and stormwater, another effluent source is washing water, as aggregates frequently have to be washed before use. An important difference between lime and aggregate production effluents is in the size of the suspended solids particles. Suspended solids from aggregate quarries tend to be larger than those from limestone quarries, resulting in faster settling rates. Effluent from aggregate production are discussed in further detail in Section 14.1 of the Cement and Concrete study.[1]

6.2.3 Sand-Lime Brick Processing

In the absence of any information regarding the effluent due to sand-lime brick processing, considering the similarity between concrete brick and sand-lime brick forming and curing process, we assume the same effluent volume of 12.5 l/m^3 and the same pollutants for the sand-lime brick as for concrete masonry brick.[4]

6.2.4 Sand-Lime Brick Effluent Summary

Effluent volume, pH and pollutant concentration estimates from all three calcium silicate brick process stages are summarized in Table 6.2.1. The estimates for liquid effluent flows per tonne of lime and aggregate were then adjusted to take into account the volumes of these materials used in the calcium silicate brick (from Table 3.1). The resulting estimates of effluent flow per unit of brick production were added to the effluent flow from the brick manufacturing step (Table 14.3) to produce the estimates of total effluent flows per unit of brick, expressed alternately per tonne, m^3 or 1000 of CB25, ES26 or VB31 bricks, and shown in Table 6.2.2

TABLE 6.2.1
EFFLUENT FROM INDIVIDUAL PRODUCTION STAGES

	Lime Production			*Aggregate Production*	*Brick Production*
	Lime Plant	*Quarry water*	*Stormwater*		
Flow	3295.43 [L/t of lime]	1827.46 [L/t of lime]	3.55 [L/t of lime]	234.88 [L/t of aggregate]	12.50 [L/m^3 of sand-lime brick mix]
pH	8.30	8.21	8.84	7.85	8.00
			[mg/L of effluent]		
Suspended Solids	59.04	103.70	137.62	8.68	87.50
Aluminum	0.16	0.76			
Phenolics	0.00	0.01	0.00		
Oil & Grease	1.41	1.77	0.67	0.97	7.50
Nitrate, Nitrite	0.42	2.90	1.96		
DOC	2.60	2.49			
Chlorides	44.92	1290.03	162.55		
Sulfates	104.57	217.71	163.59		
Sulfides	0.00	0.04			
Ammonia, -um		1.41			
Phosphorus		0.01			
Zinc	0.00	0.00			

* DOC - dissolved organic compounds
Notes: Lime plant and quarry water data are based on 365 days/year
Stormwater data as per occurrence, assumed 7 occurrences per year
pH is the symbol used to express the acidity or alkalinity of a solution on a scale from 0 to 14, where less than 7 represents the degree of acidity, 7 represent neutrality, and more than 7 represents the degree of alkalinity .

TABLE 6.2.2
RAW MATERIALS USAGE AND ASSIGNED EFFLUENT FLOW PER TONNE OF SAND-LIME BRICK

tonnes of lime/tonne of bricks	0.06
tonnes of aggregates/tonne of bricks	0.94
liters of lime plant water / tonne	197.73
liters of quarry water /tonne	109.65
liters of stormwater / tonne	0.21
liters of aggregate quarry water / tonne	220.79
liters of sand-lime brick process water / tonne	12.5
total liters/tonne of bricks	***540.87***
total liters/m^3 of bricks	1116.36
total liters/1000 CB25 bricks	2229.53
total liters/1000 ES26 bricks	1599.64
total liters/1000 VB31 bricks	2017.23

Table 6.2.3 presents the final estimates of weighted average effluent characteristics per liter of effluent flow for calcium silicate brick. These estimates were derived by combining the relevant data from Table 6.2.1 with adjustments to reflect the product formulation from Table 3.1.

