Development of a Performance Based (Multi-characteristic) Tool for Wall Insulation System Optimization

By

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Abstract

An insulation system, as a key feature in modern buildings, especially in green buildings, can affect various aspects of building performance. Current insulation system design approaches need to consider health, environment and fire safety characteristics. Selecting an optimum insulation system itself is challenging because of these characteristics and the wide range of possible options. To deal with this challenge, a performance based (multi-characteristic) tool for wall insulation system optimization is proposed in this research. This tool includes mathematical sub-models for five performance areas related to insulation systems: energy, soundproofing, fire safety, sustainability, and cost. The models were developed so that a designer can consider these characteristics of insulation systems for specific building scenarios. Using this multi-objective optimization tool, designers can compare various insulation systems based on their overall performance. This allows a designer to select optimum insulation systems for a specific building scenario. This tool also includes the AHP (Analytical Hierarchy Process) method to assist in estimating weights, which is a crucial but challenging part of the weighted-sum method.

The sustainability and fire safety issues of current insulation system design approaches are addressed in this research project. The Morris method, as a sensitivity analysis, is used to analyze the tool. The tool is applied in several examples, and these examples and model limit state analysis will help users to understand the tool. In addition to this, weights for the ten occupancies in IBC are also assessed using the AHP method.

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In their hearts humans plan their course, but the LORD establishes their steps. –Proverbs 16:9

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Introduction

A building is a complicated system that needs to have various performance objectives such as a comfortable indoor environment (thermal, acoustic, air quality and light), structural stability, accessibility, aesthetics, security and information technology. Relatively recently, due to the concerns of global warming and high energy costs, buildings are required to meet a sustainability goal too. In order to maximize or optimize these various characteristics, architects and building designers have started to pursue a whole building design approach in which building systems are designed as interdependent parts of the entire system, rather than focusing on individual characteristics [1]. Through this approach, a building can be optimized to satisfy the various design needs.

The International FORUM of Fire Research Directors suggested in 2012 that "(in sustainable building design), optimizing a product or system without fire performance as one of the parameters can lead to an increase in the risk of fire with serious consequences on human health, the environment and economic investment [2]." It will be beneficial if we have a design tool that allows engineers and designers to consider fire performance and other building performance systematically at an early building design phase when they decide upon materials for a building. This will allow them to choose building materials and sub-systems for better and safer building performance.

As an example of this kind of design tool, a performance based (multi-characteristics) tool for wall insulation system optimization is developed in this research. Insulation, as a key design feature in modern buildings, especially in green buildings, can affect the performance of various functions of a building, such as energy performance, soundproofing performance and fire safety performance. It would be beneficial to have a design tool to help building designers select insulation systems, taking into account all of the performance. Four main reasons and issues prompted this tool development.

1. Current insulation system design approaches in building codes have environmental and health issues, due to the implied requirements for flame retardants in foam plastic insulation to meet flame spread performance levels that the codes required without additional fire safety performance [3].
2. It will increase fire safety performance and sustainability if designers can take into account possible fire conditions of each compartment from the early design phase.
3. It would be valuable if building material selection could be based on performance of each building material in a real building or compartment. Simulation technology can help this approach.
4. There are various factors to consider in choosing an optimum insulation system. A decision analysis tool can enhance decision making in this complex decision making problem.

This report consists of three main parts. The first part is a background study and the issues of current insulation system design approaches. In the second, a new design approach is introduced and details are explained. Lastly, the design tool is applied to cases.

Background

Sustainability and green buildings

The concept of sustainability has received public attention over the last 30 years. One of the most widely quoted definitions of sustainability is from the concept of *sustainable development* which was articulated by the Brundtland Commission of the United Nations on March 20, 1987: “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”[4]. The objectives of sustainability are to allow all people to meet their basic needs and improve their quality of life, while securing that the natural systems, resources and diversity upon which they depend are maintained, for both their benefit and that of future generations [5]. The concept of sustainability is explained well with the term, ‘triple bottom line’ which consists of environmental stewardship, social responsibility and economic prosperity [6]. Environmental stewardship is about “natural capital” which considers “all the costs and benefits of a project on natural environment locally and globally”. Social responsibility is about “social capital” which considers “all the costs and benefits to the people who design, construct, live in, work in, and constitute the local community and are influenced, directly or indirectly, by a project.” Economic prosperity is about “economic capital” which considers “all the economic costs and benefits of a project for all the stakeholders.” The momentum of the shift to sustainability is given not only by the environmental issues but also by the economic issues. For example, this new paradigm can also save money through high energy efficiency. This is a win-win strategy on which “climate-change activists and hardheaded businesspeople can agree [7].”

The Office of the Federal Environmental Executive defines green building as “the practice of 1) increasing the efficiency with which buildings and their sites use energy, water, and materials, and 2) reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal-the complete building life cycle” [8]. Although green buildings have been getting more attention recently, the green building movement can be traced to many causes over the past several decades [7]. These include the Declaration of the United Nations Conference on the Human Environment (or Stockholm Declaration) in 1972, which was recognized as “the beginning of the political and public awareness of global environmental problems” [9] and the 1973 oil crisis, after which the prices of energy and various material commodities rose significantly and triggered an increased attention on energy savings. Since buildings have significant impacts on environment, society and economy, the events also affected building industries in the U.S. For example, buildings account for 38.9% of total U.S. energy consumption and 72% of total U.S. electricity consumption [10]. Thirty-nine percent of the nation’s total carbon dioxide emission was attributed to buildings [11]. In addition, indoor pollutants levels may be 2 to 5 times higher and occasionally more than 100 times higher than the level of outdoor pollutants. This is especially important because Americans spend more than 90% of their time indoors [12].

Roles (or objectives) of building insulation systems

The term “insulation” is originated from the Latin word *insula*, meaning “island.” Insulation is a material that makes an object isolated by preventing the transmission of energy or matter such as heat, electricity, sound waves or moisture. The main purpose of thermal insulation in a building is to block heat transmission through walls and ceilings/floors. Heat is, however, not the only property that building insulation should isolate because an insulation system is not an independent energy system or conservation system but a part of complex structural systems which create a building shell [13]. There are other design functions such as a sound barrier, rain barrier, air barrier, vapor barrier and fire safety performance that a building shell should provide. For these functions, many different types of building wall systems have been developed and they are introduced in Appendix A.

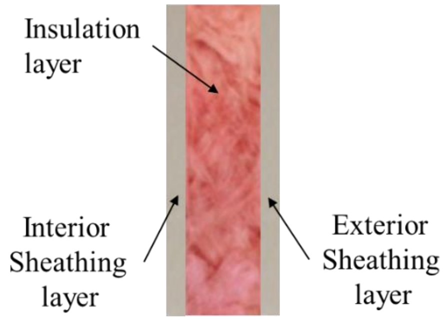

Figure 1. Insulation system: a layer of insulation, interior and exterior sheathing layers.

In this research, an *insulation system* is described as a minimum wall sub-system that needs to provide energy performance and soundproofing performance, two of the most important performance of a building shell. In addition to this, when foam plastic insulation material is used, it is crucial to protect the insulation material because it is well known that foam plastic can be a severe hazardous material when it starts to burn. For this reason, installing a thermal barrier on the insulation material is important. The insulation system is defined as a composite wall system, which consists of a layer of insulation material and two layers of sheathing that cover the insulation material (Figure 1).

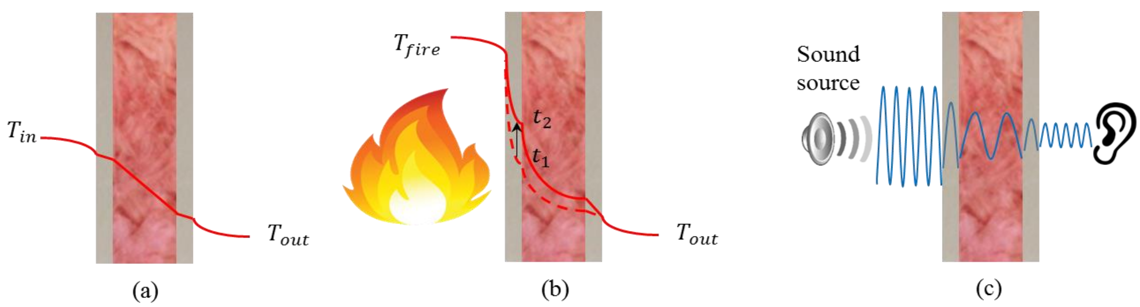

Figure 2. Three main physical performance of an insulation system: energy performance (a), fire safety performance (b) and soundproofing performance (c)

Note that, however, a wall system is usually more complex in practice. For example, there are usually structural elements in the insulation layer such as wood or steel studs in lightweight construction. These elements could affect energy performance and soundproofing performance. However, these effects will not be considered in this research.

Energy performance

Figure 2 shows the three main performance areas that an insulation system should provide. The energy performance is one of the key performance areas of insulation systems (Figure 2 (a)). It should block the heat transfer through a wall. It is important because significant heating energy is lost through poor insulation wall system (10-45% of total heat loss) [14].

Heat is transferred from the place in high temperature to the place in low temperature. The heat conduction through a wall for the energy performance is essentially a steady state thermal conduction phenomenon because it occurs over a relatively long period. One of the most important properties that govern the phenomena is the R-value of a wall system.

$$R - value = \sum_{i}^{n} \frac{l_i}{k_i} = \frac{l_1}{k_1} + \frac{l_2}{k_2} + \cdots + \frac{l_n}{k_n} \quad (1)$$

where l is the thickness of a layer and k is the conductivity of the material.

Fire safety performance

One of the most important fire hazards related to insulation systems is the burning of foam plastic insulation [3]. The minimum fire safety performance of foam plastic insulation systems is achieved by protecting foam plastic insulation from a fire for a critical duration of time. For this, current building codes require installing a thermal barrier. For the insulation system, which consists of non-combustible insulation materials, minimum fire safety performance is not required based on building codes. Even though non-combustible will not burn, however, the overall fire safety of the insulation system will improve when the insulation system can resist heat transfer through the insulation system. The detail of potential fire safety issues of insulation systems will be discussed in the next section.

A fire is inherently a transient phenomenon, and non-steady state heat conduction model is required for the analysis (Figure 2 (b)). To analyze heat transfer problems related to fires, thermal properties – conductivity (k), density (ρ) and specific heat (c_p) – and their combinations – thermal diffusivity (α) and thermal inertia are important.

$$\alpha = \frac{k}{\rho c_p} \quad (2)$$

$$thermal\ inertia = k\rho c_p \quad (3)$$

Thermal diffusivity is the ratio of the material's ability to conduct thermal energy to its ability to store thermal energy [15]. Basically, a material which has a larger α, will respond quickly to an environment's thermal change, while a small α material will take a longer time to reach a new equilibrium condition [15]. Thermal inertia is the product of the conductivity, density and specific heat of a material. It will govern the rate of increase of the surface temperature. The surface temperature of a material with low thermal inertia will increase more quickly than a material with high thermal inertia when they are heated [16]. Thermal inertia will be discussed further in the next section because it is related to fire safety issues of insulation materials.

Soundproofing performance

Sound can be "a very real form of pollution" today [17]. When it is louder than around 130 dB, people could feel pain, and people could feel discomfort even in lower levels. It is important to provide soundproofing conditions for the occupant's comfort. Interestingly enough, sound transmission and heat conduction phenomena can both be explained as "mechanical vibrations transmitted through the atomic lattice [18]." Essentially, they can transmit by the vibration or motion of atoms and molecules. One of the main differences between heat and sound transmission is frequency [18]. Most heat vibrations occur at high frequencies ("terahertz") and they can travel small distances while most sound waves occur at low frequencies ("kilohertz") and they can propagate large distances [18]. Note that there are some research efforts to develop new materials to control heat and sound. The detail of it will not be explained in this paper, but the reference by Maldovan [18] would be a good introduction for this.

There are two sound sources: airborne sound and structure-borne sound source [19]. An airborne sound source specifies the sound occurring from air such as talking or sound from speakers. Structure-borne sound source starts by direct impact on a structure. In a building, sound waves can travel between compartments with two mechanisms: direct transmission and flanking transmission [19]. Direct transmission specifies the sound energy that transmits directly across the wall and floor assemblies (Figure 3). Usually, the Sound Transmission Class (STC) of a wall, which is a measurement of the ability of the wall to block sound energy, is about blocking this direct transmission. Some of the sound energy may be transmitted by indirect paths, which is called as flanking transmission. They transmit the sound energy around a wall or ceiling.

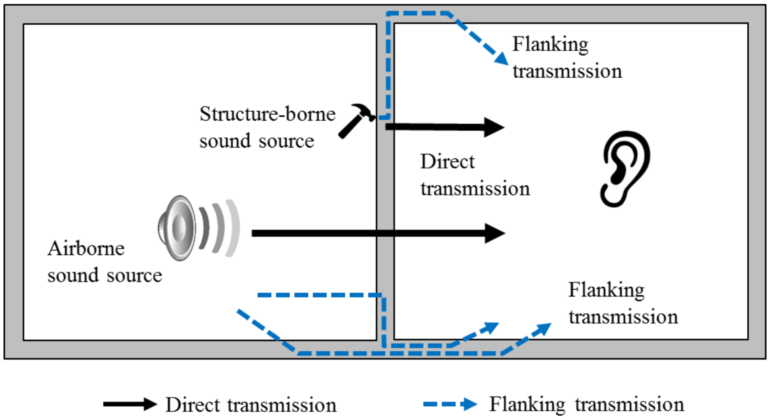

Figure 3. Sound sources (airborne and structure-borne sound sources) and sound transmission paths (direct and flanking transmissions)

For a homogenous wall, which is called as a single leaf structure, sound transmission loss is governed by the mass law, which means that the airborne sound transmission loss through the wall is governed by mass per unit area of its wall (kg/m^2). The transmission loss (TL) through a single leaf structure is [20]:

$$TL\ (dB) = 20\log(m_s f) - 48 \quad (4)$$

$$m_s = \rho l \quad (5)$$

where m_s is the mass per unit area (kg/m^2), f is frequency (Hz), ρ is density (kg/m^3) and l is the thickness (m).

For a double layered walls with absorbers such as the insulation system in this research, the sound loss though the wall governed by the depth of the air gap, the presence of sound absorbing material, and the degree of mechanical coupling layers [20].

Fire safety issues of insulation

When a fire occurs in a room in which thermal insulation is installed, there are several fire safety concerns related to insulation [21,2,22]. Due to low thermal conductivity, which is a main characteristic of insulation, more heat might be trapped inside a compartment. Since the temperature of the room might be more severe, flashover might be reached with less energy than the required energy for flashover in a non-insulated room [23,24,21]. It might decrease the time to flashover. In addition, insulation materials have low thermal inertia (kρc) because they usually have low density (ρ) and low conductivity (k). This low thermal inertia of insulation materials can cause faster temperature increases of the surface of the material than that of the material which has higher thermal inertia, and the increased thermal feedback from the hotter surface to the fuel could also cause higher room temperature and earlier flashover [25]. Above all, combustible insulations could release toxic gases and be ignited at a certain point, thus becoming an additional fuel, resulting in compartment breach and early structural collapse [3,22]. In this chapter, studies of fire safety issues related to insulation will be reviewed.

Lower thermal inertia causing higher surface temperature

Thermal inertia ($k\rho c$) is the product of the conductivity (k), density (ρ) and specific heat (c) of a material. It has been long recognized that thermal inertia is one of the main parameters that decide a surface temperature when a material is heated [25]. The effect of thermal inertia on a surface temperature can be analyzed using the analytical solutions for the semi-infinite solid [25]. The solutions for the surface temperature of the semi-infinite solid for the constant surface heat flux and the surface convection are as below [15].

Constant surface heat flux ($\dot{q}_s^{"} = \dot{q}_0^{"}$)

$$T_s(t) = \frac{2\dot{q}_0^{"}\sqrt{t}}{\sqrt{k\rho c}\sqrt{\pi}} \tag{6}$$

Surface convection ($-k\frac{\partial T}{\partial x} = h[T_\infty - T(0,t)]$)

$$\frac{T_s(t) - T_i}{T_\infty - T_i} = 1 - \left[\exp\left(\frac{h^2 t}{k\rho c}\right)\right]\left[erfc\left(\frac{h\sqrt{t}}{\sqrt{k\rho c}}\right)\right] \tag{7}$$

Based on the solutions, it is clear that the surface temperature is the function of the thermal inertia ($k\rho c$). When a material which has a low thermal inertia is heated, the surface temperature rises quickly. The effect of thermal inertia on the rate of the surface temperature increase is clearly shown in Figure 4 [16]. This figure was developed using the heat transfer solution for the semi-infinite solid with 20 W/m^2K of the convective heat transfer coefficient. With the same heat exposure situation, the surface temperature of Polyurethane Foam (PUF) with 950 of thermal inertia increases very quickly, but the surface temperature of steel with 1.6×10^8 of thermal inertia increases slowly.

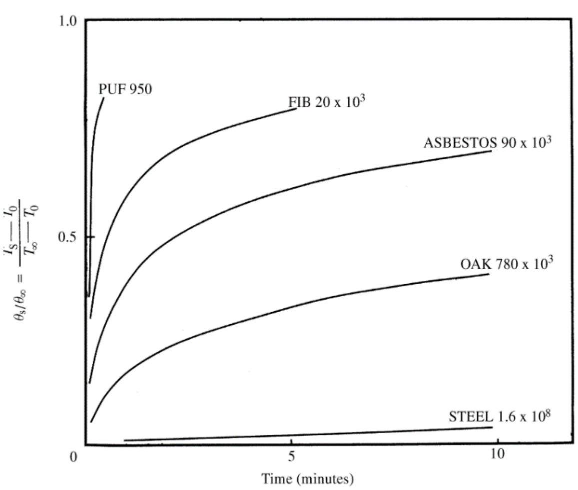

Figure 4. Effect of thermal inertia on the rate of temperature rise at the surface of a semi-infinite solid PUF (Polyurethane foam), FIB (Fiber Insulating Board) [16]

Thomas and Bullen [25] researched the effect of thermal inertia of lining materials on the growth of room fires. In their theoretical research, they suggested that the thermal inertia of a lining material has a role in fire growth. They also concluded that the time to flashover (t_f) is directly proportional to thermal inertia for the fire ($Q = \alpha t^n$). The time to flashover [25] is,

$$t_f \propto (k\rho c)^{\frac{1}{2n+1}} \qquad (8)$$

McCaffrey, Quintiere and Harkleroad [23] also showed that thermal inertia has a significant influence on the rate of energy release required to reach the flashover temperature ($\Delta T=500^{\circ}C$). With the same ventilation condition, a room with a high thermal inertia such as brick requires a higher energy release rate for flashover than a room with a lower thermal inertia such as expanded polystyrene.

Note that even though a material's thermal inertia has a significant influence on the required energy release rate for the flashover, it has much less impact on the time to flashover [23,25]. For example, when the heat release rate of a fire is expressed as αt^2, which is usually used to represent a compartment fire, the time to flashover is just proportional to one fifth power of the thermal inertia $(k\rho c)^{\frac{1}{5}}$. In addition, based on current building regulations and building customs, a thermal barrier is usually installed over insulations so that insulations are not directly exposed to a fire in the initial phase of a fire event. Since a thermal barrier should have a property that resists heat flow, the effect of insulation's thermal inertia on the time to flashover would not be significant.

Less heat loss through walls might cause higher heat accumulation

The temperature evolution of a compartment fire has been analyzed with energy conservation [16,26]. When a fire occurs in a compartment, it releases significant energy from the exothermic chemical reaction. The released energy is transferred as heat into its surroundings. Around thirty per cent of energy is transferred as radiation into the surroundings. Most of the remaining energy is transferred to its surroundings as a gas convective flow. Some of the transferred heat will go out through openings such as doors or windows, and some will be transferred through surrounding surfaces such as a ceiling, a floor or walls. If less heat is transferred through walls or openings, more heat might be accumulated inside a compartment. For the compartment where insulation is well installed, less heat might be transferred through the walls; and more heat might be accumulated and thus increasing the temperature inside [21,2,16,22]. This might increase the severity of a room condition in a fire, resulting in earlier structural failure.

Anna Back [27] performed several tests to understand the effects of insulations on fire severity. Heptane pool fires and wood crib fires were tested in an insulated compartment and a non-insulated compartment whose dimensions were 5.9 m x 2.35 m x 2.4 m height. A steel shipping storage container was used for the compartment. Rockwool was installed for insulation (k = 0.037 W/m.K and ρ = 30 kg/m^3). The experimental results are in Figure 5. For the heptane fire, the maximum gas temperature of the insulated room reaches 900 $^{\circ}$C while the maximum temperature of the non-insulated room reaches 670 $^{\circ}$C. In the insulated room, the temperature increases faster and reaches 34% higher than the non-insulated room.

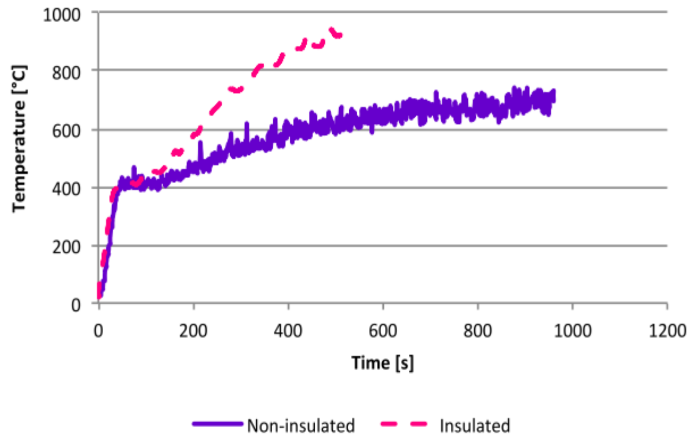

Figure 5. The gas temperature of heptane fire in the insulated room and non-insulated room [27]

In another study, K. K. Choi [28] performed similar experiments to study the effect of insulation on room fires. The tests were carried out in a test room with the following dimensions: 2.47 m x 3.66 m x 2.6 m height. Wood crib was used for fuels. Insulations were installed, and they were protected by 16 mm Type X gypsum boards, which was a more realistic condition than those used in Back's tests. Four cases were tested including 3 different insulation materials – glass fiber, sprayed polyurethane and extruded polystyrene – and a case without any insulation material. The temperatures of the four tests were "very similar," and "the effect of insulation is minimal" on fire severity [28]."

The results of Choi's experiments seem to conflict with the results of Back's test which show the significant effect on fire severity. The differences in the results could be caused by the use of different lining materials. In Back's tests, a steel storage container was used for the compartment. The insulation material was installed on the outside surface of the container, and the steel surface was exposed to the fire. The fire growth was affected by insulation much earlier because the steel sheet was thin and has higher thermal inertia [28]. In Choi's test, however, 16 mm gypsum boards were used for lining materials, and insulation was installed on the outer surface of the gypsum board. The surface temperature was not affected significantly in a room lined with gypsum boards because gypsum boards could absorb heat. Based on these tests, it seems that the effect of insulation on fire severity seems not so severe for the fire occurring in the compartment in which a thermal barrier such as gypsum boards is installed.

Releasing flammable gases and toxic species

Releasing flammable gases and toxic species from insulation materials can be a main hazard for occupants and structures in the event of fire [3,22]. When combustible insulation reaches its pyrolysis temperature, they start to release flammable gases and/or toxic gases. The flammable gases mixed with oxygen can burn when they are above their lower flammable limit. When it begins to burn, it could contribute to more heat release rate in the compartment, and consequently this could lead to the compartmentalization breach and possible structure failure [22]. Releasing toxic gases from insulation material can also be a significant hazard [3]. Most of fire casualties are caused by inhalation of toxic gases including carbon monoxide, smoke, soot particles, and irritant gases such as hydrogen cyanide (HCN) and hydrogen chloride (HCL) [29].

Hidalgo, Welch and Torero [22] suggested that "the onset of pyrolysis" is related to the main failure mode for combustible insulation systems and "the origin of any hazard with regard to the use of combustible insulation materials." Based on their findings, they stressed that it is important to consider "the onset of pyrolysis" of combustible insulation materials when an insulation wall system is designed.

The hazards of the burning of combustible insulation materials are relatively well known through data derived from numerous fire accidents and research. In order to protect insulation material from fire, building codes require a thermal barrier that prevents or delays the foam's involvement in a fire. A thermal barrier is designed to protect insulation material from a fire during an initial critical time required for occupants to evacuate a fire. However, there are some arguments about the current design and test process of the thermal barrier that will be explained in the next sections.

Current insulation system design approach and challenges

Since combustible insulation might increase fire hazard when it is exposed to fire, current building codes require two measures: a thermal barrier and a surface flame and smoke characteristic. However, there are some issues and critiques of this design approach in terms of fire safety and sustainability. The current design approaches for insulation material in building codes will be introduced, and their sustainable and fire safety issues will be explained in this section.

Current design approach by building codes for fire safety

Building code requirements for fire safety of insulation systems

Current building regulations have two measures to provide fire safety performance of insulation. The regulations require that insulation should meet a certain level of flame and smoke characteristics requirements, and it also requires installing a thermal barrier when foam plastic insulation is used. For the flame and smoke characteristics of the foam insulation, foam plastic insulations should be tested by ASTM E84 [30], and it shall have a flame spread index of not more than 75 and a smoke developed index of not more than 450.

The building code also requires having a thermal barrier on plastic insulation. Based on codes, a ½ inch gypsum board can be used as a thermal barrier. In addition to the gypsum board, other materials can also be used if they meet the acceptance criteria based on two standard tests in NFPA 275: the temperature transmission fire test and the integrity fire test.

The temperature transmission fire test is the method used to test if a new material can block heat transfer from the fire source to an insulation material during a 15 min time period in a standard fire. This test is almost identical to the test in ASTM E119, in which a thermal barrier is tested using a temperature-time curve. Normally, a ½ inch gypsum board can endure around 15 min in the standard fire condition.

In this test method, the temperatures of the back face of a thermal barrier are measured using nine thermocouples. The average temperature of the nine thermocouples shall not exceed 250°F (120°C), and the individual temperature of any thermocouple among the nine thermocouples shall not exceed 325°F (160°C). These two temperatures represent "conservative indications" in which a material behind the thermal barrier might ignite [31].

The integrity fire test is to test how an insulation system reacts in a pre-flashover fire, while the temperature transmission test is to test how a thermal barrier reacts in a post-flashover fire. The integrity fire test in NFPA 275 [32] is a standard method to evaluate the contribution of thermal barriers and foam plastic insulation to room fire growth. This method is based NFPA 286 [33], Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth. In this test, thermal barriers and insulation materials are installed in the interior of the standard room of NFPA 286. A gas burner with a 30.5cm x 30.5cm porous top surface is located in the corner of the room. The test duration is also a total of 15 minutes, and the procedure consists of two steps: 40 kW for 5 minutes and 160 kW for 10 minutes.

Sustainability issues in requiring the surface-burning characteristics of insulation materials

There is criticism of the design approach in the current building codes for foam plastic insulation systems. Babrauskas et al. [3] criticized that ASTM E84 test requirements on plastic foam insulation materials are not necessary when a thermal barrier is installed. It may even problematic because of the flame retardant's health and sustainability issues [3,34]. Flame retardants often are applied to insulation materials to meet the ASTM E 84 requirements. In addition to this, the cost of foam plastic insulation is increased because of the necessity to use a flame retardant. Due to the relatively high price, people might hesitate to use a foam plastic insulation even though it provides higher energy performance. Some countries such as Sweden and Norway allow non-flame retarded EPS/XPS when it is protected by a thermal barrier [3,34]. Even in the U.S., some governmental organizations such as the Office of the State Fire Marshal in California have begun to discuss this issue [34].

There are significant health and environment concerns related to using flame retardant materials. Most foam plastic insulation materials need flame retardants in order to meet the requirements of ASTM E84. The two major flame retardants for plastic insulations are hexabromocyclododecane (HBCD or HBCDD) and tris (1-chloro-2-propyl) phosphate (TCPP). HBCD is usually used for EPS and XPS, and TCPP is used for most polyurethane, and it is also often used in polyisocyanurate boards. These flame retardants can decrease the rate of flame spread and can decrease the total amount of smoke released by releasing active halogen atoms that can reduce the chemical reaction in the flame [35,3]. The flame retardants, however, are chemicals of concern because of their health and environmental effects through their lifetime (Figure 6). HBCD is a chemical of concern because of its potential for bioaccumulation, aquatic toxicity, and possible human health effects such as thyroid hormone disruption and affecting the developing nervous system [3,36,11]. TCPP is also a chemical of concern due to its potential for "long-range transport, persistence, toxicity and human exposure." The flame retardants can also increase fire toxicity in the event of fire because the effluents contain additional carbon monoxide, irritant acid gases (hydrogen chloride or hydrogen bromide), and a mixture of respiratory irritants including unburned and partially burned hydrocarbons [37].

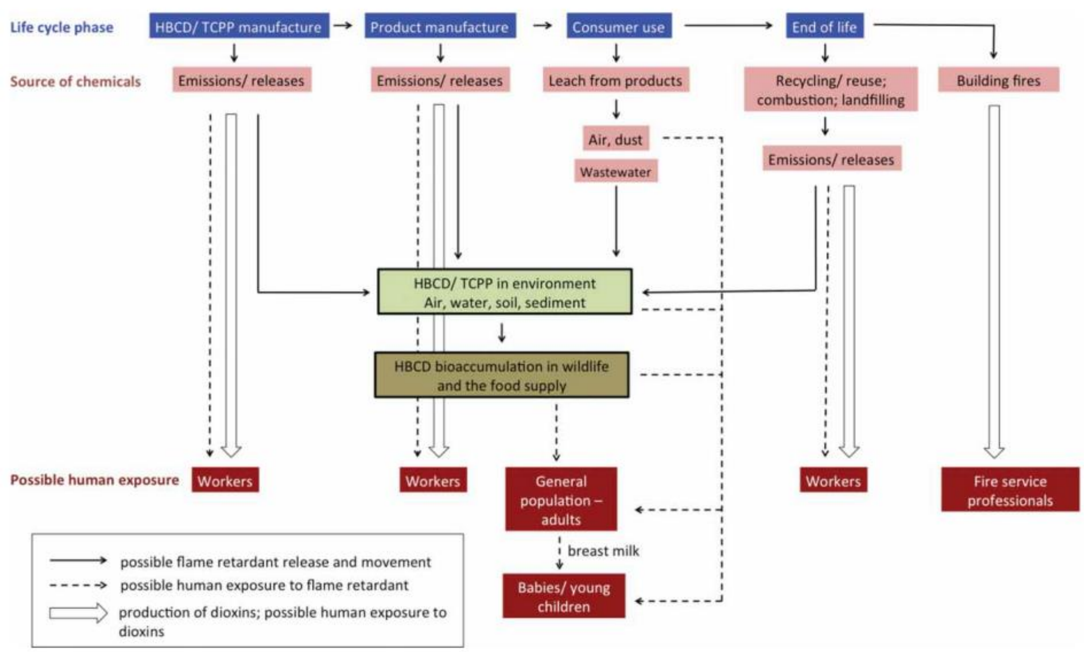

Figure 6. Sources of HBCD/TCPP and their by-products in the environment and in human exposure [3]

In addition, many studies and literature argue that ASTM E84 is "unreliable in assessing the hazards of plastic foam [3]," and "should be disregarded for foam plastics [38]." One of the main reasons for this is related to "the mounting geometry [3,22]." In the standard test, the specimen is mounted on the ceiling in the tunnel-shape furnace, with the burner at the end of the tunnel. In this situation, thermoplastic foam insulation is likely to melt and drip onto the floor. The burner flame cannot reach the insulation material so the results could be rendered inaccurate.

Above all, a thermal barrier for plastic insulation alone could be enough to keep insulation materials from a fire during a critical time so that the requirements of ASTM E84 do not provide additional benefit in terms of fire safety [3]. However, there are also some issues of the current thermal barrier test methods which will be discussed in the next section.

Fire safety issues of current time-temperature curve in ASTM E119

A thermal barrier is designed to keep fire, heat and ignition sources from affecting foam plastic insulation during an initial critical time in a building fire. This measure is crucial for building fire safety because combustible foam plastic insulation which usually surrounds a compartment could release a significant amount of toxic gases and smoke when they are involved in a fire. Based on current building codes, the temperature-time curve from ASTM E119 is used to test and design a thermal barrier. There are, however, many critiques about the validity of using the temperature-time curve because the standard temperature-time curve for thermal barrier tests does not provide the characteristics of natural and modern fires [39]. Figure 7 shows the different patterns of the temperature-time curves of standard fire and natural fires. The fire temperature-time curve of ISO 834 is almost the same as the temperature-time curve of ASTM E 119.

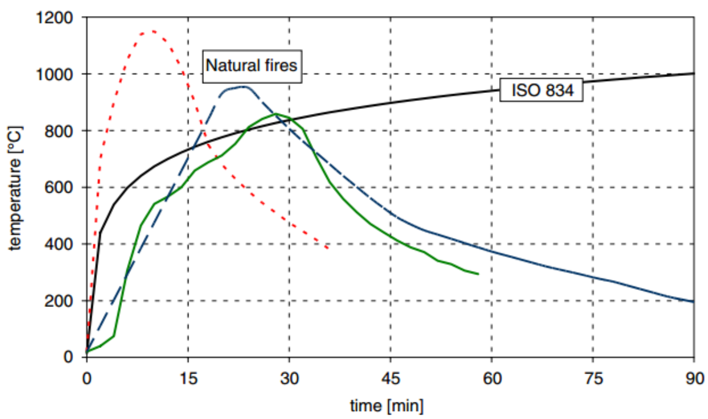

Figure 7. Comparison of temperature-time curves in natural fires with ISO 834 standard fire [40]

The first edition of ASTM E119 was issued in 1918, and the fire condition of the test has not changed significantly [41]. When the standard was developed, the fire condition was decided based on experimental tests of wood fuels which were the most common combustibles in compartments in that period [41]; and it was a little bit modified for the gas fueled furnace test [39]. However, the common contents in a building have changed significantly in the century following this. There are significant synthetic materials in most modern compartments, which usually have higher heat release rates, resulting in faster fire propagation and shorter time to flashover [42]. In addition to this, the typical house size in the early 1900s was less than 93m^2 [43]. Currently, the average home size is more than 200m^2 [44,42]. These changes generally cause faster and more severe fire conditions in a modern building, and this should be considered for a thermal barrier design process. These changes should be considered in a thermal barrier design process. Specifically, if a natural and modern compartment fire might cause more severe fire conditions during the initial period, this might cause much earlier failure of a thermal barrier. Figure 8 shows the comparison between modern and traditional buildings fire timelines. The flashover time is much faster in a modern building. A collapse of a protected floor of a legacy house started from 50 min, but a protected floor of a modern house could start after 10 min.

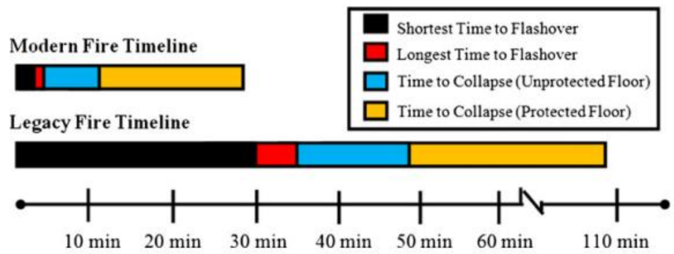

Figure 8. Modern and traditional house fire timelines [42]

In addition, the test based on the standard test does not include the effect of insulation materials. Because of an insulation layer next to gypsum boards, the gypsum boards heat up "much faster" than does an empty cavity, resulting in earlier dehydration process and failure [45]. It is necessary to check the effect of insulation on the failure of a thermal barrier when it is designed for a specific compartment.

Various design objectives for insulation and insulation system

Energy performance is a key design objective of a thermal insulation. It is, however, not the only property that insulation should provide but it also satisfies other design objectives as discussed previously. As a part of complex structural systems, other design properties such as a soundproofing performance also should be considered. A designer should also take into account factors such as sustainability, cost and fire safety for sustainable, fire safe and cost-effective design solution.

It is important to consider these intrinsic and extrinsic properties efficiently in order to choose an optimum insulation system. It is, however, hard to consider these parameters systematically when an architect and a designer choose an insulation system. Based on ref [46], the quality of design solutions is decreased exponentially when the design variables are increased

There are some design tools to optimize various properties of insulations, but there are few design tools to help designers to choose an insulation system with consideration of fire safety issues as well as other design objectives [47,22].

Introduction to a performance based (multi-characteristic) tool for wall insulation system optimization

Necessity of a new design tool

A number of design tools to help designers evaluate or select building materials and systems have been developed. As we discussed, a building, as a human shelter, needs to meet various objectives of a human. In order to meet these objectives, we have developed numerous systems, sub-systems and materials through our human history. Since it is important and challenging to select or evaluate a system or material for a building, many design tools were developed. A number of tools can deal with only one design objective, while others can deal with multiple objectives. Some design tools are for a building element selection, while others are for building systems or sub-systems. Some tools provide frameworks for selection or evaluation based on material's specification provided by manufactures such as standard test data. Some tools can evaluate a building system based on the performance of building systems. Therefore, the tools can be categorized based on several standards: 1) design object (element or system), 2) number of design objectives (single objective or multiple objectives) and 3) evaluation (or design) approaches (specification-based or performance-based design). Figure 9 is a schematic of the categorization of selection of evaluation tools for building materials and systems. Based on these three standards, there are overall eight types of design tools. Table 1 lists the categorization and the examples. In general, a design tool becomes more sophisticated as the type number of the tool is increased.

Table 1. Categorization of building material selection or evaluation tools

Type of design tool	Design object	Number of design objective	Evaluation approach	Examples
1.	Building element	Single objective	Specification-based design	
2.	Building element	Multiple objectives	Specification-based design	[48,49,47]
3.	Building element	Single objective	Performance-based design	[50]
4.	Building element	Multiple objectives	Performance-based design	[51]
5.	Building system	Single objective	Specification-based design	
6.	Building system	Multiple objectives	Specification-based design	[52-55]
7.	Building system	Single objective	Performance-based design	[56]
8.	Building system	Multiple objectives	Performance-based design	[57-59]

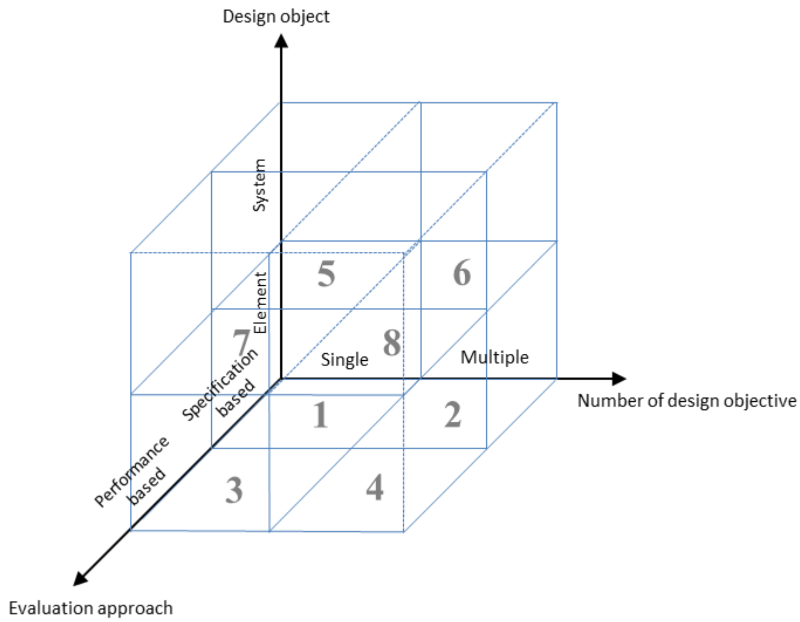

Figure 9. Diagram for categorization of building material selection or evaluation tools

This research proposes a tool to help building designers and architects design optimum insulation systems based on the issues and concerns of the current insulation system design approach. There are four main reasons why this tool will be beneficial and necessary.

1. Selecting (or designing) proper elements for a wall insulation system from numerous options is a complex decision problem, and it is challenging for a designer to consider all design options without the help of an assistant design tool. A decision analysis model will be beneficial for this complex decision problem. Providing various information and knowledge is not always helpful for a decision maker in choosing or designing effective insulation systems [46]. A decision making analysis tool, that could allow designers and architects to take into account the various effects and performance of a material's choice in a systematic way, could go a long way toward making these decisions more effective, cost-effective and precise.

2. To increase sustainability without decreasing fire safety, a new design approach is necessary. As discussed previously, current regulations indirectly require putting flame retardant materials into foam plastic insulation even in the case where there might be no additional fire safety benefits. This is problematic because the materials have environmental and health issues. In addition to this, adding flame retardant materials would increase the cost of foam plastic insulations that usually have higher R-values. This would eventually limit the customer's options to build better energy efficient buildings.

3. For better fire safety performance, a new design approach is necessary. Using ½ inch gypsum boards for buildings without consideration of specific building conditions could create fire safety issues when a compartment has a more severe fire condition than the standard fire condition. In addition, installing a proper thermal barrier is an essential prerequisite for not using flame retardants in foam plastic insulations. A tool to design proper thermal barriers should be included in the proposed design approach.

4. It would be valuable if building material selection could be based on how each building material might react in a real building or compartment. Simulation technology might help this approach. For this, simple mathematical sub-models are developed, and/or previously developed models are utilized, such as an energy performance sub-model, a soundproofing performance sub-model and a fire safety sub-model.

A design approach taking most of the aforementioned issues into account is proposed. This tool belongs to Type 8 in Table 1. This performance based, multi-objectives decision analysis tool will help building designers or architects decide on an optimum wall insulation system. As we previously discussed, there are various attributes and numerous design options that they need to consider; and it is significantly complex to take all these factors into account without the help of a design tool. The proposed design tool could allow designers to evaluate the effects of each insulation system on the required performance. Based on each performance, the design tool could assist in recommending an optimum insulation system. In addition to this, this approach could provide a guide and insight into the close relationship between insulation system selection and building performance.

Structure and steps of the design tool

Figure 10 shows the design flow of the design tool. This design tool follows 5 main steps:

1) Input of a building characteristics, weather and material information by designers;
2) Quantification of performance levels of all insulation system options for each design objective;
3) Normalization of the performance quantifications for the all insulation system options;
4) Calculation of performance scores for each insulation system option;
5) Selection of optimum insulation systems.

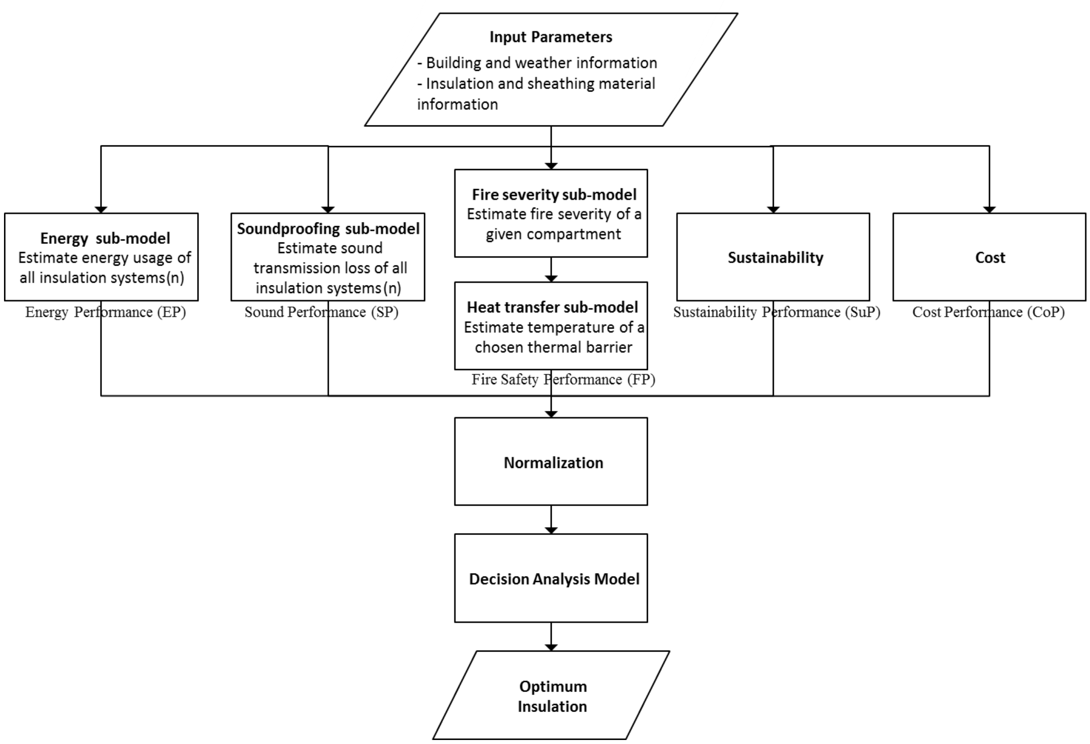

Figure 10. Design flow of the proposed tool

As the first step of the design process, a designer should input building information (compartment and opening dimensions, etc.), material information (insulation and thermal barrier/sheathing) and weather information (average monthly temperature). In the second step, each sub-model estimates the performance levels of each insulation system option. There are three mathematical models in this design tool: energy performance (EP) sub-model, soundproofing performance (SP) sub-model, and fire safety performance (FP) sub-model. The energy performance sub-model estimates the amount of energy consumed when an insulation system option is installed; the soundproofing sub-model will calculate the sound wave degradation when sound is transmitted through the insulation system. The fire safety performance sub-model, which consists of fire severity model and heat transfer model, can estimate a time-temperature curve of a specific compartment; and it will compute a temperature profile inside of layers of the insulation system in order to determine the failure time of the insulation. Further detail of the sub-models will be explained in the next section. Since other attributes such as sustainability and cost are also important factors for insulation system design, these are also estimated. The third step is to normalize the estimated performance levels. This normalization allows us to compare the performance which have different units. Then the decision analysis model will integrate all performance levels of an insulation system option, and it will provide a performance score for each an insulation option at the fourth step. In the last step, the optimum insulation systems will be selected based on the performance scores of each option. Note that the developed sub-models are approximate mathematical models to show the potential of this design approach. The validation efforts for sub-models are included in Appendix D.

Details of each sub-model

Energy performance sub-model

An energy performance sub-model estimates how much energy will be consumed in a given building. For the development of simple energy performance sub-model, an energy balance approach is applied with the following assumptions:

- The temperature in the room (T_g) is uniform (one zone assumption).
- The interior and exterior surface temperatures are uniform, respectively.
- Outdoor temperature is uniform, and average monthly temperatures are used for each month's temperature (the average monthly temperatures of a local area are available in the web page of National Centers for Environmental Information.)
- The thermal mass in the wall over a sufficiently long period has no significant impact on total heat flow [60].
- Heat is transferred in one direction only (1d heat transfer).

The control volume for a simple building is illustrated in Figure 11.

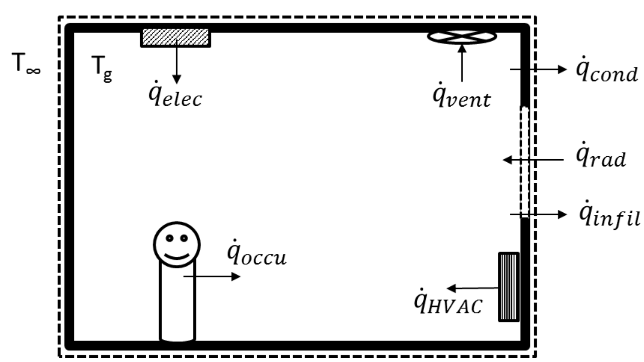

Figure 11. Schematic diagram for energy balance in the energy performance sub-model

Energy balance can be expressed as,

$$\dot{q}_{st} = \dot{q}_{in} - \dot{q}_{out} + \dot{q}_{gen} \quad (9)$$

Equation (9) can be specified as equation (10) using the control volumes and the conditions in Figure 11.

$$\rho c V \frac{dT}{dt} = (\dot{q}_{rad} + \dot{q}_{occu} + \dot{q}_{elec}) - (\dot{q}_{cond} + \dot{q}_{vent} + \dot{q}_{infil}) + \dot{q}_{HVAC} \quad (10)$$

where $\dot{q}_{rad}$ is the solar radiation gain; $\dot{q}_{occu}$ is the heat gain by occupants; $\dot{q}_{elec}$ is the heat gain by using electrical devices; $\dot{q}_{cond}$ is the conduction heat loss; $\dot{q}_{vent}$ is the ventilation heat loss with heat recovery; $\dot{q}_{infil}$ is the infiltration heat loss through leakages in a building; $\dot{q}_{HVAC}$ is the heat gain by HVAC system.

Note that the solar heat radiation absorption occurs through windows and walls. For brevity, we can assume that the radiation gain occurs only through windows because it is more significant than through a wall. The net solar radiation to a building will change based on various physical factors including the view factors between the sun and the building and the temperature of the building. For the simple approach, the average value for it is used. The solar radiation gain is used as follows,

$$\dot{q}_{rad} = \chi A_{fen} G \quad (11)$$

where χ is the solar heat gain coefficient (SHGC) (0.75 is used). A_{fen} is the area of building fenestration. G is the irradiation of the sun to the building fenestration (W/m^2).

Note that SHGC is the fraction of solar radiation that results in heat gain to the space. Based on the assumption of the quasi-steady state condition, the heat loss through the wall is as below,

$$\dot{q}_{cond} = \frac{A_w}{R}(T_g - T_\infty) \quad (12)$$

where

$$R = \left(\frac{1}{h_{ext}}\right) + \sum \left(\frac{L_n}{k_n}\right) + \left(\frac{1}{h_{int}}\right) \quad (13)$$

where h_{ext} and h_{int} are exterior and interior convective transfer coefficient $\left(\frac{W}{m^2 K}\right)$; k_n is thermal conductivity $\left(\frac{W}{m.K}\right)$; A_w is the area of walls (m^2); and L_n is the thickness (m)

The ventilation heat loss is,

$$\dot{q}_{vent} = (1 - \frac{\beta}{100}) c_{p,0} \rho_0 \dot{V} A_f (T_g - T_\infty) \quad (14)$$

where β is heat recovery efficiency (%); $c_{p,0}$ is specific heat of air $\left(\frac{J}{kg.K}\right)$; ρ_0 is density of air $\left(\frac{kg}{m^3}\right)$; $\dot{V}$ is ventilation rate per floor area ($m^3/(s.m^2)$); A_f is area of floor (m^2)

The net heat loss by air infiltration is,

$$\dot{q}_{infil} = c_{p,0} \rho_0 n V (T_g - T_\infty) \quad (15)$$

where n is air replacement per second $\left(\frac{1}{\text{sec}}\right)$, V is building volume (m^3)

Assuming the inside temperature (comfort temperature) should keep a constant temperature, $Q_{st} = 0$.

The energy balance becomes,

$$0 = (\dot{q}_{rad} + \dot{q}_{occu} + \dot{q}_{elec}) - (\dot{q}_{cond} + \dot{q}_{vent} + \dot{q}_{infil}) + \dot{q}_{HVAC} \tag{16}$$

Note that Q_{HVAC} is used for heating or cooling to keep the inside temperature as constant comfort temperature.

$$\dot{q}_{HVAC} = (\dot{q}_{cond} + \dot{q}_{vent} + \dot{q}_{infil}) - (\dot{q}_{rad} + \dot{q}_{occu} + \dot{q}_{elec}) \tag{17}$$

For the outside temperature, monthly average temperatures at a location can be used.

Annual total heating or cooling consumption can be calculated,

$$Q_{total} = \frac{\dot{q}_{HVAC}}{1000} 24[hours]365[days] = 8.76\, \dot{q}_{HVAC}\ [kWh] \tag{18}$$

This annual heating and cooling consumption is used to represent the energy performance of insulation wall systems.

Fire safety performance sub-model

The fire safety performance sub-model will estimate the temperature profile of an insulation system to find the time to failure of insulation systems when they are exposed to a possible fire in a specific compartment. For this, the fire safety performance sub-model consists of the fire severity sub-model and the heat transfer sub-model. Since the fire severity in a compartment is mainly governed by the fuel load, the compartment's size and lining materials and ventilation conditions, the fire severity model will determine the possible time-temperature curves for a given compartment not just using a standard time-temperature curve. Then the heat transfer model will calculate the temperature profiles of the insulation systems.

A number of numerical models to estimate temperatures of the post-flashover have been developed. Most of these were developed based on the energy balance with the one zone assumption. Because of the excessive turbulent characteristics of the post-flashover, a field model is also not easily applicable to post-flashover [61].

Initially we follow the approach of the energy balance approach that Magnusson and Thelandersson did for the so-called "Swedish" fire curves. The energy balance is:

$$\dot{q}_{st} = \dot{q}_{in} - \dot{q}_{out} \tag{19}$$

Assumptions:

- A fire is fully developed in a compartment so that the condition of the room (T_g) is uniform (one zone assumption).
- Combustion occurs within the compartment.
- The interior and exterior surface temperatures are uniform, respectively.
- The interior surface temperature is the same as the gas temperature.
- Gas is grey ($\varepsilon_g = \alpha_g$), opaque, and no reflection ($\rho = 0$) and the gas and the surface have the same emissivity.
- The walls, ceiling and floor are inert, with no heat generation.

The control volume for the fire model is in Figure 12.

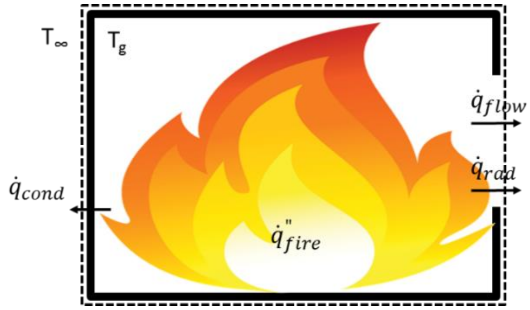

Figure 12. Energy balance model for the fire severity sub-model

The energy balance for this is as below.

$$\dot{q}_{st} = \dot{q}_{fire} - \dot{q}_{cond} - \dot{q}_{rad} - \dot{q}_{flow} \quad (20)$$

where $\dot{q}_{st}$ is the rate of heat stored inside of the compartment; $\dot{q}_{fire}$ is the heat release rate from a fire inside a compartment; $\dot{q}_{cond}$ is the heat loss rate through the wall; $\dot{q}_{rad}$ is the rate of the net radiation heat loss through the opening; $\dot{q}_{flow}$ is the rate of the net heat loss because of the hot gas flow out.

Based on the assumption that all air coming in burns, the heat release rate is defined as,

$$\dot{q}_{fire} = 0.23\dot{m}_a \Delta H_{c,O2} \quad (21)$$

where $\Delta H_{c,O2}$ is the heat release per unit mass of oxygen ($13.1\frac{MJ}{kg}$) and

$$\dot{m}_a \approx 0.5A_0\sqrt{H_0}\ (\frac{kg}{s}) \quad (22)$$

For the conduction loss, one-dimensional heat diffusion equation is calculated,

$$\frac{\partial}{\partial \mathrm{x}}\left(k\frac{\partial \mathrm{T(x,t)}}{\partial \mathrm{x}}\right) = \rho c \frac{\partial \mathrm{T(x,t)}}{\partial \mathrm{t}} \quad (23)$$

where k, ρ and c are conductivity (W/m^2.K), density (kg/m^3) and specific heat (J/kg.K) of a wall, respectively.

The net radiation heat transfer through opening is as below,

$$\dot{q}_{rad} = A_o\varepsilon_g\sigma(T_g^4 - T_{out}^4) \quad (24)$$

where A_o is opening area (m^2), ε_g is emissivity of gas, σ is the Stefan boltzmann number (5.67x10^{-8}W.m/K^4), T_g is the gas temperature (K) and T_{out} is the outside temperature (K).

The net heat loss by the convective flow is,

$$\dot{q}_{flow} = c\dot{m}_g(T_g - T_\infty) \quad (25)$$

The energy balance becomes,

$$\rho cV\left(\frac{dT}{dt}\right)=\dot{q}_{fire}-\dot{q}_{rad}-\dot{q}_{flow}-\dot{q}_{cond} \tag{26}$$

Note that the stored energy is less significant than other terms. For the typical enclosure fires, it is less than 1% of the total energy [62]. Therefore, the equation becomes as below.

$$0=\dot{q}_{fire}-\dot{q}_{rad}-\dot{q}_{flow}-\dot{q}_{cond} \tag{27}$$

The gas temperature (T_g) can be solved from the equation 27.

Note that in this simple model, the heat released rate is defined with equation 21 and 22, but it is only for the peak heat release rate. In order to define transient heat release rates, heat release rates data or transient air entrainment rate is necessary. In the case which this information is not available, one of the options is to use previously developed time-temperature curves. The Eurocode parametric time-temperature curve [63] is one of the most widely used fire severity model. This curve is also included in the decision model so that designers can choose a fire severity model based on their conditions. Details about the model are included in Appendix B.

The heat transfer phenomenon is simulated using a one dimensional transient heat diffusion equation without heat generation:

$$\frac{\partial}{\partial \mathrm{x}}\left(k(T)\frac{\partial \mathrm{T}(\mathrm{x},\mathrm{t})}{\partial \mathrm{x}}\right)=\rho(T)c(T)\frac{\partial \mathrm{T}(\mathrm{x},\mathrm{t})}{\partial \mathrm{t}} \tag{28}$$

where $\mathrm{T}(\mathrm{x},\mathrm{t})$ is the temperature at the location x, at the time, t ($^{\circ}$C); $k(T), \rho(T)$ and $c(T)$ are conductivity (W/m^2.K), density (kg/m^3) and specific heat (J/kg.K) at a temperature, T, respectively.

This partial differential equation can be solved numerically using the Finite Difference Method (FDM). The process to solve the equation using FDM is explained in Appendix C. Based on the calculation, the failure time at which an insulation layer reaches the failure temperature is calculated and this represents the fire safety performance of insulation systems.

Soundproofing performance sub-model

The propagation of sound wave through a stationary medium is governed by the wave equation [64]. Using the wave equation, the sound transmission of the insulation system can be calculated. A simple form of the wave equation, the Helmholtz equation is one of the easiest ways to solve acoustic problems. Equation 15 is the one-dimensional form of the Helmholtz equation, which governs the spatial variation of pressure.

$$\frac{d^2p_i}{dx^2}+k^2p_i=0 \tag{29}$$

where k is the wavenumber ($k=\omega/c$, where $\omega=2\pi f$ (the angular frequency), where f is frequency) and p is the sound pressure.

For the soundproofing performance sub-model, the one-dimensional sound model of layered partitions which was developed by Poblet-Puig [65] is used. Figure 13 is the schematic diagram of the one-dimensional sound model for the layered partition with absorber.

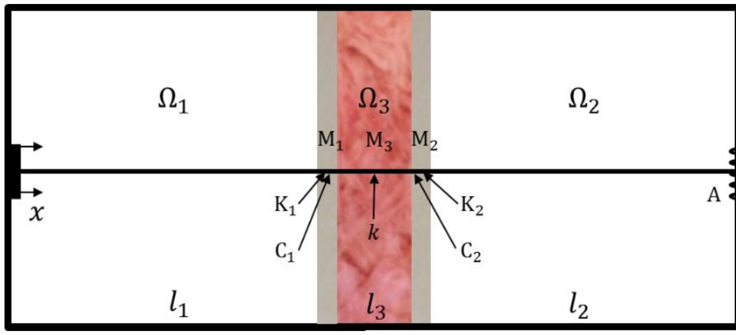

Figure 13. Schematic diagram of one-dimensional soundproofing performance sub-model: x is the sound source; $\boldsymbol{\Omega_i}$ is the acoustic domain, i (e.g. rooms); $\boldsymbol{l_i}$ is the length of the acoustic domain, i (m); $\boldsymbol{M_i}$ is mass of the layer (particle); $\boldsymbol{K_i}$ is the stiffness of the layer; $\boldsymbol{C_i}$ is the damping coefficient; $\boldsymbol{k_i}$ is the material propagation constant; A is admittance (m^3/Ns) (Figure is modified from reference [65])

Using the appropriate boundary conditions, the reference [65] provides the analytical solutions for the problem. The reference [65] provides analytical solutions for each region Ω_1, Ω_2 and Ω_3.

$$\hat{p}_1(\hat{x}) = C_1 e^{iN\hat{x}} + C_2 e^{-iN\hat{x}} \tag{30}$$

$$\hat{p}_2(\hat{x}) = C_3 e^{iN\hat{x}} + C_4 e^{-iN\hat{x}} \tag{31}$$

$$\hat{p}_3(\hat{x}) = C_5 e^{i\gamma N\hat{x}} + C_6 e^{-i\gamma N\hat{x}} \tag{32}$$

where $\hat{p}_i$ is the normalization of pressure in an acoustic domain, i; C_j is arbitrary constants of analytical solution which are determined from boundary conditions; i is the imaginary unit in an complex number; N is the waves in an acoustic domain ($N = kl_i$); γ is the ratio of the wave number of the medium and the air ($\gamma = k_{med}/k_{air}$).

Note that the symbol ∧ ("hat") above each variable denotes the corresponding dimensionless variable. For example, $\hat{x}$ denotes the normalization of x (distance) by dividing unit x. Reference [65] provides linear systems of equations to determine the arbitrary constants as a form of equation (33 and 34). The detail about the governing equations and boundary conditions can be found in reference [65].

$$Ac = b \tag{33}$$

$$c = (C_1, C_2, C_5, C_6, C_3, C_4) \tag{34}$$

Note that A and b are provided as a 6x6 matrix and a 6x1 matrix forms, respectively in reference [65].

The sound pressure level can be expressed as,

$$L = 10log_{10}\left(\frac{|p|^2}{2p_0^2}\right) \tag{35}$$

where p_0 is a reference pressure value ($p_0 = 10 \cdot 10^{-5} Pa$, the lowest limit of audible pressure typically used [65]). The sound level difference between acoustic domains can be expressed as [65],

$$D = \frac{\int_{\Omega_1} L_1(x)\,dx}{l_1} - \frac{\int_{\Omega_2} L_2(x)\,dx}{l_2} \tag{36}$$

The sound level difference is used to represent a soundproofing performance of an insulation system.

Sustainability

Under this sustainability objective, the factors only related to environment will be included because these factors are unique aspects in sustainability, and other factors can be considered for other objectives. For sustainability, three factors which were chosen by Roberts [47] will be used: carbon dioxide equivalent (CO_{2e}), total energy usage (MJ) and water consumption (kg). "Cradle-to-grave" with full landfill disposal as the products' last state are considered for all the factors [47]. The functional unit of insulation material is one square meter of insulation material with a thickness that provides 1m^2K/W of R-value.

Note that carbon footprint is one of the widely used terms for environmental impacts by human activities, and it is defined as "a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product [66]." Even though carbon dioxide (CO_2) is one of the most common greenhouse gases, there are other greenhouse gases such as methane (CH_4) or nitrous oxide (N_2O). CO_{2e}, or carbon dioxide equivalent, is a standard unit to measure carbon footprint. This unit expresses the amount of impact of each greenhouse gas in terms of the amount of CO_2 [66]. For example, the global warming potential for methane over 100 years is 21 of CO_{2e} and it represents an equivalence of one ton of methane emissions to 21 tons of carbon dioxide emission [67].

The carbon dioxide equivalent of an insulation system is calculated as below,

$$x_{co_{2e}} = x_{co_{2e},SH1} + x_{co_{2e},IN} + x_{co_{2e},SH2} \tag{37}$$

where $x_{co_{2e},SH1}$, $x_{co_{2e},IN}$ and $x_{co_{2e},SH2}$ is the carbon dioxide equivalent values for interior sheathing (SH1), insulation material (IN) and outside sheathing (SH2), respectively.

The total energy usage of an insulation system is estimated as below,

$$x_{eu} = x_{eu,SH1} + x_{eu,IN} + x_{eu,SH2} \tag{38}$$

where $x_{eu,SH1}$, $x_{eu,IN}$ and $x_{eu,SH2}$ is the total energy usage (MJ) for interior sheathing (SH1), insulation material (IN) and outside sheathing (SH2), respectively.

The total water consumption of an insulation system is estimated as below,

$$x_{wc} = x_{wc,SH1} + x_{wc,IN} + x_{wc,SH2} \tag{39}$$

where $x_{wc,SH1}$, $x_{wc,IN}$ and $x_{wc,SH2}$ is the water consumption (kg) for interior sheathing (SH1), insulation material (IN) and outside sheathing (SH2), respectively.

Cost

Cost of insulation includes the cost of materials, labor, and equipment that the installing contractor might pay [68]. Cost of insulation is based on per unit area of insulation (m^2). It represents the cost for one unit of work. Note that some insulation materials require special tools such as spray guns for spray foam insulation materials.

$$x_{co} = x_{co,S1} + x_{co,IN} + x_{co,S2} \tag{40}$$

where $x_{co,S1}$, $x_{co,IN}$ and $x_{co,S2}$ is the cost ($) values for interior sheathing (S1), insulation material (IN) and outside sheathing (S2), respectively.

Decision analysis model

Multi-attribute decision analysis model

A multi-attribute decision analysis model can help to compare and evaluate the various attributes and alternatives systematically [69]. Equation 41 is an additive form of multi-attribute evaluation which is the most widely used. The performance score, v, is:

$$v(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} w_i r_i(x_i) \quad (41)$$

where w_i is the weight and r_i is the individual normalizing function of x_i, respectively.

Note that the additive form requires additive independence condition in which "the contribution to the overall satisfaction level of an attribute is independent of the level of the other attributes [70]."

Normalization

In order to compare the physical outputs of each sub-model and parameters from manufactures, data transformation techniques are necessary because they have different units of measurement [71]. It is required to convert the data into a homogenous data type. This could be done by a normalization function. The linear normalization function is the most common form of normalization [71]. Considering normalization, attributes can be categorized as two types: beneficial attributes and detrimental attributes. For beneficial attributes, the attribute values are increased as the preference conditions are increased, such as the sound transmission loss through a wall in which more sound transmission loss means better sound blocking performance of the wall. If the preference condition is decreased as the attribute values are increased, it is a detrimental attribute. The output value from the energy performance sub-model is a good example of this because the model provides a measure of the amount of energy consumed, and less energy consumption is preferred.

For the beneficial attributes, the normalization function can be expressed as,

$$r_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (42)$$

where x_{max} and x_{min} are the maximum and minimum values of attribute, i.

For the detrimental attributes, the normalization function can be expressed as,

$$r_i = \frac{x_{max} - x_i}{x_{max} - x_{min}} \quad (43)$$

Types of each sub-attribute and used normalization functions are listed in Table 2.

Table 2. Normalization function for each type of sub-attributes

Attribute	Sub-attribute	Type of attribute	Normalization function
Energy performance	Annual energy consumption	Detrimental attribute	Equation (42)
Soundproofing	Sound transmission loss	Beneficial attribute	Equation (43)

performance			
Fire safety performance	Failure time	Beneficial attribute	Equation (43)
	Carbon dioxide equivalent	Detrimental attribute	Equation (42)
Sustainability	Total energy usage	Detrimental attribute	Equation (42)
	Total water consumption	Detrimental attribute	Equation (42)
Cost	Cost	Detrimental attribute	Equation (42)

Weights

One of the important steps for weighted-sum method is to decide weights for attributes. Not all attributes are equally important. An attribute might be important to a decision maker, but it might be not important to other decision makers. This different preference can be reflected in a decision making process using weights. When an attribute is important to a decision maker, a relatively high weight should be allocated while lower weight should be used for the attribute which is relatively not important. In general, weights are normalized to sum to one [71].

$$\sum_{i=1}^{n} w_i = 1 \tag{44}$$

It is important to reflect the intent of a decision maker when weights are decided. If a decision maker has a mind on specific weights for each attribute, those should be used. However, it is often hard for a decision maker to decide the appropriate weights. There are some tools to help to find appropriate weights for attributes. One of them is the Analytical Hierarchy Process (AHP). AHP was developed as one of the multiple criteria decision-making tools, which was developed by Saaty [72]. It has been widely reviewed and applied in many literature resources [73,74]. It simplifies the preference rating processes using pair wise comparisons in which complex decision problem can be broken down into a series of small judgments, thus allowing the decision process to be more simple and efficient. It also provides a measure to check the consistency of judgments, thereby increasing the credibility of weighting results. Even though the pair wise comparisons are relatively convenient, people who use this could make mistakes due to lack of knowledge, human nature and improper use of the discrete scale in AHP [72]. The consistency of the pair wise comparisons could be checked by the consistency ratio in AHP, thus increasing its credibility.

Note that it is hard to use AHP when there are many elements such as more than eight or nine because the number of comparison increases significantly (the number of comparison= $\frac{n(n-1)}{2}$, where n is the number of elements).

Since our case involves much more factors including attributes and possible alternatives, it is hard to use AHP as a decision making tool to select insulation systems. It can be, however, used to select *weights* of attributes [75] because we have five attributes only. Further detail of AHP method will be explained in the next section. If weights for all attributes were developed, the multi-attribute evaluation process can be used for the decision analysis tool.

Following is a detail description of AHP. A square matrix is established by pair wise comparisons. For example, a_{ij} denotes how much attribute i is preferred over attribute j. The judgements are assigned a number on a scale. Table 3 is the scale of relative importance developed by Saaty [72].

Table 3. The fundamental scale of relative importance (modified from reference [72])

Intensity of relative importance	Definition	Explanation
1	Equal importance	Two attributes contribute equally to the objective. For example, one prefers soundproofing and energy efficiency performance equally.
2	Weak or slight	
3	Moderate importance	Experience and judgement strongly favor one attribute over another. For example, when a residential building is designed, a builder might think sustainability is important but he or she prefers cost to sustainability. In this case, the builder might think cost is moderately more important than sustainability.
4	Moderate plus	
5	Strong importance	
6	Strong plus	
7	Very strong or demonstrated importance	An attribute is favored very strongly over another; its dominance demonstrated in practice. For example, when a conference room is designed, the building owner might think of soundproofing as being tremendously important, with fire safety issues occupying a role of lesser importance.
8	Very, very strong	
9	Extreme importance	The evidence favoring one attribute over another is of the highest possible order of affirmation. For example, when a builder designs a building, he or she may believe fire safety is extremely important no matter what the cost.
Reciprocals of above	If attribute i has one of the above non-zero numbers assigned to it when compared with attribute j, then j has the reciprocal value when compared with i.	A reasonable assumption

Figure 14 shows the scale of relative importance more intuitively. For example, when a building owner compares fire safety (i) to sustainability (j), various preferences can be chosen. When the owner might think both attributes are equally important, the judgment value should be one. For the case where the owner favors fire safety above all and sustainability as not important at all, the scale should be nine. If he or she strongly prefers fire safety to sustainability, the comparison scale would be five. Note that the scale represents a relative comparison and it is an inevitably subjective judgment. However, through this pair wise comparison, the process can be more transparent and efficient.

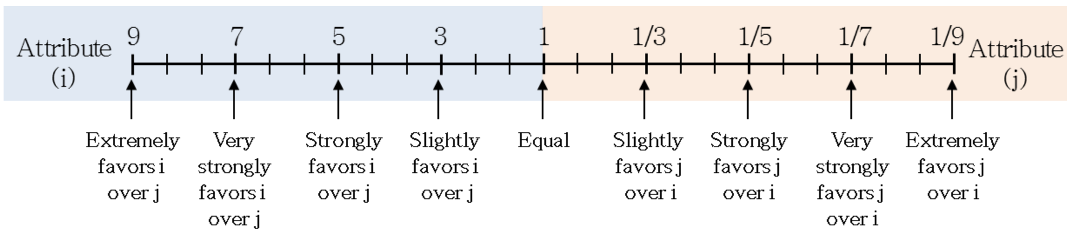

Figure 14. The scale of relative importance

As you can see, when one prefers attribute i, to attribute j, the number should be checked in left side of one, and the actual value should be put in the comparison matrix. For the case when one prefers attribute j to attribute i, one of the judgment values in the right side of one should be checked. In this case, the reciprocal values should be put in the matrix.

For the case where there are five attributes, a 5 x 5 square matrix will be developed (equation 45). Note that $a_{ij} = \frac{1}{a_{ji}}$ for i≠j and $a_{ij} = 1$ for i=j (reciprocal matrix).

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{pmatrix} \quad (45)$$

In the next step, a normalized pair wise matrix (A_{norm}) is generated by dividing each element in the matrix by its column total ($\sum_{i=1}^{n} a_{ij}$)

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (46)$$

$$A_{norm} = \begin{pmatrix} \bar{a}_{11} & \bar{a}_{12} & \bar{a}_{13} & \bar{a}_{14} & \bar{a}_{15} \\ \bar{a}_{21} & \bar{a}_{22} & \bar{a}_{23} & \bar{a}_{24} & \bar{a}_{25} \\ \bar{a}_{31} & \bar{a}_{32} & \bar{a}_{33} & \bar{a}_{34} & \bar{a}_{35} \\ \bar{a}_{41} & \bar{a}_{42} & \bar{a}_{43} & \bar{a}_{44} & \bar{a}_{45} \\ \bar{a}_{51} & \bar{a}_{52} & \bar{a}_{53} & \bar{a}_{54} & \bar{a}_{55} \end{pmatrix} \quad (47)$$

Finally, the criteria weight vector W_i is generated by averaging the entries on each row of A_{norm}.

$$W_i = \frac{\sum_{j=1}^{n} \bar{a}_{ij}}{n} \tag{48}$$

$$W_i = \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \\ W_5 \end{bmatrix} \tag{49}$$

Since the AHP process involves many pair wise comparisons, it might contribute some incosistencies between the comparisons. AHP includes an effective technique for chekcing the consistency of the comparisons made by the decision maker. The first step for the consistency check is to calculate Consistency Index (CI)

Consistency vectors (CV_i) can be calculated.

$$CV_1 = \frac{1}{W_1}[a_{11}W_1 + a_{12}W_2 + a_{13}W_3 + a_{14}W_4 + a_{15}W_5] \tag{50}$$

$$CV_2 = \frac{1}{W_2}[a_{21}W_1 + a_{22}W_2 + a_{23}W_3 + a_{24}W_4 + a_{25}W_5] \tag{51}$$

$$CV_3 = \frac{1}{W_3}[a_{31}W_1 + a_{32}W_2 + a_{33}W_3 + a_{34}W_4 + a_{35}W_5] \tag{52}$$

$$CV_4 = \frac{1}{W_4}[a_{41}W_1 + a_{42}W_2 + a_{43}W_3 + a_{44}W_4 + a_{45}W_5] \tag{53}$$

$$CV_5 = \frac{1}{W_5}[a_{51}W_1 + a_{52}W_2 + a_{53}W_3 + a_{54}W_4 + a_{55}W_5] \tag{54}$$

λ can be calculated by averaging the consistency vectors.

$$\lambda = \sum_{i=1}^{n} CV_n \tag{55}$$

Consistency index (CI) is calculated,

$$CI = \frac{\lambda - n}{n - 1} \tag{56}$$

where n is the number of attributes.

Consistency Ratio (C_r) is the ratio of CI to the Random Inconsistency Index (RI), and it should be less than 0.1 to be consistent [72]. If it is larger than 0.1, it means there is inconstancy so that one should check the pair wise comparisons until the Consistency Ratio become less than 0.1. Note that RI is from reference [72].

$$C_r = \frac{CI}{RI} < 0.1 \tag{57}$$

Table 4. Random Inconsistency Index (RI) (Source from [72])

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Insulation systems – materials and insulation system options

The tool includes material data base for sheathings and insulations-17 sheathing materials and 7 insulation materials. This is an example and users can add more options for sheathing and insulation materials.

Sheathing materials

Various types of materials are used for sheathing materials such as plywood, OSB (Oriented Strand Board), 12.7mm (½ inch) fiberboard, cementitious boards, gypsum boards, XPS (Extruded foam), EPS (Expanded foam) and Polyisocyanurate (also referred PIR, Polyiso, or ISO). Many of them can be used as an interior or exterior sheathing layer. Among them, OSB is the most widely used sheathing type in the US home (75% in 2008) and especially 11.1mm (7/16 inch) thickness of OSB is the most widely used thickness (55% in 2008). The second widely used exterior sheathing material is plywood (10%). Other materials each represent less than 5% usage. In the current model, OSB, plywood and gypsum boards with various thicknesses are included for interior and exterior sheathing materials. Table 5 shows 17 types of sheathing material options.

Table 5. Thermal properties and sustainable properties of sheathing materials

SH2 No.	Material	Conductivity [W/m.K]	Density [kg/m^3]	Specific Heat [J/kg.K]	Possible thickness options [mm]	CO_2 emission† [Kg-$CO_{2,eq}$/m^2]	Energy use† [MJ/m^2]	Water use† [Kg/m^2]	Cost* [$]
1	Gypsum board	0.2	800	950-1600	6.4 (1/4”)	2.2	37.4	27.5	3.79
2					7.9 (5/16”)	2.5	41.5	30.5	3.62
3					9.5 (3/8”)	2.8	46.1	33.9	3.45
4					12.7 (1/2”)	3.1‡	51.3	37.7	4.58
5					15.9 (5/8”) ±	3.4	56.9	41.9	4.69
6					19.0 (3/4”)	3.7	62.6	46.1	4.80
7					25.4 (1”)	4.1	68.9	50.7	8.4
8	Plywoodŧ	0.12	545	1215	6.4 (1/4”)	3.89	72.2	3.3	6.99
9					9.5 (3/8”)	5	92.9	4.2	6.99
10					12.7 (1/2”)	6.67	123.9	5.6	10.7
11					15.9 (5/8”)	8.33	155	7.10	10.15
12					17.5 (2/3”	9.44	175	8.0	12.78
13	OSBł	0.13	650		9.5 (3/8”)	2.3	39.9	3.89	4.72

14	11.11 (4/9")	2.3	39.9	3.89	5.06
15	12.7 (1/2")	2.3	39.9	3.89	6.38
16	15.9 (5/8")	2.3	39.9	3.89	6.61
17	19.05 (3/4")	2.3	39.9	3.89	7.46

† Values for CO_2 equivalent, energy use are from ref [76] unless otherwise noted. Ref [76] provides values for 5/8" gypsum board, and values for other thicknesses were extrapolated based on the assumption that the values increase as the thickness of gypsum board increases.
‡ is from [77]
± is from [78]
*Values for cost is from ref [68]. Values for 7.9 mm and 19 mm are presented as a median of two adjacent values.
Ť For plywood, thermal properties and sustainability values are from [15] and [79], respectively. Cost is from [68].
ɨ For OSB, thermal properties and sustainability properties are from [80] and it is assumed that OSBs which have different thicknesses have the same sustainability properties. Cost is from [81]

Thermal barrier materials

Most of sheathing materials can be used as an interior sheathing layer with an "inert" insulation material which is non-foam plastic insulation. However, a thermal barrier needs to be installed as an interior sheathing when a foam plastic insulation material is used. Based on the IBC, 12.7mm (1/2 inch) gypsum wallboard is defined as a prescribed thermal barrier. As mentioned previously, it is problematic to use 12.7mm (1/2 inch) gypsum wallboard without real fire consideration. The IBC also allows to use "equivalent thermal barrier." Some materials can be considered as an option for this such as spray-applied cementitious materials, spray-applied cellulose materials, Portland cement plaster and other materials [82] For now, the model includes only gypsum wallboards with various thicknesses as thermal barriers. It is mainly because gypsum wallboard has strong fire resistant characteristics of the gypsum wallboard and there are relatively many data on the thermal properties of the material. Other materials can also be an option if it has an equivalent thermal behavior, and they can be included in the model later if the properties of the material and the thermal behavior are well known. In this section, the thermal characteristics of gypsum wallboard will be reviewed.

In general, there are three types of gypsum boards on the market: regular plasterboard, type X and type C. Regular plasterboard provides some fire resistance due to the presence of gypsum in the core, but it is not fire rated. Type X plasterboard is fire rated. In type X plasterboard, the core, which is primarily gypsum, is reinforced with the addition of glass fibers, increasing its strain to failure, reducing cracking when exposed to fire and providing fire resistance ratings when used in tested assemblies.

In the event of fire, the properties of gypsum boards changes dramatically so that the change should be considered in the fire sub-model. When gypsum board is exposed to a fire, bonded water from the gypsum is released. This process absorbs heat but also causes large volume changes in the core which result in shrinkage cracking in the gypsum and eventually causing the panel to fail due to loss of structural integrity.

Even though these different types of gypsum boards affect their mechanical properties significantly, their thermal properties are quite similar [83]. The reinforcement of core, for example, generally improves the mechanical properties of gypsum board such as shrinkage, cracking, ablation and falling off after dehydration [83]. On the other hand, the energy performance of different types of gypsum boards are quite similar [83]. Figure 15 (b) shows the effect of the gypsum board type on the fire. Note that categorization of GF, GP type A and GP type F in the figure are based on EN 15283-2 [84], an Austrian standard for the gypsum board, and signify gypsum fiberboard, gypsum plasterboard of type A and gypsum plasterboard of type F, respectively. GP type A is a regular common gypsum board, and GP type F may be considered similar to gypsum board type X [83].

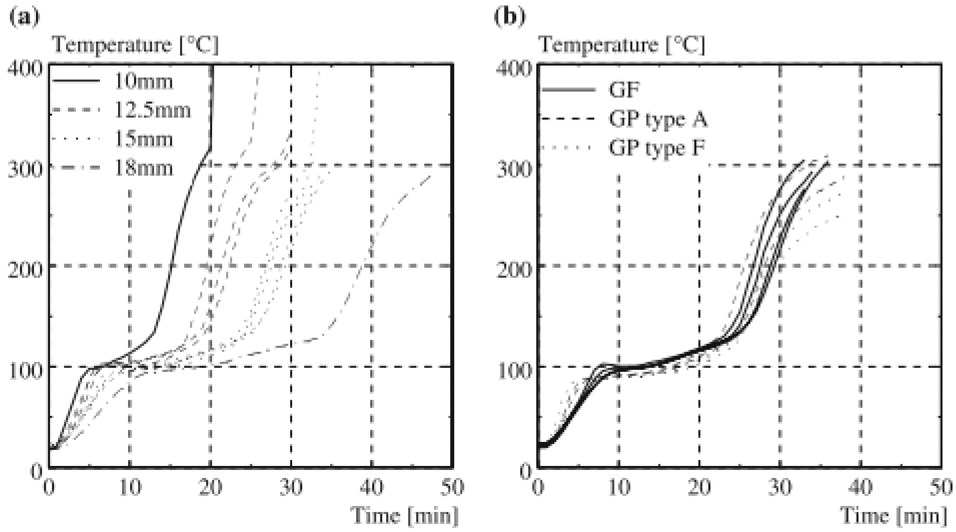

Figure 15 (a) Temperature development on the fire-unexposed side of gypsum fibreboards of different thickness tested as a single board; (b) temperature development on the fire-unexposed side of different types of 15 mm thick gypsum boards tested as a single board [83].

Gypsum board typically consists of a gypsum core between two paper layers. The paper layers provide adequate tensile strength for handling and usage. Gypsum plaster consists of calcium sulfate hemihydrate ($CaSO_4 \cdot ½H_2O$) and more than 20% water ($CaSO_4 \cdot 2H_2O$). When it is heated, the fully hydrated gypsum plaster is calcinated, or returned to hemihydrate ($CaSO_4 \cdot ½H_2O$) around 90 to 120 °C, and fully anhydrous ($CaSO_4$) at around 200 °C [85].

$$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 \cdot \frac{1}{2}H_2O + \frac{3}{2}H_2O \quad (58)$$

$$CaSO_4 \cdot \frac{1}{2}H_2O \rightarrow CaSO_4 + \frac{1}{2}H_2O \quad (59)$$

Figure 16 is the result of the TGA test of a gypsum plaster [86], and it shows these phenomena. In this TGA test, the gypsum plaster was heated at a heating rate of 20 °C/min. After 100 °C, the weight is decreased because water is released. In the two reactions (equation 58 and equation 59), the 10-20% of weight is lost between 100 to 200 °C. The derivative of the weight loss shows these two phenomena more clearly through the two peaks. These reactions are endothermic reactions which absorb heat. In addition, when the released water is vaporized, it also absorbs significant heat without increasing temperature. These are important reasons why gypsum board is a good material for thermal barriers.

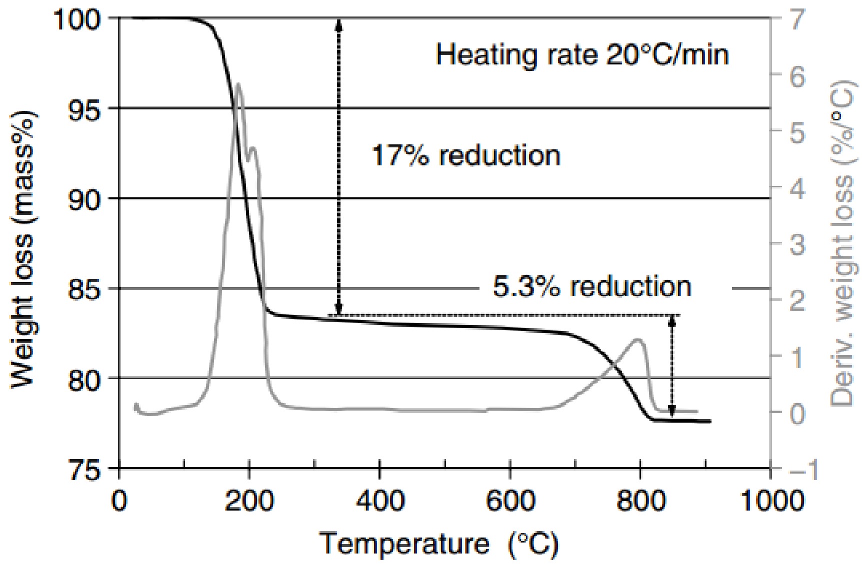

Figure 16 Curves of the thermogravimetric analysis (TGA) of gypsum in dry air [86]

After 700 °C, there is one more peak showing another big weight loss. For this phenomenon, there are differing explanations. Some research explains it as another dehydration [87,88]. Walkili et al., suggest it as the decomposition of $CaSO_3$ because most of moisture comes out [86].

$$CaSO_3 \rightarrow CaO + CO_2 \tag{60}$$

These characteristics of gypsum boards govern how heat transfers as a gypsum board is heated. It is, therefore, important to represent these phenomena when they are simulated using proper thermal properties. There are many studies that report thermal properties of gypsum boards. Figure 17 shows the thermal conductivities of gypsum boards from various investigative resources. At an ambient temperature, the thermal conductivity is within a range of 0.2-0.25 $W/m^2.K$ in all the investigative studies. This range decreases rather uniformly in the studies to 0.1-0.13 $W/m^2.K$ during the dehydration process. As temperature increases beyond this level, the conductivity ranges also increase, as well as the diversity of results within the investigative studies. Note that the “proposed” properties in the figures (Figure 17, Figure 18 and Figure 19) are the thermal property values that are chosen for the further heat transfer analysis in this research.

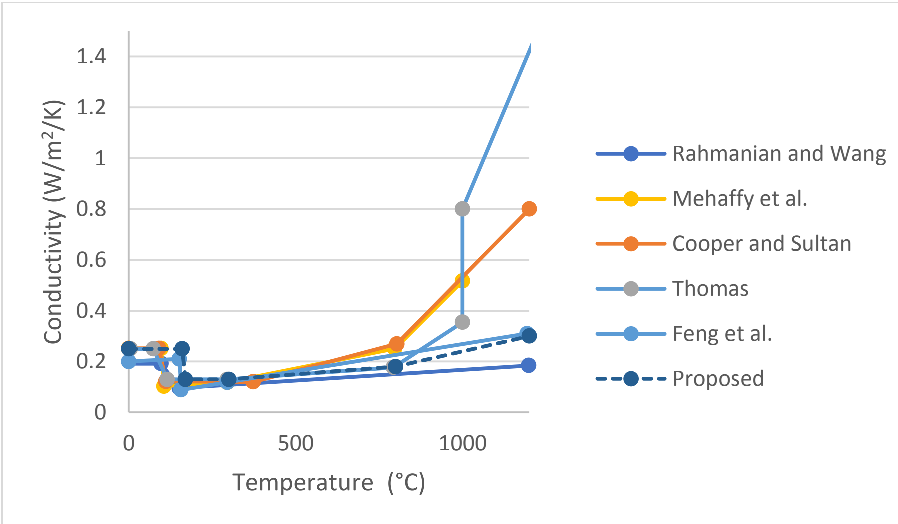

Figure 17 Conductivities of gypsum boards at different temperatures in various references

Figure 18 represents the specific heat of gypsum boards. It is around 950-1604 J/kg.K in the ambient temperature. It increases substantially as the dehydration process starts and decreases to the initial value of specific heat as the dehydration process ends. Around 600-700 °C, the specific heat increases again, and this is related to the decomposition of $CaSO_3$ as we discussed above.

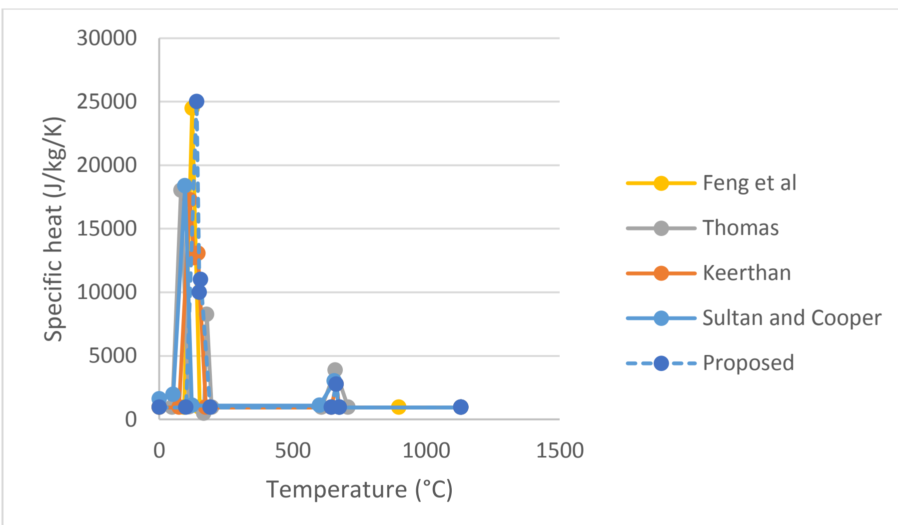

Figure 18 Specific heats of gypsum boards at different temperatures in various references

Figure 19 shows the relative density of gypsum boards. At an ambient temperature, the density of gypsum board is around 550-850 kg/m^3 [89]. It decreases during the dehydration process; and decreased density continues until around 600-700 °C, at which point $CaSO_3$ is decomposed.

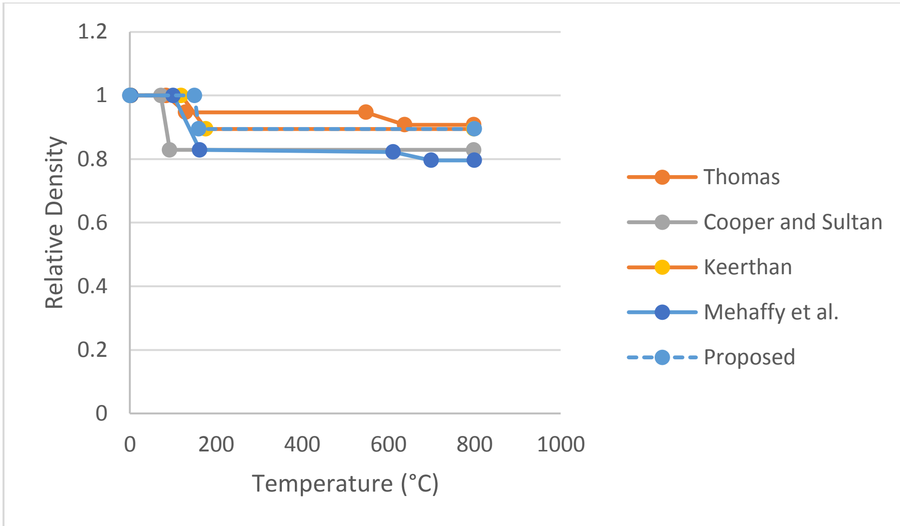

Figure 19 Relative densities of gypsum boards at different temperatures in various references

As discussed, the thermal properties of gypsum boards are affected by the dehydration process significantly.

Insulation materials

Various types of insulation materials are used in building industries. Fiberglass (batt and blown) is the most wildly used insulation in the US home (~60% and 10%, respectively). In addition, people use cellulose blown (~ 9%), foam board (~7%), spray foam (~5%), and Rockwool batt and blown (~1%). Table 6 includes the thermal properties and sustainable properties of insulation materials. Note that the insulation material selection are based on Robert's work [47].