TABLE 6.2.3
WEIGHTED AVERAGE EFFLUENT OF SAND-LIME BRICKS

pH	8.09
	[mg/L of effluent]
Suspended Solids	48.2255
Aluminum	0.2111
Phenolics	0.0033
Oil & Grease	1.4435
Nitrate, Nitrite	0.7433
DOC	1.4542
Chlorides	278.0028
Sulfates	82.4274
Sulfides	0.0084
Ammonia, -um	0.2855
Phosphorus	0.0016
Zinc	0.0000

* DOC - Dissolved organic compounds

Combining the pollutant estimates from Table 6.2.3 with the flow estimates from Table 6.2.2 yields the effluent estimates per unit of sand-lime brick production shown in Table 6.2.4 (in total as well as broken down to the individual effluent sources), expressed in grams per tonne of bricks. In Table 6.2.5 the total weighted average effluent is further expressed in grams/m^3 and grams per 1000 CB25, ES26 and VB31 sand-lime bricks..

TABLE 6.2.4
WEIGHTED AVERAGE EFFLUENT FROM SAND-LIME BRICK PRODUCTION
[G/TONNE OF BRICKS]

	lime plant	quarry water	storm water	aggregate	brick processing	total
Suspended Solids	11.6740	11.3704	0.0293	1.9164	1.0938	26.0839
Aluminum	0.0308	0.0834	0.0000	0.0000	0.0000	0.1142
Phenolics	0.0004	0.0014	0.0000	0.0000	0.0000	0.0018
Oil & Grease	0.2783	0.1943	0.0001	0.2142	0.0938	0.7808
Nitrate, Nitrite	0.0839	0.3178	0.0004	0.0000	0.0000	0.4020
DOC	0.5138	0.2727	0.0000	0.0000	0.0000	0.7865
Chlorides	8.8810	141.4487	0.0346	0.0000	0.0000	150.3644
Sulfates	20.6767	23.8712	0.0348	0.0000	0.0000	44.5828
Sulfides	0.0006	0.0040	0.0000	0.0000	0.0000	0.0046
Ammonia, -um	0.0000	0.1544	0.0000	0.0000	0.0000	0.1544
Phosphorus	0.0000	0.0009	0.0000	0.0000	0.0000	0.0009
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* DOC - Dissolved organic compounds

TABLE 6.2.5
WEIGHTED AVERAGE EFFLUENT FROM SAND-LIME BRICK PRODUCTION

			CB25	ES26	VB31
	[g/tonne of bricks]	g/m3	g/1000 bricks	g/1000 bricks	g/1000 bricks
Suspended Solids	26.0839	53.8371	107.5201	77.1432	97.2819
Aluminum	0.1142	0.2356	0.4706	0.3376	0.4258
Phenolics	0.0018	0.0037	0.0074	0.0053	0.0067
Oil & Grease	0.7808	1.6115	3.2183	2.3091	2.9119
Nitrate, Nitrite	0.4020	0.8298	1.6572	1.1890	1.4994
DOC	0.7865	1.6234	3.2422	2.3262	2.9335
Chlorides	150.3644	310.3521	619.8153	444.7035	560.7960
Sulfates	44.5828	92.0189	183.7743	131.8539	166.2752
Sulfides	0.0046	0.0094	0.0188	0.0135	0.0170
Ammonia, -um	0.1544	0.3188	0.6366	0.4568	0.5760
Phosphorus	0.0009	0.0018	0.0035	0.0025	0.0032
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000

* DOC - Dissolved organic compounds

6.3 Concrete Masonry Brick

6.3.1 Three Sources of Effluent

In comparison with other concrete products, concrete masonry products use relatively small amounts of water. Even they, however, contain about 3% by weight of mix water. In addition, water is used extensively in concrete operations for housekeeping and equipment clean up.[1] Water use and management is discussed in detail in Section 12 of the ATHENA™ Cement and Concrete study.[1]

Use of water in concrete processing and in production of its constituent raw materials result in some effluent. Effluent from the following three sources were combined to estimate total effluent associated with concrete production:

- effluent from cement production;
- effluent from aggregate production; and
- effluent from concrete manufacturing.