Table 6. Thermal properties and sustainable properties of insulations

INS No.	Materials	Conductivity‡ [W/m/K]	Density† [Kg/m^3]	Specific Heat† [J/kg.K]	CO_2 emission‡ [Kg CO_{2e}]	Energy use‡ [MJ]	Water use‡ [kg]	Cost‡ [$]
1	Fiberglass batt-Unfaced (FG-U)	0.039	32	835	0.76	19.5	9.7	2.83
2	Fiberglass batt Kraft-faced (FG-K)	0.039	28	-	0.62	9.9	4.8	2.83
3	Rockwool batt (RW-B)	0.034	190	-	1.81	25.2	6.3	3.86
4	Cellulose blown (C-B)	0.040	48-64‡‡	-	7.83	26.2	0.8	5.02
5	Spray polyurethane foam-Open cell (SPF-OC)	0.039	6.4-19.2*	-	2.4	52.1	457	8.28
6	Spray polyurethane foam-Closed cell (SPF-CC)	0.021	31*	-	26.65	97.5	761	9.71
7	Extruded polystyrene (XPS)	0.029	55	1210	60.8	80.7	37.9	14.06

‡ sustainable properties are from [47]. The functional unit is 1/m^2 with a thickness that provides 1m^{2}K/W of R-value.
† is from [15], unless otherwise noted.
*is from [90].
‡‡ is from [91].

Insulations system options

As suggested previously, an insulation system in this research is defined as a composite system that includes an interior sheathing layer (SH1), an insulation (IN) and an outer sheathing layer (SH2) (Figure 20).

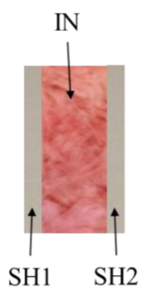

Figure 20. Insulation system: interior sheathing (SH1), insulation (IN) and exterior sheathing (SH2)

This design tool currently includes 17 types of interior sheathing materials, 7 different insulation options and 17 types of sheathing materials. In this, a total of 2023 types of insulation systems are possible combinations (Appendix E. for all systems). Table 7 shows some of the total insulation systems (#1-50).

Table 7. Configurations of Insulation systems (#1-50 systems out of 2023 insulation systems)

Insulation System #	Interior Sheathing (SH1) [m]	Insulation (IN)	Exterior Sheathing (SH2) [m]	Insulation System #	Interior Sheathing (SH1) [m]	Insulation (IN)	Exterior Sheathing (SH2) [m]
1	'GB-0.0064'	'FG-U'	'GB-0.0064'	**26**	'GB-0.0064'	'FG-K'	'PW-0.0095'
2	'GB-0.0064'	'FG-U'	'GB-0.0079'	**27**	'GB-0.0064'	'FG-K'	'PW-0.0127'
3	'GB-0.0064'	'FG-U'	'GB-0.0095'	**28**	'GB-0.0064'	'FG-K'	'PW-0.0159'
4	'GB-0.0064'	'FG-U'	'GB-0.0127'	**29**	'GB-0.0064'	'FG-K'	'PW-0.0175'
5	'GB-0.0064'	'FG-U'	'GB-0.0159'	**30**	'GB-0.0064'	'FG-K'	'OSB-0.0095'
6	'GB-0.0064'	'FG-U'	'GB-0.0191'	**31**	'GB-0.0064'	'FG-K'	'OSB-0.0111'
7	'GB-0.0064'	'FG-U'	'GB-0.0254'	**32**	'GB-0.0064'	'FG-K'	'OSB-0.0127'
8	'GB-0.0064'	'FG-U'	'PW-0.0064'	**33**	'GB-0.0064'	'FG-K'	'OSB-0.0159'
9	'GB-0.0064'	'FG-U'	'PW-0.0095'	**34**	'GB-0.0064'	'FG-K'	'OSB-0.0191'
10	'GB-0.0064'	'FG-U'	'PW-0.0127'	**35**	'GB-0.0064'	'RW-B'	'GB-0.0064'
11	'GB-0.0064'	'FG-U'	'PW-0.0159'	**36**	'GB-0.0064'	'RW-B'	'GB-0.0079'
12	'GB-0.0064'	'FG-U'	'PW-0.0175'	**37**	'GB-0.0064'	'RW-B'	'GB-0.0095'
13	'GB-0.0064'	'FG-U'	'OSB-0.0095'	**38**	'GB-0.0064'	'RW-B'	'GB-0.0127'
14	'GB-0.0064'	'FG-U'	'OSB-0.0111'	**39**	'GB-0.0064'	'RW-B'	'GB-0.0159'
15	'GB-0.0064'	'FG-U'	'OSB-0.0127'	**40**	'GB-0.0064'	'RW-B'	'GB-0.0191'
16	'GB-0.0064'	'FG-U'	'OSB-0.0159'	**41**	'GB-0.0064'	'RW-B'	'GB-0.0254'
17	'GB-0.0064'	'FG-U'	'OSB-0.0191'	**42**	'GB-0.0064'	'RW-B'	'PW-0.0064'
18	'GB-0.0064'	'FG-K'	'GB-0.0064'	**43**	'GB-0.0064'	'RW-B'	'PW-0.0095'
19	'GB-0.0064'	'FG-K'	'GB-0.0079'	**44**	'GB-0.0064'	'RW-B'	'PW-0.0127'
20	'GB-0.0064'	'FG-K'	'GB-0.0095'	**45**	'GB-0.0064'	'RW-B'	'PW-0.0159'
21	'GB-0.0064'	'FG-K'	'GB-0.0127'	**46**	'GB-0.0064'	'RW-B'	'PW-0.0175'

22	'GB-0.0064'	'FG-K'	'GB-0.0159'	**47**	'GB-0.0064'	'RW-B'	'OSB-0.0095'
23	'GB-0.0064'	'FG-K'	'GB-0.0191'	**48**	'GB-0.0064'	'RW-B'	'OSB-0.0111'
24	'GB-0.0064'	'FG-K'	'GB-0.0254'	**49**	'GB-0.0064'	'RW-B'	'OSB-0.0127'
25	'GB-0.0064'	'FG-K'	'PW-0.0064'	**50**	'GB-0.0064'	'RW-B'	'OSB-0.0159'

Sensitivity analysis

Sensitivity analysis helps us understand how the uncertainties of the model inputs affect the model's outputs. In general, there are two types of approaches for the sensitivity analysis: local analysis and global analysis [92]. A local sensitivity analysis is usually based on one-at-a-time approach, by checking the effect of one variable while keeping other parameters constant. A global sensitive analysis is an approach to evaluate parameters by varying all other factors as well. There are many sensitive analysis methods developed [93]. Among them, the Morris method [94] is regarded a global sensitivity analysis because the final measure is achieved by averaging local measures. Note that the Morris method can be used to rank factors, but the drawback of the method is that it is not quantitative so that it cannot be used to understand the "percentage of output variance [95]."

It evaluates global sensitivity with a set of local derivatives (elementary effects). For a model, $y = y(x_1, \dots x_k)$, with input factors, x_i, the Elementary Effect for the ith input factor is:

$$EE(x_1, \dots, x_k) = \frac{y(x_1, x_2, \dots, x_{i-1}, x_i + \Delta, x_{i+1}, \dots, x_k) - y(x_1, \dots, x_k)}{\Delta} \quad (61)$$

The sensitivity of a model is estimated using the mean value and the standard deviation of the elementary effects. The mean value of the Elementary Effect is:

$$\mu = \frac{1}{r}\sum_{i=1}^{r}|EE_i| \quad (62)$$

where *r* is the number of checking elementary effects for each parameter. The standard deviation of the Elementary Effect is:

$$\sigma = \sqrt{\frac{1}{r}\sum_{i=1}^{r}(EE_i - \mu)^2} \quad (63)$$

The mean value, μ, estimates the importance of a factor. A high μ value of an input parameter specifies that the parameter has an important impact on the output results, while a low μ value of an input parameter specifies that the parameter has less impact on the output results. If σ for an input parameter is small, it means that a perturbation is similar along the range of the input, specifying a linear relation between the input and the output [96]. If σ for an input parameter is large, the input parameter can be considered to have non-linear relations between the input and the output or to have an interaction with other variables [96].

In our models, there are three types of input parameters – 1) parameters that are related to a building, 2) parameters of sheathing materials, and 3) parameters of insulation materials. Minimum and maximum values for each parameter can be found from building material data. The values of parameters vary from minimum to maximum with 10% increment for the Morris method. These three types of parameters were checked for the three mathematical models – fire safety performance sub-model, energy performance sub-model and soundproofing sub-model.

Fire safety performance sub-model

The output of the fire safety model is the failure time. The effects of input parameters on failure times were investigated. The input parameters and the range of values are listed in the table below.

Table 8. Selected input parameters and their ranges for the fire safety model

	Parameters	Unit	Min	Max
Building	compartment width	[m]	4.5	8.4
	ventilation height	[m]	0.5	2.4
	ventilation width	[m]	0.5	2.4
	fire load	[MJ/m^2]	10	500
	critical temperature	[ºC]	100	200
Sheathing	thickness (SH1)	[m]	0.0064	0.0254
	conductivity (SH1)	[W/m.K]	0.12	0.20
	density (SH1)	[kg/m^3]	545	800
	specific heat (SH1)	[kJ/kg.K]	1215	1552
Insulation	conductivity (IN)	[W/m.K]	0.021	0.040
	density (IN)	[kg/m^3]	12.8	190.0

Figure 21 shows the results of the sensitivity analysis. It shows the average of the Elementary Effect, μ, and the standard deviation of the Elementary Effect, σ, of the input parameters on the failure time. It also includes a dashed line in the middle. If a point is located above the dashed line, suggesting it has high σ, there is a "reasonable probability" that the parameter acts in a nonlinear way or that it is related to other parameters and cannot be considered as an independent parameter [92].

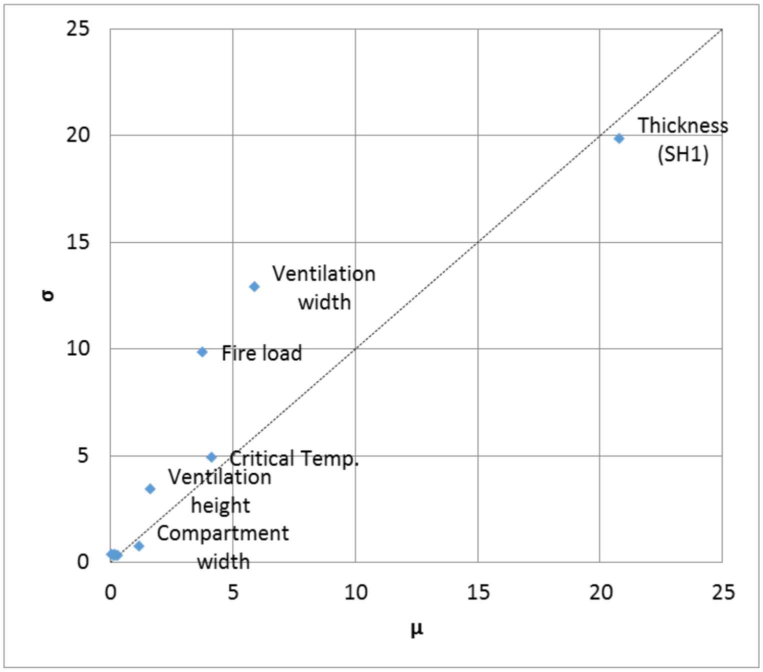

Figure 21. Results of the sensitivity analysis for the fire safety performance sub-model on the failure time

The failure time is influenced by the internal sheathing (SH1) thickness, the ventilation width, the critical temperature, the fire load, the ventilation height, and the compartment width, in the order of their importance. The most important input parameter is the thickness of the interior sheathing. By modifying the thickness of the sheathing material, a designer can achieve better failure time performance easily. Even though other factors have relatively low impact on the failure time compared to the thickness, however, designers should remember that those also impact on the failure time. This implies the importance of a performance based-design approach for insulation system design because a specific building design affects the performance of insulation systems and it should be considered for their design.

Energy performance sub-model

The effects of input parameters on annual energy consumption were investigated. The input parameters and the range of values are listed in Table 9.

Table 9. Selected input parameters and their ranges for the energy performance model

	Parameters	Unit	Min	Max
Building	ventilation height	[m]	0.5	2.4
	ventilation width	[m]	0.5	2.4
Sheathing	thickness (SH1)	[m]	0.0064	0.0254
	thickness (SH2)	[m]	0.0064	0.0254
	conductivity (SH1)	[W/m.K]	0.120	0.200
Insulation	conductivity (IN)	[W/m.K]	0.004*	0.040
	thickness (IN)	[m]	0.1016	0.2032

*It is the conductivity of vacuum insulation panels (VIP) [97].

Figure 22 shows the results of the sensitivity analysis. The annual energy consumption is influenced by the insulation (IN) conductivity, the insulation (IN) thickness, the ventilation width, the ventilation height, the exterior sheathing (SH2) thickness, the interior sheathing (SH1) thickness, and the interior sheathing (SH1) conductivity, in the order of their importance. The two most important parameters are the conductivity and thickness of insulation materials, which are elements of the R-value of the insulation materials. It is well known that these two elements are important for the energy performance of a building. However, it should be noted that other factors also can affect energy performance, and they also should be considered for insulation system design.

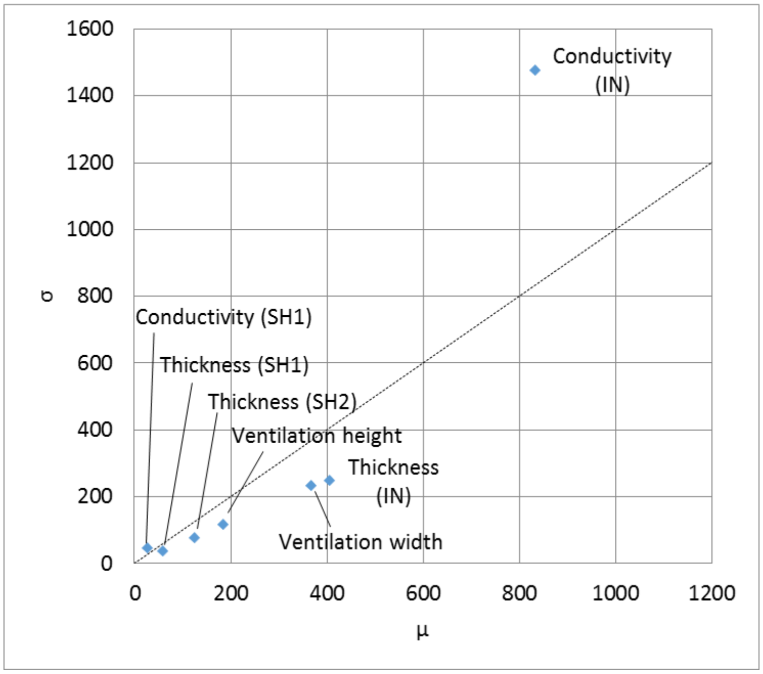

Figure 22. Results of the sensitivity analysis for the energy performance sub-model on the annual energy consumption

Soundproofing performance sub-model

The effects of input parameters on sound performance were investigated. Table 10 is the selected input parameters and their ranges for the soundproofing performance sub-model.

Table 10. Selected input parameters and their ranges for the soundproofing performance sub-model

	Parameters	Unit	Min	Max
Building	width	[m]	4.47	8.37
Sheathing	thickness (SH1)	[m]	0.00640	0.02540
	thickness (SH2)	[m]	0.00640	0.02540
	density (SH1)	[kg/m^3]	545	800
	density (SH2)	[kg/ m^3]	545	800
Insulation	thickness	[m]	0.10160	0.20320
	density	[kg/ m^3]	12.8	190
	speed of sound	[m/s]	340	5200

Figure 23 shows the results of the sensitivity analysis for the soundproofing model. The input parameters and the range of values are listed in the table below. The sound transmission loss is influenced by the speed of sound in insulation (IN), the insulation (IN) density, the compartment width, the interior sheathing (SH1) thickness, the interior sheathing (SH1) density, the insulation (IN) thickness, the exterior sheathing (SH2) thickness, and the exterior sheathing (SH2) thickness, in the order of their importance. As seen, the soundproofing performance of an insulation system is affected not only by insulation systems but also by building designs.

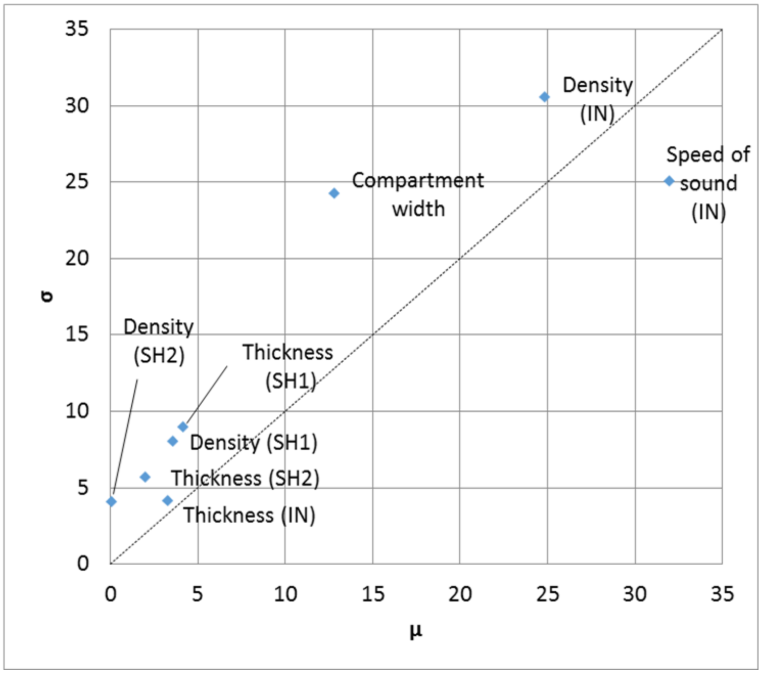

Figure 23. Results of the sensitivity analysis for the soundproofing performance sub-model on the sound transmission loss

Through the sensitivity analysis on the models, it is found that the three performance depend on various parameters. Especially, insulation materials and interior sheathing materials influence the performance significantly. However, a designer should always remember that other factors such as parameters related buildings and exterior sheathing materials also affect the performance. In addition to this, designers should remember that effects of a parameter depend on each performance. For example, for soundproofing performance, the parameters related to insulation material are important. Therefore, when a designer selects an insulation system for a project in which a soundproofing performance is the most important, he or she should focus on this fact. Sometimes, they might have non-linear behavior and/or correlations with other input parameters. It is important that a designer understand what factors have this tendency when they design.

Note that the sensitivity analysis results are based on the range of the input parameters, and they are affected by changes in the range of the parameters. Because of this, the sensitivity results in this section are only valid for the given ranges of the input parameters.

Model limit state analysis

In this section, the cases in which one characteristic is dominant are tested. All conditions, except weights, are the same as the example in the next section. Each case will have a dominant weight (W_i=1). This will provide individual aspects of the design tool as part of a verification and validation of the tool.

Case #1 (W_{EP}=1)

Case #1 is the case in which only the energy performance is important (W_{EP}=1) and other design objectives are unimportant. Based on this condition, the tool calculates the performance scores for all insulation systems (2023 systems). Figure 24 is the result of the tool. Based on the calculation, the insulation system #816 (0.0254m GB + SPF-CC + 0.0191m OSB) has the highest performance score. This system provides the following performance: 8806kWh annual energy consumption (20% lower than the annual energy consumption of the reference system), 53.8 dB (8.9% higher than the reference system), and 34 min for failure time (161% increase than the reference system).

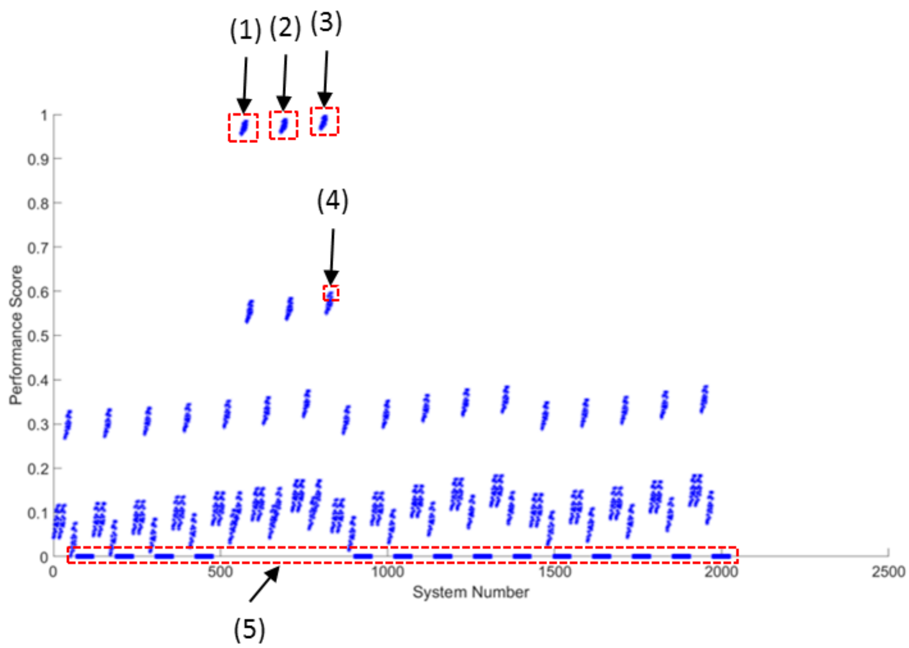

Figure 24. Performance scores of all systems for the case with W_{EP}=1

Even though insulation system #816 has the highest performance score, there are other systems that have relatively high performance scores ((1), (2) and (3) in Figure 24). They are the insulation systems which have SPF-CC. This is because SPF-CC has the lowest conductivity (0.021W/m/K) resulting in the highest R-value with the same thickness among the insulation options. This agrees with the sensitivity analysis result showing that the conductivity of insulation material is the most significant factor in the energy performance model. The performance scores of the insulation systems in (1), (2) and (3) in Figure 24 are similar and are positioned between 0.9563 and 0.9953. Their annual energy consumption difference is less than 2% (8806 ~ 8901kWh). The insulation system which has the next highest performance score to the insulation systems with SPF-CC, however, is insulation #833 which has 0.0254m GB+XPS+0.0191m OSB ((4) in Figure 24). The annual energy consumption of this insulation system is 9783kWh, which represents an energy consumption increase of more than 10% over the worst insulation system using SPF-CC. Selecting this insulation system is not recommended.

When insulation systems have a higher performance score, sheathing layers have little or no affect to performance scores when insulation systems have a higher performance score. For example, the insulation system #812, which consists of 0.0254m GB, SPF-CC and 0.0095m OSB, reached 0.9779 of the performance score; but the insulation system #816, which consists of the same interior sheathing and insulation material except for the different thickness of exterior sheathing (0.0191m OSB), had 0.9954 of the performance score (only 1.8% increases). However, they affect more when performance score is low. For example, insulation system #13, which consists of 0.0064m GB, FG-U and 0.0095m OSB, had 0.0694 of the performance score; and the insulation system #17, that has the same interior sheathing and insulation material except for the different thickness of exterior sheathing (0.0191m OSB), had 0.1154 of the performance score (a 66% increase). This analysis can be useful when a project has a relatively high energy performance weight. When designers select interior and exterior sheathing materials, for example, they have more freedom of selection if they have already chosen high energy performance insulation materials.

Figure 25 is a 3-D plot of performance scores of the insulation systems for this case. The X-axis is the number of insulation materials (INS), and the tool currently includes seven insulation materials (Table 6). The Y-axis and the Z-axis are interior sheathing materials (SH1) and exterior sheathing materials (SH2), respectively. Seventeen sheathing materials are currently included (Table 5). Each dot represents an insulation system so that there are a total of 2023 dots. The performance score of each insulation system is expressed by the color indicated in the color bar next to the figure.

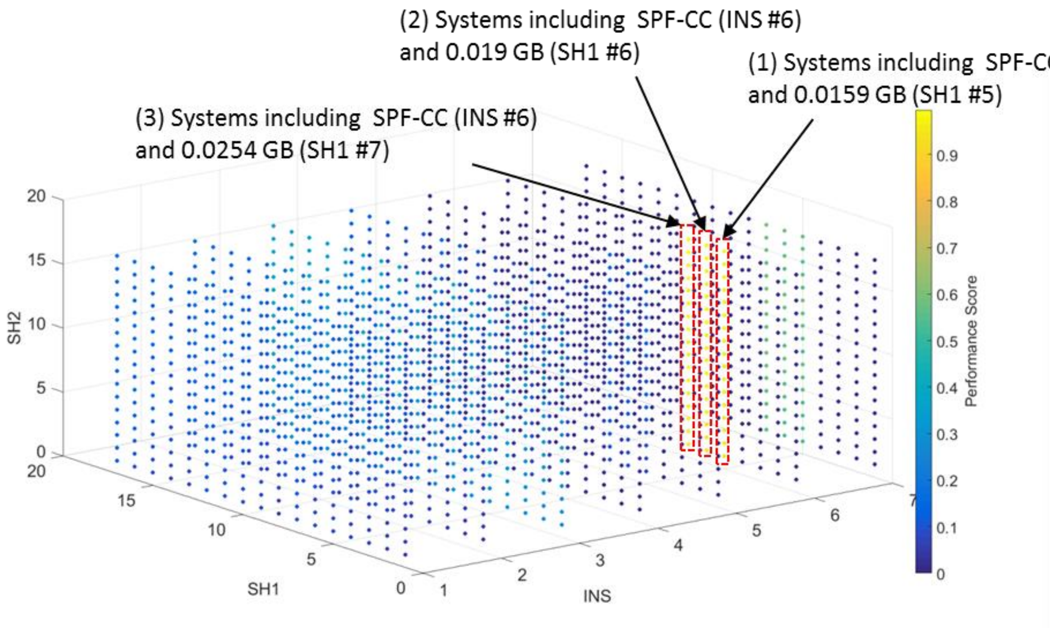

Figure 25. 3-D plot of performance scores of all systems for the case with W_{EP}=1

Note that based on the fire simulation results, only three gypsum boards (0.0159, 0.019 and 0.0254m) satisfy the minimum failure time. The insulation systems which include foam plastic insulation and could not satisfy the minimum failure time should not be used. The model cut off these insulation systems and they had a performance of zero, as represented in Figure 24 ((5) in Figure 24).

Case #2 (W_{SP}=1)

When the weight for sound performance is 1, the model recommends insulation system #789 (0.0254m GB + SPF-OC + 0.0254m GB). This system exhibits the following performance levels: 64dB for sound transmission loss (30% higher than that of the reference system), 34 min for failure time, and 10847kWh annual energy consumption. Along with this insulation system, the insulation systems which include insulation #5 (SPF-OC) recorded high performance scores ((1), (2) and (3) in Figure 26 and Figure 27); and this implies that insulation material is the most important factor for the soundproofing performance as well. This also agrees with the sensitivity analysis results on the sound performance model which shows that insulation density and the speed of sound in insulation are the biggest factors on the model. However, interior and exterior sheathing materials affect the soundproofing performance. For example, insulation system #789 (the highest one of (3) in Figure 26) had 64dB for sound transmission loss; and insulation system #783 (the lowest one of (3) in Figure 26), which has the same insulation and the same interior sheathing but different exterior sheathing (0.0064m GB), had 60dB (a 7% decrease). Therefore, when having a maximum soundproofing performance is a design goal, it is important to choose appropriate sheathing materials. In addition, the degree of influence is quite similar in both the high performance region and the low performance region. Figure 27 shows a 3 D representation of the performance scores.

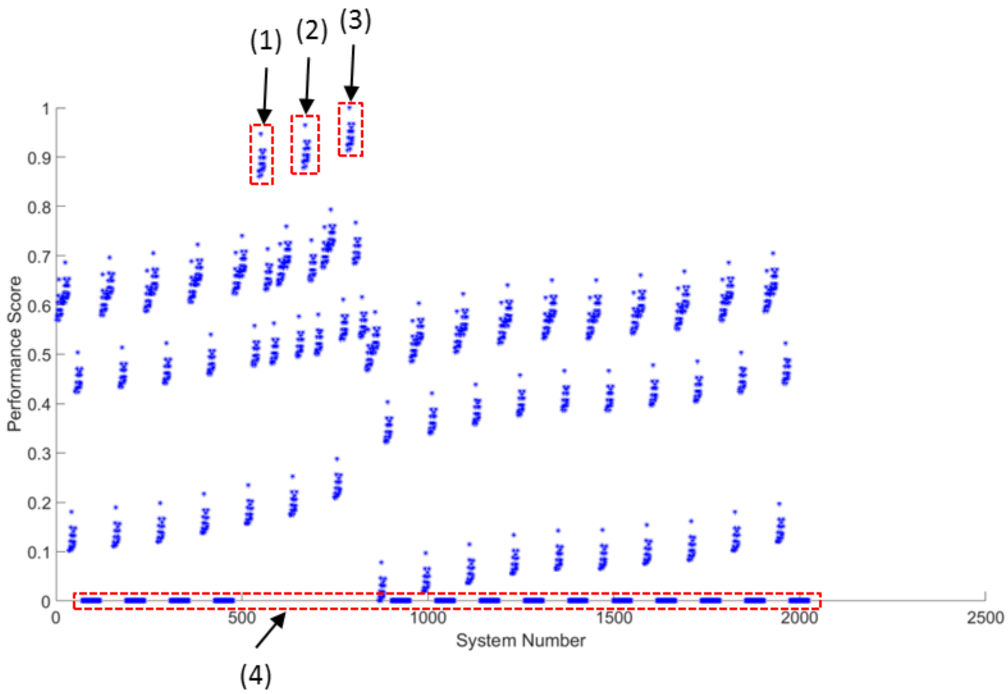

Figure 26. Performance score of the case with W_{SP}=1

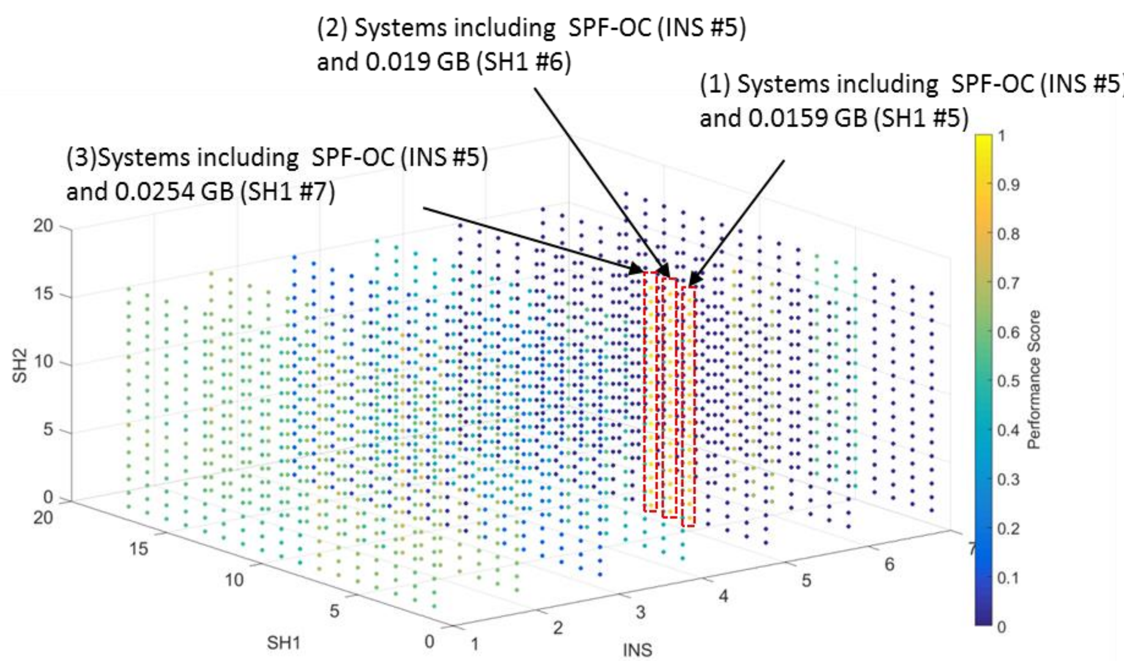

Figure 27. 3-D plot of performance scores of all systems for the case with W_{SP} =1

Note that since this is also foam plastic insulation, interior sheathings should provide at least a 15 min failure time. Insulation system that have less than a 15 min fire resistant time should not be used, and the tool removes the insulation systems ((4) in Figure 26).

Case #3 (W_{FP}=1)

When the weight for the fire safety performance is 1, the insulation systems which have 0.0254m GB (SH1 #7) as an interior sheathing get the highest performance score ((1) in Figure 28). This is because of the assumption of the tool that the fire safety performance primarily depends on the failure time of the interior sheathing material (SH1), and higher failure times have better fire safety performance. Figure 28 shows the result of the tool analysis. The patterns in Figure 28 are directly related to the failure time of the internal sheathing material in the estimated fire conditions. The insulation systems that include foam plastic insulation materials should have failure times of 15 min or more. The insulation systems with foam plastic insulation but with less than 15 min failure times showed a zero performance score ((2) in Figure 28).

Figure 29 clearly shows the factors of the fire safety performance. SH1 #7 is the 0.0254 gypsum board (SH1) which provides the longest failure time. As seen, the type of interior sheathings and insulation materials are the main factors for fire safety performance, whereas the types of exterior sheathings do not affect the results.

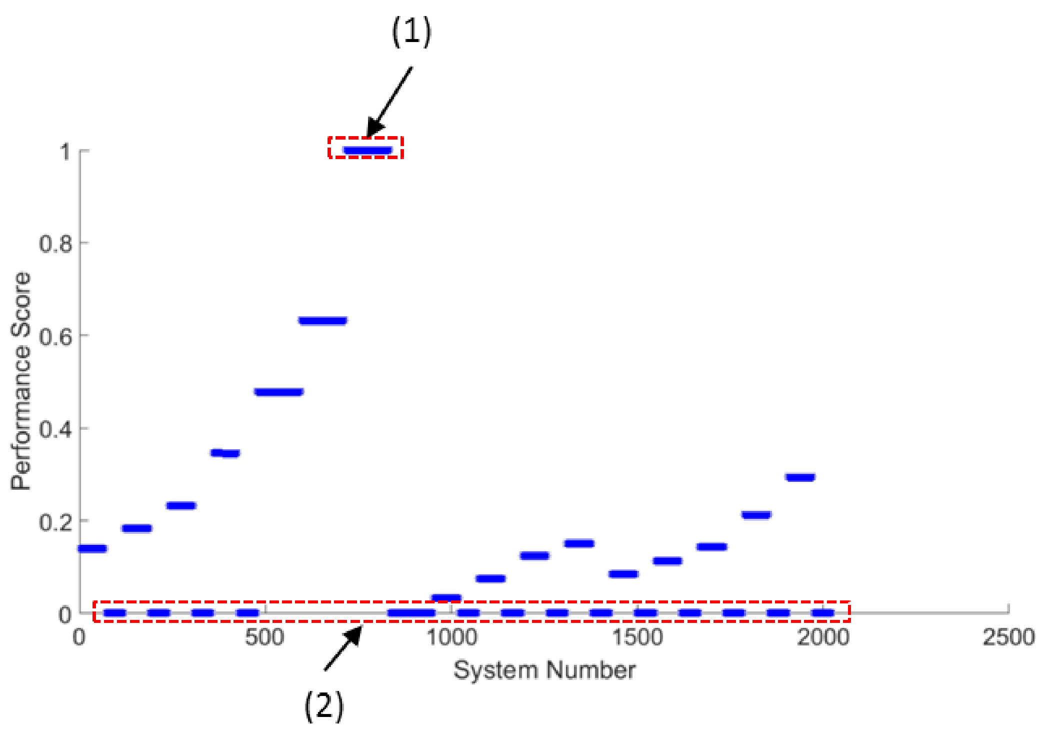

Figure 28. Performance score of the case with W_{FP}=1

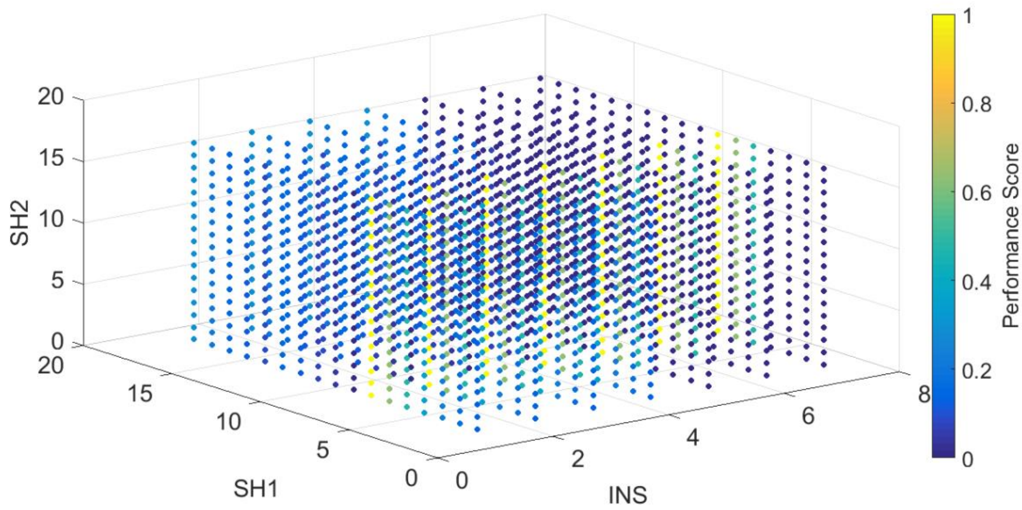

Figure 29. 3-D plot of performance scores of all systems for the case with W_{FP}=1

Case #4 (W_{SuP}=1)

This is the case in which the weight for sustainability performance is one (W_{SuP}=1). Figure 30 and Figure 31 show that the results of the tool analysis. Insulation system #1458 (0.0095m OSB + FG-K + 0.0095m OSB) recorded the highest performance score. However, there are some insulation systems that showed high performance scores as well. In these cases, the interior and exterior sheathing materials as well as insulation materials affect the performance scores. Figure 30 shows the pattern. Insulation systems in region (1) are the insulation systems which includes gypsum board as interior sheathings. The insulation systems in region (2) are insulation systems which have plywood sheathing for the interior sheathing materials. The insulation systems in region (3) are the insulation systems that have OSB for their interior sheathings. As interior sheathing material varies, the performance score varies significantly. Exterior sheathing also affects significantly as you see the color differences in Figure 31. This is one of the biggest differences between sustainability performance and other design objectives. When designers select insulations with high weights of sustainability, they should be careful to regard the sustainability values of sheathing materials and insulation materials.

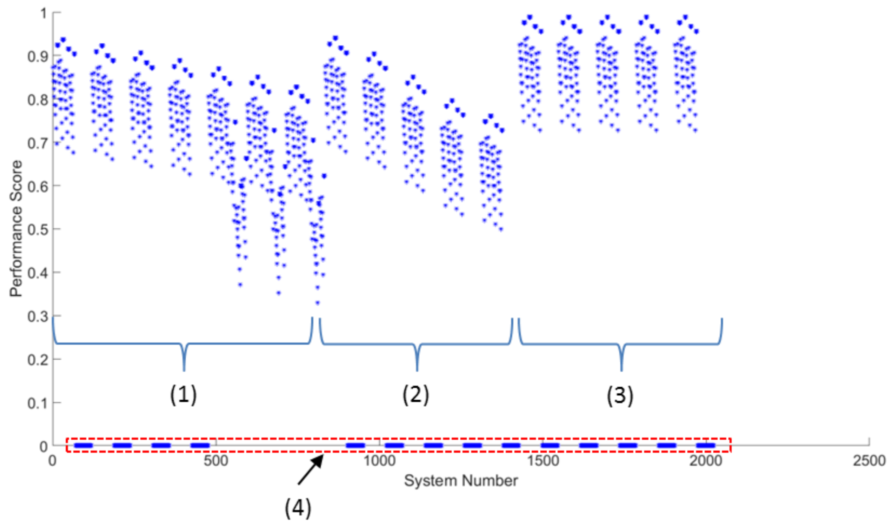

Figure 30. Performance score of the case with W_{SuP}=1

Note that insulation systems that have foam plastic material but less than 15 min fire resistant time should not be used, and the design tool removes the insulation systems ((4) in Figure 30).

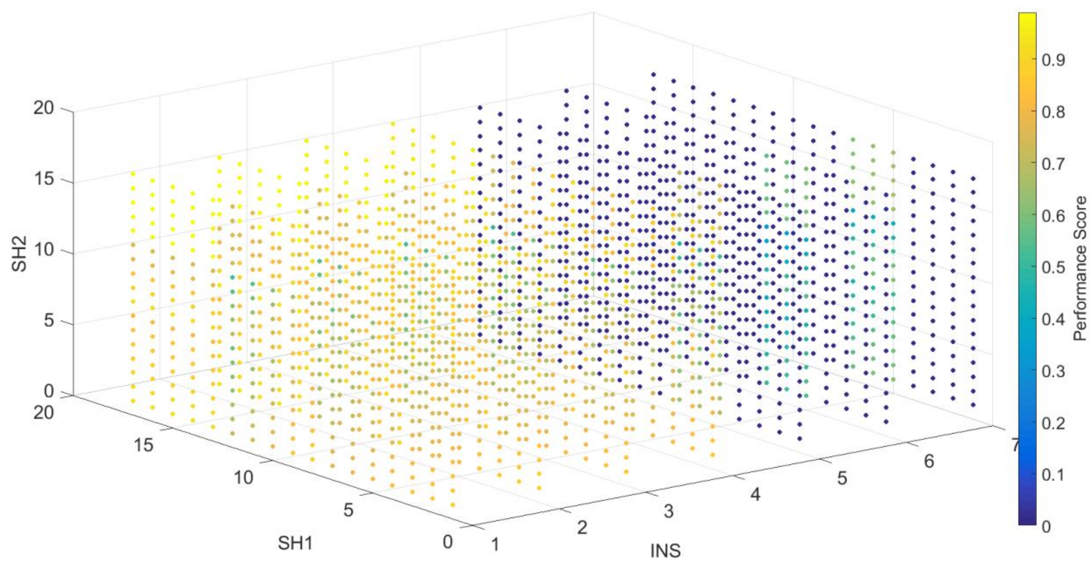

Figure 31. 3-D plot of performance scores of all systems for the case with W_{SuP}=1

Case #5 (W_{CoP}=1)

This is the case where the cost performance is one. The costs of sheathing material and insulation material have similar effects on the performance scores in this case. As in case #4, this case also can be divided into three regions based on interior sheathing materials ((1), (2) and (3) in Figure 32). In each region, the different insulation and exterior sheathing materials affect performance scores significantly. In terms of cost, usually clients and designers have some values in mind, and the insulation systems they choose should reflect these considerations.

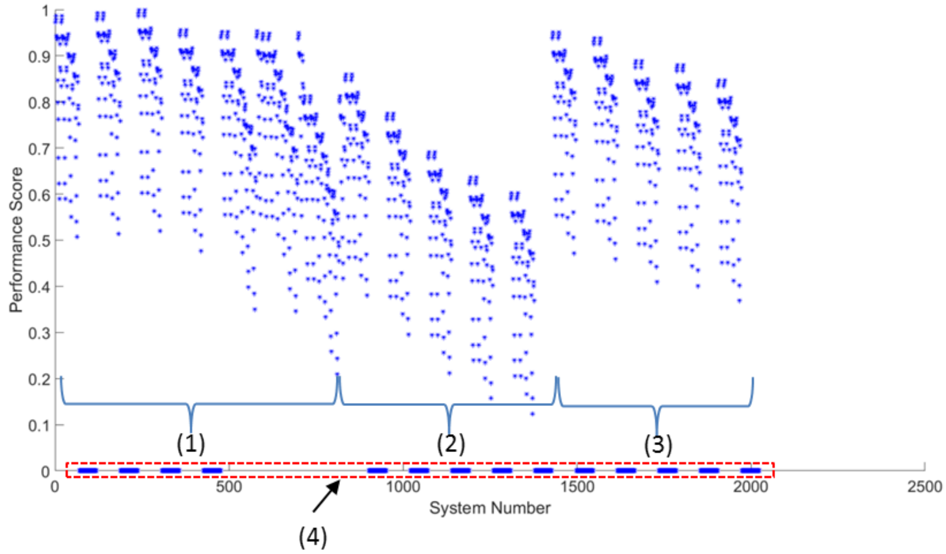

Figure 32. Performance score of the case with W_{CoP}=1

Note that insulation system that have foam plastic material but less than 15 min fire resistant time should not be used, and the model removes the insulation systems ((4) in Figure 30).

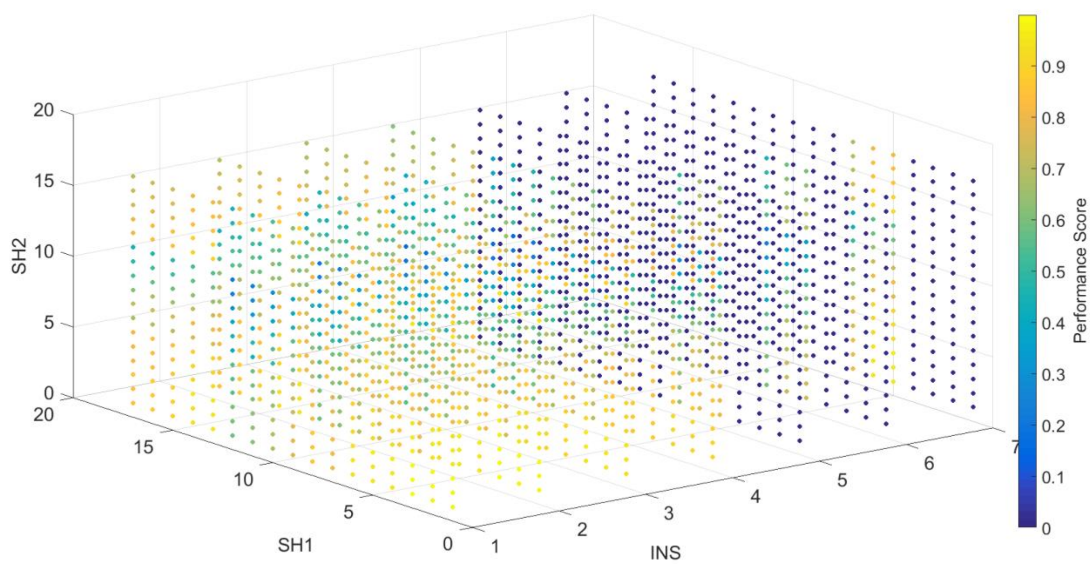

Figure 33. 3-D plot of performance scores of all systems for the case with W_{CoP}=1

Weights for the occupancy in IBC

The IBC divides buildings into ten groups called occupancies based on their intended use. Under each occupancy, there are subdivisions to refine each occupancy. For example, the factory group F is divided into moderate-hazard occupancy (F-1) and low-hazard occupancy (F-2) based on the relative hazards of the operations. One of the main standards to categorize the ten occupancies can be found in the provision that directs classification of atypical occupancies [98]: "where a structure is proposed for a purpose that is not specifically provided for in this code, such structure shall be classified in the group which the occupancy most nearly resembles, according to the fire safety and related hazard involved (IBC 2012 Section 302.1)." Each occupancy has unique fire safety issues regarding property and occupant protections. Based on the issues, the IBC specifies requirements for each occupancy such as the allowable area and height of a building, means of egress, and type of construction.

In this section, performance weights for the occupancy groups are estimated based on the AHP process. Since the occupancy was categorized based on "the fire safety and related hazard," it is relatively straightforward to estimate the degree of importance of fire safety for each occupancy, which is necessary for the first step of the AHP. For soundproofing performance, it is also relatively easy to estimate the importance based on the necessity of soundproofing performance for each occupancy. However, it is not straightforward to provide the degree of importance for energy performance, sustainability performance and cost performance because the degree of importance of the performance strongly depends on the intent of a client and/or designer. Due to this, it is assumed that all occupancy has the same "mid" intensity of importance for the energy performance, sustainability performance and cost performance. Note that final weights for real projects should be decided upon by the cooperation of a client and designer. This section can serve as an example that they can use as a reference.

The ten occupancy groups are 1) Assembly group A, 2) Business group B, 3) Educational group E, 4) Factory group F, 5) High-hazard group H, 6) Institutional group I, 7) Mercantile group M, 8) Residential group R, 9) Storage group S, and 10) Utility and miscellaneous group U. Table 11 lists the occupancy groups and an example of each group. It also includes estimations of the intensity of importance of each performance for the occupancy groups. For simplicity, the intensity of importance is provided using the scale. This scale includes five categories: low, mid-low, mid, mid-high and high, depending on their degree of importance.

It should be noted that the fire safety performance in Table 11 is related to the performance of insulation systems, not the overall fire safety performance of the occupancy. For example, it is not related to the means of egress, but it is related to the toxic gases that a foam plastic insulation could release. The institutional group I has "high" importance for the fire safety because the institutional groups are the places that occupants have special restrictions such as hospitalized patents and they are more vulnerable when toxic gases are released or insulation systems fail. The residential group R also has "high" importance for fire safety because the occupants require sleep, and they could be more vulnerable when insulation systems fail. The high hazard group H also has a "high" rating for fire safety importance. However, it should be noted that there are special requirements for the wall system design for this group (IBC 2012 Section 307). The control area for the high hazards group, for example, must be separated by 1-hour fire-barrier walls. The assembly group (A) is a place where large groups of people occupy relatively small spaces, so they could be vulnerable when insulation systems fail. However, the risk level would be lower than the institutional group or the residential groups so that it marked as "mid-high". For the soundproofing performance, a concert hall, as an example of the assembly group, needs to provide high soundproofing performance, so this is rated as "high."

Table 11. IBC occupancy groups and their estimated degree of importance

Occupancy group	Example	Fire safety performance	Soundproofing performance	Energy performance	Sustainability performance	Cost performance
Assembly (A)	A concert hall	Mid-high	High	Mid	Mid	Mid
Business (B)	An office	Mid-high	Mid-high	Mid	Mid	Mid

Education (E)	A classroom	Mid	Mid-high	Mid	Mid	Mid
Factory and industrial (F)	A factory	Mid-high	Low	Mid	Mid	Mid
High hazard (H)	A flammable gas storage	High	Low	Mid	Mid	Mid
Institutional (I)	Hospitals	High	Mid-high	Mid	Mid	Mid
Mercantile (M)	Department stores	Mid	Mid	Mid	Mid	Mid
Residential (R)	Hotels Apartment houses	High	Mid-high	Mid	Mid	Mid
Storage (S)	A storage	Mid-high	Low	Mid	Mid	Mid
Utility and miscellaneous (U)	Agricultural buildings	Low	Low	Mid	Mid	Mid

Next step in the AHP is to generate a pairwise comparison matrix (equation 45). For this, a designer should decide the relative importance of attribute i over attribute j based on each pairwise comparison. Table 12 provides a standard for the relative importance of attribute i over attribute j (refer Table 3 also). For example, when an occupancy has “high” importance for fire safety performance (attribute i) and “high” importance for energy performance (attribute j), the relative importance of i over j is “1” (refer Table 3 also). When the occupancy has “high” importance for fire safety performance (attribute i) and “low” importance for energy performance, the relative importance of i over j is “9.” Using this approach, a pairwise comparison matrix for the all occupancies can be developed.

Table 12. Relative importance of attribute i over j

Number of cases	Attribute i	Attribute j	Relative importance of i over j
1	High	High	1
2	High	Mid-high	3
3	High	Mid	5
4	High	Mid-low	7
5	High	Low	9
6	Mid-high	High	1/3
7	Mid-high	Mid-high	1
8	Mid-high	Mid	3
9	Mid-high	Mid-low	5
10	Mid-high	Low	7
11	Mid	High	1/5

12	Mid	Mid-high	1/3
13	Mid	Mid	1
14	Mid	Mid-low	3
15	Mid	Low	5
16	Mid-low	High	1/7
17	Mid-low	Mid-high	1/5
18	Mid-low	Mid	1/3
19	Mid-low	Mid-low	1
20	Mid-low	Low	3
21	Low	High	1/9
22	Low	Mid-high	1/7
23	Low	Mid	1/5
24	Low	Mid-low	1/3
25	Low	Low	1

Based on the process of the AHP that was explained in detail previously, the weights for all occupants can be developed in Table 13. As mentioned above, it is important to note that designers should choose weights for each projects based on cooperation with clients and Table 13 can be a reference for this.

Table 13. Estimated weights for occupancy in the IBC

Occupancy group	Example	Fire safety performance	Soundproofing performance	Energy performance	Sustainability performance	Cost performance
Assembly (A)	A concert hall	0.24	0.50	0.09	0.09	0.09
Business (B)	An office	0.33	0.33	0.11	0.11	0.11
Education (E)	A classroom	0.14	0.43	0.14	0.14	0.14
Factory and industrial (F)	A factory	0.44	0.04	0.17	0.17	0.17
High hazard (H)	A storage having more than a maximum allowable flammable gas	0.55	0.04	0.14	0.14	0.14
Institutional (I)	Hospitals	0.50	0.24	0.09	0.09	0.09
Mercantile (M)	Department stores	0.20	0.20	0.20	0.20	0.20
Residential (R)	Hotels Apartment	0.50	0.24	0.09	0.09	0.09

	houses					
Storage (S)	A storage	0.44	0.04	0.17	0.17	0.17
Utility and miscellaneous (U)	Agricultural buildings	0.06	0.06	0.29	0.29	0.29

Application of the design tool

In this section, three examples were developed to show how the proposed design tool is applied. Insulation systems for three different types of compartments will be decided: 1) an apartment house, 2) a conference room, and 3) a compartment which requires higher fire safety performance. For the scenarios, we assume several points:

- The building owner wants to build the building in the Boston area. The location data is necessary to get the weather information for energy performance (Data is available on the web page of the National Centers for Environmental Information [99]).
- The prototype of a building has a dimension of 8m x 8m x 2.5m with a fenestration (0.5m x 1m).
- Wall systems consist of three layers: interior sheathing material, insulation and outer sheathing material.
- For the thickness of insulation, a 10.16cm (4”) thickness, which is generally used in lightweight construction, is used.
- In this example, 2023 different insulation systems (17 interior sheathing options x 7 types of insulation materials x 17 types of exterior sheathing materials) will be tested. (Refer to the table in Appendix E.)
- For the fire safety sub-model, $125MJ/m^2$ of fire density is assumed for all cases.

Performing the AHP process for weighting

The first step is to find specific weights for each performance. The building owner and the architect decide to use AHP. For this, they perform pair wise comparisons of the required performance: energy performance (EP), soundproofing performance (SP), fire safety performance (FP), sustainable performance (SuP) and cost (CoP) (Table 14). For the example of an apartment, it is assumed that the order of importance of performance attribute is sustainability performance > cost performance > energy performance = sound performance = fire safety performance. Each attribute should be compared with all attributes, including itself. The scale in Table 3 is used for the comparison. The criteria on the left are one by one compared with the criteria on top as to which one is more important in terms of the goal of an optimum insulation system. For example, at the first low, energy performance (EP) is compared with all attributes. When it is compared with itself (a_{11}), it should be 1 (equal importance). When the energy performance (EP) is compared with soundproofing performance (SP), which is assumed equal in this example, the vector is 1 (a_{12}). Due to the reciprocity, a_{21} automatically becomes 1. Because the sustainability performance is very strongly favored over the energy performance, a_{14} should be 1/7, and a_{41} becomes 7 automatically. In this way, a pair wise comparison matrix for an apartment can be developed (Table 14).

Table 14. A pair wise comparison matrix for apartment

	EP	*SP*	*FP*	*SuP*	*CoP*
EP	1	1	1	1/7	1/5
SP	1	1	1	1/7	1/5
FP	1	1	1	1/7	1/5
SuP	7	7	7	1	3
CoP	5	5	5	1/3	1

The order of importance of performance attribute for a conference room can be soundproofing performance > fire safety performance > energy performance > sustainability performance = cost performance. Table 15 shows the pair wise comparisons matrix for the conference room.

Table 15. A pair wise comparison matrix for a conference room

	EP	*SP*	*FP*	*SuP*	*CoP*
EP	1	1/5	1/3	5	5
SP	5	1	3	9	9
FP	3	1/3	1	7	7
SuP	1/5	1/9	1/7	1	1
CoP	1/5	1/9	1/7	1	1

For a room requiring high fire safety, it is assumed that fire safety performance is paramount. In this case, the order of the performance factors would be fire safety performance > sustainability performance = cost performance > energy performance = sound performance. Table 16 shows the pair wise comparison matrix for this room. Note that it is assumed that there are no additional code requirements for this case. If there is a code requirement for this special occupancy, the code requirement should be followed first.

Table 16. A pair wise comparison matrix for a room requiring high fire safety

	EP	*SP*	*FP*	*SuP*	*CoP*
EP	1	1	1/9	1/7	1/7
SP	1	1	1/9	1/7	1/7
FP	9	9	1	3	3
SuP	7	7	1/3	1	1
CoP	7	7	1/3	1	1

After the pair wise comparison matrix is developed, the next step is to generate a normalized pair wise matrix (A_{norm}). In this step, using the apartment as the example case, we can show development of a normalized pair wise matrix, step by step, using equation 46. For example, the normalized vector ($\bar{a}_{11}$) for the element at the first low and the first column can be calculated as below:

$$\bar{a}_{11} = \frac{1}{(1+1+1+7+5)} = 0.06 \quad (64)$$

With this method, we can develop the normalized pair wise matrix (equation 65).

$$A_{norm} = \begin{pmatrix} 0.06 & 0.06 & 0.06 & 0.09 & 0.03 \\ 0.06 & 0.06 & 0.06 & 0.09 & 0.03 \\ 0.06 & 0.06 & 0.06 & 0.09 & 0.03 \\ 0.41 & 0.41 & 0.41 & 0.65 & 0.45 \\ 0.29 & 0.29 & 0.29 & 0.22 & 0.15 \end{pmatrix} \quad (65)$$

The next step is to generate a weight vector using equation 48.

$$W_1 = \frac{\sum_{j=1}^{n} \bar{a}_{ij}}{n} = \frac{(0.06 + 0.06 + 0.06 + 0.09 + 0.03)}{5} = 0.06 \qquad (66)$$

Based on this approach, we can have the weight set for the apartment: the weight for the energy performance (EP), soundproofing performance (SP), the fire safety performance (FP), the sustainability performance (SuP) and the cost performance (CoP) are 0.49, 0.04, 0.15, 0.24 and 0.08, respectively.

$$W = \begin{pmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \\ W_5 \end{pmatrix} = \begin{pmatrix} 0.06 \\ 0.06 \\ 0.06 \\ 0.47 \\ 0.25 \end{pmatrix} \qquad (67)$$

Developing weights for each attribute is a process to objectify one's intention which is essentially subjective. Even though it is a crucial part for multi-objective design problems, it is always challenging to do it. That is a reason why a method such as the AHP is valuable because it makes a challenging problem easire to handle. People can make a decision more efficiently and clearly when a problem is simpler. Therfore, in our decision tool, by changing the five attributes comparison problem into pair wise comparison problems, one can make a decision more efficeintly and clearly; and it could make consequently better weight sets. Note that Table 17 shows weight examples of three different locations: an apartment, a conference room, and a room requiring high fire safety.

Table 17. Weights example for an apartment, a conference room and a room requiring high fire safety

Type	Energy performance (EP)	Soundproofing performance (SP)	Fire safety performance (FP)	Sustainability performance (SuP)	Cost (CoP)	Consistency ratio (C_r)
Apartment	0.06	0.06	0.06	0.47	0.25	0.02
Conference room	0.15	0.51	0.27	0.04	0.04	0.05
Room requiring high fire safety	0.04	0.04	0.48	0.22	0.22	0.03

Applying physical sub-models into real cases

The following sub-models simulate each performance with all alternatives, which represent all possible combinations of layers for an insulation system (different thickness and different materials for sheathings and insulation).

Energy performance sub-model

The energy performance sub-model simulates monthly and annual energy consumption of the prototype building with various insulation system options. The energy performance sub-model requires input variables including insulation wall information, building information, and weather information (monthly averaged irradiation of the sun and temperature in Boston).

For the building configuration, the fenestration (0.5x1m) in the prototype building is assumed as a glass window facing south (Table 18)

Table 18. Properties of glass window

Material	Conductivity [W/m·K]	Thickness [mm]
Glass plate	1.4	10

For weather information, the monthly average temperature and irradiation for the local area is necessary. Table 19 is monthly average temperature and irradiation for Boston. The solar irradiation is for flat-plate collector facing south at 90° tilt. Data is from ref [100].

Table 19. Weather information in Boston, MA: Monthly average temperature and irradiation (90° south face) [100]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Temperature [°C]	-1.5	0	3	9	14.5	19.5	23	20	15	12	7	1.5
Irradiation [kWh/m^2/day]	3.4	3.9	3.7	3.1	2.8	2.6	2.8	3.1	3.5	3.6	3	2.9

Figure 34 shows a sample of the simulation results from the energy sub-model. They are monthly heating and cooling energy usages of 6 selected insulation systems (Table 20).

Table 20 Insulation systems for examples

Insulation system	Interior sheathing (SH1)	Insulation (IN)	Exterior sheathing (SH2)
1	Gypsum board (0.0064m)	FG-U	Gypsum board (0.0064m)
18	Gypsum board (0.0064m)	FG-K	Gypsum board (0.0064m)
35	Gypsum board (0.0064m)	RW-B	Gypsum board (0.0064m)
52	Gypsum board (0.0064m)	C-B	Gypsum board (0.0064m)
68	Gypsum board (0.0064m)	SPF-OC	Gypsum board (0.0064m)
103	Gypsum board (0.0064m)	SPF-CC	Gypsum board (0.0064m)

The heating and cooling energies are the required energies to keep the compartment at a comfortable temperature (20°C in this example). Note that the energy is positive for the cold period, while it is negative in the hot season. This is related to the way to set up energy equations in the energy sub-model. Based on this data, a designer can estimate the total annual energy consumption of insulation systems.

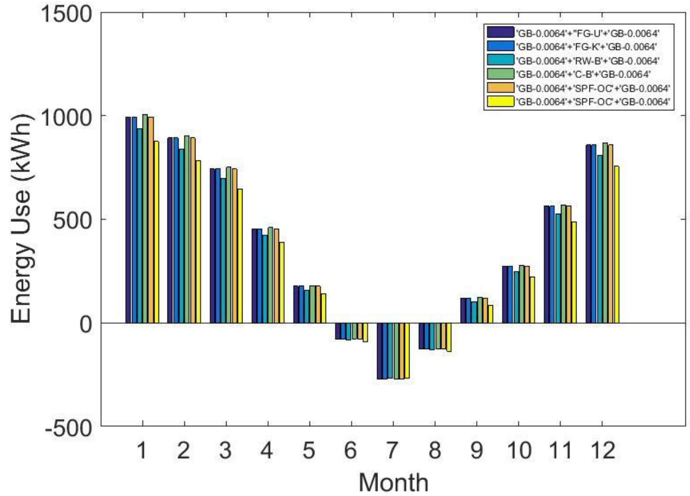

Figure 34. Examples of monthly energy consumptions estimated by the energy performance sub-model: System number #1 (GB-0.0064m+FG-U+GB-0.0064m), #18 (GB-0.0064m+FG-K+GB-0.0064m), #35 (GB-0.0064m+RW-B+GB-0.0064m), #52 (GB-0.0064m+C-B+GB-0.0064m), #69 (GB-0.0064m+SPF-OC+GB-0.0064m) and #103 (GB-0.0064m+SPF-CC+GB-0.0064m)

Soundproofing performance sub-model

A sound performance sub-model simulates the sound transmission loss (dB) through an insulation system between two compartments. The sound transmission loss through a partition varies based on frequencies. A typical person can sense, or hear, sound waves between 20 and 20,000Hz frequencies. In general, an insulation wall can block high frequency sound waves better than lower frequency sound waves.

Figure 13 shows the schematic diagram of an one-dimensional sub-model for a double-layered partition wall. For the simulation, the mass, stiffness and material propagation constant for layers should be specified. Table 21 includes acoustic properties of building materials. The material propagation constant for insulation layer is defined as [65]:

$$k_{med} = \frac{\omega}{c_{med}} \tag{68}$$

where ω is the angular frequency ($\omega = 2\pi f, f$ is frequency (Hz)) and c_{med} is the speed of sound in a medium. It is assumed that the all insulation types have the same speed of sound as polyethylene. Note that the two compartments in the Figure 13 are assumed as the same.

Table 21. Acoustic properties of building materials

Material	**Density** [kg/m^3]	**Speed of sound‡** [m/s]	**Stiffness†** [N/m]	**Damping coefficient**
Gypsum board	800	6790	350000	0.018
Plywood	600	3100	389000	0.030
Wood (oak)	770	3860	-	0.008

Polyethylene	935	765	-	0.010
Brick	1800	3800	-	0.015
OSB	-	-	909000	-

Data is from [101] unless otherwise noted.
‡ is the longitudinal speed of sound.
† stiffness data are from [102].

Figure 35 shows the sound transmission loss of insulation systems (Insulation systems #1, #18, #35, #52, #69 and #103). The frequency is between 0 and 4000 Hz, and this range is based on STC (Sound Transmission Class) rating system, which is specified by ASTM E 413 [103]. The STC rating is one of the widely used sound classification rating systems in the U.S. in order to characterize the effectiveness of interior partitions, ceiling/floors, doors, windows and exterior walls in isolating airborne noise [103]. The frequency range in the STC is between 125 Hz and 4000 Hz which is a range for human speech, television, radio and similar sources [103]. To compare the sound proofing capabilities of insulations systems in our decision model, the value at 2000 Hz of each insulation system will be used. For more detailed information on the STC process, refer the ASTM E 413.

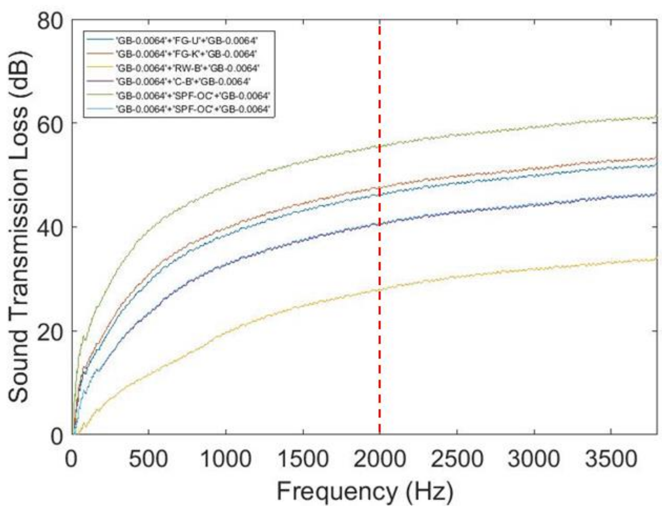

Figure 35 Sound Transmission Losses of six insulation systems estimated by soundproofing performance sub-model: System number #1 (GB-0.0064m+FG-U+GB-0.0064m), #18 (GB-0.0064m+FG-K+GB-0.0064m), #35 (GB-0.0064m+RW-B+GB-0.0064m), #52 (GB-0.0064m+C-B+GB-0.0064m), #69 (GB-0.0064m+SPF-OC+GB-0.0064m), #103 (GB-0.0064m+SPF-CC+GB-0.0064m)

Fire safety performance sub-model

The fire safety sub-model consists of two models: fire severity sub-model and heat transfer sub-model. The fire severity sub-model estimates a time-temperature curve for a specific compartment with a possible fire load. For the fire severity sub-model, the design algorithm includes two options: the developed mathematical model and the Eurocode parametric time-temperature equation. Users can decide the model that they want to use based on the availability of the heat release rate data. In this example, the time temperature curve was produced by Eurocode parametric equation with the compartment information. It was assumed that the ventilation (0.5x1m) is fully opened, and the fire load is $125MJ/m^2$. With the time-temperature curve, the heat transfer sub-model calculates temperature profiles of various insulation systems which have different thicknesses and thermal properties.

For the foam plastic insulation material, it is crucial to have a thermal barrier which protects the foam plastic insulation during an initial critical time in the event of a fire. The temperature of the foam plastic insulation should not reach the critical temperature of the foam plastic material, at which point, foam plastic could start to burn. For the initial critical time, building codes specify 15 minutes. The heat transfer sub-model will estimate the time to reach the critical temperature of insulation systems. For the incombustible insulation material, a thermal barrier is not required based on the building code. However, it could be assumed that overall fire safety is increased as the ability of an insulation system to block heat transfer is increased.

In this sub-model, the fire safety of an insulation system which has foam plastic insulation should not reach the critical temperature during the 15 min time period, and it is assumed that the fire safety performance is increased from the minimum requirement. If an insulation system having foam plastic insulation reaches the critical temperature during the 15 min time period, it is assumed that the insulation system cannot be used. For an insulation system which has non-combustible insulation materials, it is assumed that fire safety performance is increased as the time to reach the critical temperature is increased. Figure 36 shows the times to reach the critical temperature (120°C) of all insulation systems.

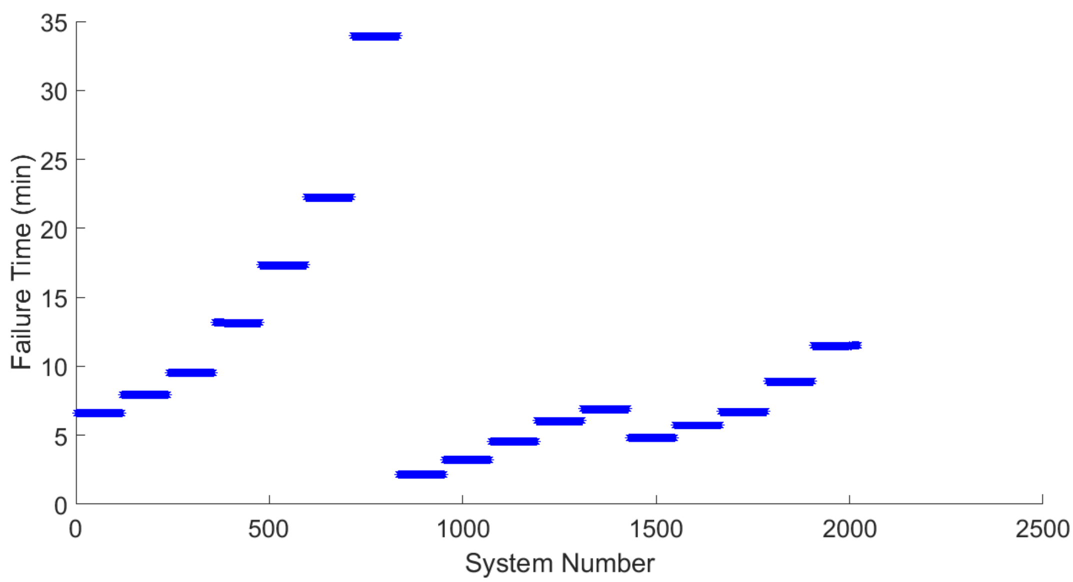

Figure 36. An example of failure time simulation for insulation systems

Sustainability performance in this model consists of carbon dioxide equivalent, water consumption and energy consumption. For an insulation system, these values for an interior sheathing, insulation material and an exterior sheathing should be added to get sustainability performance values. Note that the data could be available from manufactures, but currently many manufactures do not provide the values. Cost performance of an insulation system is estimated with the same approach as the sustainability. The cost of each layer should be added, and this will represent the total cost of an insulation system.

Reference insulation system

It is necessary to analyze a solution of the developed design tool. The reference insulation system will work as a reference point for the analysis, and the design solution can be compared with the reference insulation system. A reference insulation system was chosen which consists of most widely used elements for insulation systems. In the U.S., ½ inch gypsum boards are the most widely used interior sheathing material while 7/16 (3/8) inch OSB layer (approximately 65% for home 2008) is the most widely used exterior wall sheathing materials. For insulation, fiberglass batt is the most widely used (approximately 73% for home 2008).

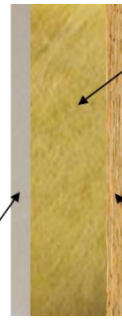

Figure 37. Reference insulation system

Based on the condition of the example, the reference system provides each performance (Table 22).

Table 22 Performance of reference insulation system

System No	Annual energy consumption (kWh)	Sound transmission loss at 2000Hz (dB)	Failure time (min)	Sustainability (Norm.)	Cost (Norm)
370 (Reference)	11021	49.4	13	0.8756	0.9085

Decision making

The attribute's performance values should be normalized using equations 42 and 43. Since the energy performance, sustainability and cost performance are detrimental attributes, the detrimental normalization equation (equation 43) should be applied for the normalization. For the sound transmission loss and fire safety performance, equation 42 should be used for the normalization because they are beneficial attributes. For example, for energy performance, the minimum annual energy use is 8795kWh, and the maximum annual energy use is 11239 kWh. Therefore, the normalized energy performance of an insulation system can be calculated as below,

$$r_i = \frac{11239 - x_i}{11239 - 8795} \quad (69)$$

With the normalized performance values and the estimated weights, the performance score of an insulation system can be calculated with equation 41.

Figure 38 is the performance score calculation for the conference room case as an example. It shows that the performance scores of all 2023 insulation systems. X-axis is system numbers, and Y-axis is performance scores of all insulation systems. The insulation systems that are close to 1 provide better performance. For this case, insulation system 789 achieved the highest performance score. This is the insulation system at the top in (1) in Figure 38. The insulation system consists of 0.0254m of gypsum board (SH1 #7), SPF-OC (INS #5) and 0.0254m of gypsum board (SH2 #7) (Figure 39). Compared to the reference insulation system, this system can improve 28.9% of soundproofing performance, and reduce 1.6% of annual energy consumption. It also improves the fire safety performance by improving the failure time by 158%.

The most important parameter for this case is insulation material. The insulation systems which have SPF-OC (INS #5) and SPF-CC (INS #6) have high scores. This is directly related to the weights for this case. In this case, the most important performance is the sound performance (W_{SP}=0.51), and the SPF-OC has the lowest density values. In addition, the second most important performance is the energy performance, and the SPF-CC has the lowest conductivity. Therefore, the insulation systems which include both insulation materials are shown to have good performance scores; and this agrees with the results of the sensitivity analysis results showing insulation materials as the most important factor of the soundproofing and energy performance models.

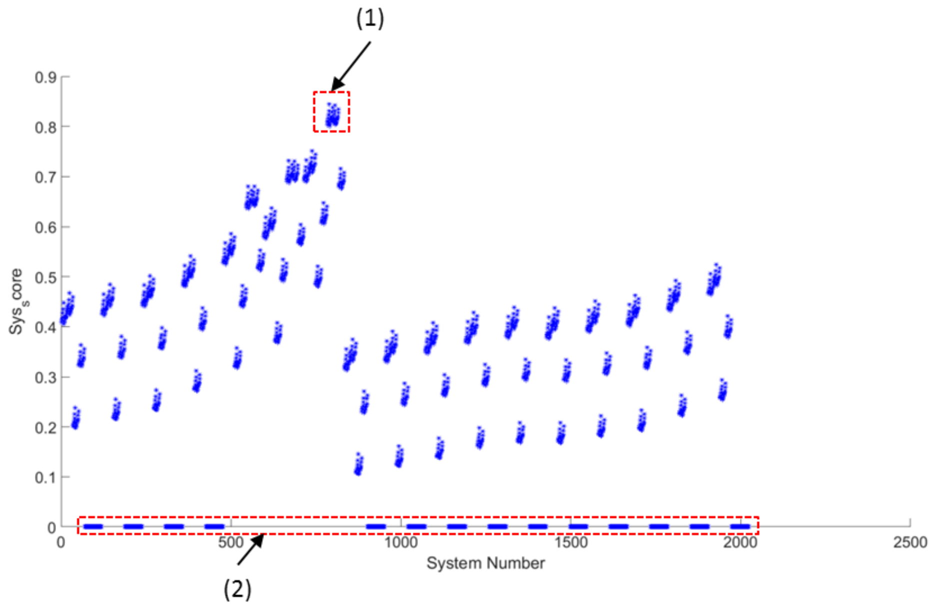

Figure 38. Performance scores of systems for a conference room

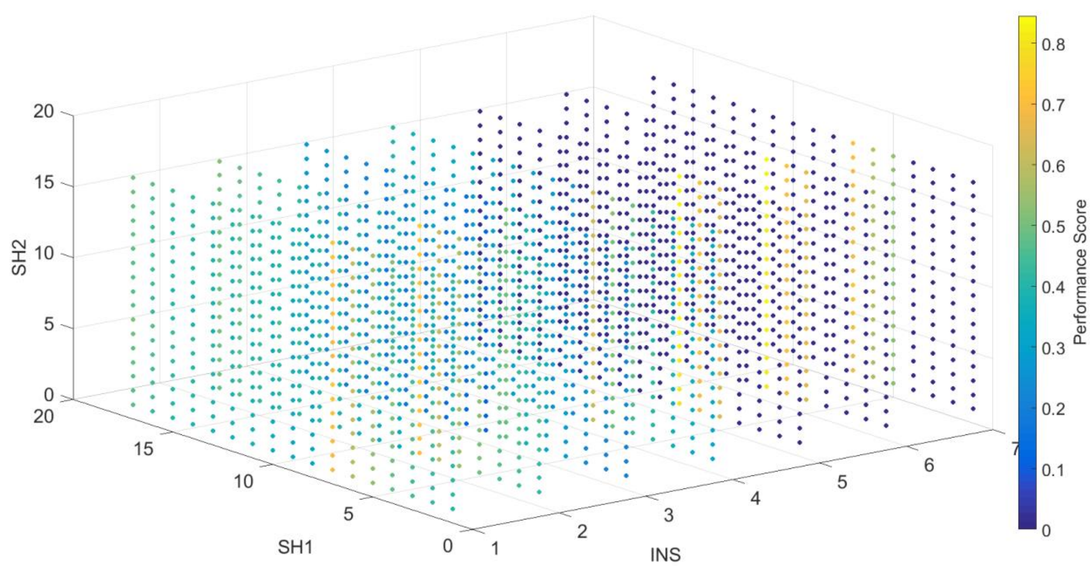

Figure 39. 3-D plot of performance scores of all systems for a conference room

Even though #789 has the highest performance score, all insulation systems in (1) of Figure 38 (783-815) have relatively high performance scores (0.8-0.845). They can also be considered as candidates for the insulation systems. In this situation, a designer should look into the physical performance of the insulation systems. It is especially important to check soundproofing performance and annual energy consumption because they are the two most important design objectives to the designer in this example. Figure 40 shows the soundproofing and annual energy consumption performance of the insulation systems (789-815) in (1) in Figure 38. The insulation systems between 783 and 799 have relatively high soundproofing performance (60-63dB), but they have relatively low energy performance (10819-10987kWh). The situation is the opposite for the insulation systems between 800 and 815. They have relatively low soundproofing performance (52-55dB), but they have high energy performance (8807-8873kWh). The designer should make a decision based on this data. For example, if a sound transmission loss above 60dB is necessary, the designer should choose one of the insulation systems of 783-799. However, if it is all right to use less than 50dB of performance, then an insulation system of 800-815 can also be an option.

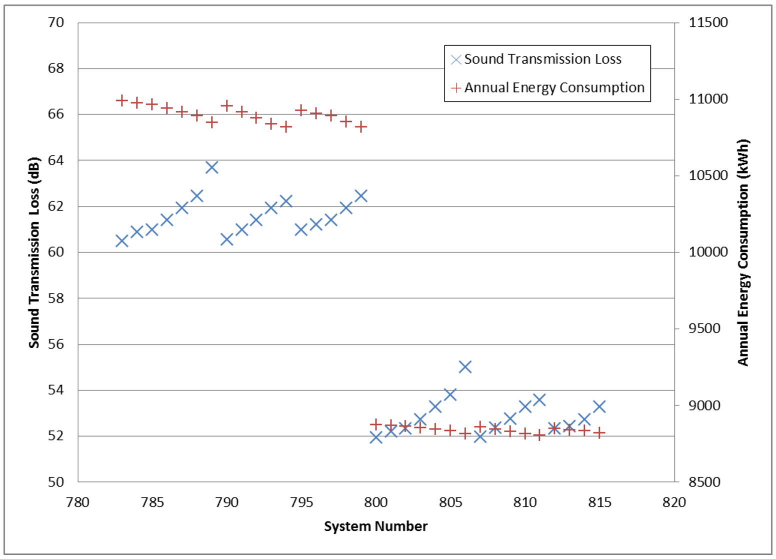

Figure 40. Soundproofing and energy performance of insulation systems (#783-815)

Note that insulation systems that have foam plastic material but less than 15 min fire resistant time should not be used, and the model removes the insulation systems ((2) in Figure 38).

Table 23 shows the insulation systems that provide the highest performance scores for the three cases. The insulation system #1458 is chosen for an apartment room. The system consists of OSB (0.0095m), fiberglass batt kraft-faced (FG-K) and OSB (0.0095m). For the compartment requiring high fire safety, insulation system #744 is selected based on the decision model. This system consists of GB (0.0254m), fiberglass batt kraft-faced (FG-K) and GB (0.0095m). The detail of the performance results of the insulation systems are in Table 23. As we discussed, it is sometimes necessary for a designer to look into the physical performance of insulation systems when there are some insulation systems having similar high performance scores. In this case, they can use the systematic data profile that this design tool provides.

Table 23. Optimum insulation systems for three example cases

Type	Insulation System Number	Layers of insulation systems	Performance Results				
			Annual energy consumption (kWh)	Sound transmission loss at 2000Hz (dB)	Fire resistant time (min)	Sustainability (Norm.)	Cost (Norm.)

Apartment	1458	OSB-0.0095m+FG-K+OSB-0.0095m	11006 (0.1%↑)	48 (1%↑)	4.8 (63%↓)	0.99 (13%↑)	0.903 (0.6%↓)
Conference room	789	GB-0.0254m+SPF-OC+GB-0.0254m	10847 (1.6%↑)	64 (28.9%↑)	34 (158%↑)	0.55 (38%↓)	0.47 (48%↓)
Compartment requiring high fire safety	744	GB-0.0254m+FG-K+OSB-0.0095m	10925 (0.86%↑)	53 (7.9%↑)	34 (158%↑)	0.83 (5.4%↓)	0.76 (15.8%↓)

Conclusion and recommendations

A performance based (multi-characteristic) design tool for insulation system optimization is proposed. This design approach provides various benefits including,

1. This tool can help building designers or architects to design (or select) an optimum insulation system based on a specific building design and its environment. Since this tool allows us to consider a unique building design and its environment, this approach provides a potential to find an optimum solution for a specific building.

2. Building designers can understand how a building material selection could affect related performance systematically. This can provide the insight about the building material selection process. For example, they can understand how much increasing the thickness of a sheathing material could affect sustainability, energy performance as well as fire safety performance. This systematical knowledge can be a good insight for the insulation system design process.

3. This design approach can help building designer's decision making process. To make a decision on insulation system design is a complex decision making. There are numerous factors that building designers should consider. In many cases, they depend on the previous decisions without considering all factors. This design approach provides a framework so that designers can consider various factors systematically and it provides one optimum solution. It depends on designer whether he or she uses the design option but they can have the insight how a design solution can affect various performance.

However, it should be noted that there are some limitations on the current design tool because this model includes approximate mathematical sub-models. Even though sub-models can capture each main phenomenon, they have some limitations to simulate all related phenomena. For example, it was assumed that a layer of insulation in the three physical models consists of an insulation material. However, the configuration is usually more complicated (ex, wood or steel studs). Developing more sophisticated models to consider the complicated phenomena can be one of the future works to improve this kind of decision tool.

Bibliography

1. Prowler D (2012) Whole Building Design. http://www.wbdg.org/wbdg_approach.php. Accessed 03/10 2015
2. Krause U, Grosshandler W, Gritzo L (2012) The International FORUM of Fire Research Directors: A position paper on sustainability and fire safety. Fire Safety Journal 49 (0):79-81. doi:http://dx.doi.org/10.1016/j.firesaf.2012.01.003
3. Vytenis Babrauskas DL, David Eisenberg, Veena Singla, Michel Dedeo, Arlene Blum (2012) Flame retardants in building insulation: a case for re-evaluating building codes. Building Research & Information 40 (6):738-755
4. Assembly UNG (1987) Report of the World Commission on Environment and Development: Our Common Future.
5. Annie R. Pearce YHA, Hanmi Global (2012) Sustainable Buildings and Infrastructre. Routledge, 711 Third Avenue, New York, NY 10017
6. Elkington J (1999) Cannibals with Folks: the Triple Bottom Line of 21st Century Business. Capstone Publishing Ltd,
7. Yudelson J (2008) The Green Building Revolution. Islandpress, 1718 Connecticut Ave, NW, Washington, DC20009
8. Executive OotFE (2003) The Fedral Commitment of Green Building: Experiences and Expectations. Office of the Fedral Enviormental Executive,
9. Baylis J (2005) The Globalization of World Politics. 3rd Edition edn. Oxford University Press,
10. US Department of Energy and Annual Energy Review 2007 DOE/EIA-0384 (2007) (2007).
11. USEPA (2008) Emissions of Greenhouse Gases in the United States 2007.
12. IEA Policies for New Buildings. International Energy Agency,
13. Papadopoulos AM (2005) State of the art in thermal insulation materials and aims for future developments. Energy and Buildings 37:77-86
14. Walker R, Pavía S (2015) Thermal performance of a selection of insulation materials suitable for historic buildings. Building and Environment 94:155-165
15. Incropera FP, Dewitt DP, Bergman TL, Lavine AS (2007) Fundamentals of heat and mass transfer. Sixth edn. John Wiley & Sons,
16. Drysdale D (2011) An Introduction to Fire Dynamics. Third Edition edn. John Wiley and Sons, Ltd,
17. Reid E (1984) Understanding Building. The MIT Press, Cambridge, Massachusetts
18. Maldovan M (2013) Sound and heat revolutions in phononics. Nature 503 (7475):209-217. doi:10.1038/nature12608
19. J.D. Quirt, T.R.T. Nightingale, King F (2006) Guide for sound insulation in wood frame construction National Research Council Canada,
20. A.C.C. Warnock (1985) Factors affecting sound transmission loss. vol CBD-239. National research council canada,
21. B.J. Meacham BP, J. Echeverria, R. Cheng (2012) Fire Safety Challenges of Green Buildings. Fire Protection Research Foundation,
22. Juan P. Hidalgo, Stephen Welch, Jose L. Torero (2015) Performance criteria for the fire safe use of thermal insulation in buildings Construction and Building Materials 100:285-297
23. B.J. McCaffrey, J.G. Quintiere, Harkleroad MF (1981) Estimating room fire temperature and the likelihood of flashover using fire test data correlations. Fire Technology 17 (2):98-119
24. Lie TT (1981) Effects of Insulation on Fire Safety. National Research Council Canada, Division of Building Research,
25. Thomas PH, Bullen ML (1979) On the role of kpC of room lining materials in the growth of room fire. Fire and Materials 3 (2):68-73
26. JOSÉ L. TORERO, AGUSTIN H. MAJDALANI, CECILIA ABECASSIS-EMPIS, COWLARD A Revisiting the Compartment Fire. In: International Association for Fire Safety Science, 2014. pp 28-45
27. Back A (2012) Fire development in insulated compartments: Effects from improved thermal insulation. Lund University,
28. Choi K (1987) Effects of insulation on postflashover room fire. Fire Technology 23 (1):19-25
29. Jr JRH (2011) Fatal effects of fire National Fire Protection Association Quincy, MA
30. International A (2016) Standard Test Method for Surface Burning Characteristics of Building Materials (ASTM E84 - 16). ASTM International, West Conshohocken, PA
31. Buchanan AH (2001) Structural Design Fire Safety. John Wiley and Sons, Ltd,

32. Assocation NFP (2017) Standard Method of Fire Tests for the Evaluation of Thermal Barriers (NFPA 275). National Fire Protection Assocation, Quincy, MA
33. NFPA (2011) Standard method of fire tests for evaluating contribution of wall and ceiling interior finish to room fire growth. NFPA 286.
34. Flammability standards for building insulation materials-Working group report and recommendations (2015). vol CAL FIRE - Office of the state fire marshal.
35. Umberto Berardi, Brian J. Meacham, Dembsey NA, You Y-G (2014) Fire performance assessment of a fiber reinforced polymer wall panel used in a single family dwelling. Fire Technology 50:1607-1617
36. Marvin CH, Tomy GT, Armitage JM, Arnot JA, McCarty L, Covaci A, Palace V (2011) Hexabromo-cyclododecane: current understanding of chemistry, environ-mental fate and toxicology and implications for global management. Environmental Science and Technology 45 (20):8613-8623
37. Stec AA, Hull TR (2011) Assessment of the fire toxicity of building insulation materials Energy and Buildings 43:498-506
38. Mutual F (1978) Foamed Polystyrene for Construction (Data Sheet 1-58). Norwood, MA
39. Keerthan P, Mahendran M (2013) Thermal Performance of Composite Panels Under Fire Conditions Using Numerical Studies: Plasterboards, Rockwool, Glass Fibre and Cellulose Insulations. Fire Technology 49:329-356
40. Zehfuss J, Hosser D (2007) A parametric natural fire model for the structural fire design of multi-storey buildings. Fire Safety Journal 42:115-126
41. Babrauskas VW, R.B. Fire (1978) The historical basis of fire resistance testing — Part I. Fire Technology 14 (3):184-194
42. Kerber S (2012) Analysis of Changing Residential Fire Dynamics and Its Implications on Firefighter Operational Timeframes. Fire Technology 48 (4):865-891
43. Review of structural materials and methods for home building in the united states: 1900 to 2000 (2001). NAHB Research center, Inc. , Upper Marlboro, MD
44. 2010 Characteristics of new housing (2010). US Department of Commerce,
45. Kodur MASR (2000) Light-Weight Frame Wall Assemblies: Parameters for Consideration in Fire Resistance Performance-Based Design. Fire Technology 36:75-88
46. Flager F, Gerber DJ, Kallman B (2014) Measuring the impact of scale and coupling on solution quality for building design problems. Design Studies 35 (2):180-199. doi:https://doi.org/10.1016/j.destud.2013.11.001
47. B.C. Roberts MEW, O.A. Ezekoye (2015) Development of a multi-objective optimization tool for selecting thermal insulation materials in sustainable designs. Energy and Buildings 105:358-367
48. Akadiri PO, Olomolaiye PO, Chinyio EA (2013) Multi-criteria evaluation model for the selection of sustainable materials for building projects. Automation in Construction 30:113-125. doi:https://doi.org/10.1016/j.autcon.2012.10.004
49. A.H. Fanney, K.M. Whitter, T.B. Cohn (1995) 2nd International green building conference and exposition vol NIST SP 888. National Institute of Standards and Technology, Gaithersburg, MD
50. Hidalgo JP (2015) Performance-based methodology for the fire safe design of insulation materials in energy efficient buildings. University of Edinburgh,
51. Goia F, Haase M, Perino M (2013) Optimizing the configuration of a façade module for office buildings by means of integrated thermal and lighting simulations in a total energy perspective. Applied Energy 108:515-527. doi:https://doi.org/10.1016/j.apenergy.2013.02.063
52. Takano A, Hughes M, Winter S (2014) A multidisciplinary approach to sustainable building material selection: A case study in a Finnish context. Building and Environment 82:526-535. doi:https://doi.org/10.1016/j.buildenv.2014.09.026
53. Evins R, Pointer P, Vaidyanathan R, Burgess S (2012) A case study exploring regulated energy use in domestic buildings using design-of-experiments and multi-objective optimisation. Building and Environment 54:126-136. doi:https://doi.org/10.1016/j.buildenv.2012.02.012
54. Castro-Lacouture D, Sefair JA, Flórez L, Medaglia AL (2009) Optimization model for the selection of materials using a LEED-based green building rating system in Colombia. Building and Environment 44 (6):1162-1170. doi:https://doi.org/10.1016/j.buildenv.2008.08.009
55. Wang W, Zmeureanu R, Rivard H (2005) Applying multi-objective genetic algorithms in green building design optimization. Building and Environment 40 (11):1512-1525. doi:https://doi.org/10.1016/j.buildenv.2004.11.017
56. Prianto E, Depecker P (2003) Optimization of architectural design elements in tropical humid region with thermal comfort approach. Energy and Buildings 35 (3):273-280. doi:https://doi.org/10.1016/S0378-7788(02)00089-0