There are three specific environmental concerns regarding effluent from concrete production facilities:

- *pH:* High pH is toxic to fish. A pH of 9.0–9.5 is likely harmful to salmonid fish, and a pH >10 will kill salmonid fish in minutes.

- *Total suspended solids (TSS):* High TSS is harmful to fish, contributes to oxygen depletion, may contain leachable toxic substances, and can destroy habitat.

- *Oil and grease:* Oil and grease in effluent typically arises from mechanical equipment and is toxic to aquatic organisms. The level of concern is highly variable with species. Crude oil, for example, is extremely toxic at 0.3 mg/L.

While the above issues are mainly of concern in the ready mixed concrete plants due to their higher water consumption, they are also valid for any other concrete products, including concrete brick and cement mortar.

Effluent from cement production, aggregates extraction and processing, and concrete processing were discussed respectively in Sections 6.0, 14.1 and 14.2 of the ATHENA™ Cement and Concrete study[1]. We will, therefore, limit ourselves here to the summary tables of effluent from the above three sources only, referring the parties interested in more detail back to that study.

TABLE 6.3.1
EFFLUENT DUE TO PRODUCTION OF CEMENT
(G/TONNE OF CEMENT)

	Cement Plant		***Quarry water***		***Stormwater***		***Total***
	(wght. avg.)	(range)	(wght. avg.)	(range)	(wght. avg.)	(range)	(wght. avg.)
Suspended Solids	118.73	19.52-200.05	93.16	15.17-363.46	0.72	11.13-81.6	212.61
Aluminum	0.48	0.04-1.08	0.30	0.00-0.53			0.78
Phenolics	0.01	0.00-0.01	0.01	0.00-0.02	0.00	0.00	0.01
Oil & Grease	4.27	1.63-6.65	2.55	0.25-12.21	0.00	0.00-0.52	6.83
Nitrate, Nitrite	1.41	0.28-3.10	3.93	0.23-11.09	0.01	0.15-0.97	5.35
DOC*	8.16	0.30-14.67	4.34	0.09-16.63			12.49
Chlorides	137.06	39.5- 353.0	521.87	18.01-1247.5	1.04	2.37-85.50	659.97
Sulfates	253.62	46.0- 868.1	303.82	60.2-1027.6	1.05	3.57-83.03	558.49
Sulfides	0.01	0.00-0.09	0.05	0.00-0.33			0.06
Ammonia, -um			0.86	0.09-1.83			0.86
Phosphorus			0.00	0.00-0.01			0.00
Zinc	0.01	0.00-0.11	0.02	0.00-0.18			0.02

* DOC - dissolved organic compounds
Notes: Calculations assume 59.2% industry utilization ;
Cement plant and quarry water data are based on 365 days/year;
Stormwater data as per occurrence, assumed 7 occurrences per year.

TABLE 6.3.2
EFFLUENT DUE TO PRODUCTION OF CEMENT
(MG/L OF EFFLUENT)

	Cement Plant		***Quarry water***		***Stormwater***	
	(wght. avg.)	(range)	(wght. avg.)	(range)	(wght. avg.)	(range)
Suspended Solids	59.04	10.34-150.89	103.70	24.68-219.22	137.62	32.09-249.27
Aluminum	0.16	0.05-0.29	0.76	0.00-1.66		
Phenolics	0.00	0.00-0.01	0.01	0.00-0.03	0.00	0.00-0.01
Oil & Grease	1.41	1.18-2.41	1.77	0.89-3.07	0.67	0.00-1.49
Nitrate, Nitrite	0.42	0.00-0.57	2.90	0.27-6.76	1.96	0.42-5.26
DOC*	2.60	0.45-5.00	2.49	0.27-4.68		
Chlorides	44.92	14.51-134.57	1290.03	17.41-3930.89	162.55	12.78-262.10
Sulfates	104.57	20.14-584.81	217.71	81.48-331.77	163.59	19.28-239.39
Sulfides	0.00	0.00-0.02	0.04	0.00-0.10		
Ammonia, -um			1.41	0.31-3.46		
Phosphorus			0.01	0.00-0.04		
Zinc	0.00	0.00-0.11	0.00	0.00		
pH	8.30	8.25-8.41	8.21	7.79-8.88	8.84	8.13-10.5

* DOC - dissolved organic compounds
Notes: Cement plant and quarry water data are based on 365 days/year
Stormwater data as per occurrence, assumed 7 occurrences per year
pH is the symbol used to express the acidity or alkalinity of a solution on a scale from 0 to 14, where less than 7 represents the degree of acidity, 7 represent neutrality, and more than 7 represents the degree of alkalinity .