57. Yu W, Li B, Jia H, Zhang M, Wang D (2015) Application of multi-objective genetic algorithm to optimize energy efficiency and thermal comfort in building design. Energy and Buildings 88:135-143. doi:https://doi.org/10.1016/j.enbuild.2014.11.063
58. Futrell BJ, Ozelkan EC, Brentrup D (2015) Bi-objective optimization of building enclosure design for thermal and lighting performance. Building and Environment 92:591-602. doi:https://doi.org/10.1016/j.buildenv.2015.03.039
59. Bambrook SM, Sproul AB, Jacob D (2011) Design optimisation for a low energy home in Sydney. Energy and Buildings 43 (7):1702-1711. doi:https://doi.org/10.1016/j.enbuild.2011.03.013
60. Biddulph P, Gori V, Elwell CA, Scott C, Rye C, Lowe R, Oreszczyn T (2014) Inferring the thermal resistance and effective thermal mass of a wall using frequent temperature and heat flux measurements. Energy and Buildings 78:10-16. doi:http://dx.doi.org/10.1016/j.enbuild.2014.04.004
61. Roger Feasey, Buchanan A (2002) Post-flashover fires for structural design. Fire safety journal 37:83-105
62. Hagglund B (1986) Simulating Fire in Natural and Forced Ventilated Enclosures. National Defense Research Institute, Stockholm
63. Eurocode (1995) Eurocode 1: Basis of Design and Actions on Structures. Part 2-2: Actions on Structures Exposed to Fires. ENV 1991-2-2.
64. Hopkins C (2007) Sound insulation Butterworth-Heinemann,
65. Poblet-Puig J (2008) Numerical Modeling of Sound Transmission in Lightweight Structures. Universitat Politècnica de Catalunya
66. Pertsova CC (2007) Ecological economics research trends. Nova publishers,
67. Carbon dioxide equivalent. (2013) OECD. https://stats.oecd.org/glossary/detail.asp?ID=285. Accessed 08/18 2017
68. RSmeans Building construction cost data (2015). Construction Publishers & Consultants,
69. Keeney RL (1982) Decision analysis: An overview. Operations Research 30 (5):803-838
70. Esfstratios Nikolaidis, Mourelatos ZP, Pandey V (2011) Design Decisions under Uncertainty with Limited Information. CRC Press,
71. John M. Watts J Fire risk assessment using multiattribute evaluation In: International Association for Fire Safety Science, 1997.
72. Saaty TL (1980) The analytical hierarchy process McGraw-Hill, NY
73. Donegan HA (2008) Decision analysis. In: The SFPE of fire protection engineering Fourth edition edn.,
74. Park H, Meacham B, Dembsey N, Goulthorpe M (2015) Conceptual Model Development for Holistic Building Fire Safety Performance Analysis. Fire Technology 51 (1):173-193. doi:10.1007/s10694-013-0374-1
75. SFPE Handbook of Fire Protection Engineering (2008). Fourth edn. the National Fire Protection Association Quincy, Massachusetts
76. Environmental Product Declaration (2014). North America Gypsum Boards. Gypsum association
77. Marsh D (2008) WRAP: Comprehensive life-cycle analysis of plasterboard. Global gypsum magazine.
78. Environmental product declaration - Typical (5/8" Type X) North American Gypsum Boards (2014). Gypsum assocation
79. Environmental product declaration-Plywood (2015). Forest and Wood Products Australia
80. Panel Guide Version 4 (2014). the Wood Panel Industries Federation
81. . https://www.menards.com/main/home.html. Accessed 10/24 2017
82. Thermal barriers and ignition barriers for the spray polyurethane foam industry (2011). Spry polyurethane foam alliance,
83. Andre Frangi, Schleifer V, Fontana M, Hugi E (2010) Experimental and numerical analysis of gypsum plasterboards in fire. Fire Technology 46:149-167
84. Institute AS (2009) Gypsum boards with Fibrous reinforcement - Definition, requirements and test methods Part 2: Gypsum fibre boards, vol EN 15283-2. Austrian Standards Institute,
85. Ryan JV (1962) Study of Gypsum Plasters Exposed to Fire. Journal of Research of the National Bureau of Standards – C Engineering and Instrumentation 66:373-387
86. K. GHAZI WAKILI, E. HUGI, WULLSCHLEGER L, FRANK T (2007) Gypsum Board in Fire – Modeling and Experimental Validation. Journal of Fire Science 25
87. Sultan MA (1996) A Model for Predicting Heat Transfer Through Noninsulated Unloaded Steel-Stud Gypsum Board Wall Assemblies Exposed to Fire. Fire Technology 32 (3):239-259
88. Axenenko O, Thorpe G (1996) The Modelling of Dehydration and Stress Analysis of Gypsum Plasterboards Exposed to Fire. Computational Materials Science 6 (3):281-294

89. Keerthan P, Mahendran M (2012) Numerical studies of gypsum plasterboard panels under standard fire conditions. Fire Safety Journal 53:105-119
90. Open cell vs. closed cell. Energy efficient solutions. http://www.energyefficientsolutions.com/open-cell-vs-closed-cell.asp. Accessed 08/13 2017
91. Information brief-Wet spray and dense pack insulation Minnesota sustainable housing initiative. http://www.mnshi.umn.edu/kb/scale/insulation_densepack.html. Accessed 08/13 2017
92. Brohus H, Nielsen PV, Petersen AJ, Sommerlund-Larsen K Sensitivity Analysis of Fire Dynamics Simulation. In: Proceedings of Roomvent Helsinki, 13-15 June 2007.
93. Sensitivity analysis of model output. In: Kenneth M. Hanson, Hemez FM (eds) The 4th International conference on sensitivity analysis of model output (SAMO 2004), Santa Fe, New Mexcio, 2004. Los Alamos National Laboratory,
94. Morris MD (1991) Factorial Sampling Plans for Preliminary Computational Experiments. Technometrics 33 (2):161-174. doi:10.1080/00401706.1991.10484804
95. Campolongo F, Cariboni J, Saltelli A, Schoutens W Enhancing the Morris Method. In: the 4th International conference on sensitivity analysis of model output (SAMO 2004), Los Alamos National Laboratory, 2005.
96. Iooss B, Lemaître P (2015) A Review on Global Sensitivity Analysis Methods. In: Dellino G, Meloni C (eds) Uncertainty Management in Simulation-Optimization of Complex Systems: Algorithms and Applications. Springer US, Boston, MA, pp 101-122. doi:10.1007/978-1-4899-7547-8_5
97. Jelle BP (2011) Traditional, state-of-the-art and future thermal building insulation materials and solutions – Properties, requirements and possibilities. Energy and Buildings 43 (10):2549-2563. doi:https://doi.org/10.1016/j.enbuild.2011.05.015
98. Francis D. K. Ching, Winkel SR (2016) Building codes illustrated Wiley,
99. the National Centers for Environmental Information. https://www.ncdc.noaa.gov/.
100. NREL Solar radiation data manual for flat-plate and concentrating collectors. National Renewable Energy Laboratory
101. Barron RF (20003) Industrial noise control and acoustics. Marcel Dekker, Inc,
102. Okabe M, Kawai N, Takada S (2000) Experimental analysis for estimating strength and stiffness of shear walls in wood-framed construction. Proc of the WCTE
103. ASTM E413 Classification for rating sound insulation (2016). ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959
104. Lstiburek J (2010) The perfect wall. Building Science Corporation,
105. Lstiburek J (2015) Vitruvius does veneers: Drilling into cavities. Building Science Corporation,
106. You Y-G, Yin M, Martin D, Meacham B, Dembsey N, Gollner M, Marshall A, Maisto P, Ahrens M, Grant C, Rodrigue T (2014) Quantification of Green Building Features on Firefighter Safety. Paper presented at the SFPE 10th International Conference on Performance-Based Codes and Fire Safety Design Methods, Brisbane, Australia,
107. Wall- 2x6 Advanced frame wall construction (2014). Building Science Corporation,
108. Straube J (2007) Interior insulation retrofits of load-bearing masonry walls in cold climates. Building Science Corporation,
109. Wall - SIPs wall construction (2014). Building Science Corporation,
110. Wall - ICF Wall construction (2014). Building Science Corporation,
111. Babrauskas V (1979) COMPF2: a program for calculating post-flashover fire temperature. NBS Technical Note 991. National Bureau of Standards,
112. Emrath P (2013) Space in New Homes. NAHB. https://www.nahb.org/en/research/housing-economics/special-studies/spaces-in-new-homes-2013.aspx. Accessed 04/17 2017
113. S. E. Magnusson, Thelandersson S (1970) Temperature-Time Curves of Complete Process of Fire Development. Lund Institute of Technology Lund, Sweden
114. Kolarkar PN (2010) Structural and thermal performance of cold-formed steel stud wall systems under fire conditions. Queensland Unversity of Technology,

Appendices

Appendix A. Insulation wall systems

There are various types of wall systems. They have been developed based on the available materials or available techniques in a region. The purpose of all wall systems, however, is clear and one that is an environment separator [104]. For this, wall systems should control rain, air, vapor, and heat. This is important not only for people but also for structures because these physical elements can damage structures. Wall systems should provide the four key control layers listed below, in descending order of their importance [104]:

- A rain control layer
- An air control layer
- A vapor control layer
- A thermal control layer

Because rain itself can contain air and vapor, a vapor control layer is rendered useless in the absence of a rain control layer and an air control layer. Because air and vapor flow can also carry significant heat, a thermal control layer is meaningless without other three layers. The necessity to have four layers does not mean that four physically separated layers are required. A commercially available layer can perform as multiple control layers. For example, a barrier product can serve as an air and vapor layers.

Thermal insulation is a specially designed measure to provide the thermal control layer and a key aspect for energy efficient buildings' walls. The main wall typologies for buildings are identified as in Figure 41 which is modified from Hidalgo, et al [50]. The typology divides wall systems into the classic systems and the innovative systems. The classis systems have been widely used; and these include masonry cavity walls, framing board walls and masonry solid walls. The innovative systems were relatively newly developed compared to the classic systems. Typically, they are provided as a composite system that provides higher thermal properties as well as a less complex installation on site.

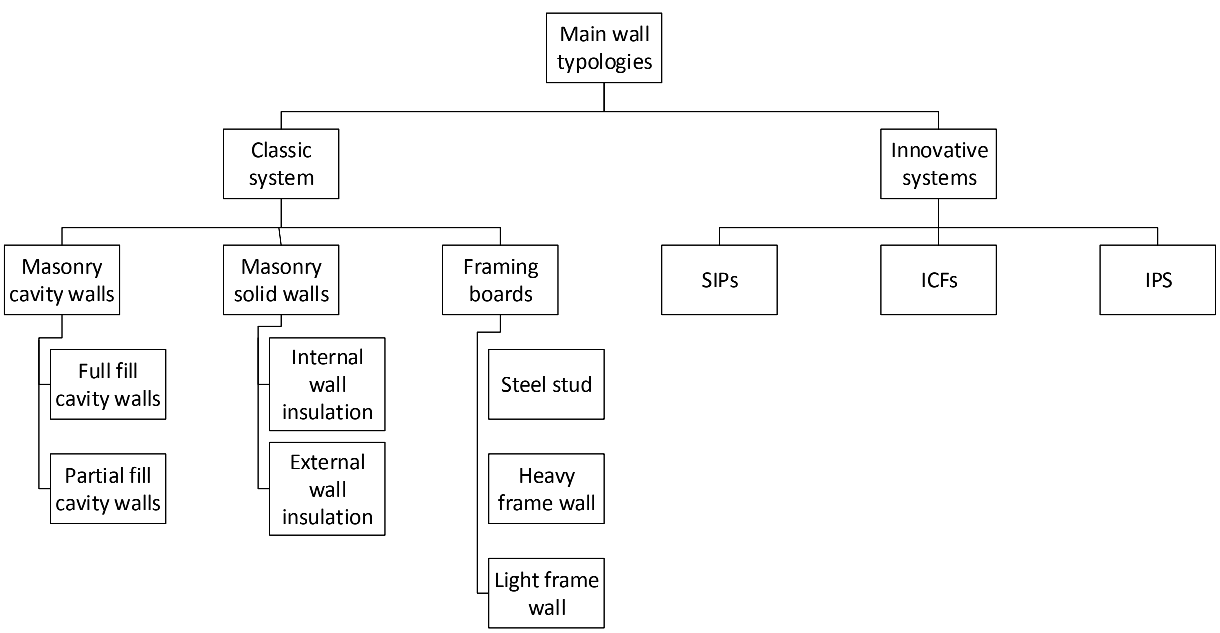

Figure 41. A schematic diagram of wall typologies for energy efficient buildings (Modified from Hidalgo [50])

Masonry Cavity Walls

Masonry is bricks or pieces of stone which stick together with mortar such as cement. The masonry cavity walls are the wall systems that consist of two wythes of masonry separated by an air space in which insulation materials are filled in. There are two types of masonry cavity walls: full fill cavity walls and partial fill cavity walls. A full fill cavity wall is filled only with insulation materials, while a partial fill cavity wall is filled not only with insulation materials but also with other layers in the cavity. Since a partial fill cavity wall provides an effective barrier to moisture penetration and further ventilation, it is used in more severe environments [50].

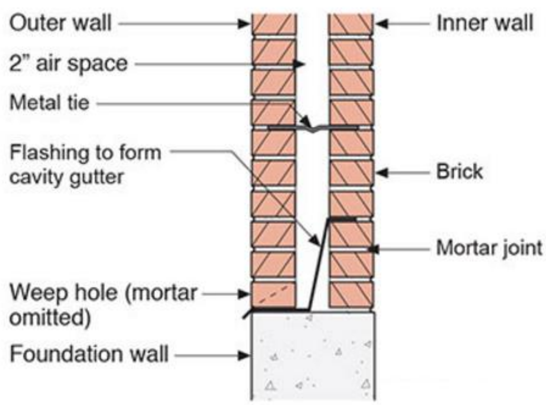

Figure 42. Masonry cavity walls [105]

Framing Boards

The framing board in these typologies means the light-frame construction. The light-frame construction consists of a framing structure for which standardized dimensional lumbers or steel studs are used and sheathing materials that cover the framings. For outside sheathings, oriented strand board (OSB), plywood or rigid foam sheathings is usually used. For inside sheathings, gypsum board, or drywall is used. Insulation materials are filled in the space between studs which are timbers or steels.

The *lightweight wood framing wall* is one of the most widely used framings in the U.S. There are two types of lightweight wood framings: the traditional wood framing and the advanced framings. The traditional lightweight wood framing uses 2x4 or 2x6 inches wood studs spaced 16 inches on center while the advanced wood framing uses 2x6 inches wood studs with increased wall stud spacing (spaced 24 inches on center). The advanced framing walls were developed to provide larger spaces for insulation materials using fewer studs resulting in better thermal bridging, which otherwise could be a path for energy loss in this type of wall. Because of these characteristics, the advanced framing has been highly recommended for energy efficient buildings. More detail information about the advanced framing is included in You., et al [106].

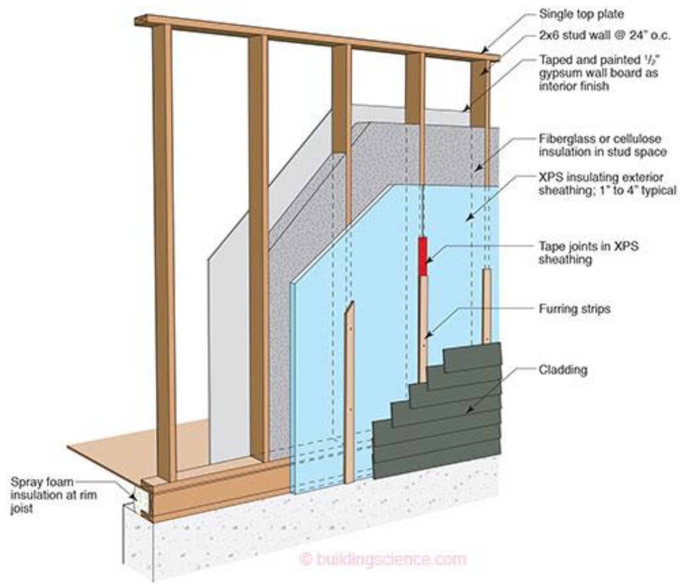

Figure 43. Wood studs framing walls [107]

Masonry Solid Walls

Masonry solid walls usually consist of a layer of solid brick and insulation material is installed on one side of the solid brick. Since it does not provide a cavity, the energy performance is clearly lower than the masonry cavity walls [50]. This system was used before the first half of the twentieth century or in the regions having mild climates [50]. There are two types of masonry solid walls, based on the insulation location: internal wall location and external wall location.

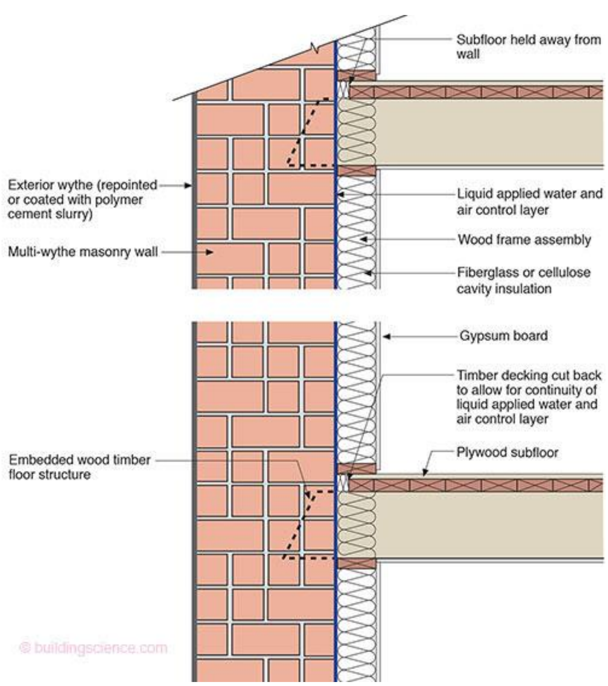

Figure 44. Masonry solid wall [108]

Structural Insulated Panels (SIPs)

Structural Insulated Panels (SIPs) is a composite building material which is manufactured in a factory. A SIP consists of insulating rigid core foam located between two structural facings materials. This panel can be used for external walls, interior walls, ceilings and floors. For insulation materials, PUR and PIR are used, and expanded polystyrene foam (EPS) or extruded polystyrene foam (XPS) can also be used. For the structural facing materials, typically oriented strand board (OSB) is used; but sheet metal and plywood can also be used. These panels have higher insulating properties, and a well-built house with SIPs has a tighter building envelope allowing the house to have higher energy efficiency [106].

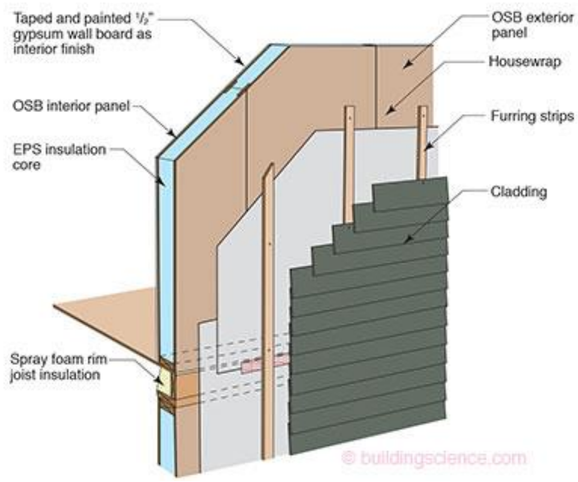

Figure 45. A wall construed with Structural Insulated Panels [109]

Insulated Concrete Forms (ICFs)

Insulated Concrete Forms (ICFs) is a building construction system which consists of a concrete layer between lightweight foam blocks. Usually, expanded polystyrene (EPS) or extruded polystyrene (XPS) are "stacked" together to make wall shapes, and then the space between the foam blocks is filled with concrete.

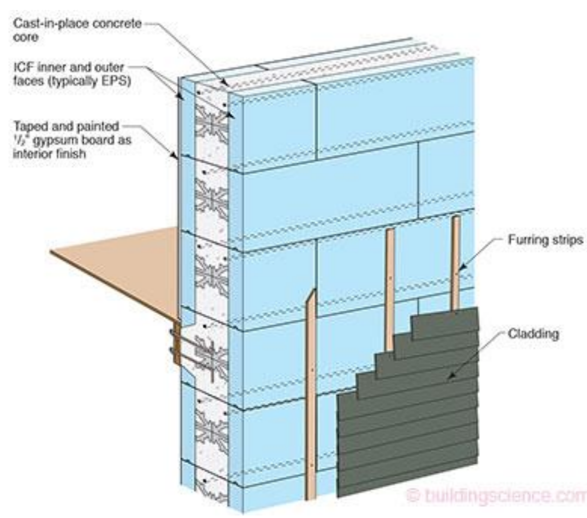

Figure 46. Structure of ICFs [110]

Appendix B. EUROCODE parametric temperature-time curve

Eurocode parametric temperature-time equations

The EUROCODE provides equations to produce parametric temperature-time curves based on fuel load, compartment dimensions such as room size and ventilation openings and wall lining materials. The equations for parametric temperature-time curve consist of three main phase: the heating phase, the maximum temperature and the cooling phase.

The equation for the heating phase is,

$$T_g = 20 + 1325\left(1 - 0.324e^{-0.2t^*} - 0.204e^{-1.7t^*} - 0.472e^{-19t^*}\right) \tag{70}$$

where t^* is a fictitious time (h) which is defined as

$$t^* = \Gamma t \tag{71}$$

where t is a real time (h) and Γ is a parameter showing the relations between the opening factor and the thermal inertia of lining materials, defined as,

$$\Gamma = \frac{\left(\frac{O}{O_{ref}}\right)^2}{\left(\frac{b}{b_{ref}}\right)^2} \tag{72}$$

where O is an opening factor, O_{ref} is the reference value of the opening factor, b is the thermal inertia of the lining material and b_{ref} is the reference value of the lining material.

The opening factor is defined as,

$$O = \frac{A_v\sqrt{h_{eq}}}{A_t} \tag{73}$$

where A_v is the total area of openings on all walls, A_t is the total area of enclosure (walls, ceilings, and floor, including opening) and h_{eq} is the weighted average of window heights on all walls.

The maximum temperature occurs after the duration of heating, and the duration time which is the time to maximum is calculated using the equation below,

$$t_{max} = \max\left[\left(0.2 \cdot 10^{-3} \cdot \frac{q_{t,d}}{O}\right);\ t_{lim}\right] \tag{74}$$

where t_{lim} is the parameter that limit the duration time based on the fire growth phase, $q_{t,d}$ is the design value of the fire load density related to the total enclosure surface area and it is defined as below.

$$q_{t,d} = q_{f,d} \cdot \frac{A_f}{A_t} \tag{75}$$

where $q_{f,d}$ is the design value of the fire load density related to the surface area, A_f. It is almost impossible to get the accurate value of $q_{f,d}$. However, the Eurocode provides a method to estimate the values based on the occupancy types and the compartment area (Annex E).

The temperature-time curves in the cooling phase are given by:

$$T_g = T_{max} - 625(t^* - t^*_{max} \cdot x) \qquad for\ t^*_{max} \leq 0.5 \tag{76}$$

$$T_g = T_{max} - 250(3 - t^*_{max}) \cdot (t^* - t^*_{max} \cdot x) \qquad for\ 0.5 < t^*_{max} \leq 2 \tag{77}$$

$$T_g = T_{max} - 250(t^* - t^*_{max} \cdot x) \qquad for\ t^*_{max} \geq 2 \tag{78}$$

where t^*_{max} is the fictitious heating duration time, and it is defined as below.

$$t^*_{max} = \left(0.2 \cdot 10^{-3} \cdot \frac{q_{t,d}}{O}\right) \cdot \Gamma \tag{79}$$

The EUROCODE parametric fire curves have been used frequently for performance-based design. There are some research studies that check the validity of the curves. Feasey and Buchanan [61] studied the parametric fire curves, and they provided some modification to produce better estimations of temperatures in post-flashover fires as below. These modifications are based on design fires calculated using the COMFP2 program [111] which was calibrated with a large number of realistic fire test results.

- Change the reference value of b_{ref} from 1160 to 1900 $W \cdot s^{0.5}/m^2K$
- Remove the lower limit of the thermal inertia (1000 $W \cdot s^{0.5}/m^2K$), and use the actual value of the thermal inertia
- Use a new fictitious time that is based on square root rather than squared terms.

The modified EUROCODE temperature-time equations were used for the further analysis.

Results of EUROCODE temperature-time curves

The temperature-time curves are changed based on the ventilation opening dimensions (area and height of opening), the room size and the fire density as discussed previously. In this section, the effect of the parameters on the EUROCODE temperature-time curves is studied.

Bed rooms such as master bedrooms and other bedrooms were used an example of the variety of the room sizes and the fire densities. Based on a recent survey report for the average sizes of individual rooms in new homes in the U.S. [112], the average size of bed rooms including mater bedrooms ranges from 21.5 m^2 to 66.2 m^2 by its home sizes. Table 24 shows the average compartment sizes by home sizes.

Table 24. Compartment sizes by home sizes [70]

	All New Homes	By Home Size		
		Under 2,000 square feet	2,000-2,999 square feet	3,000 square feet plus
Master Bedroom	309	231	271	411
Other Bedrooms	481	261	416	713
Master Bathroom	160	115	144	210
Other Bathrooms	191	93	146	313
Laundry Room	102	67	87	145
Entry Foyer	101	65	89	138
Separate Kitchen	306	193	275	423
Separate Dining Room	216	148	196	281
Separate Living Room	330	256	319	393
Separate Family Room	404	311	355	503
Great Room	550	487	481	680
Other Finished Space	530	270	435	825
Closet Space	146	106	125	201
Walk-in Kitchen Pantry	37	17	31	51

For a reference condition, 40 m^2 of floor area, a 500 MJ/kg of design value of fire density (estimated with bed room occupancy condition based on Annex E in the EUROCODE [63]), a 1m x 2m of a door size opening are used. With fixed other values, the various values of the interested parameters were examined. The EUROCODE temperature-time curve based on the reference condition will be used for further analysis as an example.

Seven different floor areas were simulated, ranging from 20 m^2 to 66.2 m^2. It is assumed that the length and width of a compartment are the same. The results are in Figure 47, which also includes the temperature-time curve by ASTM E119 for comparison. The time to reach the peak temperature gets faster as the room size is decreased, and all temperatures during the initial 15 min are higher than the temperature in the standard fire test.

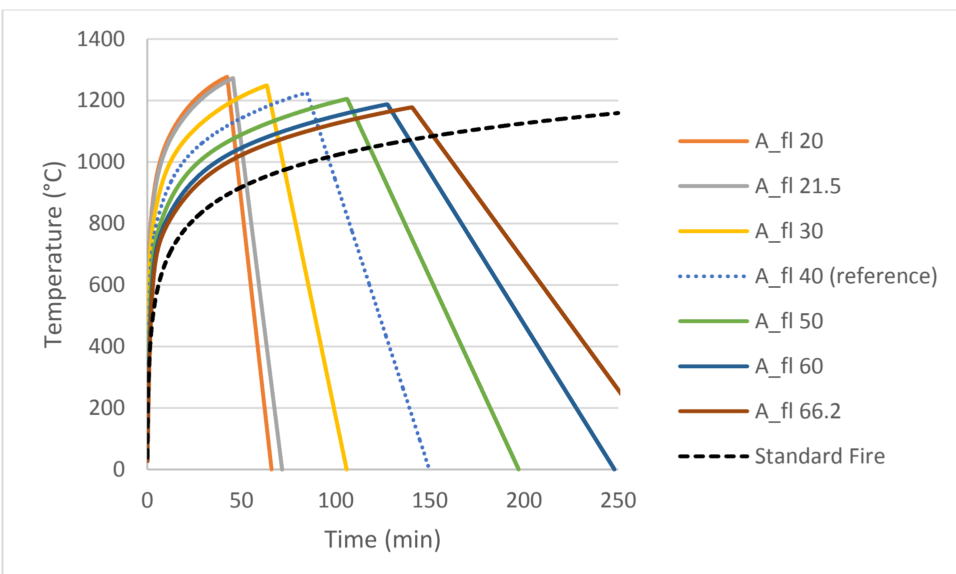

Figure 47. Time-Temperature curves in EUROCODE by room sizes

For the opening dimensions, the various area and heights of opening were examined. In the initial phase of fire, the fire is governed by available oxygen which is called “ventilation-controlled”. The higher and faster peak temperatures are reached as the opening area is increased. It is interesting that the temperature-time curve with the 0.5 m of the opening size, which represents a small ventilation area, is almost the same with the temperature-time curve of ASTM E119.

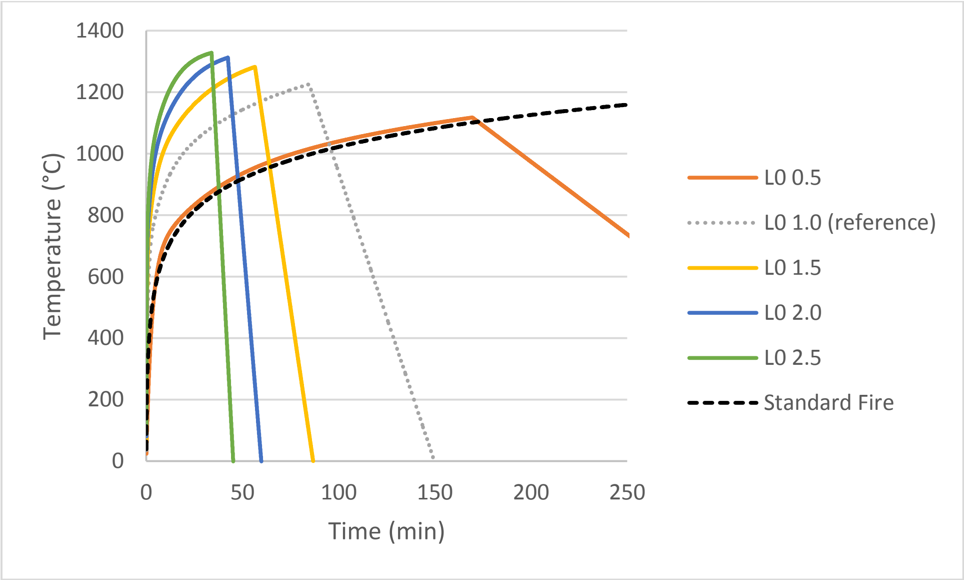

Figure 48. Time-Temperature curves in EUROCODE by opening length

Differing heights ranging from 0.5m to 2.4m were also examined. In this example, the temperature is decreased as the height of the opening is decreased. The temperature of the room having less than 1.0m height of an opening is less than the temperature-time curve when other conditions are not changed.

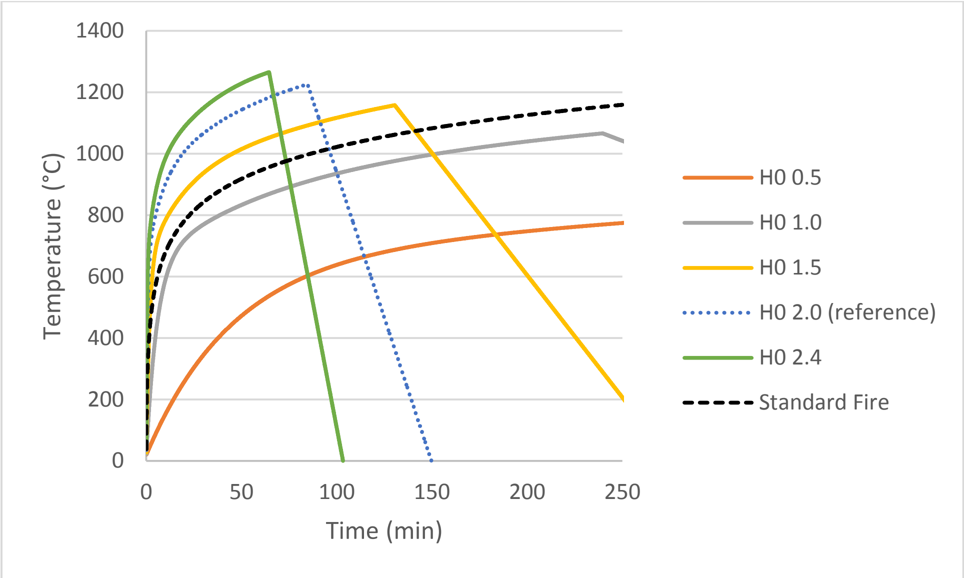

Figure 49. Time-Temperature curves in EUROCODE by opening height

Figure 50 shows the temperature-time curves using various design values of fire load, $q_{f,d}$, ranging from 10 to 700 MJ/m^2. For normal bed rooms, the design value of fire load is around 500 MJ/m^2 based on Annex E in EUROCODE [63]. As the fire load is increased, the peak temperature is increased; and the heating duration time is increased.

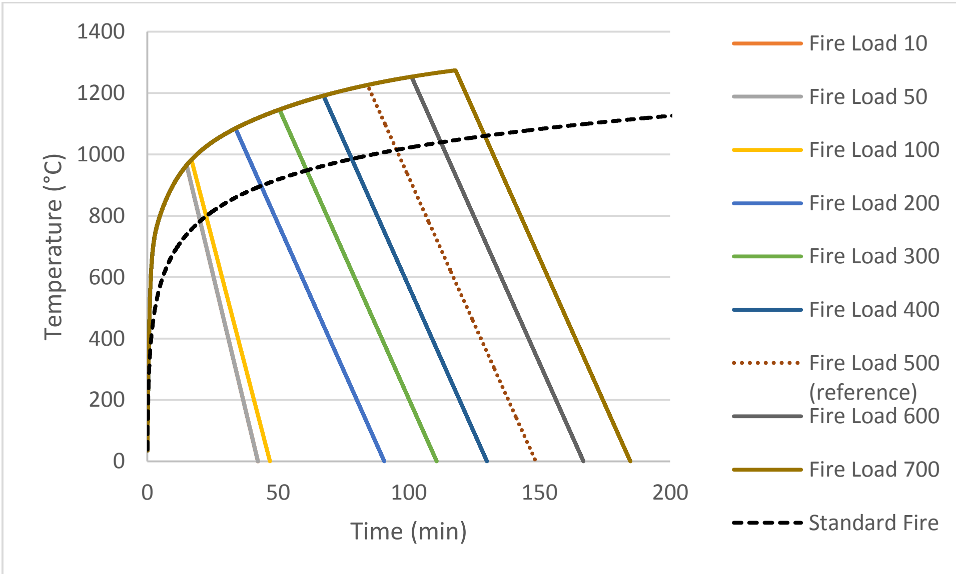

Figure 50. Time-Temperature curves in EUROCODE by fire load

The temperature-time curves are changed significantly based on the parameters. Most of the temperature-time curves here are higher than the standard temperature curve. This is especially true in the initial period (~15min). Therefore, it might be important to check the effect of the temperature-time curve to the performance of a thermal barrier.

Appendix C. Heat diffusion equation and explicit finite difference method

The heat diffusion equation for 1D transient problem without heat generation is

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2}$$

where α is thermal diffusivity $(\frac{k}{\rho c})$ (m/s^2)

In order to solve this equation using FDM (Finite Difference Method), we should derive finite difference representation for the equation. Using Taylor series expansion, we can change each partial derivative $(\frac{\partial T}{\partial t}$ and $\frac{\partial^2 T}{\partial x^2})$ in the equation to finite difference representations.

Taylor series is,

$$f(x + \Delta x) = f(x) + \frac{\partial f(x)}{\partial x}\Delta x + \frac{\partial^2 f(x)}{\partial x^2}\frac{\Delta x^2}{2!} + \frac{\partial^3 f(x)}{\partial x^3}\frac{\Delta x^3}{3!} + \frac{\partial^4 f(x)}{\partial x^4}\frac{\Delta x^4}{4!} + \cdots$$

At first, let's derive the finite difference representation for the first order partial derivative with respect to time $(\frac{\partial T}{\partial t})$ using Taylor series.

$$f(t+\Delta t) = f(t) + \frac{\partial f(t)}{\partial t}\Delta t + \frac{\partial^2 f(t)}{\partial t^2}\frac{\Delta t^2}{2!} + \frac{\partial^3 f(t)}{\partial t^3}\frac{\Delta t^3}{3!} + \cdots$$

The first order derivative form ($\frac{\partial T}{\partial t}$) is in the right hand side of this equation. We can develop this equation for it.

$$\frac{\partial f(t)}{\partial t} = \frac{f(t+\Delta t) - f(t)}{\Delta t} - \frac{\partial^2 f(t)}{\partial t^2}\frac{\Delta t}{2!} - \frac{\partial^3 f(t)}{\partial t^3}\frac{\Delta t^2}{3!} - \cdots$$

Since the first term in the right hand side is quite larger than the rest of the terms, we can truncate the terms.

Therefore, we can rewrite the equation.

$$\frac{\partial f(t)}{\partial t} = \frac{f(t+\Delta t) - f(t)}{\Delta t} + O(\Delta t) \approx \frac{\mathbf{f(t+\Delta t) - f(t)}}{\mathbf{\Delta t}}$$

Therefore, we got finite difference representation for the time derivative and we called the representation as “forward method”. Note that error is included by the truncation. The lowest-order term in the truncation involves Δt to the first power so that the finite difference representation is called “first-order-accurate”.

Secondly, we should derive finite difference representation for the second order partial derivative with respect to space ($\frac{\partial^2 T}{\partial x^2}$). Let’s derive using Taylor series.

$$f(x+\Delta x) = f(x) + \frac{\partial f(x)}{\partial x}\Delta x + \frac{\partial^2 f(x)}{\partial x^2}\frac{\Delta x^2}{2} + \frac{\partial^3 f(x)}{\partial x^3}\frac{dx^3}{6} + \frac{\partial^4 f(x)}{\partial x^4}\frac{\Delta x^4}{24} + \cdots$$

$$f(x-\Delta x) = f(x) - \frac{\partial f(x)}{\partial x}\Delta x + \frac{\partial^2 f(x)}{\partial x^2}\frac{\Delta x^2}{2} - \frac{\partial^3 f(x)}{\partial x^3}\frac{\Delta x^3}{6} + \frac{\partial^4 f(x)}{\partial x^4}\frac{\Delta x^4}{24} - \cdots$$

Add the second equation to the first equation,

$$f(x+\Delta x) + f(x-\Delta x) = 2f(x) + 2\frac{\partial^2 f(x)}{\partial x^2}\frac{\Delta x^2}{2} + 2\frac{\partial^4 f(x)}{\partial x^4}\frac{\Delta x^4}{24}$$

The second order derivative form ($\frac{\partial^2 T}{\partial x^2}$) is in the right hand side of this equation. We can develop this equation for it.

$$\frac{\partial^2 f(x)}{\partial x^2} = \frac{f(x+\Delta x) + f(x-\Delta x) - 2f(x)}{\Delta x^2} - \frac{\partial^4 f(x)}{\partial x^4}\frac{\Delta x^2}{12} + \cdots$$

$$\frac{\partial^2 f(x)}{\partial x^2} = \frac{f(x+\Delta x) + f(x-\Delta x) - 2f(x)}{\Delta x^2} + O(\Delta x^2) \approx \frac{f(x+\Delta x) - 2f(x) + f(x-\Delta x)}{\Delta x^2}$$

Therefore, we got finite difference representation for the space derivative and we called the representation as “central method”. Note that error is also included by the truncation. The lowest-order term in the truncation involves Δx to the second power so that the finite difference representation is called “second-order-accurate”.

Therefore, our governing equation

$$\frac{\partial T}{\partial t} = \alpha \frac{d^2 T}{dx^2}$$

can be

$$\frac{f(t + \Delta t) - f(t)}{\Delta t} = \alpha \frac{f(x + \Delta x) - 2f(x) + f(x - \Delta x)}{\Delta x^2}$$

We can rewrite this equation using different notation.

$$\frac{T_m^{i+1} - T_m^i}{dt} = \alpha \frac{T_{m-1}^i - 2T_m^i + T_{m+1}^i}{dx^2}$$

where i specifies time and m specifies space.

We can develop the equation for T_m^{i+1}which is the temperature at location m and time i+1.

$$T_m^{i+1} = \frac{\alpha(dt)}{dx^2}\left(T_{m-1}^i + T_{m+1}^i\right) + (1 - 2\frac{\alpha(dt)}{dx^2})T_m^i$$

Since $\frac{\alpha(dt)}{dx^2}$ is the finite expression of Fourier number ($\frac{\alpha t}{x^2}$), we can rewrite the equation using Fo.

$$T_m^{i+1} = Fo\left(T_{m-1}^i + T_{m+1}^i\right) + (1 - 2Fo)T_m^i \qquad (1)$$

This is the equation only for interior nodes because it is impossible to get T_{m-1}^i and T_{m+1}^i for the exposed surface node and the back face node respectively. For the surfaces-exposed surface and back face, we should develop new equations using boundary conditions.

For general conduction problems, we can consider three kinds of boundary conditions-constant surface temperature, constant surface heat flux (includes finite heat flux and insulated surface) and convection surface condition.

Here, let's derive general equations for each boundary condition.

For the constant surface temperature (T_s) boundary condition, we don't need an equation to calculate the surface temperature because it is already specified.

$$T_1^i = T_s$$

For the constant net surface heat flux (q''), we can write the boundary condition as below.

$$-k\frac{\partial T}{\partial x} = q''$$

Using Taylor series, we can develop finite difference representation for this boundary condition.

From the Taylor series,

$$f(x + \Delta x) = f(x) + \frac{\partial f(x)}{\partial x}\Delta x + \frac{\partial^2 f(x)}{\partial x^2}\frac{\Delta x^2}{2} + \frac{\partial^3 f(x)}{\partial x^3}\frac{\Delta x^3}{6} + \frac{\partial^4 f(x)}{\partial x^4}\frac{\Delta x^4}{24} + \cdots$$

$$f(x - \Delta x) = f(x) - \frac{\partial f(x)}{\partial x}\Delta x + \frac{\partial^2 f(x)}{\partial x^2}\frac{\Delta x^2}{2} - \frac{\partial^3 f(x)}{\partial x^3}\frac{\Delta x^3}{6} + \frac{\partial^4 f(x)}{\partial x^4}\frac{\Delta x^4}{24} - \cdots$$

Subtract the second equation from the first equation,

$$f(x+\Delta x)-f(x-\Delta x)=2\frac{\partial f(x)}{\partial x}\Delta x+2\frac{\partial^3 f(x)}{\partial x^3}\frac{\Delta x^3}{6}+\cdots$$

$$\frac{\partial f(x)}{\partial x}=\frac{f(x+\Delta x)-f(x-\Delta x)}{2\Delta x}+\frac{\partial^3 f(x)}{\partial x^3}\frac{\Delta x^2}{3}+\cdots$$

$$\approx\frac{f(x+\Delta x)-f(x-\Delta x)}{2\Delta x}$$

Therefore,

$$-k\frac{\partial T}{\partial x}=-k\frac{T_{m+1}-T_{m-1}}{2dx}=q''$$

$$T_{m-1}=\frac{2dxq''}{k}+T_{m+1}$$

Therefore, we can put this equation in the equation (1) in order to consider the boundary condition.

Therefore, we can get the equation for the exposed surface for the boundary condition.

$$T_m^{i+1}=Fo\left(\frac{2dxq''}{k}+2T_{m+1}^{i}\right)+(1-2Fo)T_m^i \qquad (2)$$

Adiabatic or perfect insulation boundary condition is a special case in the constant heat flux. ($q''=0$)

$$-k\frac{\partial T}{\partial x}=0=\frac{\partial T}{\partial x}$$

Finite expression using the method which we derived in the previous boundary condition is,

$$-k\frac{T_{m+1}-T_{m-1}}{2dx}=0$$

$$T_{m+1}=T_{m-1}$$

Therefore, we can put this equation in the equation (1) in order to consider the boundary condition.

Therefore, we can get the equation for the surface for the boundary condition.

$$T_m^{i+1}=2FoT_{m+1}^{i}+(1-2Fo)T_m^i \qquad (3)$$

For the back face, the equation can be like the equation below.

$$T_m^{i+1}=2FoT_{m-1}^{i}+(1-2Fo)T_m^i \qquad (4)$$

For the convection surface condition,

$$-k\frac{\partial T}{\partial x}=h(T_g-T_m)$$

Finite expression using the method which we derived in the previous boundary condition is,

$$-k\frac{T_{m+1} - T_{m-1}}{2dx} = h(T_g - T_m)$$

$$T_{m-1} = T_{m+1} + \frac{2(dx)h}{k}\left(T_g - T_m\right)$$

Since $\frac{(dx)h}{k}$ is the finite expression of Biot number ($\frac{hx}{k^2}$), we can rewrite the equation.

$$T_{m-1} = T_{m+1} + 2Bi\left(T_g - T_m\right)$$

Therefore, we can put this equation in the equation (1) in order to consider the boundary condition.

Therefore, we can get the equation for the surface for the boundary condition.

$$T_m^{i+1} = 2BiFoT_g + 2FoT_{m+1} + (1 - 2Fo - 2FoBi)T_m^i \qquad (5)$$

Explicit method that we derived is not unconditionally stable. Therefore, we should keep a condition for stability that the coefficient associated with the node of interest at the previous time is greater than or equal to zero [15].

Therefore, $(1 - 2Fo)$ in the equation (1) should be greater than or equal to zero.

$$1 - 2Fo \geq 0$$

$$0.5 \geq Fo$$

$$\text{where } Fo = \frac{\alpha(dt)}{dx^2}, \alpha = \frac{k}{\rho c}\,[m^2/s]$$

For the internal nodes,

$$T_m^{i+1} = \frac{\alpha(dt)}{dx^2}\left(T_{m-1}^i + T_{m+1}^i\right) + (1 - 2\frac{\alpha(dt)}{dx^2})T_m^i$$

Equation for the surface node when B.C is q”,

$$T_m^{i+1} = \left(\left(\frac{k}{\rho c}\right)\frac{dt}{dx^2}\right)\left(\frac{2dxq''}{k} + 2T_{m+1}^i\right) + \left(1 - 2\left(\left(\frac{k}{\rho c}\right)\frac{dt}{dx^2}\right)\right)T_m^i$$

Appendix D. Model validation

Energy performance sub-model

The input values for the energy model are in the table below.

Table 25. Input for energy performance modeling

Description	Values	Note
Building dimension	3.4m x 3m x 2.4m	Prototype building
Windows	1.62m (height) x 0.616m (wide)	Prototype building
Bulk wall thickness	0.125m	
Bulk wall conductivity	1.7 W/m/K	
Wall R-value	3.5 m^2K/W [R-20 $[h \cdot ft^2 \cdot °F/Btu]$	IECC Table 402.1.1
Window U-value	0.32 W/m^2K	IECC Table 402.1.1
Average metabolic rate for occupants	75W/person	
Solar heat gain coefficient	0.75	
(SHGC)		
Heat recovery efficiency	85%	
Ventilation rate per unit floor	0.3 $liter/sec.m^2$	(0.0003m^3/s/m^2) Hanam. 2010
Air volume flow rate	0.05~ m^3/sec	AREN 20
Air replacements per second	0.00008 1/sec	
Air specific heat	1007 J/kg/K	
Air density	1.1614 kg/m^3	
Ambient and initial temperature	20°C	

For the validation, the prototype building is simulated with the developed energy model and eQuest, an energy model that was developed by Department of Energy. For the eQuest model, the schematic simulation version is used. Weather information at Boston, Massachusetts, is used [100]. Monthly average temperature and monthly average solar radiation for-plate collectors facing south at a fixed title are used from the literature data [100]. Since the parameters for both models are not identical, the comparison will be used to check the appropriateness of the model as the first order analysis tool. For example, in the eQuest modeling, water heating is included but water heating is not included in our model. The figure below shows the energy usage by the developed model. Q_HVAC includes all energy needed to heat (negative values) and to cool (positive values). Q_elec is the energy needed for lighting and other equipment.