TABLE 6.3.3
EFFLUENT DUE TO THE PRODUCTION OF AGGREGATE

	Units	Average	Range
pH		7.85	7.4–8.3
Suspended Solids	[mg/L of effluent]	8.68	4.24–12.60
Oil and Grease	[mg/L of effluent]	0.97	0.0–2.9
Flow	[m^3/day]	1016	40–2880

TABLE 6.3.4
EFFLUENT CHARACTERISTICS FROM CONCRETE MANUFACTURING

	pH	TSS [mg/L]	Oil and Grease [mg/L]	Flow [L/m^3 of concrete]
Concrete Brick	8	87.5	7.5	12.5
Cement Mortar	8	87.5	7.5	25

TSS - total suspended solids

6.3.2 Estimate of Effluent for Concrete Brick Production

Our estimate of total effluent from all stages of concrete brick production was derived by combining the above estimates for cement and aggregate production and concrete processing. To derive the totals, we first had to estimate the total effluent flow from cement, aggregate and concrete production for the concrete brick. The effluent characteristics could then be applied to the flow to estimate total liquid effluent per m^3 of concrete brick mix or, eventually, per 1000 bricks.

For a cement plant, the weighted average effluent flow is about 3,295 litres per tonne of cement; for quarry water, it is about 1,827 litres per tonne of cement; and for stormwater, assuming an average of seven storm occurrences per year, it is about 3.5 litres per tonne of cement.[1] For aggregate, a weighted average discharge flow of 235 liters of effluent per tonne of coarse or fine aggregate was estimated.[1]

The above estimates for effluent flows per tonne of cement and aggregate were then adjusted to take into account the volumes of these materials used in the concrete masonry brick (from Table 3.1). The resulting estimates of effluent flow per m^3 of concrete brick were added to the effluent flows from the concrete manufacturing step (Table 6.3.4) to derive the estimates of total effluent flows per m^3 of concrete brick shown in Table 6.3.5.

TABLE 6.3.5
ESTIMATED EFFLUENT FLOWS FOR CONCRETE BRICK (LITERS/M^3 OF CONCRETE)

Cement plant water	715.11
Quarry water	396.56
Stormwater	0.77
Aggregate quarry water	456.61
Concrete process water	12.5
Total	1581.54

The first column of Table 6.3.6 presents the final estimates of weighted average effluent characteristics per liter of effluent flow for concrete masonry brick. Further, combining these with the flow estimates from Table 6.3.5 yields the liquid effluent estimates per m^3 of concrete and/or 1000 concrete bricks of various CSA types, as per Section 4.3.

TABLE 6.3.6
WEIGHTED AVERAGE EFFLUENT FOR CONCRETE MASONRY BRICK

			A1	***A2***	***B1***	***B2***
	[mg/L of effluent]	[g/m^3]	[g/1000 bricks]			
pH	8.15					
Suspended Solids	55.9624	88.5070	86.2641	75.0059	136.1646	118.4832
Aluminum	0.2611	0.4129	0.4024	0.3499	0.6352	0.5527
Phenolics	0.0041	0.0065	0.0063	0.0055	0.0100	0.0087
Oil & Grease	1.4206	2.2468	2.1898	1.9040	3.4566	3.0077
Nitrate, Nitrite	0.9194	1.4540	1.4172	1.2322	2.2370	1.9465
DOC	1.7987	2.8446	2.7726	2.4107	4.3764	3.8081
Chlorides	343.8525	543.8179	530.0369	460.8626	836.6429	728.0025
Sulfates	101.9517	161.2412	157.1551	136.6451	248.0633	215.8516
Sulfides	0.0104	0.0165	0.0161	0.0140	0.0253	0.0221
Ammonia, -um	0.3532	0.5586	0.5444	0.4734	0.8593	0.7477
Phosphorus	0.0020	0.0031	0.0030	0.0026	0.0048	0.0042
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* DOC - Dissolved organic compounds

6.4 Cement Mortar

Liquid effluent for the cement mortar was derived in a similar manner to that for concrete brick, both being mixes containing cement, aggregate and water. Data from Tables 6.3.1 through to 6.3.4 are therefore equally applicable to cement mortar as well, and serve as a base for extrapolation of effluent estimates for this product.

Using analogous methodology, the following effluent estimates were developed:

TABLE 6.4.1
ESTIMATED EFFLUENT FLOWS FOR CONCRETE BRICK
(LITERS/M^3 OF CONCRETE)

Cement plant water	1011.70
Quarry water	561.03
Stormwater	1.09
Aggregate quarry water	184.38
Concrete process water	25
Total	1783.20

TABLE 6.4.2
WEIGHTED AVERAGE EFFLUENT FOR CEMENT MORTAR

	[mg/L of effluent]	[g/m^3]
pH	8.22	
Suspended Solids	68.3314	121.8484
Aluminum	0.3276	0.5841
Phenolics	0.0051	0.0092
Oil & Grease	1.5622	2.7857
Nitrate, Nitrite	1.1536	2.0571
DOC	2.2569	4.0245
Chlorides	431.4521	769.3644
Sulfates	127.9249	228.1154
Sulfides	0.0131	0.0233
Ammonia, -um	0.4431	0.7902
Phosphorus	0.0025	0.0044
Zinc	0.0000	0.0000

* DOC - Dissolved organic compounds

While the above effluent estimates are tabulated in grams per m^3 of cement mortar, if desired they can be multiplied by appropriate factors, such as those in Table 4.4.3 for typical concrete masonry bricks, to estimate effluent discharges associated with the cement mortar use expressed per 1000 bricks of the given size at the typical 10 mm (3/8") mortar bed thickness.

References

1. *"Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates: Cement and Structural Concrete Products"*, CANMET and Radian Canada Inc., prepared for the ATHENA™ Sustainable Materials Institute, Ottawa, October 1993.
2. Data from Ontario Ministry of Energy and Environment, Water Resources Branch, G. Rees, 4/19/93, *MISA Monitoring Data for Ontario Limestone Quarries and Cement Plants*.
3. Verbal information, Dr. K. Donyina, Ontario Ministry of Energy and Environment, Water Resources Branch, 8/31/93.
4. *"Present and Future Use of Energy in the Cement and Concrete Industries in Canada"*, Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993.
5. Data from Ontario Ministry of the Environment, Environmental Monitoring and Reporting Branch, A. Radman, 7/28/98, *MISA Monitoring Data for Ontario Clay Quarries and Brick Plants*.
6. Confidential Canadian clay brick industry survey, prepared for VG&A and the ATHENA™ study, and consolidated by Martyn, Dooley & Partners, June 1998.

7.0 SOLID WASTES

This section addresses solid waste produced by the respective brick industries, including off-specification products, equipment cleanout residues, sediment residues from wastewater treatment systems, and also wastes associated with cement and aggregate production where applicable.

7.1 Clay Brick

In extracting clay or shale, overburden, top soil and subsoil have to be removed before a new quarry can commence operation. The industry survey indicates that up to 0.2 tonnes of such materials are generated per tonne of extracted clay / shale.[8] While some soil can be resold, in modern operations it is stockpiled for eventual open pit reclamation and is not considered waste.

In the clay brick industry, all off-specification green brick is recycled back into the production. Most of the finished ware that is either damaged in the processing, handling or transport, or does not meet specifications, can also be recycled back into the raw materials, perhaps to the tune of 4 to 8% by volume of the total raw materials.[7] If not recycled back into production, such solid waste is landfilled. Another source of solid waste is the sludge settled at the bottoms of the effluent settling ponds, which is only rarely reused in the production, and is usually landfilled.