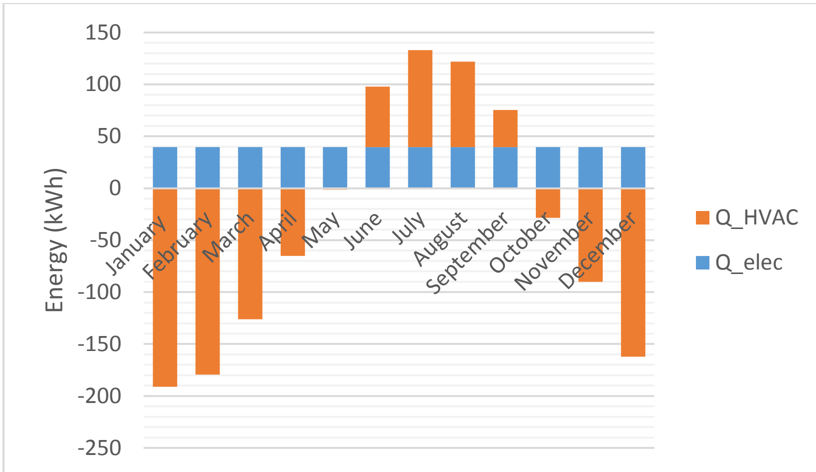

Figure 51. Energy performance results by developed energy performance sub-model

The figure below shows the energy usage using the eQuest model. Basic values from the table were used. Default values in the eQuest except the values are used. In the model, gas is used for heating. The unit Btu can be converted into the unit kWh by multiplying 0.000293. Therefore, 800,000 Btu at January without water heating can be converted to 230kWh. Therefore, for January, 350kWh (120kWh+230kWh) is needed. In our model, total 230kWh is needed (190kWh is needed for heating and 40kWh is needed for other equipment). Therefore, the total difference between the models is 34%. For July, 105kWh is needed using eQuest but 170kWh is needed using the developed model. The difference between them is 38%.

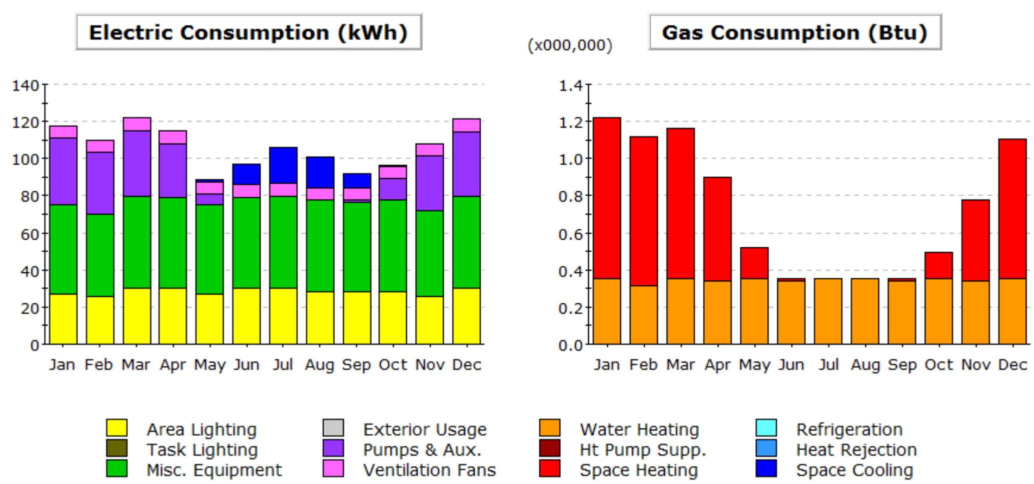

Figure 52. Energy performance results by eQuest

Fire severity sub-model

The fire model is tested to simulate fire experiments in the report by Magnusson and Thelandersson [113]. The experimental data was used to develop the Swedish fire curves.

Table 26. Model input data for fire severity sub-model

Description	Values
Building dimension	3.4m x 3m x 2.4m
Opening	1.62m (height) x 0.616m (wide)
Wall thickness	0.125m
Air specific heat	1007 J/kg.K
Air density	1.16 kg/m^3
Ambient and initial temperature	20°C

The figures below show the comparisons of model results with experiments (Test A1 and Test A2). Given HRR data in the report are used. An empirical constant was used to calibrate the model. Two experimental data were used to validate the model. The model estimates the peak temperatures relatively well. In the decay phase, the model predicts the pattern of the temperature curves relatively well but it underestimates the temperature slightly. For the detail validation of the model, comparison with more broad experimental data would be needed later.

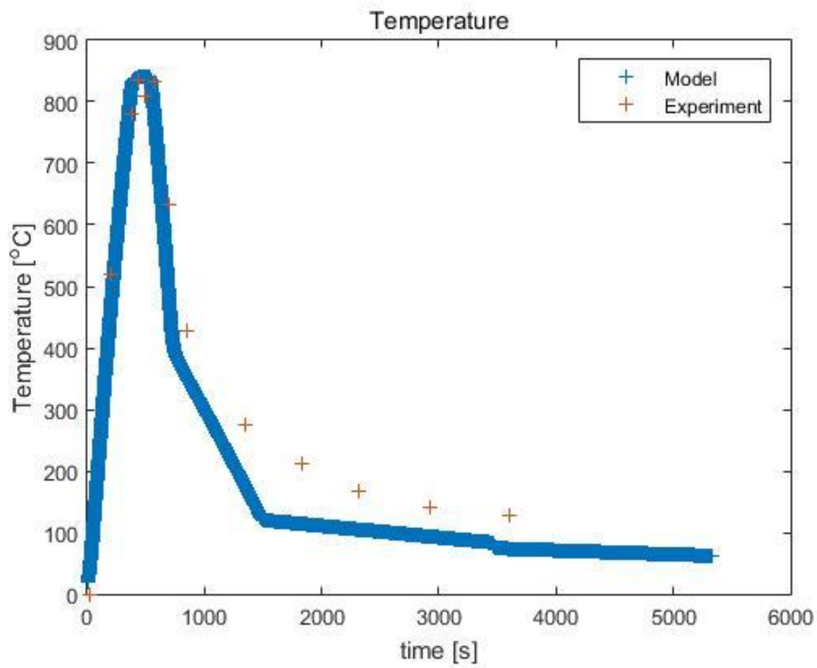

Figure 53. Comparison of fire severity sub-model and experiment (Experiment is test A1 in ref. [113])

Simulation result and test A1.

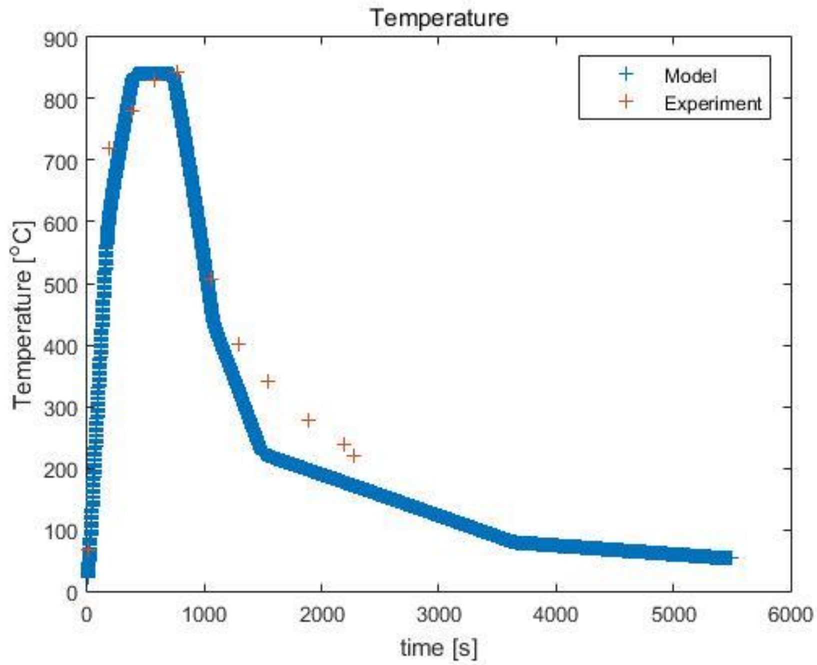

Figure 54. Comparison of fire severity sub-model and experiment (Experiment is test A2 in ref. [90])

Heat transfer performance sub-model

For model validation, the experiments results by Kolarkar [114] was used. In this test, the standard fire condition of AS 1530.4 which is similar to ASTM E119 was used. In their tests, two different thickness gypsum board (type X) were tested (13mm and 16mm), and insulation systems which consist of a gypsum board layer and a thermal insulation layer were also tested. Figure 55 shows the experimental set-up for the tests of 16mm gypsum board. The temperatures of the fire exposed surface, in depth of the gypsum board and the back surface of gypsum boards were measured.

(a) Test Specimen 2 at the Start of Test (b) Test Specimen 2 at the End of Test

Figure 55. Gypsum board fire test using AS 1530.4 [114]

Figure 56 and Figure 57 are the temperature profiles by experiments and models for 13mm gypsum board and 16mm gypsum board, respectively. The figures compare the temperature at the exposed surface to the fire, in-depth locations and back surface of the gypsum boards. Figure 58 shows the temperature profiles of the insulation system which consists of a gypsum board layer and an insulation layer. In the experiment, the system which consists of a 32mm glass fiber insulation layer sandwiched between 16mm gypsum board layers. In the experiment, the temperatures at the fire exposed surface, the location between the exposed gypsum board and the insulation layer and the location between the insulation and the unexposed gypsum board were measured. In the simulation, two layers which are a 16mm gypsum board and a 32mm glass fiber insulation layer were simulated, and the temperatures were measured at the exposed surface, the location between the gypsum board and insulation, and the unexposed surface of the insulation.

The figures show that the heat transfer model predicts the temperature profiles of gypsum board with good accuracy. The good comparisons between the model and the experimental results confirm that the use of the model and thermal properties of gypsum board. The back surface temperature is especially important because the thermal analysis in this study focuses on the location.

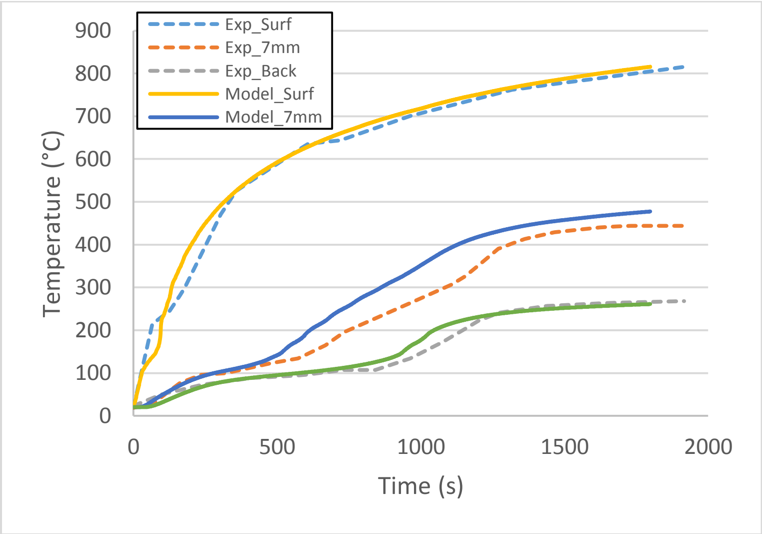

Figure 56. Temperature profiles for 13mm gypsum board test by experiments and the heat transfer model

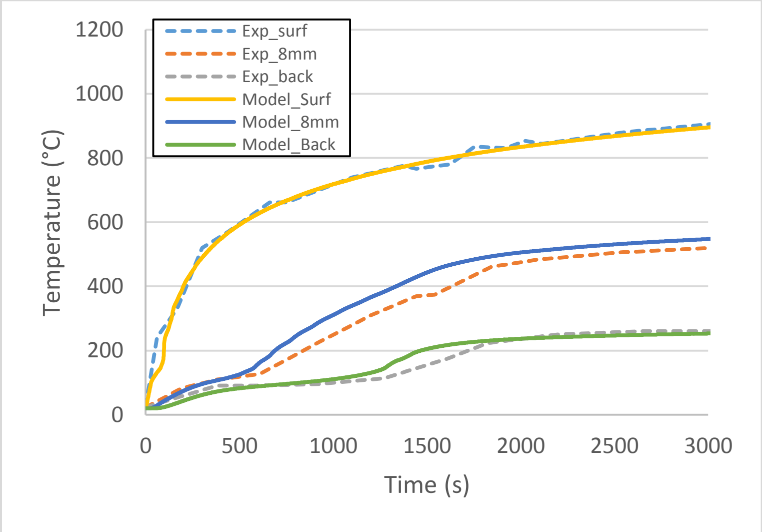

Figure 57. Temperature profiles for 16mm gypsum board test by experiments and the heat transfer model

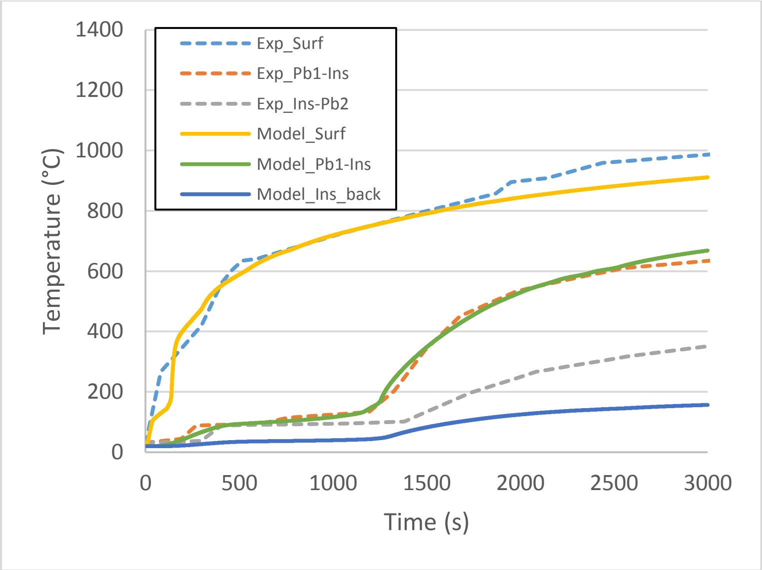

Figure 58. Temperature profiles of the insulation system of 16mm gypsum board and 32mm glass fiber by experiments and the heat transfer model (Pb1-Ins: the location between gypsum board and the insulation, Ins-Pb2: the location between the insulation and the gypsum board)

Figure 59 below shows the reference fire which was decided in section 6.1.2. Using this fire, various insulation systems with different thickness of gypsum boards were tested (Figure 60). Based on the test results, the 13mm gypsum board failed around 10 min. It seems that a 16 mm gypsum board is a proper thickness for this fire condition.

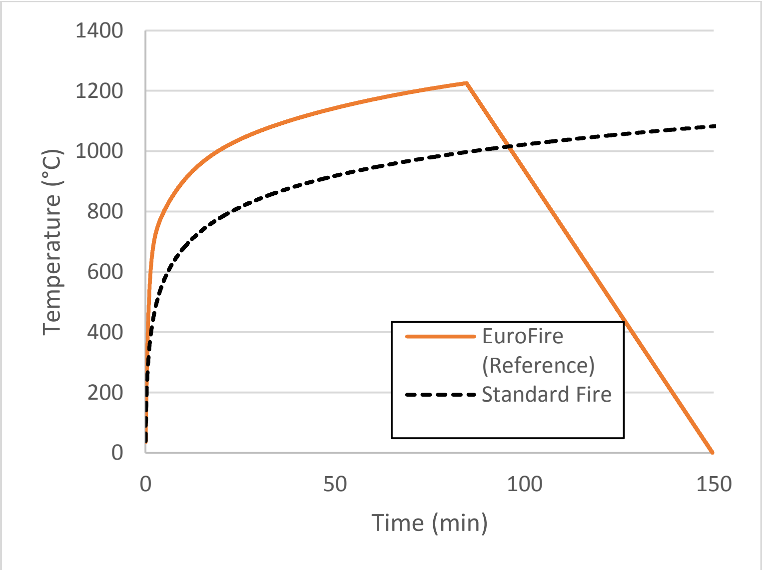

Figure 59. Reference fire curve by EUROCODE

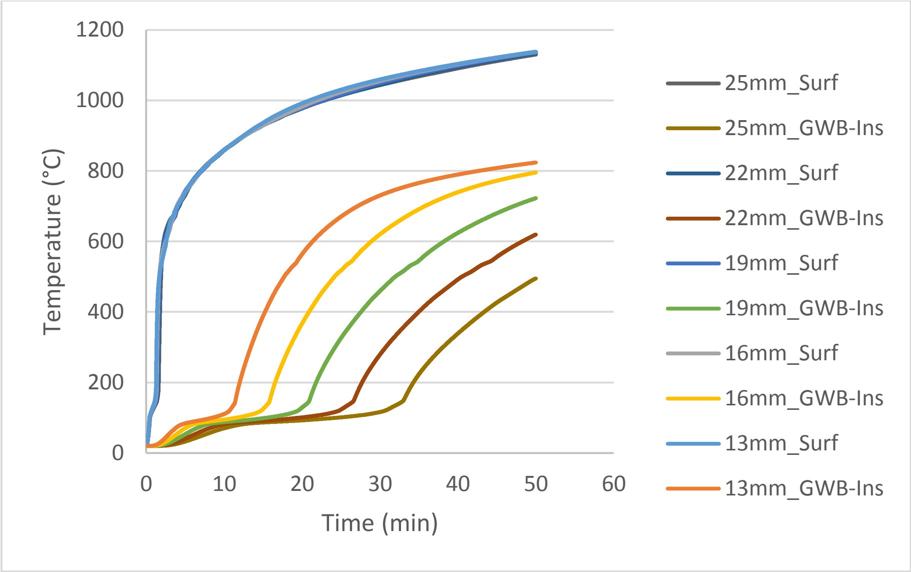

Figure 60. Heat transfer test results based on the reference fire

Appendix E. Insulation system number

Number of Insulation Systems	Interior sheathing (SH1)	Insulation (IN)	Exterior sheathing (SH2)
1	'GB-0.0064'	'FG-U'	'GB-0.0064'
2	'GB-0.0064'	'FG-U'	'GB-0.0079'
3	'GB-0.0064'	'FG-U'	'GB-0.0095'
4	'GB-0.0064'	'FG-U'	'GB-0.0127'
5	'GB-0.0064'	'FG-U'	'GB-0.0159'
6	'GB-0.0064'	'FG-U'	'GB-0.0191'
7	'GB-0.0064'	'FG-U'	'GB-0.0254'
8	'GB-0.0064'	'FG-U'	'PW-0.0064'
9	'GB-0.0064'	'FG-U'	'PW-0.0095'
10	'GB-0.0064'	'FG-U'	'PW-0.0127'
11	'GB-0.0064'	'FG-U'	'PW-0.0159'
12	'GB-0.0064'	'FG-U'	'PW-0.0175'
13	'GB-0.0064'	'FG-U'	'OSB-0.0095'
14	'GB-0.0064'	'FG-U'	'OSB-0.0111'
15	'GB-0.0064'	'FG-U'	'OSB-0.0127'
16	'GB-0.0064'	'FG-U'	'OSB-0.0159'
17	'GB-0.0064'	'FG-U'	'OSB-0.0191'
18	'GB-0.0064'	'FG-K'	'GB-0.0064'
19	'GB-0.0064'	'FG-K'	'GB-0.0079'
20	'GB-0.0064'	'FG-K'	'GB-0.0095'
21	'GB-0.0064'	'FG-K'	'GB-0.0127'
22	'GB-0.0064'	'FG-K'	'GB-0.0159'
23	'GB-0.0064'	'FG-K'	'GB-0.0191'
24	'GB-0.0064'	'FG-K'	'GB-0.0254'
25	'GB-0.0064'	'FG-K'	'PW-0.0064'
26	'GB-0.0064'	'FG-K'	'PW-0.0095'
27	'GB-0.0064'	'FG-K'	'PW-0.0127'
28	'GB-0.0064'	'FG-K'	'PW-0.0159'
29	'GB-0.0064'	'FG-K'	'PW-0.0175'
30	'GB-0.0064'	'FG-K'	'OSB-0.0095'
31	'GB-0.0064'	'FG-K'	'OSB-0.0111'
32	'GB-0.0064'	'FG-K'	'OSB-0.0127'
33	'GB-0.0064'	'FG-K'	'OSB-0.0159'
34	'GB-0.0064'	'FG-K'	'OSB-0.0191'
35	'GB-0.0064'	'RW-B'	'GB-0.0064'
36	'GB-0.0064'	'RW-B'	'GB-0.0079'
37	'GB-0.0064'	'RW-B'	'GB-0.0095'
38	'GB-0.0064'	'RW-B'	'GB-0.0127'
39	'GB-0.0064'	'RW-B'	'GB-0.0159'

40	'GB-0.0064'	'RW-B'	'GB-0.0191'
41	'GB-0.0064'	'RW-B'	'GB-0.0254'
42	'GB-0.0064'	'RW-B'	'PW-0.0064'
43	'GB-0.0064'	'RW-B'	'PW-0.0095'
44	'GB-0.0064'	'RW-B'	'PW-0.0127'
45	'GB-0.0064'	'RW-B'	'PW-0.0159'
46	'GB-0.0064'	'RW-B'	'PW-0.0175'
47	'GB-0.0064'	'RW-B'	'OSB-0.0095'
48	'GB-0.0064'	'RW-B'	'OSB-0.0111'
49	'GB-0.0064'	'RW-B'	'OSB-0.0127'
50	'GB-0.0064'	'RW-B'	'OSB-0.0159'
51	'GB-0.0064'	'RW-B'	'OSB-0.0191'
52	'GB-0.0064'	'C-B'	'GB-0.0064'
53	'GB-0.0064'	'C-B'	'GB-0.0079'
54	'GB-0.0064'	'C-B'	'GB-0.0095'
55	'GB-0.0064'	'C-B'	'GB-0.0127'
56	'GB-0.0064'	'C-B'	'GB-0.0159'
57	'GB-0.0064'	'C-B'	'GB-0.0191'
58	'GB-0.0064'	'C-B'	'GB-0.0254'
59	'GB-0.0064'	'C-B'	'PW-0.0064'
60	'GB-0.0064'	'C-B'	'PW-0.0095'
61	'GB-0.0064'	'C-B'	'PW-0.0127'
62	'GB-0.0064'	'C-B'	'PW-0.0159'
63	'GB-0.0064'	'C-B'	'PW-0.0175'
64	'GB-0.0064'	'C-B'	'OSB-0.0095'
65	'GB-0.0064'	'C-B'	'OSB-0.0111'
66	'GB-0.0064'	'C-B'	'OSB-0.0127'
67	'GB-0.0064'	'C-B'	'OSB-0.0159'
68	'GB-0.0064'	'C-B'	'OSB-0.0191'
69	'GB-0.0064'	'SPF-OC'	'GB-0.0064'
70	'GB-0.0064'	'SPF-OC'	'GB-0.0079'
71	'GB-0.0064'	'SPF-OC'	'GB-0.0095'
72	'GB-0.0064'	'SPF-OC'	'GB-0.0127'
73	'GB-0.0064'	'SPF-OC'	'GB-0.0159'
74	'GB-0.0064'	'SPF-OC'	'GB-0.0191'
75	'GB-0.0064'	'SPF-OC'	'GB-0.0254'
76	'GB-0.0064'	'SPF-OC'	'PW-0.0064'
77	'GB-0.0064'	'SPF-OC'	'PW-0.0095'
78	'GB-0.0064'	'SPF-OC'	'PW-0.0127'
79	'GB-0.0064'	'SPF-OC'	'PW-0.0159'
80	'GB-0.0064'	'SPF-OC'	'PW-0.0175'
81	'GB-0.0064'	'SPF-OC'	'OSB-0.0095'
82	'GB-0.0064'	'SPF-OC'	'OSB-0.0111'

83	'GB-0.0064'	'SPF-OC'	'OSB-0.0127'
84	'GB-0.0064'	'SPF-OC'	'OSB-0.0159'
85	'GB-0.0064'	'SPF-OC'	'OSB-0.0191'
86	'GB-0.0064'	'SPF-CC'	'GB-0.0064'
87	'GB-0.0064'	'SPF-CC'	'GB-0.0079'
88	'GB-0.0064'	'SPF-CC'	'GB-0.0095'
89	'GB-0.0064'	'SPF-CC'	'GB-0.0127'
90	'GB-0.0064'	'SPF-CC'	'GB-0.0159'
91	'GB-0.0064'	'SPF-CC'	'GB-0.0191'
92	'GB-0.0064'	'SPF-CC'	'GB-0.0254'
93	'GB-0.0064'	'SPF-CC'	'PW-0.0064'
94	'GB-0.0064'	'SPF-CC'	'PW-0.0095'
95	'GB-0.0064'	'SPF-CC'	'PW-0.0127'
96	'GB-0.0064'	'SPF-CC'	'PW-0.0159'
97	'GB-0.0064'	'SPF-CC'	'PW-0.0175'
98	'GB-0.0064'	'SPF-CC'	'OSB-0.0095'
99	'GB-0.0064'	'SPF-CC'	'OSB-0.0111'
100	'GB-0.0064'	'SPF-CC'	'OSB-0.0127'
101	'GB-0.0064'	'SPF-CC'	'OSB-0.0159'
102	'GB-0.0064'	'SPF-CC'	'OSB-0.0191'
103	'GB-0.0064'	'XPS'	'GB-0.0064'
104	'GB-0.0064'	'XPS'	'GB-0.0079'
105	'GB-0.0064'	'XPS'	'GB-0.0095'
106	'GB-0.0064'	'XPS'	'GB-0.0127'
107	'GB-0.0064'	'XPS'	'GB-0.0159'
108	'GB-0.0064'	'XPS'	'GB-0.0191'
109	'GB-0.0064'	'XPS'	'GB-0.0254'
110	'GB-0.0064'	'XPS'	'PW-0.0064'
111	'GB-0.0064'	'XPS'	'PW-0.0095'
112	'GB-0.0064'	'XPS'	'PW-0.0127'
113	'GB-0.0064'	'XPS'	'PW-0.0159'
114	'GB-0.0064'	'XPS'	'PW-0.0175'
115	'GB-0.0064'	'XPS'	'OSB-0.0095'
116	'GB-0.0064'	'XPS'	'OSB-0.0111'
117	'GB-0.0064'	'XPS'	'OSB-0.0127'
118	'GB-0.0064'	'XPS'	'OSB-0.0159'
119	'GB-0.0064'	'XPS'	'OSB-0.0191'
120	'GB-0.0079'	'FG-U'	'GB-0.0064'
121	'GB-0.0079'	'FG-U'	'GB-0.0079'
122	'GB-0.0079'	'FG-U'	'GB-0.0095'
123	'GB-0.0079'	'FG-U'	'GB-0.0127'
124	'GB-0.0079'	'FG-U'	'GB-0.0159'
125	'GB-0.0079'	'FG-U'	'GB-0.0191'

126	'GB-0.0079'	'FG-U'	'GB-0.0254'
127	'GB-0.0079'	'FG-U'	'PW-0.0064'
128	'GB-0.0079'	'FG-U'	'PW-0.0095'
129	'GB-0.0079'	'FG-U'	'PW-0.0127'
130	'GB-0.0079'	'FG-U'	'PW-0.0159'
131	'GB-0.0079'	'FG-U'	'PW-0.0175'
132	'GB-0.0079'	'FG-U'	'OSB-0.0095'
133	'GB-0.0079'	'FG-U'	'OSB-0.0111'
134	'GB-0.0079'	'FG-U'	'OSB-0.0127'
135	'GB-0.0079'	'FG-U'	'OSB-0.0159'
136	'GB-0.0079'	'FG-U'	'OSB-0.0191'
137	'GB-0.0079'	'FG-K'	'GB-0.0064'
138	'GB-0.0079'	'FG-K'	'GB-0.0079'
139	'GB-0.0079'	'FG-K'	'GB-0.0095'
140	'GB-0.0079'	'FG-K'	'GB-0.0127'
141	'GB-0.0079'	'FG-K'	'GB-0.0159'
142	'GB-0.0079'	'FG-K'	'GB-0.0191'
143	'GB-0.0079'	'FG-K'	'GB-0.0254'
144	'GB-0.0079'	'FG-K'	'PW-0.0064'
145	'GB-0.0079'	'FG-K'	'PW-0.0095'
146	'GB-0.0079'	'FG-K'	'PW-0.0127'
147	'GB-0.0079'	'FG-K'	'PW-0.0159'
148	'GB-0.0079'	'FG-K'	'PW-0.0175'
149	'GB-0.0079'	'FG-K'	'OSB-0.0095'
150	'GB-0.0079'	'FG-K'	'OSB-0.0111'
151	'GB-0.0079'	'FG-K'	'OSB-0.0127'
152	'GB-0.0079'	'FG-K'	'OSB-0.0159'
153	'GB-0.0079'	'FG-K'	'OSB-0.0191'
154	'GB-0.0079'	'RW-B'	'GB-0.0064'
155	'GB-0.0079'	'RW-B'	'GB-0.0079'
156	'GB-0.0079'	'RW-B'	'GB-0.0095'
157	'GB-0.0079'	'RW-B'	'GB-0.0127'
158	'GB-0.0079'	'RW-B'	'GB-0.0159'
159	'GB-0.0079'	'RW-B'	'GB-0.0191'
160	'GB-0.0079'	'RW-B'	'GB-0.0254'
161	'GB-0.0079'	'RW-B'	'PW-0.0064'
162	'GB-0.0079'	'RW-B'	'PW-0.0095'
163	'GB-0.0079'	'RW-B'	'PW-0.0127'
164	'GB-0.0079'	'RW-B'	'PW-0.0159'
165	'GB-0.0079'	'RW-B'	'PW-0.0175'
166	'GB-0.0079'	'RW-B'	'OSB-0.0095'
167	'GB-0.0079'	'RW-B'	'OSB-0.0111'
168	'GB-0.0079'	'RW-B'	'OSB-0.0127'

169	'GB-0.0079'	'RW-B'	'OSB-0.0159'
170	'GB-0.0079'	'RW-B'	'OSB-0.0191'
171	'GB-0.0079'	'C-B'	'GB-0.0064'
172	'GB-0.0079'	'C-B'	'GB-0.0079'
173	'GB-0.0079'	'C-B'	'GB-0.0095'
174	'GB-0.0079'	'C-B'	'GB-0.0127'
175	'GB-0.0079'	'C-B'	'GB-0.0159'
176	'GB-0.0079'	'C-B'	'GB-0.0191'
177	'GB-0.0079'	'C-B'	'GB-0.0254'
178	'GB-0.0079'	'C-B'	'PW-0.0064'
179	'GB-0.0079'	'C-B'	'PW-0.0095'
180	'GB-0.0079'	'C-B'	'PW-0.0127'
181	'GB-0.0079'	'C-B'	'PW-0.0159'
182	'GB-0.0079'	'C-B'	'PW-0.0175'
183	'GB-0.0079'	'C-B'	'OSB-0.0095'
184	'GB-0.0079'	'C-B'	'OSB-0.0111'
185	'GB-0.0079'	'C-B'	'OSB-0.0127'
186	'GB-0.0079'	'C-B'	'OSB-0.0159'
187	'GB-0.0079'	'C-B'	'OSB-0.0191'
188	'GB-0.0079'	'SPF-OC'	'GB-0.0064'
189	'GB-0.0079'	'SPF-OC'	'GB-0.0079'
190	'GB-0.0079'	'SPF-OC'	'GB-0.0095'
191	'GB-0.0079'	'SPF-OC'	'GB-0.0127'
192	'GB-0.0079'	'SPF-OC'	'GB-0.0159'
193	'GB-0.0079'	'SPF-OC'	'GB-0.0191'
194	'GB-0.0079'	'SPF-OC'	'GB-0.0254'
195	'GB-0.0079'	'SPF-OC'	'PW-0.0064'
196	'GB-0.0079'	'SPF-OC'	'PW-0.0095'
197	'GB-0.0079'	'SPF-OC'	'PW-0.0127'
198	'GB-0.0079'	'SPF-OC'	'PW-0.0159'
199	'GB-0.0079'	'SPF-OC'	'PW-0.0175'
200	'GB-0.0079'	'SPF-OC'	'OSB-0.0095'
201	'GB-0.0079'	'SPF-OC'	'OSB-0.0111'
202	'GB-0.0079'	'SPF-OC'	'OSB-0.0127'
203	'GB-0.0079'	'SPF-OC'	'OSB-0.0159'
204	'GB-0.0079'	'SPF-OC'	'OSB-0.0191'
205	'GB-0.0079'	'SPF-CC'	'GB-0.0064'
206	'GB-0.0079'	'SPF-CC'	'GB-0.0079'
207	'GB-0.0079'	'SPF-CC'	'GB-0.0095'
208	'GB-0.0079'	'SPF-CC'	'GB-0.0127'
209	'GB-0.0079'	'SPF-CC'	'GB-0.0159'
210	'GB-0.0079'	'SPF-CC'	'GB-0.0191'
211	'GB-0.0079'	'SPF-CC'	'GB-0.0254'

212	'GB-0.0079'	'SPF-CC'	'PW-0.0064'
213	'GB-0.0079'	'SPF-CC'	'PW-0.0095'
214	'GB-0.0079'	'SPF-CC'	'PW-0.0127'
215	'GB-0.0079'	'SPF-CC'	'PW-0.0159'
216	'GB-0.0079'	'SPF-CC'	'PW-0.0175'
217	'GB-0.0079'	'SPF-CC'	'OSB-0.0095'
218	'GB-0.0079'	'SPF-CC'	'OSB-0.0111'
219	'GB-0.0079'	'SPF-CC'	'OSB-0.0127'
220	'GB-0.0079'	'SPF-CC'	'OSB-0.0159'
221	'GB-0.0079'	'SPF-CC'	'OSB-0.0191'
222	'GB-0.0079'	'XPS'	'GB-0.0064'
223	'GB-0.0079'	'XPS'	'GB-0.0079'
224	'GB-0.0079'	'XPS'	'GB-0.0095'
225	'GB-0.0079'	'XPS'	'GB-0.0127'
226	'GB-0.0079'	'XPS'	'GB-0.0159'
227	'GB-0.0079'	'XPS'	'GB-0.0191'
228	'GB-0.0079'	'XPS'	'GB-0.0254'
229	'GB-0.0079'	'XPS'	'PW-0.0064'
230	'GB-0.0079'	'XPS'	'PW-0.0095'
231	'GB-0.0079'	'XPS'	'PW-0.0127'
232	'GB-0.0079'	'XPS'	'PW-0.0159'
233	'GB-0.0079'	'XPS'	'PW-0.0175'
234	'GB-0.0079'	'XPS'	'OSB-0.0095'
235	'GB-0.0079'	'XPS'	'OSB-0.0111'
236	'GB-0.0079'	'XPS'	'OSB-0.0127'
237	'GB-0.0079'	'XPS'	'OSB-0.0159'
238	'GB-0.0079'	'XPS'	'OSB-0.0191'
239	'GB-0.0095'	'FG-U'	'GB-0.0064'
240	'GB-0.0095'	'FG-U'	'GB-0.0079'
241	'GB-0.0095'	'FG-U'	'GB-0.0095'
242	'GB-0.0095'	'FG-U'	'GB-0.0127'
243	'GB-0.0095'	'FG-U'	'GB-0.0159'
244	'GB-0.0095'	'FG-U'	'GB-0.0191'
245	'GB-0.0095'	'FG-U'	'GB-0.0254'
246	'GB-0.0095'	'FG-U'	'PW-0.0064'
247	'GB-0.0095'	'FG-U'	'PW-0.0095'
248	'GB-0.0095'	'FG-U'	'PW-0.0127'
249	'GB-0.0095'	'FG-U'	'PW-0.0159'
250	'GB-0.0095'	'FG-U'	'PW-0.0175'
251	'GB-0.0095'	'FG-U'	'OSB-0.0095'
252	'GB-0.0095'	'FG-U'	'OSB-0.0111'
253	'GB-0.0095'	'FG-U'	'OSB-0.0127'
254	'GB-0.0095'	'FG-U'	'OSB-0.0159'

255	'GB-0.0095'	'FG-U'	'OSB-0.0191'
256	'GB-0.0095'	'FG-K'	'GB-0.0064'
257	'GB-0.0095'	'FG-K'	'GB-0.0079'
258	'GB-0.0095'	'FG-K'	'GB-0.0095'
259	'GB-0.0095'	'FG-K'	'GB-0.0127'
260	'GB-0.0095'	'FG-K'	'GB-0.0159'
261	'GB-0.0095'	'FG-K'	'GB-0.0191'
262	'GB-0.0095'	'FG-K'	'GB-0.0254'
263	'GB-0.0095'	'FG-K'	'PW-0.0064'
264	'GB-0.0095'	'FG-K'	'PW-0.0095'
265	'GB-0.0095'	'FG-K'	'PW-0.0127'
266	'GB-0.0095'	'FG-K'	'PW-0.0159'
267	'GB-0.0095'	'FG-K'	'PW-0.0175'
268	'GB-0.0095'	'FG-K'	'OSB-0.0095'
269	'GB-0.0095'	'FG-K'	'OSB-0.0111'
270	'GB-0.0095'	'FG-K'	'OSB-0.0127'
271	'GB-0.0095'	'FG-K'	'OSB-0.0159'
272	'GB-0.0095'	'FG-K'	'OSB-0.0191'
273	'GB-0.0095'	'RW-B'	'GB-0.0064'
274	'GB-0.0095'	'RW-B'	'GB-0.0079'
275	'GB-0.0095'	'RW-B'	'GB-0.0095'
276	'GB-0.0095'	'RW-B'	'GB-0.0127'
277	'GB-0.0095'	'RW-B'	'GB-0.0159'
278	'GB-0.0095'	'RW-B'	'GB-0.0191'
279	'GB-0.0095'	'RW-B'	'GB-0.0254'
280	'GB-0.0095'	'RW-B'	'PW-0.0064'
281	'GB-0.0095'	'RW-B'	'PW-0.0095'
282	'GB-0.0095'	'RW-B'	'PW-0.0127'
283	'GB-0.0095'	'RW-B'	'PW-0.0159'
284	'GB-0.0095'	'RW-B'	'PW-0.0175'
285	'GB-0.0095'	'RW-B'	'OSB-0.0095'
286	'GB-0.0095'	'RW-B'	'OSB-0.0111'
287	'GB-0.0095'	'RW-B'	'OSB-0.0127'
288	'GB-0.0095'	'RW-B'	'OSB-0.0159'
289	'GB-0.0095'	'RW-B'	'OSB-0.0191'
290	'GB-0.0095'	'C-B'	'GB-0.0064'
291	'GB-0.0095'	'C-B'	'GB-0.0079'
292	'GB-0.0095'	'C-B'	'GB-0.0095'
293	'GB-0.0095'	'C-B'	'GB-0.0127'
294	'GB-0.0095'	'C-B'	'GB-0.0159'
295	'GB-0.0095'	'C-B'	'GB-0.0191'
296	'GB-0.0095'	'C-B'	'GB-0.0254'
297	'GB-0.0095'	'C-B'	'PW-0.0064'

298	'GB-0.0095'	'C-B'	'PW-0.0095'
299	'GB-0.0095'	'C-B'	'PW-0.0127'
300	'GB-0.0095'	'C-B'	'PW-0.0159'
301	'GB-0.0095'	'C-B'	'PW-0.0175'
302	'GB-0.0095'	'C-B'	'OSB-0.0095'
303	'GB-0.0095'	'C-B'	'OSB-0.0111'
304	'GB-0.0095'	'C-B'	'OSB-0.0127'
305	'GB-0.0095'	'C-B'	'OSB-0.0159'
306	'GB-0.0095'	'C-B'	'OSB-0.0191'
307	'GB-0.0095'	'SPF-OC'	'GB-0.0064'
308	'GB-0.0095'	'SPF-OC'	'GB-0.0079'
309	'GB-0.0095'	'SPF-OC'	'GB-0.0095'
310	'GB-0.0095'	'SPF-OC'	'GB-0.0127'
311	'GB-0.0095'	'SPF-OC'	'GB-0.0159'
312	'GB-0.0095'	'SPF-OC'	'GB-0.0191'
313	'GB-0.0095'	'SPF-OC'	'GB-0.0254'
314	'GB-0.0095'	'SPF-OC'	'PW-0.0064'
315	'GB-0.0095'	'SPF-OC'	'PW-0.0095'
316	'GB-0.0095'	'SPF-OC'	'PW-0.0127'
317	'GB-0.0095'	'SPF-OC'	'PW-0.0159'
318	'GB-0.0095'	'SPF-OC'	'PW-0.0175'
319	'GB-0.0095'	'SPF-OC'	'OSB-0.0095'
320	'GB-0.0095'	'SPF-OC'	'OSB-0.0111'
321	'GB-0.0095'	'SPF-OC'	'OSB-0.0127'
322	'GB-0.0095'	'SPF-OC'	'OSB-0.0159'
323	'GB-0.0095'	'SPF-OC'	'OSB-0.0191'
324	'GB-0.0095'	'SPF-CC'	'GB-0.0064'
325	'GB-0.0095'	'SPF-CC'	'GB-0.0079'
326	'GB-0.0095'	'SPF-CC'	'GB-0.0095'
327	'GB-0.0095'	'SPF-CC'	'GB-0.0127'
328	'GB-0.0095'	'SPF-CC'	'GB-0.0159'
329	'GB-0.0095'	'SPF-CC'	'GB-0.0191'
330	'GB-0.0095'	'SPF-CC'	'GB-0.0254'
331	'GB-0.0095'	'SPF-CC'	'PW-0.0064'
332	'GB-0.0095'	'SPF-CC'	'PW-0.0095'
333	'GB-0.0095'	'SPF-CC'	'PW-0.0127'
334	'GB-0.0095'	'SPF-CC'	'PW-0.0159'
335	'GB-0.0095'	'SPF-CC'	'PW-0.0175'
336	'GB-0.0095'	'SPF-CC'	'OSB-0.0095'
337	'GB-0.0095'	'SPF-CC'	'OSB-0.0111'
338	'GB-0.0095'	'SPF-CC'	'OSB-0.0127'
339	'GB-0.0095'	'SPF-CC'	'OSB-0.0159'
340	'GB-0.0095'	'SPF-CC'	'OSB-0.0191'

341	'GB-0.0095'	'XPS'	'GB-0.0064'
342	'GB-0.0095'	'XPS'	'GB-0.0079'
343	'GB-0.0095'	'XPS'	'GB-0.0095'
344	'GB-0.0095'	'XPS'	'GB-0.0127'
345	'GB-0.0095'	'XPS'	'GB-0.0159'
346	'GB-0.0095'	'XPS'	'GB-0.0191'
347	'GB-0.0095'	'XPS'	'GB-0.0254'
348	'GB-0.0095'	'XPS'	'PW-0.0064'
349	'GB-0.0095'	'XPS'	'PW-0.0095'
350	'GB-0.0095'	'XPS'	'PW-0.0127'
351	'GB-0.0095'	'XPS'	'PW-0.0159'
352	'GB-0.0095'	'XPS'	'PW-0.0175'
353	'GB-0.0095'	'XPS'	'OSB-0.0095'
354	'GB-0.0095'	'XPS'	'OSB-0.0111'
355	'GB-0.0095'	'XPS'	'OSB-0.0127'
356	'GB-0.0095'	'XPS'	'OSB-0.0159'
357	'GB-0.0095'	'XPS'	'OSB-0.0191'
358	'GB-0.0127'	'FG-U'	'GB-0.0064'
359	'GB-0.0127'	'FG-U'	'GB-0.0079'
360	'GB-0.0127'	'FG-U'	'GB-0.0095'
361	'GB-0.0127'	'FG-U'	'GB-0.0127'
362	'GB-0.0127'	'FG-U'	'GB-0.0159'
363	'GB-0.0127'	'FG-U'	'GB-0.0191'
364	'GB-0.0127'	'FG-U'	'GB-0.0254'
365	'GB-0.0127'	'FG-U'	'PW-0.0064'
366	'GB-0.0127'	'FG-U'	'PW-0.0095'
367	'GB-0.0127'	'FG-U'	'PW-0.0127'
368	'GB-0.0127'	'FG-U'	'PW-0.0159'
369	'GB-0.0127'	'FG-U'	'PW-0.0175'
370	'GB-0.0127'	'FG-U'	'OSB-0.0095'
371	'GB-0.0127'	'FG-U'	'OSB-0.0111'
372	'GB-0.0127'	'FG-U'	'OSB-0.0127'
373	'GB-0.0127'	'FG-U'	'OSB-0.0159'
374	'GB-0.0127'	'FG-U'	'OSB-0.0191'
375	'GB-0.0127'	'FG-K'	'GB-0.0064'
376	'GB-0.0127'	'FG-K'	'GB-0.0079'
377	'GB-0.0127'	'FG-K'	'GB-0.0095'
378	'GB-0.0127'	'FG-K'	'GB-0.0127'
379	'GB-0.0127'	'FG-K'	'GB-0.0159'
380	'GB-0.0127'	'FG-K'	'GB-0.0191'
381	'GB-0.0127'	'FG-K'	'GB-0.0254'
382	'GB-0.0127'	'FG-K'	'PW-0.0064'
383	'GB-0.0127'	'FG-K'	'PW-0.0095'

384	'GB-0.0127'	'FG-K'	'PW-0.0127'
385	'GB-0.0127'	'FG-K'	'PW-0.0159'
386	'GB-0.0127'	'FG-K'	'PW-0.0175'
387	'GB-0.0127'	'FG-K'	'OSB-0.0095'
388	'GB-0.0127'	'FG-K'	'OSB-0.0111'
389	'GB-0.0127'	'FG-K'	'OSB-0.0127'
390	'GB-0.0127'	'FG-K'	'OSB-0.0159'
391	'GB-0.0127'	'FG-K'	'OSB-0.0191'
392	'GB-0.0127'	'RW-B'	'GB-0.0064'
393	'GB-0.0127'	'RW-B'	'GB-0.0079'
394	'GB-0.0127'	'RW-B'	'GB-0.0095'
395	'GB-0.0127'	'RW-B'	'GB-0.0127'
396	'GB-0.0127'	'RW-B'	'GB-0.0159'
397	'GB-0.0127'	'RW-B'	'GB-0.0191'
398	'GB-0.0127'	'RW-B'	'GB-0.0254'
399	'GB-0.0127'	'RW-B'	'PW-0.0064'
400	'GB-0.0127'	'RW-B'	'PW-0.0095'
401	'GB-0.0127'	'RW-B'	'PW-0.0127'
402	'GB-0.0127'	'RW-B'	'PW-0.0159'
403	'GB-0.0127'	'RW-B'	'PW-0.0175'
404	'GB-0.0127'	'RW-B'	'OSB-0.0095'
405	'GB-0.0127'	'RW-B'	'OSB-0.0111'
406	'GB-0.0127'	'RW-B'	'OSB-0.0127'
407	'GB-0.0127'	'RW-B'	'OSB-0.0159'
408	'GB-0.0127'	'RW-B'	'OSB-0.0191'
409	'GB-0.0127'	'C-B'	'GB-0.0064'
410	'GB-0.0127'	'C-B'	'GB-0.0079'
411	'GB-0.0127'	'C-B'	'GB-0.0095'
412	'GB-0.0127'	'C-B'	'GB-0.0127'
413	'GB-0.0127'	'C-B'	'GB-0.0159'
414	'GB-0.0127'	'C-B'	'GB-0.0191'
415	'GB-0.0127'	'C-B'	'GB-0.0254'
416	'GB-0.0127'	'C-B'	'PW-0.0064'
417	'GB-0.0127'	'C-B'	'PW-0.0095'
418	'GB-0.0127'	'C-B'	'PW-0.0127'
419	'GB-0.0127'	'C-B'	'PW-0.0159'
420	'GB-0.0127'	'C-B'	'PW-0.0175'
421	'GB-0.0127'	'C-B'	'OSB-0.0095'
422	'GB-0.0127'	'C-B'	'OSB-0.0111'
423	'GB-0.0127'	'C-B'	'OSB-0.0127'
424	'GB-0.0127'	'C-B'	'OSB-0.0159'
425	'GB-0.0127'	'C-B'	'OSB-0.0191'
426	'GB-0.0127'	'SPF-OC'	'GB-0.0064'

427	'GB-0.0127'	'SPF-OC'	'GB-0.0079'
428	'GB-0.0127'	'SPF-OC'	'GB-0.0095'
429	'GB-0.0127'	'SPF-OC'	'GB-0.0127'
430	'GB-0.0127'	'SPF-OC'	'GB-0.0159'
431	'GB-0.0127'	'SPF-OC'	'GB-0.0191'
432	'GB-0.0127'	'SPF-OC'	'GB-0.0254'
433	'GB-0.0127'	'SPF-OC'	'PW-0.0064'
434	'GB-0.0127'	'SPF-OC'	'PW-0.0095'
435	'GB-0.0127'	'SPF-OC'	'PW-0.0127'
436	'GB-0.0127'	'SPF-OC'	'PW-0.0159'
437	'GB-0.0127'	'SPF-OC'	'PW-0.0175'
438	'GB-0.0127'	'SPF-OC'	'OSB-0.0095'
439	'GB-0.0127'	'SPF-OC'	'OSB-0.0111'
440	'GB-0.0127'	'SPF-OC'	'OSB-0.0127'
441	'GB-0.0127'	'SPF-OC'	'OSB-0.0159'
442	'GB-0.0127'	'SPF-OC'	'OSB-0.0191'
443	'GB-0.0127'	'SPF-CC'	'GB-0.0064'
444	'GB-0.0127'	'SPF-CC'	'GB-0.0079'
445	'GB-0.0127'	'SPF-CC'	'GB-0.0095'
446	'GB-0.0127'	'SPF-CC'	'GB-0.0127'
447	'GB-0.0127'	'SPF-CC'	'GB-0.0159'
448	'GB-0.0127'	'SPF-CC'	'GB-0.0191'
449	'GB-0.0127'	'SPF-CC'	'GB-0.0254'
450	'GB-0.0127'	'SPF-CC'	'PW-0.0064'
451	'GB-0.0127'	'SPF-CC'	'PW-0.0095'
452	'GB-0.0127'	'SPF-CC'	'PW-0.0127'
453	'GB-0.0127'	'SPF-CC'	'PW-0.0159'
454	'GB-0.0127'	'SPF-CC'	'PW-0.0175'
455	'GB-0.0127'	'SPF-CC'	'OSB-0.0095'
456	'GB-0.0127'	'SPF-CC'	'OSB-0.0111'
457	'GB-0.0127'	'SPF-CC'	'OSB-0.0127'
458	'GB-0.0127'	'SPF-CC'	'OSB-0.0159'
459	'GB-0.0127'	'SPF-CC'	'OSB-0.0191'
460	'GB-0.0127'	'XPS'	'GB-0.0064'
461	'GB-0.0127'	'XPS'	'GB-0.0079'
462	'GB-0.0127'	'XPS'	'GB-0.0095'
463	'GB-0.0127'	'XPS'	'GB-0.0127'
464	'GB-0.0127'	'XPS'	'GB-0.0159'
465	'GB-0.0127'	'XPS'	'GB-0.0191'
466	'GB-0.0127'	'XPS'	'GB-0.0254'
467	'GB-0.0127'	'XPS'	'PW-0.0064'
468	'GB-0.0127'	'XPS'	'PW-0.0095'
469	'GB-0.0127'	'XPS'	'PW-0.0127'

470	'GB-0.0127'	'XPS'	'PW-0.0159'
471	'GB-0.0127'	'XPS'	'PW-0.0175'
472	'GB-0.0127'	'XPS'	'OSB-0.0095'
473	'GB-0.0127'	'XPS'	'OSB-0.0111'
474	'GB-0.0127'	'XPS'	'OSB-0.0127'
475	'GB-0.0127'	'XPS'	'OSB-0.0159'
476	'GB-0.0127'	'XPS'	'OSB-0.0191'
477	'GB-0.0159'	'FG-U'	'GB-0.0064'
478	'GB-0.0159'	'FG-U'	'GB-0.0079'
479	'GB-0.0159'	'FG-U'	'GB-0.0095'
480	'GB-0.0159'	'FG-U'	'GB-0.0127'
481	'GB-0.0159'	'FG-U'	'GB-0.0159'
482	'GB-0.0159'	'FG-U'	'GB-0.0191'
483	'GB-0.0159'	'FG-U'	'GB-0.0254'
484	'GB-0.0159'	'FG-U'	'PW-0.0064'
485	'GB-0.0159'	'FG-U'	'PW-0.0095'
486	'GB-0.0159'	'FG-U'	'PW-0.0127'
487	'GB-0.0159'	'FG-U'	'PW-0.0159'
488	'GB-0.0159'	'FG-U'	'PW-0.0175'
489	'GB-0.0159'	'FG-U'	'OSB-0.0095'
490	'GB-0.0159'	'FG-U'	'OSB-0.0111'
491	'GB-0.0159'	'FG-U'	'OSB-0.0127'
492	'GB-0.0159'	'FG-U'	'OSB-0.0159'
493	'GB-0.0159'	'FG-U'	'OSB-0.0191'
494	'GB-0.0159'	'FG-K'	'GB-0.0064'
495	'GB-0.0159'	'FG-K'	'GB-0.0079'
496	'GB-0.0159'	'FG-K'	'GB-0.0095'
497	'GB-0.0159'	'FG-K'	'GB-0.0127'
498	'GB-0.0159'	'FG-K'	'GB-0.0159'
499	'GB-0.0159'	'FG-K'	'GB-0.0191'
500	'GB-0.0159'	'FG-K'	'GB-0.0254'
501	'GB-0.0159'	'FG-K'	'PW-0.0064'
502	'GB-0.0159'	'FG-K'	'PW-0.0095'
503	'GB-0.0159'	'FG-K'	'PW-0.0127'
504	'GB-0.0159'	'FG-K'	'PW-0.0159'
505	'GB-0.0159'	'FG-K'	'PW-0.0175'
506	'GB-0.0159'	'FG-K'	'OSB-0.0095'
507	'GB-0.0159'	'FG-K'	'OSB-0.0111'
508	'GB-0.0159'	'FG-K'	'OSB-0.0127'
509	'GB-0.0159'	'FG-K'	'OSB-0.0159'
510	'GB-0.0159'	'FG-K'	'OSB-0.0191'
511	'GB-0.0159'	'RW-B'	'GB-0.0064'
512	'GB-0.0159'	'RW-B'	'GB-0.0079'

513	'GB-0.0159'	'RW-B'	'GB-0.0095'
514	'GB-0.0159'	'RW-B'	'GB-0.0127'
515	'GB-0.0159'	'RW-B'	'GB-0.0159'
516	'GB-0.0159'	'RW-B'	'GB-0.0191'
517	'GB-0.0159'	'RW-B'	'GB-0.0254'
518	'GB-0.0159'	'RW-B'	'PW-0.0064'
519	'GB-0.0159'	'RW-B'	'PW-0.0095'
520	'GB-0.0159'	'RW-B'	'PW-0.0127'
521	'GB-0.0159'	'RW-B'	'PW-0.0159'
522	'GB-0.0159'	'RW-B'	'PW-0.0175'
523	'GB-0.0159'	'RW-B'	'OSB-0.0095'
524	'GB-0.0159'	'RW-B'	'OSB-0.0111'
525	'GB-0.0159'	'RW-B'	'OSB-0.0127'
526	'GB-0.0159'	'RW-B'	'OSB-0.0159'
527	'GB-0.0159'	'RW-B'	'OSB-0.0191'
528	'GB-0.0159'	'C-B'	'GB-0.0064'
529	'GB-0.0159'	'C-B'	'GB-0.0079'
530	'GB-0.0159'	'C-B'	'GB-0.0095'
531	'GB-0.0159'	'C-B'	'GB-0.0127'
532	'GB-0.0159'	'C-B'	'GB-0.0159'
533	'GB-0.0159'	'C-B'	'GB-0.0191'
534	'GB-0.0159'	'C-B'	'GB-0.0254'
535	'GB-0.0159'	'C-B'	'PW-0.0064'
536	'GB-0.0159'	'C-B'	'PW-0.0095'
537	'GB-0.0159'	'C-B'	'PW-0.0127'
538	'GB-0.0159'	'C-B'	'PW-0.0159'
539	'GB-0.0159'	'C-B'	'PW-0.0175'
540	'GB-0.0159'	'C-B'	'OSB-0.0095'
541	'GB-0.0159'	'C-B'	'OSB-0.0111'
542	'GB-0.0159'	'C-B'	'OSB-0.0127'
543	'GB-0.0159'	'C-B'	'OSB-0.0159'
544	'GB-0.0159'	'C-B'	'OSB-0.0191'
545	'GB-0.0159'	'SPF-OC'	'GB-0.0064'
546	'GB-0.0159'	'SPF-OC'	'GB-0.0079'
547	'GB-0.0159'	'SPF-OC'	'GB-0.0095'
548	'GB-0.0159'	'SPF-OC'	'GB-0.0127'
549	'GB-0.0159'	'SPF-OC'	'GB-0.0159'
550	'GB-0.0159'	'SPF-OC'	'GB-0.0191'
551	'GB-0.0159'	'SPF-OC'	'GB-0.0254'
552	'GB-0.0159'	'SPF-OC'	'PW-0.0064'
553	'GB-0.0159'	'SPF-OC'	'PW-0.0095'
554	'GB-0.0159'	'SPF-OC'	'PW-0.0127'
555	'GB-0.0159'	'SPF-OC'	'PW-0.0159'

556	'GB-0.0159'	'SPF-OC'	'PW-0.0175'
557	'GB-0.0159'	'SPF-OC'	'OSB-0.0095'
558	'GB-0.0159'	'SPF-OC'	'OSB-0.0111'
559	'GB-0.0159'	'SPF-OC'	'OSB-0.0127'
560	'GB-0.0159'	'SPF-OC'	'OSB-0.0159'
561	'GB-0.0159'	'SPF-OC'	'OSB-0.0191'
562	'GB-0.0159'	'SPF-CC'	'GB-0.0064'
563	'GB-0.0159'	'SPF-CC'	'GB-0.0079'
564	'GB-0.0159'	'SPF-CC'	'GB-0.0095'
565	'GB-0.0159'	'SPF-CC'	'GB-0.0127'
566	'GB-0.0159'	'SPF-CC'	'GB-0.0159'
567	'GB-0.0159'	'SPF-CC'	'GB-0.0191'
568	'GB-0.0159'	'SPF-CC'	'GB-0.0254'
569	'GB-0.0159'	'SPF-CC'	'PW-0.0064'
570	'GB-0.0159'	'SPF-CC'	'PW-0.0095'
571	'GB-0.0159'	'SPF-CC'	'PW-0.0127'
572	'GB-0.0159'	'SPF-CC'	'PW-0.0159'
573	'GB-0.0159'	'SPF-CC'	'PW-0.0175'
574	'GB-0.0159'	'SPF-CC'	'OSB-0.0095'
575	'GB-0.0159'	'SPF-CC'	'OSB-0.0111'
576	'GB-0.0159'	'SPF-CC'	'OSB-0.0127'
577	'GB-0.0159'	'SPF-CC'	'OSB-0.0159'
578	'GB-0.0159'	'SPF-CC'	'OSB-0.0191'
579	'GB-0.0159'	'XPS'	'GB-0.0064'
580	'GB-0.0159'	'XPS'	'GB-0.0079'
581	'GB-0.0159'	'XPS'	'GB-0.0095'
582	'GB-0.0159'	'XPS'	'GB-0.0127'
583	'GB-0.0159'	'XPS'	'GB-0.0159'
584	'GB-0.0159'	'XPS'	'GB-0.0191'
585	'GB-0.0159'	'XPS'	'GB-0.0254'
586	'GB-0.0159'	'XPS'	'PW-0.0064'
587	'GB-0.0159'	'XPS'	'PW-0.0095'
588	'GB-0.0159'	'XPS'	'PW-0.0127'
589	'GB-0.0159'	'XPS'	'PW-0.0159'
590	'GB-0.0159'	'XPS'	'PW-0.0175'
591	'GB-0.0159'	'XPS'	'OSB-0.0095'
592	'GB-0.0159'	'XPS'	'OSB-0.0111'
593	'GB-0.0159'	'XPS'	'OSB-0.0127'
594	'GB-0.0159'	'XPS'	'OSB-0.0159'
595	'GB-0.0159'	'XPS'	'OSB-0.0191'
596	'GB-0.0191'	'FG-U'	'GB-0.0064'
597	'GB-0.0191'	'FG-U'	'GB-0.0079'
598	'GB-0.0191'	'FG-U'	'GB-0.0095'

599	'GB-0.0191'	'FG-U'	'GB-0.0127'
600	'GB-0.0191'	'FG-U'	'GB-0.0159'
601	'GB-0.0191'	'FG-U'	'GB-0.0191'
602	'GB-0.0191'	'FG-U'	'GB-0.0254'
603	'GB-0.0191'	'FG-U'	'PW-0.0064'
604	'GB-0.0191'	'FG-U'	'PW-0.0095'
605	'GB-0.0191'	'FG-U'	'PW-0.0127'
606	'GB-0.0191'	'FG-U'	'PW-0.0159'
607	'GB-0.0191'	'FG-U'	'PW-0.0175'
608	'GB-0.0191'	'FG-U'	'OSB-0.0095'
609	'GB-0.0191'	'FG-U'	'OSB-0.0111'
610	'GB-0.0191'	'FG-U'	'OSB-0.0127'
611	'GB-0.0191'	'FG-U'	'OSB-0.0159'
612	'GB-0.0191'	'FG-U'	'OSB-0.0191'
613	'GB-0.0191'	'FG-K'	'GB-0.0064'
614	'GB-0.0191'	'FG-K'	'GB-0.0079'
615	'GB-0.0191'	'FG-K'	'GB-0.0095'
616	'GB-0.0191'	'FG-K'	'GB-0.0127'
617	'GB-0.0191'	'FG-K'	'GB-0.0159'
618	'GB-0.0191'	'FG-K'	'GB-0.0191'
619	'GB-0.0191'	'FG-K'	'GB-0.0254'
620	'GB-0.0191'	'FG-K'	'PW-0.0064'
621	'GB-0.0191'	'FG-K'	'PW-0.0095'
622	'GB-0.0191'	'FG-K'	'PW-0.0127'
623	'GB-0.0191'	'FG-K'	'PW-0.0159'
624	'GB-0.0191'	'FG-K'	'PW-0.0175'
625	'GB-0.0191'	'FG-K'	'OSB-0.0095'
626	'GB-0.0191'	'FG-K'	'OSB-0.0111'
627	'GB-0.0191'	'FG-K'	'OSB-0.0127'
628	'GB-0.0191'	'FG-K'	'OSB-0.0159'
629	'GB-0.0191'	'FG-K'	'OSB-0.0191'
630	'GB-0.0191'	'RW-B'	'GB-0.0064'
631	'GB-0.0191'	'RW-B'	'GB-0.0079'
632	'GB-0.0191'	'RW-B'	'GB-0.0095'
633	'GB-0.0191'	'RW-B'	'GB-0.0127'
634	'GB-0.0191'	'RW-B'	'GB-0.0159'
635	'GB-0.0191'	'RW-B'	'GB-0.0191'
636	'GB-0.0191'	'RW-B'	'GB-0.0254'
637	'GB-0.0191'	'RW-B'	'PW-0.0064'
638	'GB-0.0191'	'RW-B'	'PW-0.0095'
639	'GB-0.0191'	'RW-B'	'PW-0.0127'
640	'GB-0.0191'	'RW-B'	'PW-0.0159'
641	'GB-0.0191'	'RW-B'	'PW-0.0175'

642	'GB-0.0191'	'RW-B'	'OSB-0.0095'
643	'GB-0.0191'	'RW-B'	'OSB-0.0111'
644	'GB-0.0191'	'RW-B'	'OSB-0.0127'
645	'GB-0.0191'	'RW-B'	'OSB-0.0159'
646	'GB-0.0191'	'RW-B'	'OSB-0.0191'
647	'GB-0.0191'	'C-B'	'GB-0.0064'
648	'GB-0.0191'	'C-B'	'GB-0.0079'
649	'GB-0.0191'	'C-B'	'GB-0.0095'
650	'GB-0.0191'	'C-B'	'GB-0.0127'
651	'GB-0.0191'	'C-B'	'GB-0.0159'
652	'GB-0.0191'	'C-B'	'GB-0.0191'
653	'GB-0.0191'	'C-B'	'GB-0.0254'
654	'GB-0.0191'	'C-B'	'PW-0.0064'
655	'GB-0.0191'	'C-B'	'PW-0.0095'
656	'GB-0.0191'	'C-B'	'PW-0.0127'
657	'GB-0.0191'	'C-B'	'PW-0.0159'
658	'GB-0.0191'	'C-B'	'PW-0.0175'
659	'GB-0.0191'	'C-B'	'OSB-0.0095'
660	'GB-0.0191'	'C-B'	'OSB-0.0111'
661	'GB-0.0191'	'C-B'	'OSB-0.0127'
662	'GB-0.0191'	'C-B'	'OSB-0.0159'
663	'GB-0.0191'	'C-B'	'OSB-0.0191'
664	'GB-0.0191'	'SPF-OC'	'GB-0.0064'
665	'GB-0.0191'	'SPF-OC'	'GB-0.0079'
666	'GB-0.0191'	'SPF-OC'	'GB-0.0095'
667	'GB-0.0191'	'SPF-OC'	'GB-0.0127'
668	'GB-0.0191'	'SPF-OC'	'GB-0.0159'
669	'GB-0.0191'	'SPF-OC'	'GB-0.0191'
670	'GB-0.0191'	'SPF-OC'	'GB-0.0254'
671	'GB-0.0191'	'SPF-OC'	'PW-0.0064'
672	'GB-0.0191'	'SPF-OC'	'PW-0.0095'
673	'GB-0.0191'	'SPF-OC'	'PW-0.0127'
674	'GB-0.0191'	'SPF-OC'	'PW-0.0159'
675	'GB-0.0191'	'SPF-OC'	'PW-0.0175'
676	'GB-0.0191'	'SPF-OC'	'OSB-0.0095'
677	'GB-0.0191'	'SPF-OC'	'OSB-0.0111'
678	'GB-0.0191'	'SPF-OC'	'OSB-0.0127'
679	'GB-0.0191'	'SPF-OC'	'OSB-0.0159'
680	'GB-0.0191'	'SPF-OC'	'OSB-0.0191'
681	'GB-0.0191'	'SPF-CC'	'GB-0.0064'
682	'GB-0.0191'	'SPF-CC'	'GB-0.0079'
683	'GB-0.0191'	'SPF-CC'	'GB-0.0095'
684	'GB-0.0191'	'SPF-CC'	'GB-0.0127'

685	'GB-0.0191'	'SPF-CC'	'GB-0.0159'
686	'GB-0.0191'	'SPF-CC'	'GB-0.0191'
687	'GB-0.0191'	'SPF-CC'	'GB-0.0254'
688	'GB-0.0191'	'SPF-CC'	'PW-0.0064'
689	'GB-0.0191'	'SPF-CC'	'PW-0.0095'
690	'GB-0.0191'	'SPF-CC'	'PW-0.0127'
691	'GB-0.0191'	'SPF-CC'	'PW-0.0159'
692	'GB-0.0191'	'SPF-CC'	'PW-0.0175'
693	'GB-0.0191'	'SPF-CC'	'OSB-0.0095'
694	'GB-0.0191'	'SPF-CC'	'OSB-0.0111'
695	'GB-0.0191'	'SPF-CC'	'OSB-0.0127'
696	'GB-0.0191'	'SPF-CC'	'OSB-0.0159'
697	'GB-0.0191'	'SPF-CC'	'OSB-0.0191'
698	'GB-0.0191'	'XPS'	'GB-0.0064'
699	'GB-0.0191'	'XPS'	'GB-0.0079'
700	'GB-0.0191'	'XPS'	'GB-0.0095'
701	'GB-0.0191'	'XPS'	'GB-0.0127'
702	'GB-0.0191'	'XPS'	'GB-0.0159'
703	'GB-0.0191'	'XPS'	'GB-0.0191'
704	'GB-0.0191'	'XPS'	'GB-0.0254'
705	'GB-0.0191'	'XPS'	'PW-0.0064'
706	'GB-0.0191'	'XPS'	'PW-0.0095'
707	'GB-0.0191'	'XPS'	'PW-0.0127'
708	'GB-0.0191'	'XPS'	'PW-0.0159'
709	'GB-0.0191'	'XPS'	'PW-0.0175'
710	'GB-0.0191'	'XPS'	'OSB-0.0095'
711	'GB-0.0191'	'XPS'	'OSB-0.0111'
712	'GB-0.0191'	'XPS'	'OSB-0.0127'
713	'GB-0.0191'	'XPS'	'OSB-0.0159'
714	'GB-0.0191'	'XPS'	'OSB-0.0191'
715	'GB-0.0254'	'FG-U'	'GB-0.0064'
716	'GB-0.0254'	'FG-U'	'GB-0.0079'
717	'GB-0.0254'	'FG-U'	'GB-0.0095'
718	'GB-0.0254'	'FG-U'	'GB-0.0127'
719	'GB-0.0254'	'FG-U'	'GB-0.0159'
720	'GB-0.0254'	'FG-U'	'GB-0.0191'
721	'GB-0.0254'	'FG-U'	'GB-0.0254'
722	'GB-0.0254'	'FG-U'	'PW-0.0064'
723	'GB-0.0254'	'FG-U'	'PW-0.0095'
724	'GB-0.0254'	'FG-U'	'PW-0.0127'
725	'GB-0.0254'	'FG-U'	'PW-0.0159'
726	'GB-0.0254'	'FG-U'	'PW-0.0175'
727	'GB-0.0254'	'FG-U'	'OSB-0.0095'

728	'GB-0.0254'	'FG-U'	'OSB-0.0111'
729	'GB-0.0254'	'FG-U'	'OSB-0.0127'
730	'GB-0.0254'	'FG-U'	'OSB-0.0159'
731	'GB-0.0254'	'FG-U'	'OSB-0.0191'
732	'GB-0.0254'	'FG-K'	'GB-0.0064'
733	'GB-0.0254'	'FG-K'	'GB-0.0079'
734	'GB-0.0254'	'FG-K'	'GB-0.0095'
735	'GB-0.0254'	'FG-K'	'GB-0.0127'
736	'GB-0.0254'	'FG-K'	'GB-0.0159'
737	'GB-0.0254'	'FG-K'	'GB-0.0191'
738	'GB-0.0254'	'FG-K'	'GB-0.0254'
739	'GB-0.0254'	'FG-K'	'PW-0.0064'
740	'GB-0.0254'	'FG-K'	'PW-0.0095'
741	'GB-0.0254'	'FG-K'	'PW-0.0127'
742	'GB-0.0254'	'FG-K'	'PW-0.0159'
743	'GB-0.0254'	'FG-K'	'PW-0.0175'
744	'GB-0.0254'	'FG-K'	'OSB-0.0095'
745	'GB-0.0254'	'FG-K'	'OSB-0.0111'
746	'GB-0.0254'	'FG-K'	'OSB-0.0127'
747	'GB-0.0254'	'FG-K'	'OSB-0.0159'
748	'GB-0.0254'	'FG-K'	'OSB-0.0191'
749	'GB-0.0254'	'RW-B'	'GB-0.0064'
750	'GB-0.0254'	'RW-B'	'GB-0.0079'
751	'GB-0.0254'	'RW-B'	'GB-0.0095'
752	'GB-0.0254'	'RW-B'	'GB-0.0127'
753	'GB-0.0254'	'RW-B'	'GB-0.0159'
754	'GB-0.0254'	'RW-B'	'GB-0.0191'
755	'GB-0.0254'	'RW-B'	'GB-0.0254'
756	'GB-0.0254'	'RW-B'	'PW-0.0064'
757	'GB-0.0254'	'RW-B'	'PW-0.0095'
758	'GB-0.0254'	'RW-B'	'PW-0.0127'
759	'GB-0.0254'	'RW-B'	'PW-0.0159'
760	'GB-0.0254'	'RW-B'	'PW-0.0175'
761	'GB-0.0254'	'RW-B'	'OSB-0.0095'
762	'GB-0.0254'	'RW-B'	'OSB-0.0111'
763	'GB-0.0254'	'RW-B'	'OSB-0.0127'
764	'GB-0.0254'	'RW-B'	'OSB-0.0159'
765	'GB-0.0254'	'RW-B'	'OSB-0.0191'
766	'GB-0.0254'	'C-B'	'GB-0.0064'
767	'GB-0.0254'	'C-B'	'GB-0.0079'
768	'GB-0.0254'	'C-B'	'GB-0.0095'
769	'GB-0.0254'	'C-B'	'GB-0.0127'
770	'GB-0.0254'	'C-B'	'GB-0.0159'

771	'GB-0.0254'	'C-B'	'GB-0.0191'
772	'GB-0.0254'	'C-B'	'GB-0.0254'
773	'GB-0.0254'	'C-B'	'PW-0.0064'
774	'GB-0.0254'	'C-B'	'PW-0.0095'
775	'GB-0.0254'	'C-B'	'PW-0.0127'
776	'GB-0.0254'	'C-B'	'PW-0.0159'
777	'GB-0.0254'	'C-B'	'PW-0.0175'
778	'GB-0.0254'	'C-B'	'OSB-0.0095'
779	'GB-0.0254'	'C-B'	'OSB-0.0111'
780	'GB-0.0254'	'C-B'	'OSB-0.0127'
781	'GB-0.0254'	'C-B'	'OSB-0.0159'
782	'GB-0.0254'	'C-B'	'OSB-0.0191'
783	'GB-0.0254'	'SPF-OC'	'GB-0.0064'
784	'GB-0.0254'	'SPF-OC'	'GB-0.0079'
785	'GB-0.0254'	'SPF-OC'	'GB-0.0095'
786	'GB-0.0254'	'SPF-OC'	'GB-0.0127'
787	'GB-0.0254'	'SPF-OC'	'GB-0.0159'
788	'GB-0.0254'	'SPF-OC'	'GB-0.0191'
789	'GB-0.0254'	'SPF-OC'	'GB-0.0254'
790	'GB-0.0254'	'SPF-OC'	'PW-0.0064'
791	'GB-0.0254'	'SPF-OC'	'PW-0.0095'
792	'GB-0.0254'	'SPF-OC'	'PW-0.0127'
793	'GB-0.0254'	'SPF-OC'	'PW-0.0159'
794	'GB-0.0254'	'SPF-OC'	'PW-0.0175'
795	'GB-0.0254'	'SPF-OC'	'OSB-0.0095'
796	'GB-0.0254'	'SPF-OC'	'OSB-0.0111'
797	'GB-0.0254'	'SPF-OC'	'OSB-0.0127'
798	'GB-0.0254'	'SPF-OC'	'OSB-0.0159'
799	'GB-0.0254'	'SPF-OC'	'OSB-0.0191'
800	'GB-0.0254'	'SPF-CC'	'GB-0.0064'
801	'GB-0.0254'	'SPF-CC'	'GB-0.0079'
802	'GB-0.0254'	'SPF-CC'	'GB-0.0095'
803	'GB-0.0254'	'SPF-CC'	'GB-0.0127'
804	'GB-0.0254'	'SPF-CC'	'GB-0.0159'
805	'GB-0.0254'	'SPF-CC'	'GB-0.0191'
806	'GB-0.0254'	'SPF-CC'	'GB-0.0254'
807	'GB-0.0254'	'SPF-CC'	'PW-0.0064'
808	'GB-0.0254'	'SPF-CC'	'PW-0.0095'
809	'GB-0.0254'	'SPF-CC'	'PW-0.0127'
810	'GB-0.0254'	'SPF-CC'	'PW-0.0159'
811	'GB-0.0254'	'SPF-CC'	'PW-0.0175'
812	'GB-0.0254'	'SPF-CC'	'OSB-0.0095'
813	'GB-0.0254'	'SPF-CC'	'OSB-0.0111'

814	'GB-0.0254'	'SPF-CC'	'OSB-0.0127'
815	'GB-0.0254'	'SPF-CC'	'OSB-0.0159'
816	'GB-0.0254'	'SPF-CC'	'OSB-0.0191'
817	'GB-0.0254'	'XPS'	'GB-0.0064'
818	'GB-0.0254'	'XPS'	'GB-0.0079'
819	'GB-0.0254'	'XPS'	'GB-0.0095'
820	'GB-0.0254'	'XPS'	'GB-0.0127'
821	'GB-0.0254'	'XPS'	'GB-0.0159'
822	'GB-0.0254'	'XPS'	'GB-0.0191'
823	'GB-0.0254'	'XPS'	'GB-0.0254'
824	'GB-0.0254'	'XPS'	'PW-0.0064'
825	'GB-0.0254'	'XPS'	'PW-0.0095'
826	'GB-0.0254'	'XPS'	'PW-0.0127'
827	'GB-0.0254'	'XPS'	'PW-0.0159'
828	'GB-0.0254'	'XPS'	'PW-0.0175'
829	'GB-0.0254'	'XPS'	'OSB-0.0095'
830	'GB-0.0254'	'XPS'	'OSB-0.0111'
831	'GB-0.0254'	'XPS'	'OSB-0.0127'
832	'GB-0.0254'	'XPS'	'OSB-0.0159'
833	'GB-0.0254'	'XPS'	'OSB-0.0191'
834	'PW-0.0064'	'FG-U'	'GB-0.0064'
835	'PW-0.0064'	'FG-U'	'GB-0.0079'
836	'PW-0.0064'	'FG-U'	'GB-0.0095'
837	'PW-0.0064'	'FG-U'	'GB-0.0127'
838	'PW-0.0064'	'FG-U'	'GB-0.0159'
839	'PW-0.0064'	'FG-U'	'GB-0.0191'
840	'PW-0.0064'	'FG-U'	'GB-0.0254'
841	'PW-0.0064'	'FG-U'	'PW-0.0064'
842	'PW-0.0064'	'FG-U'	'PW-0.0095'
843	'PW-0.0064'	'FG-U'	'PW-0.0127'
844	'PW-0.0064'	'FG-U'	'PW-0.0159'
845	'PW-0.0064'	'FG-U'	'PW-0.0175'
846	'PW-0.0064'	'FG-U'	'OSB-0.0095'
847	'PW-0.0064'	'FG-U'	'OSB-0.0111'
848	'PW-0.0064'	'FG-U'	'OSB-0.0127'
849	'PW-0.0064'	'FG-U'	'OSB-0.0159'
850	'PW-0.0064'	'FG-U'	'OSB-0.0191'
851	'PW-0.0064'	'FG-K'	'GB-0.0064'
852	'PW-0.0064'	'FG-K'	'GB-0.0079'
853	'PW-0.0064'	'FG-K'	'GB-0.0095'
854	'PW-0.0064'	'FG-K'	'GB-0.0127'
855	'PW-0.0064'	'FG-K'	'GB-0.0159'
856	'PW-0.0064'	'FG-K'	'GB-0.0191'

857	'PW-0.0064'	'FG-K'	'GB-0.0254'
858	'PW-0.0064'	'FG-K'	'PW-0.0064'
859	'PW-0.0064'	'FG-K'	'PW-0.0095'
860	'PW-0.0064'	'FG-K'	'PW-0.0127'
861	'PW-0.0064'	'FG-K'	'PW-0.0159'
862	'PW-0.0064'	'FG-K'	'PW-0.0175'
863	'PW-0.0064'	'FG-K'	'OSB-0.0095'
864	'PW-0.0064'	'FG-K'	'OSB-0.0111'
865	'PW-0.0064'	'FG-K'	'OSB-0.0127'
866	'PW-0.0064'	'FG-K'	'OSB-0.0159'
867	'PW-0.0064'	'FG-K'	'OSB-0.0191'
868	'PW-0.0064'	'RW-B'	'GB-0.0064'
869	'PW-0.0064'	'RW-B'	'GB-0.0079'
870	'PW-0.0064'	'RW-B'	'GB-0.0095'
871	'PW-0.0064'	'RW-B'	'GB-0.0127'
872	'PW-0.0064'	'RW-B'	'GB-0.0159'
873	'PW-0.0064'	'RW-B'	'GB-0.0191'
874	'PW-0.0064'	'RW-B'	'GB-0.0254'
875	'PW-0.0064'	'RW-B'	'PW-0.0064'
876	'PW-0.0064'	'RW-B'	'PW-0.0095'
877	'PW-0.0064'	'RW-B'	'PW-0.0127'
878	'PW-0.0064'	'RW-B'	'PW-0.0159'
879	'PW-0.0064'	'RW-B'	'PW-0.0175'
880	'PW-0.0064'	'RW-B'	'OSB-0.0095'
881	'PW-0.0064'	'RW-B'	'OSB-0.0111'
882	'PW-0.0064'	'RW-B'	'OSB-0.0127'
883	'PW-0.0064'	'RW-B'	'OSB-0.0159'
884	'PW-0.0064'	'RW-B'	'OSB-0.0191'
885	'PW-0.0064'	'C-B'	'GB-0.0064'
886	'PW-0.0064'	'C-B'	'GB-0.0079'
887	'PW-0.0064'	'C-B'	'GB-0.0095'
888	'PW-0.0064'	'C-B'	'GB-0.0127'
889	'PW-0.0064'	'C-B'	'GB-0.0159'
890	'PW-0.0064'	'C-B'	'GB-0.0191'
891	'PW-0.0064'	'C-B'	'GB-0.0254'
892	'PW-0.0064'	'C-B'	'PW-0.0064'
893	'PW-0.0064'	'C-B'	'PW-0.0095'
894	'PW-0.0064'	'C-B'	'PW-0.0127'
895	'PW-0.0064'	'C-B'	'PW-0.0159'
896	'PW-0.0064'	'C-B'	'PW-0.0175'
897	'PW-0.0064'	'C-B'	'OSB-0.0095'
898	'PW-0.0064'	'C-B'	'OSB-0.0111'
899	'PW-0.0064'	'C-B'	'OSB-0.0127'

900	'PW-0.0064'	'C-B'	'OSB-0.0159'
901	'PW-0.0064'	'C-B'	'OSB-0.0191'
902	'PW-0.0064'	'SPF-OC'	'GB-0.0064'
903	'PW-0.0064'	'SPF-OC'	'GB-0.0079'
904	'PW-0.0064'	'SPF-OC'	'GB-0.0095'
905	'PW-0.0064'	'SPF-OC'	'GB-0.0127'
906	'PW-0.0064'	'SPF-OC'	'GB-0.0159'
907	'PW-0.0064'	'SPF-OC'	'GB-0.0191'
908	'PW-0.0064'	'SPF-OC'	'GB-0.0254'
909	'PW-0.0064'	'SPF-OC'	'PW-0.0064'
910	'PW-0.0064'	'SPF-OC'	'PW-0.0095'
911	'PW-0.0064'	'SPF-OC'	'PW-0.0127'
912	'PW-0.0064'	'SPF-OC'	'PW-0.0159'
913	'PW-0.0064'	'SPF-OC'	'PW-0.0175'
914	'PW-0.0064'	'SPF-OC'	'OSB-0.0095'
915	'PW-0.0064'	'SPF-OC'	'OSB-0.0111'
916	'PW-0.0064'	'SPF-OC'	'OSB-0.0127'
917	'PW-0.0064'	'SPF-OC'	'OSB-0.0159'
918	'PW-0.0064'	'SPF-OC'	'OSB-0.0191'
919	'PW-0.0064'	'SPF-CC'	'GB-0.0064'
920	'PW-0.0064'	'SPF-CC'	'GB-0.0079'
921	'PW-0.0064'	'SPF-CC'	'GB-0.0095'
922	'PW-0.0064'	'SPF-CC'	'GB-0.0127'
923	'PW-0.0064'	'SPF-CC'	'GB-0.0159'
924	'PW-0.0064'	'SPF-CC'	'GB-0.0191'
925	'PW-0.0064'	'SPF-CC'	'GB-0.0254'
926	'PW-0.0064'	'SPF-CC'	'PW-0.0064'
927	'PW-0.0064'	'SPF-CC'	'PW-0.0095'
928	'PW-0.0064'	'SPF-CC'	'PW-0.0127'
929	'PW-0.0064'	'SPF-CC'	'PW-0.0159'
930	'PW-0.0064'	'SPF-CC'	'PW-0.0175'
931	'PW-0.0064'	'SPF-CC'	'OSB-0.0095'
932	'PW-0.0064'	'SPF-CC'	'OSB-0.0111'
933	'PW-0.0064'	'SPF-CC'	'OSB-0.0127'
934	'PW-0.0064'	'SPF-CC'	'OSB-0.0159'
935	'PW-0.0064'	'SPF-CC'	'OSB-0.0191'
936	'PW-0.0064'	'XPS'	'GB-0.0064'
937	'PW-0.0064'	'XPS'	'GB-0.0079'
938	'PW-0.0064'	'XPS'	'GB-0.0095'
939	'PW-0.0064'	'XPS'	'GB-0.0127'
940	'PW-0.0064'	'XPS'	'GB-0.0159'
941	'PW-0.0064'	'XPS'	'GB-0.0191'
942	'PW-0.0064'	'XPS'	'GB-0.0254'

943	'PW-0.0064'	'XPS'	'PW-0.0064'
944	'PW-0.0064'	'XPS'	'PW-0.0095'
945	'PW-0.0064'	'XPS'	'PW-0.0127'
946	'PW-0.0064'	'XPS'	'PW-0.0159'
947	'PW-0.0064'	'XPS'	'PW-0.0175'
948	'PW-0.0064'	'XPS'	'OSB-0.0095'
949	'PW-0.0064'	'XPS'	'OSB-0.0111'
950	'PW-0.0064'	'XPS'	'OSB-0.0127'
951	'PW-0.0064'	'XPS'	'OSB-0.0159'
952	'PW-0.0064'	'XPS'	'OSB-0.0191'
953	'PW-0.0095'	'FG-U'	'GB-0.0064'
954	'PW-0.0095'	'FG-U'	'GB-0.0079'
955	'PW-0.0095'	'FG-U'	'GB-0.0095'
956	'PW-0.0095'	'FG-U'	'GB-0.0127'
957	'PW-0.0095'	'FG-U'	'GB-0.0159'
958	'PW-0.0095'	'FG-U'	'GB-0.0191'
959	'PW-0.0095'	'FG-U'	'GB-0.0254'
960	'PW-0.0095'	'FG-U'	'PW-0.0064'
961	'PW-0.0095'	'FG-U'	'PW-0.0095'
962	'PW-0.0095'	'FG-U'	'PW-0.0127'
963	'PW-0.0095'	'FG-U'	'PW-0.0159'
964	'PW-0.0095'	'FG-U'	'PW-0.0175'
965	'PW-0.0095'	'FG-U'	'OSB-0.0095'
966	'PW-0.0095'	'FG-U'	'OSB-0.0111'
967	'PW-0.0095'	'FG-U'	'OSB-0.0127'
968	'PW-0.0095'	'FG-U'	'OSB-0.0159'
969	'PW-0.0095'	'FG-U'	'OSB-0.0191'
970	'PW-0.0095'	'FG-K'	'GB-0.0064'
971	'PW-0.0095'	'FG-K'	'GB-0.0079'
972	'PW-0.0095'	'FG-K'	'GB-0.0095'
973	'PW-0.0095'	'FG-K'	'GB-0.0127'
974	'PW-0.0095'	'FG-K'	'GB-0.0159'
975	'PW-0.0095'	'FG-K'	'GB-0.0191'
976	'PW-0.0095'	'FG-K'	'GB-0.0254'
977	'PW-0.0095'	'FG-K'	'PW-0.0064'
978	'PW-0.0095'	'FG-K'	'PW-0.0095'
979	'PW-0.0095'	'FG-K'	'PW-0.0127'
980	'PW-0.0095'	'FG-K'	'PW-0.0159'
981	'PW-0.0095'	'FG-K'	'PW-0.0175'
982	'PW-0.0095'	'FG-K'	'OSB-0.0095'
983	'PW-0.0095'	'FG-K'	'OSB-0.0111'
984	'PW-0.0095'	'FG-K'	'OSB-0.0127'
985	'PW-0.0095'	'FG-K'	'OSB-0.0159'

986	'PW-0.0095'	'FG-K'	'OSB-0.0191'
987	'PW-0.0095'	'RW-B'	'GB-0.0064'
988	'PW-0.0095'	'RW-B'	'GB-0.0079'
989	'PW-0.0095'	'RW-B'	'GB-0.0095'
990	'PW-0.0095'	'RW-B'	'GB-0.0127'
991	'PW-0.0095'	'RW-B'	'GB-0.0159'
992	'PW-0.0095'	'RW-B'	'GB-0.0191'
993	'PW-0.0095'	'RW-B'	'GB-0.0254'
994	'PW-0.0095'	'RW-B'	'PW-0.0064'
995	'PW-0.0095'	'RW-B'	'PW-0.0095'
996	'PW-0.0095'	'RW-B'	'PW-0.0127'
997	'PW-0.0095'	'RW-B'	'PW-0.0159'
998	'PW-0.0095'	'RW-B'	'PW-0.0175'
999	'PW-0.0095'	'RW-B'	'OSB-0.0095'
1000	'PW-0.0095'	'RW-B'	'OSB-0.0111'
1001	'PW-0.0095'	'RW-B'	'OSB-0.0127'
1002	'PW-0.0095'	'RW-B'	'OSB-0.0159'
1003	'PW-0.0095'	'RW-B'	'OSB-0.0191'
1004	'PW-0.0095'	'C-B'	'GB-0.0064'
1005	'PW-0.0095'	'C-B'	'GB-0.0079'
1006	'PW-0.0095'	'C-B'	'GB-0.0095'
1007	'PW-0.0095'	'C-B'	'GB-0.0127'
1008	'PW-0.0095'	'C-B'	'GB-0.0159'
1009	'PW-0.0095'	'C-B'	'GB-0.0191'
1010	'PW-0.0095'	'C-B'	'GB-0.0254'
1011	'PW-0.0095'	'C-B'	'PW-0.0064'
1012	'PW-0.0095'	'C-B'	'PW-0.0095'
1013	'PW-0.0095'	'C-B'	'PW-0.0127'
1014	'PW-0.0095'	'C-B'	'PW-0.0159'
1015	'PW-0.0095'	'C-B'	'PW-0.0175'
1016	'PW-0.0095'	'C-B'	'OSB-0.0095'
1017	'PW-0.0095'	'C-B'	'OSB-0.0111'
1018	'PW-0.0095'	'C-B'	'OSB-0.0127'
1019	'PW-0.0095'	'C-B'	'OSB-0.0159'
1020	'PW-0.0095'	'C-B'	'OSB-0.0191'
1021	'PW-0.0095'	'SPF-OC'	'GB-0.0064'
1022	'PW-0.0095'	'SPF-OC'	'GB-0.0079'
1023	'PW-0.0095'	'SPF-OC'	'GB-0.0095'
1024	'PW-0.0095'	'SPF-OC'	'GB-0.0127'
1025	'PW-0.0095'	'SPF-OC'	'GB-0.0159'
1026	'PW-0.0095'	'SPF-OC'	'GB-0.0191'
1027	'PW-0.0095'	'SPF-OC'	'GB-0.0254'
1028	'PW-0.0095'	'SPF-OC'	'PW-0.0064'