The industry survey[8] indicates that the solid waste <u>not</u> recycled back into production equals 11.352 kg/tonne of bricks produced. Table 7.1.1 also provides the solid waste estimate per m^3 of finished bricks and per 1000 of the most typical Canadian bricks.

TABLE 7.1.1
SOLID WASTE DUE TO CLAY BRICK PROCESSING

Clay Brick	[kg/tonne]	11.3520
	[kg/m^3]	16.3015
Ontario	[kg/1000 bricks]	21.2500
Metric Modular	“	15.8891
CSR	“	23.6209
MAX	“	29.7873
Metric Closure	“	25.0880
Metric Jumbo	“	38.2923
Engineer Norman	“	29.7829
Metric Norman	“	24.2518

7.2 Calcium Silicate Brick

The lime manufacturing process, similarly to cement processing, generates lime fines. However, in comparison with production of cement, which generates a significant volume of cement kiln dust (CKD), a portion of which cannot be reused or recycled and therefore is considered solid waste (Section 7.2.1 of the Cement and Concrete study[2]), lime fines volume is relatively small, and in the recent years, industry found markets for them. In our discussion with the Canadian lime producers during the recent survey[6], all of them indicated that lime fines are sold and fully utilized by the paper, chemical and mining industries, in agricultural applications, as well as in waste management (solidification and stabilization) and water treatment. There is no waste lime dust. However, as the fines quantities are not significant, we made no co-product allocation for them.

That leaves in our discussion of solid waste from the sand-lime brick only one source, off-specification products and a small amount of wastes from sand-lime mix processing, such as mixer washout residue and sludges from settling basins. While we lack the specific information pertaining to waste solids generated in the sand-lime brick processing, due to the process similarity to that of concrete brick forming, curing and drawing, we assume that solid waste estimates developed for concrete products[2], as applied to concrete masonry brick (discussed in Section 7.3 of this report), are also applicable to the sand-lime brick. That estimate comes to 2.59 kg/m^3. Table 7.2.1 shows this solid waste estimate expressed also per tonne of bricks and per 1000 CB25, ES26 and VB31 types of sand-lime bricks.

TABLE 7.2.1
SOLID WASTE DUE TO SAND-LIME BRICK PROCESSING

Sand-Lime Brick	[kg/m^3]	2.5900
	[kg/tonne]	1.2548
CB25 Brick	[kg/1000 bricks]	5.1726
ES26 Brick	[kg/1000 bricks]	3.7112
VB31 Brick	[kg/1000 bricks]	4.6800

7.3 Concrete Masonry Brick

7.3.1 Solid Wastes from Concrete Raw Materials

Solid wastes generated in the production of cements were discussed in some detail in Section 8.0 of the ATHENA™ Cement and Concrete study.[2] As noted there, solid wastes associated with the cement industry include waste from the extraction of raw materials, cement kiln dust (CKD) generated during cement pyroprocessing, and spent refractory bricks (SRB) from rotary cement kilns. Of these solid wastes, only CKD is generated in significant volumes, and as such is addressed in our estimates. An abbreviated version of unit factor estimates for discarded waste CKD in the six specified metropolitan areas is shown here in Table 7.3.1.

Taking into consideration the tonnage of cement per m^3 for the concrete masonry brick (as well as of cement mortar) as given in Table 3.1 in Section 3, the following estimates of waste solids due to cement production were developed (Table 7.3.2).

Table 7.3.1
CEMENT KILN DUST (CKD) DISCARDED AS SOLID WASTE

Region	City	Waste CKD [kg/t of cement]
West Coast	Vancouver	15.50
Prairies	Calgary	7.47
	Winnipeg	7.47
Central	Toronto	10.87
East	Montreal	21.90
	Halifax	16.30

Table 7.3.2
SOLID WASTE DUE TO PRODUCTION OF CEMENT PER UNIT OF CONCRETE PRODUCT

	tonnes of cement/m^3 of concrete	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
				[kg/m3]			
Concrete Brick	0.2170	3.3635	1.6210	1.6210	2.3588	4.7523	3.5371
				[kg/1000 bricks]			
A1 Type		3.2783	1.5799	1.5799	2.2990	4.6319	3.4475
A2 Type		2.8504	1.3737	1.3737	1.9990	4.0274	2.9975
B1 Type		5.1746	2.4938	2.4938	3.6289	7.3112	5.4417
B2 Type		4.5027	2.1700	2.1700	3.1577	6.3618	4.7351

Sand and gravel or crushed stone are the two major components of the aggregate materials that are used with Portland cement to make concrete brick. Sand, together with cement and water, form cement mortar. The aggregate materials are usually quarried from surface deposits and require washing, crushing and size separation. However, the rock, gravel or sand is then used in its entirety and there is no further separating, refining or smelting. As a result, there is little solid waste other than mine spoil (rock material that is not used but is moved to get to the desired resource). Extraction of mineral aggregates from pits and quarries results in little environmental contamination[3], although the degree of land disturbance can be substantial.

7.3.2 Solid Waste due to Concrete Processing

Solid wastes from concrete processing include mixer washout residue, sludges from settling basins and ponds, and off-specification products. In the case of the concrete brick industry, most of the waste solids and off-spec material is reprocessed to product aggregate[1].

The manner in which waste solids from concrete production was estimated is discussed in detail in Section 15 of the ATHENA™ Cement and Concrete study.[2] It was based on rather limited information available for ready mixed concrete production in British Columbia[4,5]. Based on that information, and taking into consideration that precast materials production, including that of concrete brick, is essentially a factory operation with more process control, we estimated that solid waste due to concrete processing (mainly equipment washout) is similar to that for the central mixer of a ready mix operation: i.e., 2.59 kg/m^3 of concrete.[2] The same number is also taken for cement mortar.

Based on these estimates, Table 7.3.3 summarizes estimates for solid waste from concrete processing. In the absence of data for regions of the country other than British Columbia[4,5], it is assumed that similar amounts of solid waste are generated in concrete producing facilities in other areas as well.

TABLE 7.3.3
SOLID WASTE DUE TO CONCRETE BRICK PROCESSING

Concrete Brick		[kg/m3]	2.5900
	A1 Type	[kg/1000 bricks]	2.5244
	A2 Type	“	2.1949
	B1 Type	“	3.9846
	B2 Type	“	3.4672

7.3.3 Concrete Products Solid Waste Summary

As discussed above, solid waste due to the production of concrete brick comes primarily from two sources: from the processing of concrete itself, and from cement kiln dust, a solid waste generated in production of cement. Table 7.3.4 presents a summary of total solid wastes, as developed in the above tables.

TABLE 7.3.4
ESTIMATED TOTAL SOLID WASTE DUE TO CONCRETE PRODUCTION

	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
			[kg/m3]			
Concrete Brick	5.9535	4.2110	4.2110	4.9488	7.3423	6.1271
			[kg/1000 bricks]			
A1 Type	5.8026	4.1043	4.1043	4.8234	7.1562	5.9718
A2 Type	5.0453	3.5686	3.5686	4.1939	6.2223	5.1925
B1 Type	9.1592	6.4784	6.4784	7.6135	11.2958	9.4263
B2 Type	7.9699	5.6372	5.6372	6.6249	9.8290	8.2023

7.4 Cement Mortar

Solid waste estimates associated with production of cement mortar were developed in Section 15 of the ATHENA™ Cement and Concrete study[2] in a similar manner to that for concrete brick described above. Tables of solid waste estimates due to cement contained in cement mortar, due to Cement mortar processing, and their sums are given below.

Table 7.4.1
SOLID WASTE DUE TO CEMENT CONTENT IN CEMENT MORTAR

	tonnes of cement/m^3 of mortar	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
				[kg/m3]			
Cement Mortar	0.3070	4.7585	2.2933	2.2933	3.3371	6.7233	5.0041

Table 7.4.2
SOLID WASTE DUE TO CEMENT MORTAR PROCESSING

Cement Mortar	[kg/m^3]	2.5900

Table 7.4.3
ESTIMATED TOTAL SOLID WASTE DUE TO CEMENT MORTAR PRODUCTION

Product	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
Cement Mortar [kg/m^3]	7.3485	4.8833	4.8833	5.9271	9.3133	7.5941

7.5 The Use of Wastes in Brick Processing

As already noted, if new clay brick does not meet the manufacturer's standards, it can easily be recycled through an inexpensive crushing process. Crushed brick is reground to manufacture new, quality brick.

In addition to using its own solid waste and recycling off-specs brick, the clay brick industry has the capability to use some other solid wastes as well. According to BIA, for example, sludge brick can be produced from sewage sludge and normal brick-making materials. The end product is brick with no decrease in material properties. Contaminated soils can be combined with clay to yield a quality brick completely free of hydrocarbon contamination. To prepare contaminated soil for brick making, it is fired at temperatures exceeding 925°C for 12 hours. Materials containing various petroleum products, hydraulic fluids, transmission fluids, lubricating oils, naphthalene and mineral oils and spirits can thus be recycled into bricks, while at the same time saving the environment from contaminated waste dump sites.[9] While the use of the above wastes in the brick-making process is feasible, at this time this is not often practiced.

Possible reuse of a wide range of industrial and urban wastes by the clay brick industry were recently reviewed elsewhere, too.[10] A substantial amount of research, most of it concentrated in the 1980s, demonstrated the practical application of this type of reuse with environmental and technological advantages. The best prospects concern the materials which are rich in organic and/or carbonaceous substances, since their combustion during the firing stage can provide significant energy savings. Due to the great variety of waste composition, however, great care has to be taken in ascertaining the suitability of the specific waste to prevent negative effects on the plasticity of the green bricks and porosity and mechanical properties of the finished ware. This review[10] concludes that although the recycling of urban and industrial wastes into clay bricks is theoretically feasible, often it is not economically advantageous due to the high transport costs of wastes, and the costs for additional testing of both finished product and flue gas emissions.

More often than in the clay brick industry, the above noted wastes, as well as rubber tires, are used as waste-derived fuels in the cement manufacturing process. The cement and concrete industry is also using industrial by-products such as fly ash and blast furnace slag in the production of cement and concrete products. Such practices were discussed in more detail in Sections 7.3 and 10.2 of the Cement and Concrete study.[2]

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APPENDIX 1

Throughout the report, we reported all energy usage, emissions, effluent and solid waste in appropriate units per tonne or m^3 of finished brick, or per 1000 units of various clay, calcium silicate, or concrete bricks. In some cases, reader could also be interested in the unit factors expressed per square foot or square meter of wall. The appropriate number of bricks per single wythe wall unit area that can be used to calculate energy inputs and environmental outputs from data in the study are given in the tables below:

TABLE A1: CLAY BRICK USAGE PER WALL UNIT AREA

	number of bricks per sq. ft.	number of bricks per m^2
Ontario	6.0	64.5
Metric Modular	7.0	75.0
CSR	4.9	52.0
MAX	3.9	42.0
Metric Closure	4.5	50.0
Metric Jumbo	3.0	33.0
Engineer Norman	3.9	42.0
Metric Norman	4.6	49.8

TABLE A2: CALCIUM SILICATE BRICK USAGE PER WALL UNIT AREA

	number of bricks per sq. ft.	number of bricks per m^2
Colonial - CB 25	3.66	40
Executive - ES 26	4.9	52
Vintage - VB 31	3.9	42.0

TABLE A3: CONCRETE MASONRY UNITS USAGE PER WALL UNIT AREA

	number of bricks per sq. ft.	number of bricks per m^2
“A” type cocnrete masonry unit	7.0	75.0
“B” type concrete masonry unit	4.5	50.0