1029	'PW-0.0095'	'SPF-OC'	'PW-0.0095'
1030	'PW-0.0095'	'SPF-OC'	'PW-0.0127'
1031	'PW-0.0095'	'SPF-OC'	'PW-0.0159'
1032	'PW-0.0095'	'SPF-OC'	'PW-0.0175'
1033	'PW-0.0095'	'SPF-OC'	'OSB-0.0095'
1034	'PW-0.0095'	'SPF-OC'	'OSB-0.0111'
1035	'PW-0.0095'	'SPF-OC'	'OSB-0.0127'
1036	'PW-0.0095'	'SPF-OC'	'OSB-0.0159'
1037	'PW-0.0095'	'SPF-OC'	'OSB-0.0191'
1038	'PW-0.0095'	'SPF-CC'	'GB-0.0064'
1039	'PW-0.0095'	'SPF-CC'	'GB-0.0079'
1040	'PW-0.0095'	'SPF-CC'	'GB-0.0095'
1041	'PW-0.0095'	'SPF-CC'	'GB-0.0127'
1042	'PW-0.0095'	'SPF-CC'	'GB-0.0159'
1043	'PW-0.0095'	'SPF-CC'	'GB-0.0191'
1044	'PW-0.0095'	'SPF-CC'	'GB-0.0254'
1045	'PW-0.0095'	'SPF-CC'	'PW-0.0064'
1046	'PW-0.0095'	'SPF-CC'	'PW-0.0095'
1047	'PW-0.0095'	'SPF-CC'	'PW-0.0127'
1048	'PW-0.0095'	'SPF-CC'	'PW-0.0159'
1049	'PW-0.0095'	'SPF-CC'	'PW-0.0175'
1050	'PW-0.0095'	'SPF-CC'	'OSB-0.0095'
1051	'PW-0.0095'	'SPF-CC'	'OSB-0.0111'
1052	'PW-0.0095'	'SPF-CC'	'OSB-0.0127'
1053	'PW-0.0095'	'SPF-CC'	'OSB-0.0159'
1054	'PW-0.0095'	'SPF-CC'	'OSB-0.0191'
1055	'PW-0.0095'	'XPS'	'GB-0.0064'
1056	'PW-0.0095'	'XPS'	'GB-0.0079'
1057	'PW-0.0095'	'XPS'	'GB-0.0095'
1058	'PW-0.0095'	'XPS'	'GB-0.0127'
1059	'PW-0.0095'	'XPS'	'GB-0.0159'
1060	'PW-0.0095'	'XPS'	'GB-0.0191'
1061	'PW-0.0095'	'XPS'	'GB-0.0254'
1062	'PW-0.0095'	'XPS'	'PW-0.0064'
1063	'PW-0.0095'	'XPS'	'PW-0.0095'
1064	'PW-0.0095'	'XPS'	'PW-0.0127'
1065	'PW-0.0095'	'XPS'	'PW-0.0159'
1066	'PW-0.0095'	'XPS'	'PW-0.0175'
1067	'PW-0.0095'	'XPS'	'OSB-0.0095'
1068	'PW-0.0095'	'XPS'	'OSB-0.0111'
1069	'PW-0.0095'	'XPS'	'OSB-0.0127'
1070	'PW-0.0095'	'XPS'	'OSB-0.0159'
1071	'PW-0.0095'	'XPS'	'OSB-0.0191'

1072	'PW-0.0127'	'FG-U'	'GB-0.0064'
1073	'PW-0.0127'	'FG-U'	'GB-0.0079'
1074	'PW-0.0127'	'FG-U'	'GB-0.0095'
1075	'PW-0.0127'	'FG-U'	'GB-0.0127'
1076	'PW-0.0127'	'FG-U'	'GB-0.0159'
1077	'PW-0.0127'	'FG-U'	'GB-0.0191'
1078	'PW-0.0127'	'FG-U'	'GB-0.0254'
1079	'PW-0.0127'	'FG-U'	'PW-0.0064'
1080	'PW-0.0127'	'FG-U'	'PW-0.0095'
1081	'PW-0.0127'	'FG-U'	'PW-0.0127'
1082	'PW-0.0127'	'FG-U'	'PW-0.0159'
1083	'PW-0.0127'	'FG-U'	'PW-0.0175'
1084	'PW-0.0127'	'FG-U'	'OSB-0.0095'
1085	'PW-0.0127'	'FG-U'	'OSB-0.0111'
1086	'PW-0.0127'	'FG-U'	'OSB-0.0127'
1087	'PW-0.0127'	'FG-U'	'OSB-0.0159'
1088	'PW-0.0127'	'FG-U'	'OSB-0.0191'
1089	'PW-0.0127'	'FG-K'	'GB-0.0064'
1090	'PW-0.0127'	'FG-K'	'GB-0.0079'
1091	'PW-0.0127'	'FG-K'	'GB-0.0095'
1092	'PW-0.0127'	'FG-K'	'GB-0.0127'
1093	'PW-0.0127'	'FG-K'	'GB-0.0159'
1094	'PW-0.0127'	'FG-K'	'GB-0.0191'
1095	'PW-0.0127'	'FG-K'	'GB-0.0254'
1096	'PW-0.0127'	'FG-K'	'PW-0.0064'
1097	'PW-0.0127'	'FG-K'	'PW-0.0095'
1098	'PW-0.0127'	'FG-K'	'PW-0.0127'
1099	'PW-0.0127'	'FG-K'	'PW-0.0159'
1100	'PW-0.0127'	'FG-K'	'PW-0.0175'
1101	'PW-0.0127'	'FG-K'	'OSB-0.0095'
1102	'PW-0.0127'	'FG-K'	'OSB-0.0111'
1103	'PW-0.0127'	'FG-K'	'OSB-0.0127'
1104	'PW-0.0127'	'FG-K'	'OSB-0.0159'
1105	'PW-0.0127'	'FG-K'	'OSB-0.0191'
1106	'PW-0.0127'	'RW-B'	'GB-0.0064'
1107	'PW-0.0127'	'RW-B'	'GB-0.0079'
1108	'PW-0.0127'	'RW-B'	'GB-0.0095'
1109	'PW-0.0127'	'RW-B'	'GB-0.0127'
1110	'PW-0.0127'	'RW-B'	'GB-0.0159'
1111	'PW-0.0127'	'RW-B'	'GB-0.0191'
1112	'PW-0.0127'	'RW-B'	'GB-0.0254'
1113	'PW-0.0127'	'RW-B'	'PW-0.0064'
1114	'PW-0.0127'	'RW-B'	'PW-0.0095'

1115	'PW-0.0127'	'RW-B'	'PW-0.0127'
1116	'PW-0.0127'	'RW-B'	'PW-0.0159'
1117	'PW-0.0127'	'RW-B'	'PW-0.0175'
1118	'PW-0.0127'	'RW-B'	'OSB-0.0095'
1119	'PW-0.0127'	'RW-B'	'OSB-0.0111'
1120	'PW-0.0127'	'RW-B'	'OSB-0.0127'
1121	'PW-0.0127'	'RW-B'	'OSB-0.0159'
1122	'PW-0.0127'	'RW-B'	'OSB-0.0191'
1123	'PW-0.0127'	'C-B'	'GB-0.0064'
1124	'PW-0.0127'	'C-B'	'GB-0.0079'
1125	'PW-0.0127'	'C-B'	'GB-0.0095'
1126	'PW-0.0127'	'C-B'	'GB-0.0127'
1127	'PW-0.0127'	'C-B'	'GB-0.0159'
1128	'PW-0.0127'	'C-B'	'GB-0.0191'
1129	'PW-0.0127'	'C-B'	'GB-0.0254'
1130	'PW-0.0127'	'C-B'	'PW-0.0064'
1131	'PW-0.0127'	'C-B'	'PW-0.0095'
1132	'PW-0.0127'	'C-B'	'PW-0.0127'
1133	'PW-0.0127'	'C-B'	'PW-0.0159'
1134	'PW-0.0127'	'C-B'	'PW-0.0175'
1135	'PW-0.0127'	'C-B'	'OSB-0.0095'
1136	'PW-0.0127'	'C-B'	'OSB-0.0111'
1137	'PW-0.0127'	'C-B'	'OSB-0.0127'
1138	'PW-0.0127'	'C-B'	'OSB-0.0159'
1139	'PW-0.0127'	'C-B'	'OSB-0.0191'
1140	'PW-0.0127'	'SPF-OC'	'GB-0.0064'
1141	'PW-0.0127'	'SPF-OC'	'GB-0.0079'
1142	'PW-0.0127'	'SPF-OC'	'GB-0.0095'
1143	'PW-0.0127'	'SPF-OC'	'GB-0.0127'
1144	'PW-0.0127'	'SPF-OC'	'GB-0.0159'
1145	'PW-0.0127'	'SPF-OC'	'GB-0.0191'
1146	'PW-0.0127'	'SPF-OC'	'GB-0.0254'
1147	'PW-0.0127'	'SPF-OC'	'PW-0.0064'
1148	'PW-0.0127'	'SPF-OC'	'PW-0.0095'
1149	'PW-0.0127'	'SPF-OC'	'PW-0.0127'
1150	'PW-0.0127'	'SPF-OC'	'PW-0.0159'
1151	'PW-0.0127'	'SPF-OC'	'PW-0.0175'
1152	'PW-0.0127'	'SPF-OC'	'OSB-0.0095'
1153	'PW-0.0127'	'SPF-OC'	'OSB-0.0111'
1154	'PW-0.0127'	'SPF-OC'	'OSB-0.0127'
1155	'PW-0.0127'	'SPF-OC'	'OSB-0.0159'
1156	'PW-0.0127'	'SPF-OC'	'OSB-0.0191'
1157	'PW-0.0127'	'SPF-CC'	'GB-0.0064'

1158	'PW-0.0127'	'SPF-CC'	'GB-0.0079'
1159	'PW-0.0127'	'SPF-CC'	'GB-0.0095'
1160	'PW-0.0127'	'SPF-CC'	'GB-0.0127'
1161	'PW-0.0127'	'SPF-CC'	'GB-0.0159'
1162	'PW-0.0127'	'SPF-CC'	'GB-0.0191'
1163	'PW-0.0127'	'SPF-CC'	'GB-0.0254'
1164	'PW-0.0127'	'SPF-CC'	'PW-0.0064'
1165	'PW-0.0127'	'SPF-CC'	'PW-0.0095'
1166	'PW-0.0127'	'SPF-CC'	'PW-0.0127'
1167	'PW-0.0127'	'SPF-CC'	'PW-0.0159'
1168	'PW-0.0127'	'SPF-CC'	'PW-0.0175'
1169	'PW-0.0127'	'SPF-CC'	'OSB-0.0095'
1170	'PW-0.0127'	'SPF-CC'	'OSB-0.0111'
1171	'PW-0.0127'	'SPF-CC'	'OSB-0.0127'
1172	'PW-0.0127'	'SPF-CC'	'OSB-0.0159'
1173	'PW-0.0127'	'SPF-CC'	'OSB-0.0191'
1174	'PW-0.0127'	'XPS'	'GB-0.0064'
1175	'PW-0.0127'	'XPS'	'GB-0.0079'
1176	'PW-0.0127'	'XPS'	'GB-0.0095'
1177	'PW-0.0127'	'XPS'	'GB-0.0127'
1178	'PW-0.0127'	'XPS'	'GB-0.0159'
1179	'PW-0.0127'	'XPS'	'GB-0.0191'
1180	'PW-0.0127'	'XPS'	'GB-0.0254'
1181	'PW-0.0127'	'XPS'	'PW-0.0064'
1182	'PW-0.0127'	'XPS'	'PW-0.0095'
1183	'PW-0.0127'	'XPS'	'PW-0.0127'
1184	'PW-0.0127'	'XPS'	'PW-0.0159'
1185	'PW-0.0127'	'XPS'	'PW-0.0175'
1186	'PW-0.0127'	'XPS'	'OSB-0.0095'
1187	'PW-0.0127'	'XPS'	'OSB-0.0111'
1188	'PW-0.0127'	'XPS'	'OSB-0.0127'
1189	'PW-0.0127'	'XPS'	'OSB-0.0159'
1190	'PW-0.0127'	'XPS'	'OSB-0.0191'
1191	'PW-0.0159'	'FG-U'	'GB-0.0064'
1192	'PW-0.0159'	'FG-U'	'GB-0.0079'
1193	'PW-0.0159'	'FG-U'	'GB-0.0095'
1194	'PW-0.0159'	'FG-U'	'GB-0.0127'
1195	'PW-0.0159'	'FG-U'	'GB-0.0159'
1196	'PW-0.0159'	'FG-U'	'GB-0.0191'
1197	'PW-0.0159'	'FG-U'	'GB-0.0254'
1198	'PW-0.0159'	'FG-U'	'PW-0.0064'
1199	'PW-0.0159'	'FG-U'	'PW-0.0095'
1200	'PW-0.0159'	'FG-U'	'PW-0.0127'

1201	'PW-0.0159'	'FG-U'	'PW-0.0159'
1202	'PW-0.0159'	'FG-U'	'PW-0.0175'
1203	'PW-0.0159'	'FG-U'	'OSB-0.0095'
1204	'PW-0.0159'	'FG-U'	'OSB-0.0111'
1205	'PW-0.0159'	'FG-U'	'OSB-0.0127'
1206	'PW-0.0159'	'FG-U'	'OSB-0.0159'
1207	'PW-0.0159'	'FG-U'	'OSB-0.0191'
1208	'PW-0.0159'	'FG-K'	'GB-0.0064'
1209	'PW-0.0159'	'FG-K'	'GB-0.0079'
1210	'PW-0.0159'	'FG-K'	'GB-0.0095'
1211	'PW-0.0159'	'FG-K'	'GB-0.0127'
1212	'PW-0.0159'	'FG-K'	'GB-0.0159'
1213	'PW-0.0159'	'FG-K'	'GB-0.0191'
1214	'PW-0.0159'	'FG-K'	'GB-0.0254'
1215	'PW-0.0159'	'FG-K'	'PW-0.0064'
1216	'PW-0.0159'	'FG-K'	'PW-0.0095'
1217	'PW-0.0159'	'FG-K'	'PW-0.0127'
1218	'PW-0.0159'	'FG-K'	'PW-0.0159'
1219	'PW-0.0159'	'FG-K'	'PW-0.0175'
1220	'PW-0.0159'	'FG-K'	'OSB-0.0095'
1221	'PW-0.0159'	'FG-K'	'OSB-0.0111'
1222	'PW-0.0159'	'FG-K'	'OSB-0.0127'
1223	'PW-0.0159'	'FG-K'	'OSB-0.0159'
1224	'PW-0.0159'	'FG-K'	'OSB-0.0191'
1225	'PW-0.0159'	'RW-B'	'GB-0.0064'
1226	'PW-0.0159'	'RW-B'	'GB-0.0079'
1227	'PW-0.0159'	'RW-B'	'GB-0.0095'
1228	'PW-0.0159'	'RW-B'	'GB-0.0127'
1229	'PW-0.0159'	'RW-B'	'GB-0.0159'
1230	'PW-0.0159'	'RW-B'	'GB-0.0191'
1231	'PW-0.0159'	'RW-B'	'GB-0.0254'
1232	'PW-0.0159'	'RW-B'	'PW-0.0064'
1233	'PW-0.0159'	'RW-B'	'PW-0.0095'
1234	'PW-0.0159'	'RW-B'	'PW-0.0127'
1235	'PW-0.0159'	'RW-B'	'PW-0.0159'
1236	'PW-0.0159'	'RW-B'	'PW-0.0175'
1237	'PW-0.0159'	'RW-B'	'OSB-0.0095'
1238	'PW-0.0159'	'RW-B'	'OSB-0.0111'
1239	'PW-0.0159'	'RW-B'	'OSB-0.0127'
1240	'PW-0.0159'	'RW-B'	'OSB-0.0159'
1241	'PW-0.0159'	'RW-B'	'OSB-0.0191'
1242	'PW-0.0159'	'C-B'	'GB-0.0064'
1243	'PW-0.0159'	'C-B'	'GB-0.0079'

1244	'PW-0.0159'	'C-B'	'GB-0.0095'
1245	'PW-0.0159'	'C-B'	'GB-0.0127'
1246	'PW-0.0159'	'C-B'	'GB-0.0159'
1247	'PW-0.0159'	'C-B'	'GB-0.0191'
1248	'PW-0.0159'	'C-B'	'GB-0.0254'
1249	'PW-0.0159'	'C-B'	'PW-0.0064'
1250	'PW-0.0159'	'C-B'	'PW-0.0095'
1251	'PW-0.0159'	'C-B'	'PW-0.0127'
1252	'PW-0.0159'	'C-B'	'PW-0.0159'
1253	'PW-0.0159'	'C-B'	'PW-0.0175'
1254	'PW-0.0159'	'C-B'	'OSB-0.0095'
1255	'PW-0.0159'	'C-B'	'OSB-0.0111'
1256	'PW-0.0159'	'C-B'	'OSB-0.0127'
1257	'PW-0.0159'	'C-B'	'OSB-0.0159'
1258	'PW-0.0159'	'C-B'	'OSB-0.0191'
1259	'PW-0.0159'	'SPF-OC'	'GB-0.0064'
1260	'PW-0.0159'	'SPF-OC'	'GB-0.0079'
1261	'PW-0.0159'	'SPF-OC'	'GB-0.0095'
1262	'PW-0.0159'	'SPF-OC'	'GB-0.0127'
1263	'PW-0.0159'	'SPF-OC'	'GB-0.0159'
1264	'PW-0.0159'	'SPF-OC'	'GB-0.0191'
1265	'PW-0.0159'	'SPF-OC'	'GB-0.0254'
1266	'PW-0.0159'	'SPF-OC'	'PW-0.0064'
1267	'PW-0.0159'	'SPF-OC'	'PW-0.0095'
1268	'PW-0.0159'	'SPF-OC'	'PW-0.0127'
1269	'PW-0.0159'	'SPF-OC'	'PW-0.0159'
1270	'PW-0.0159'	'SPF-OC'	'PW-0.0175'
1271	'PW-0.0159'	'SPF-OC'	'OSB-0.0095'
1272	'PW-0.0159'	'SPF-OC'	'OSB-0.0111'
1273	'PW-0.0159'	'SPF-OC'	'OSB-0.0127'
1274	'PW-0.0159'	'SPF-OC'	'OSB-0.0159'
1275	'PW-0.0159'	'SPF-OC'	'OSB-0.0191'
1276	'PW-0.0159'	'SPF-CC'	'GB-0.0064'
1277	'PW-0.0159'	'SPF-CC'	'GB-0.0079'
1278	'PW-0.0159'	'SPF-CC'	'GB-0.0095'
1279	'PW-0.0159'	'SPF-CC'	'GB-0.0127'
1280	'PW-0.0159'	'SPF-CC'	'GB-0.0159'
1281	'PW-0.0159'	'SPF-CC'	'GB-0.0191'
1282	'PW-0.0159'	'SPF-CC'	'GB-0.0254'
1283	'PW-0.0159'	'SPF-CC'	'PW-0.0064'
1284	'PW-0.0159'	'SPF-CC'	'PW-0.0095'
1285	'PW-0.0159'	'SPF-CC'	'PW-0.0127'
1286	'PW-0.0159'	'SPF-CC'	'PW-0.0159'

1287	'PW-0.0159'	'SPF-CC'	'PW-0.0175'
1288	'PW-0.0159'	'SPF-CC'	'OSB-0.0095'
1289	'PW-0.0159'	'SPF-CC'	'OSB-0.0111'
1290	'PW-0.0159'	'SPF-CC'	'OSB-0.0127'
1291	'PW-0.0159'	'SPF-CC'	'OSB-0.0159'
1292	'PW-0.0159'	'SPF-CC'	'OSB-0.0191'
1293	'PW-0.0159'	'XPS'	'GB-0.0064'
1294	'PW-0.0159'	'XPS'	'GB-0.0079'
1295	'PW-0.0159'	'XPS'	'GB-0.0095'
1296	'PW-0.0159'	'XPS'	'GB-0.0127'
1297	'PW-0.0159'	'XPS'	'GB-0.0159'
1298	'PW-0.0159'	'XPS'	'GB-0.0191'
1299	'PW-0.0159'	'XPS'	'GB-0.0254'
1300	'PW-0.0159'	'XPS'	'PW-0.0064'
1301	'PW-0.0159'	'XPS'	'PW-0.0095'
1302	'PW-0.0159'	'XPS'	'PW-0.0127'
1303	'PW-0.0159'	'XPS'	'PW-0.0159'
1304	'PW-0.0159'	'XPS'	'PW-0.0175'
1305	'PW-0.0159'	'XPS'	'OSB-0.0095'
1306	'PW-0.0159'	'XPS'	'OSB-0.0111'
1307	'PW-0.0159'	'XPS'	'OSB-0.0127'
1308	'PW-0.0159'	'XPS'	'OSB-0.0159'
1309	'PW-0.0159'	'XPS'	'OSB-0.0191'
1310	'PW-0.0175'	'FG-U'	'GB-0.0064'
1311	'PW-0.0175'	'FG-U'	'GB-0.0079'
1312	'PW-0.0175'	'FG-U'	'GB-0.0095'
1313	'PW-0.0175'	'FG-U'	'GB-0.0127'
1314	'PW-0.0175'	'FG-U'	'GB-0.0159'
1315	'PW-0.0175'	'FG-U'	'GB-0.0191'
1316	'PW-0.0175'	'FG-U'	'GB-0.0254'
1317	'PW-0.0175'	'FG-U'	'PW-0.0064'
1318	'PW-0.0175'	'FG-U'	'PW-0.0095'
1319	'PW-0.0175'	'FG-U'	'PW-0.0127'
1320	'PW-0.0175'	'FG-U'	'PW-0.0159'
1321	'PW-0.0175'	'FG-U'	'PW-0.0175'
1322	'PW-0.0175'	'FG-U'	'OSB-0.0095'
1323	'PW-0.0175'	'FG-U'	'OSB-0.0111'
1324	'PW-0.0175'	'FG-U'	'OSB-0.0127'
1325	'PW-0.0175'	'FG-U'	'OSB-0.0159'
1326	'PW-0.0175'	'FG-U'	'OSB-0.0191'
1327	'PW-0.0175'	'FG-K'	'GB-0.0064'
1328	'PW-0.0175'	'FG-K'	'GB-0.0079'
1329	'PW-0.0175'	'FG-K'	'GB-0.0095'

1330	'PW-0.0175'	'FG-K'	'GB-0.0127'
1331	'PW-0.0175'	'FG-K'	'GB-0.0159'
1332	'PW-0.0175'	'FG-K'	'GB-0.0191'
1333	'PW-0.0175'	'FG-K'	'GB-0.0254'
1334	'PW-0.0175'	'FG-K'	'PW-0.0064'
1335	'PW-0.0175'	'FG-K'	'PW-0.0095'
1336	'PW-0.0175'	'FG-K'	'PW-0.0127'
1337	'PW-0.0175'	'FG-K'	'PW-0.0159'
1338	'PW-0.0175'	'FG-K'	'PW-0.0175'
1339	'PW-0.0175'	'FG-K'	'OSB-0.0095'
1340	'PW-0.0175'	'FG-K'	'OSB-0.0111'
1341	'PW-0.0175'	'FG-K'	'OSB-0.0127'
1342	'PW-0.0175'	'FG-K'	'OSB-0.0159'
1343	'PW-0.0175'	'FG-K'	'OSB-0.0191'
1344	'PW-0.0175'	'RW-B'	'GB-0.0064'
1345	'PW-0.0175'	'RW-B'	'GB-0.0079'
1346	'PW-0.0175'	'RW-B'	'GB-0.0095'
1347	'PW-0.0175'	'RW-B'	'GB-0.0127'
1348	'PW-0.0175'	'RW-B'	'GB-0.0159'
1349	'PW-0.0175'	'RW-B'	'GB-0.0191'
1350	'PW-0.0175'	'RW-B'	'GB-0.0254'
1351	'PW-0.0175'	'RW-B'	'PW-0.0064'
1352	'PW-0.0175'	'RW-B'	'PW-0.0095'
1353	'PW-0.0175'	'RW-B'	'PW-0.0127'
1354	'PW-0.0175'	'RW-B'	'PW-0.0159'
1355	'PW-0.0175'	'RW-B'	'PW-0.0175'
1356	'PW-0.0175'	'RW-B'	'OSB-0.0095'
1357	'PW-0.0175'	'RW-B'	'OSB-0.0111'
1358	'PW-0.0175'	'RW-B'	'OSB-0.0127'
1359	'PW-0.0175'	'RW-B'	'OSB-0.0159'
1360	'PW-0.0175'	'RW-B'	'OSB-0.0191'
1361	'PW-0.0175'	'C-B'	'GB-0.0064'
1362	'PW-0.0175'	'C-B'	'GB-0.0079'
1363	'PW-0.0175'	'C-B'	'GB-0.0095'
1364	'PW-0.0175'	'C-B'	'GB-0.0127'
1365	'PW-0.0175'	'C-B'	'GB-0.0159'
1366	'PW-0.0175'	'C-B'	'GB-0.0191'
1367	'PW-0.0175'	'C-B'	'GB-0.0254'
1368	'PW-0.0175'	'C-B'	'PW-0.0064'
1369	'PW-0.0175'	'C-B'	'PW-0.0095'
1370	'PW-0.0175'	'C-B'	'PW-0.0127'
1371	'PW-0.0175'	'C-B'	'PW-0.0159'
1372	'PW-0.0175'	'C-B'	'PW-0.0175'

1373	'PW-0.0175'	'C-B'	'OSB-0.0095'
1374	'PW-0.0175'	'C-B'	'OSB-0.0111'
1375	'PW-0.0175'	'C-B'	'OSB-0.0127'
1376	'PW-0.0175'	'C-B'	'OSB-0.0159'
1377	'PW-0.0175'	'C-B'	'OSB-0.0191'
1378	'PW-0.0175'	'SPF-OC'	'GB-0.0064'
1379	'PW-0.0175'	'SPF-OC'	'GB-0.0079'
1380	'PW-0.0175'	'SPF-OC'	'GB-0.0095'
1381	'PW-0.0175'	'SPF-OC'	'GB-0.0127'
1382	'PW-0.0175'	'SPF-OC'	'GB-0.0159'
1383	'PW-0.0175'	'SPF-OC'	'GB-0.0191'
1384	'PW-0.0175'	'SPF-OC'	'GB-0.0254'
1385	'PW-0.0175'	'SPF-OC'	'PW-0.0064'
1386	'PW-0.0175'	'SPF-OC'	'PW-0.0095'
1387	'PW-0.0175'	'SPF-OC'	'PW-0.0127'
1388	'PW-0.0175'	'SPF-OC'	'PW-0.0159'
1389	'PW-0.0175'	'SPF-OC'	'PW-0.0175'
1390	'PW-0.0175'	'SPF-OC'	'OSB-0.0095'
1391	'PW-0.0175'	'SPF-OC'	'OSB-0.0111'
1392	'PW-0.0175'	'SPF-OC'	'OSB-0.0127'
1393	'PW-0.0175'	'SPF-OC'	'OSB-0.0159'
1394	'PW-0.0175'	'SPF-OC'	'OSB-0.0191'
1395	'PW-0.0175'	'SPF-CC'	'GB-0.0064'
1396	'PW-0.0175'	'SPF-CC'	'GB-0.0079'
1397	'PW-0.0175'	'SPF-CC'	'GB-0.0095'
1398	'PW-0.0175'	'SPF-CC'	'GB-0.0127'
1399	'PW-0.0175'	'SPF-CC'	'GB-0.0159'
1400	'PW-0.0175'	'SPF-CC'	'GB-0.0191'
1401	'PW-0.0175'	'SPF-CC'	'GB-0.0254'
1402	'PW-0.0175'	'SPF-CC'	'PW-0.0064'
1403	'PW-0.0175'	'SPF-CC'	'PW-0.0095'
1404	'PW-0.0175'	'SPF-CC'	'PW-0.0127'
1405	'PW-0.0175'	'SPF-CC'	'PW-0.0159'
1406	'PW-0.0175'	'SPF-CC'	'PW-0.0175'
1407	'PW-0.0175'	'SPF-CC'	'OSB-0.0095'
1408	'PW-0.0175'	'SPF-CC'	'OSB-0.0111'
1409	'PW-0.0175'	'SPF-CC'	'OSB-0.0127'
1410	'PW-0.0175'	'SPF-CC'	'OSB-0.0159'
1411	'PW-0.0175'	'SPF-CC'	'OSB-0.0191'
1412	'PW-0.0175'	'XPS'	'GB-0.0064'
1413	'PW-0.0175'	'XPS'	'GB-0.0079'
1414	'PW-0.0175'	'XPS'	'GB-0.0095'
1415	'PW-0.0175'	'XPS'	'GB-0.0127'

1416	'PW-0.0175'	'XPS'	'GB-0.0159'
1417	'PW-0.0175'	'XPS'	'GB-0.0191'
1418	'PW-0.0175'	'XPS'	'GB-0.0254'
1419	'PW-0.0175'	'XPS'	'PW-0.0064'
1420	'PW-0.0175'	'XPS'	'PW-0.0095'
1421	'PW-0.0175'	'XPS'	'PW-0.0127'
1422	'PW-0.0175'	'XPS'	'PW-0.0159'
1423	'PW-0.0175'	'XPS'	'PW-0.0175'
1424	'PW-0.0175'	'XPS'	'OSB-0.0095'
1425	'PW-0.0175'	'XPS'	'OSB-0.0111'
1426	'PW-0.0175'	'XPS'	'OSB-0.0127'
1427	'PW-0.0175'	'XPS'	'OSB-0.0159'
1428	'PW-0.0175'	'XPS'	'OSB-0.0191'
1429	'OSB-0.0095'	'FG-U'	'GB-0.0064'
1430	'OSB-0.0095'	'FG-U'	'GB-0.0079'
1431	'OSB-0.0095'	'FG-U'	'GB-0.0095'
1432	'OSB-0.0095'	'FG-U'	'GB-0.0127'
1433	'OSB-0.0095'	'FG-U'	'GB-0.0159'
1434	'OSB-0.0095'	'FG-U'	'GB-0.0191'
1435	'OSB-0.0095'	'FG-U'	'GB-0.0254'
1436	'OSB-0.0095'	'FG-U'	'PW-0.0064'
1437	'OSB-0.0095'	'FG-U'	'PW-0.0095'
1438	'OSB-0.0095'	'FG-U'	'PW-0.0127'
1439	'OSB-0.0095'	'FG-U'	'PW-0.0159'
1440	'OSB-0.0095'	'FG-U'	'PW-0.0175'
1441	'OSB-0.0095'	'FG-U'	'OSB-0.0095'
1442	'OSB-0.0095'	'FG-U'	'OSB-0.0111'
1443	'OSB-0.0095'	'FG-U'	'OSB-0.0127'
1444	'OSB-0.0095'	'FG-U'	'OSB-0.0159'
1445	'OSB-0.0095'	'FG-U'	'OSB-0.0191'
1446	'OSB-0.0095'	'FG-K'	'GB-0.0064'
1447	'OSB-0.0095'	'FG-K'	'GB-0.0079'
1448	'OSB-0.0095'	'FG-K'	'GB-0.0095'
1449	'OSB-0.0095'	'FG-K'	'GB-0.0127'
1450	'OSB-0.0095'	'FG-K'	'GB-0.0159'
1451	'OSB-0.0095'	'FG-K'	'GB-0.0191'
1452	'OSB-0.0095'	'FG-K'	'GB-0.0254'
1453	'OSB-0.0095'	'FG-K'	'PW-0.0064'
1454	'OSB-0.0095'	'FG-K'	'PW-0.0095'
1455	'OSB-0.0095'	'FG-K'	'PW-0.0127'
1456	'OSB-0.0095'	'FG-K'	'PW-0.0159'
1457	'OSB-0.0095'	'FG-K'	'PW-0.0175'
1458	'OSB-0.0095'	'FG-K'	'OSB-0.0095'

1459	'OSB-0.0095'	'FG-K'	'OSB-0.0111'
1460	'OSB-0.0095'	'FG-K'	'OSB-0.0127'
1461	'OSB-0.0095'	'FG-K'	'OSB-0.0159'
1462	'OSB-0.0095'	'FG-K'	'OSB-0.0191'
1463	'OSB-0.0095'	'RW-B'	'GB-0.0064'
1464	'OSB-0.0095'	'RW-B'	'GB-0.0079'
1465	'OSB-0.0095'	'RW-B'	'GB-0.0095'
1466	'OSB-0.0095'	'RW-B'	'GB-0.0127'
1467	'OSB-0.0095'	'RW-B'	'GB-0.0159'
1468	'OSB-0.0095'	'RW-B'	'GB-0.0191'
1469	'OSB-0.0095'	'RW-B'	'GB-0.0254'
1470	'OSB-0.0095'	'RW-B'	'PW-0.0064'
1471	'OSB-0.0095'	'RW-B'	'PW-0.0095'
1472	'OSB-0.0095'	'RW-B'	'PW-0.0127'
1473	'OSB-0.0095'	'RW-B'	'PW-0.0159'
1474	'OSB-0.0095'	'RW-B'	'PW-0.0175'
1475	'OSB-0.0095'	'RW-B'	'OSB-0.0095'
1476	'OSB-0.0095'	'RW-B'	'OSB-0.0111'
1477	'OSB-0.0095'	'RW-B'	'OSB-0.0127'
1478	'OSB-0.0095'	'RW-B'	'OSB-0.0159'
1479	'OSB-0.0095'	'RW-B'	'OSB-0.0191'
1480	'OSB-0.0095'	'C-B'	'GB-0.0064'
1481	'OSB-0.0095'	'C-B'	'GB-0.0079'
1482	'OSB-0.0095'	'C-B'	'GB-0.0095'
1483	'OSB-0.0095'	'C-B'	'GB-0.0127'
1484	'OSB-0.0095'	'C-B'	'GB-0.0159'
1485	'OSB-0.0095'	'C-B'	'GB-0.0191'
1486	'OSB-0.0095'	'C-B'	'GB-0.0254'
1487	'OSB-0.0095'	'C-B'	'PW-0.0064'
1488	'OSB-0.0095'	'C-B'	'PW-0.0095'
1489	'OSB-0.0095'	'C-B'	'PW-0.0127'
1490	'OSB-0.0095'	'C-B'	'PW-0.0159'
1491	'OSB-0.0095'	'C-B'	'PW-0.0175'
1492	'OSB-0.0095'	'C-B'	'OSB-0.0095'
1493	'OSB-0.0095'	'C-B'	'OSB-0.0111'
1494	'OSB-0.0095'	'C-B'	'OSB-0.0127'
1495	'OSB-0.0095'	'C-B'	'OSB-0.0159'
1496	'OSB-0.0095'	'C-B'	'OSB-0.0191'
1497	'OSB-0.0095'	'SPF-OC'	'GB-0.0064'
1498	'OSB-0.0095'	'SPF-OC'	'GB-0.0079'
1499	'OSB-0.0095'	'SPF-OC'	'GB-0.0095'
1500	'OSB-0.0095'	'SPF-OC'	'GB-0.0127'
1501	'OSB-0.0095'	'SPF-OC'	'GB-0.0159'

1502	'OSB-0.0095'	'SPF-OC'	'GB-0.0191'
1503	'OSB-0.0095'	'SPF-OC'	'GB-0.0254'
1504	'OSB-0.0095'	'SPF-OC'	'PW-0.0064'
1505	'OSB-0.0095'	'SPF-OC'	'PW-0.0095'
1506	'OSB-0.0095'	'SPF-OC'	'PW-0.0127'
1507	'OSB-0.0095'	'SPF-OC'	'PW-0.0159'
1508	'OSB-0.0095'	'SPF-OC'	'PW-0.0175'
1509	'OSB-0.0095'	'SPF-OC'	'OSB-0.0095'
1510	'OSB-0.0095'	'SPF-OC'	'OSB-0.0111'
1511	'OSB-0.0095'	'SPF-OC'	'OSB-0.0127'
1512	'OSB-0.0095'	'SPF-OC'	'OSB-0.0159'
1513	'OSB-0.0095'	'SPF-OC'	'OSB-0.0191'
1514	'OSB-0.0095'	'SPF-CC'	'GB-0.0064'
1515	'OSB-0.0095'	'SPF-CC'	'GB-0.0079'
1516	'OSB-0.0095'	'SPF-CC'	'GB-0.0095'
1517	'OSB-0.0095'	'SPF-CC'	'GB-0.0127'
1518	'OSB-0.0095'	'SPF-CC'	'GB-0.0159'
1519	'OSB-0.0095'	'SPF-CC'	'GB-0.0191'
1520	'OSB-0.0095'	'SPF-CC'	'GB-0.0254'
1521	'OSB-0.0095'	'SPF-CC'	'PW-0.0064'
1522	'OSB-0.0095'	'SPF-CC'	'PW-0.0095'
1523	'OSB-0.0095'	'SPF-CC'	'PW-0.0127'
1524	'OSB-0.0095'	'SPF-CC'	'PW-0.0159'
1525	'OSB-0.0095'	'SPF-CC'	'PW-0.0175'
1526	'OSB-0.0095'	'SPF-CC'	'OSB-0.0095'
1527	'OSB-0.0095'	'SPF-CC'	'OSB-0.0111'
1528	'OSB-0.0095'	'SPF-CC'	'OSB-0.0127'
1529	'OSB-0.0095'	'SPF-CC'	'OSB-0.0159'
1530	'OSB-0.0095'	'SPF-CC'	'OSB-0.0191'
1531	'OSB-0.0095'	'XPS'	'GB-0.0064'
1532	'OSB-0.0095'	'XPS'	'GB-0.0079'
1533	'OSB-0.0095'	'XPS'	'GB-0.0095'
1534	'OSB-0.0095'	'XPS'	'GB-0.0127'
1535	'OSB-0.0095'	'XPS'	'GB-0.0159'
1536	'OSB-0.0095'	'XPS'	'GB-0.0191'
1537	'OSB-0.0095'	'XPS'	'GB-0.0254'
1538	'OSB-0.0095'	'XPS'	'PW-0.0064'
1539	'OSB-0.0095'	'XPS'	'PW-0.0095'
1540	'OSB-0.0095'	'XPS'	'PW-0.0127'
1541	'OSB-0.0095'	'XPS'	'PW-0.0159'
1542	'OSB-0.0095'	'XPS'	'PW-0.0175'
1543	'OSB-0.0095'	'XPS'	'OSB-0.0095'
1544	'OSB-0.0095'	'XPS'	'OSB-0.0111'

1545	'OSB-0.0095'	'XPS'	'OSB-0.0127'
1546	'OSB-0.0095'	'XPS'	'OSB-0.0159'
1547	'OSB-0.0095'	'XPS'	'OSB-0.0191'
1548	'OSB-0.0111'	'FG-U'	'GB-0.0064'
1549	'OSB-0.0111'	'FG-U'	'GB-0.0079'
1550	'OSB-0.0111'	'FG-U'	'GB-0.0095'
1551	'OSB-0.0111'	'FG-U'	'GB-0.0127'
1552	'OSB-0.0111'	'FG-U'	'GB-0.0159'
1553	'OSB-0.0111'	'FG-U'	'GB-0.0191'
1554	'OSB-0.0111'	'FG-U'	'GB-0.0254'
1555	'OSB-0.0111'	'FG-U'	'PW-0.0064'
1556	'OSB-0.0111'	'FG-U'	'PW-0.0095'
1557	'OSB-0.0111'	'FG-U'	'PW-0.0127'
1558	'OSB-0.0111'	'FG-U'	'PW-0.0159'
1559	'OSB-0.0111'	'FG-U'	'PW-0.0175'
1560	'OSB-0.0111'	'FG-U'	'OSB-0.0095'
1561	'OSB-0.0111'	'FG-U'	'OSB-0.0111'
1562	'OSB-0.0111'	'FG-U'	'OSB-0.0127'
1563	'OSB-0.0111'	'FG-U'	'OSB-0.0159'
1564	'OSB-0.0111'	'FG-U'	'OSB-0.0191'
1565	'OSB-0.0111'	'FG-K'	'GB-0.0064'
1566	'OSB-0.0111'	'FG-K'	'GB-0.0079'
1567	'OSB-0.0111'	'FG-K'	'GB-0.0095'
1568	'OSB-0.0111'	'FG-K'	'GB-0.0127'
1569	'OSB-0.0111'	'FG-K'	'GB-0.0159'
1570	'OSB-0.0111'	'FG-K'	'GB-0.0191'
1571	'OSB-0.0111'	'FG-K'	'GB-0.0254'
1572	'OSB-0.0111'	'FG-K'	'PW-0.0064'
1573	'OSB-0.0111'	'FG-K'	'PW-0.0095'
1574	'OSB-0.0111'	'FG-K'	'PW-0.0127'
1575	'OSB-0.0111'	'FG-K'	'PW-0.0159'
1576	'OSB-0.0111'	'FG-K'	'PW-0.0175'
1577	'OSB-0.0111'	'FG-K'	'OSB-0.0095'
1578	'OSB-0.0111'	'FG-K'	'OSB-0.0111'
1579	'OSB-0.0111'	'FG-K'	'OSB-0.0127'
1580	'OSB-0.0111'	'FG-K'	'OSB-0.0159'
1581	'OSB-0.0111'	'FG-K'	'OSB-0.0191'
1582	'OSB-0.0111'	'RW-B'	'GB-0.0064'
1583	'OSB-0.0111'	'RW-B'	'GB-0.0079'
1584	'OSB-0.0111'	'RW-B'	'GB-0.0095'
1585	'OSB-0.0111'	'RW-B'	'GB-0.0127'
1586	'OSB-0.0111'	'RW-B'	'GB-0.0159'
1587	'OSB-0.0111'	'RW-B'	'GB-0.0191'

1588	'OSB-0.0111'	'RW-B'	'GB-0.0254'
1589	'OSB-0.0111'	'RW-B'	'PW-0.0064'
1590	'OSB-0.0111'	'RW-B'	'PW-0.0095'
1591	'OSB-0.0111'	'RW-B'	'PW-0.0127'
1592	'OSB-0.0111'	'RW-B'	'PW-0.0159'
1593	'OSB-0.0111'	'RW-B'	'PW-0.0175'
1594	'OSB-0.0111'	'RW-B'	'OSB-0.0095'
1595	'OSB-0.0111'	'RW-B'	'OSB-0.0111'
1596	'OSB-0.0111'	'RW-B'	'OSB-0.0127'
1597	'OSB-0.0111'	'RW-B'	'OSB-0.0159'
1598	'OSB-0.0111'	'RW-B'	'OSB-0.0191'
1599	'OSB-0.0111'	'C-B'	'GB-0.0064'
1600	'OSB-0.0111'	'C-B'	'GB-0.0079'
1601	'OSB-0.0111'	'C-B'	'GB-0.0095'
1602	'OSB-0.0111'	'C-B'	'GB-0.0127'
1603	'OSB-0.0111'	'C-B'	'GB-0.0159'
1604	'OSB-0.0111'	'C-B'	'GB-0.0191'
1605	'OSB-0.0111'	'C-B'	'GB-0.0254'
1606	'OSB-0.0111'	'C-B'	'PW-0.0064'
1607	'OSB-0.0111'	'C-B'	'PW-0.0095'
1608	'OSB-0.0111'	'C-B'	'PW-0.0127'
1609	'OSB-0.0111'	'C-B'	'PW-0.0159'
1610	'OSB-0.0111'	'C-B'	'PW-0.0175'
1611	'OSB-0.0111'	'C-B'	'OSB-0.0095'
1612	'OSB-0.0111'	'C-B'	'OSB-0.0111'
1613	'OSB-0.0111'	'C-B'	'OSB-0.0127'
1614	'OSB-0.0111'	'C-B'	'OSB-0.0159'
1615	'OSB-0.0111'	'C-B'	'OSB-0.0191'
1616	'OSB-0.0111'	'SPF-OC'	'GB-0.0064'
1617	'OSB-0.0111'	'SPF-OC'	'GB-0.0079'
1618	'OSB-0.0111'	'SPF-OC'	'GB-0.0095'
1619	'OSB-0.0111'	'SPF-OC'	'GB-0.0127'
1620	'OSB-0.0111'	'SPF-OC'	'GB-0.0159'
1621	'OSB-0.0111'	'SPF-OC'	'GB-0.0191'
1622	'OSB-0.0111'	'SPF-OC'	'GB-0.0254'
1623	'OSB-0.0111'	'SPF-OC'	'PW-0.0064'
1624	'OSB-0.0111'	'SPF-OC'	'PW-0.0095'
1625	'OSB-0.0111'	'SPF-OC'	'PW-0.0127'
1626	'OSB-0.0111'	'SPF-OC'	'PW-0.0159'
1627	'OSB-0.0111'	'SPF-OC'	'PW-0.0175'
1628	'OSB-0.0111'	'SPF-OC'	'OSB-0.0095'
1629	'OSB-0.0111'	'SPF-OC'	'OSB-0.0111'
1630	'OSB-0.0111'	'SPF-OC'	'OSB-0.0127'

1631	'OSB-0.0111'	'SPF-OC'	'OSB-0.0159'
1632	'OSB-0.0111'	'SPF-OC'	'OSB-0.0191'
1633	'OSB-0.0111'	'SPF-CC'	'GB-0.0064'
1634	'OSB-0.0111'	'SPF-CC'	'GB-0.0079'
1635	'OSB-0.0111'	'SPF-CC'	'GB-0.0095'
1636	'OSB-0.0111'	'SPF-CC'	'GB-0.0127'
1637	'OSB-0.0111'	'SPF-CC'	'GB-0.0159'
1638	'OSB-0.0111'	'SPF-CC'	'GB-0.0191'
1639	'OSB-0.0111'	'SPF-CC'	'GB-0.0254'
1640	'OSB-0.0111'	'SPF-CC'	'PW-0.0064'
1641	'OSB-0.0111'	'SPF-CC'	'PW-0.0095'
1642	'OSB-0.0111'	'SPF-CC'	'PW-0.0127'
1643	'OSB-0.0111'	'SPF-CC'	'PW-0.0159'
1644	'OSB-0.0111'	'SPF-CC'	'PW-0.0175'
1645	'OSB-0.0111'	'SPF-CC'	'OSB-0.0095'
1646	'OSB-0.0111'	'SPF-CC'	'OSB-0.0111'
1647	'OSB-0.0111'	'SPF-CC'	'OSB-0.0127'
1648	'OSB-0.0111'	'SPF-CC'	'OSB-0.0159'
1649	'OSB-0.0111'	'SPF-CC'	'OSB-0.0191'
1650	'OSB-0.0111'	'XPS'	'GB-0.0064'
1651	'OSB-0.0111'	'XPS'	'GB-0.0079'
1652	'OSB-0.0111'	'XPS'	'GB-0.0095'
1653	'OSB-0.0111'	'XPS'	'GB-0.0127'
1654	'OSB-0.0111'	'XPS'	'GB-0.0159'
1655	'OSB-0.0111'	'XPS'	'GB-0.0191'
1656	'OSB-0.0111'	'XPS'	'GB-0.0254'
1657	'OSB-0.0111'	'XPS'	'PW-0.0064'
1658	'OSB-0.0111'	'XPS'	'PW-0.0095'
1659	'OSB-0.0111'	'XPS'	'PW-0.0127'
1660	'OSB-0.0111'	'XPS'	'PW-0.0159'
1661	'OSB-0.0111'	'XPS'	'PW-0.0175'
1662	'OSB-0.0111'	'XPS'	'OSB-0.0095'
1663	'OSB-0.0111'	'XPS'	'OSB-0.0111'
1664	'OSB-0.0111'	'XPS'	'OSB-0.0127'
1665	'OSB-0.0111'	'XPS'	'OSB-0.0159'
1666	'OSB-0.0111'	'XPS'	'OSB-0.0191'
1667	'OSB-0.0127'	'FG-U'	'GB-0.0064'
1668	'OSB-0.0127'	'FG-U'	'GB-0.0079'
1669	'OSB-0.0127'	'FG-U'	'GB-0.0095'
1670	'OSB-0.0127'	'FG-U'	'GB-0.0127'
1671	'OSB-0.0127'	'FG-U'	'GB-0.0159'
1672	'OSB-0.0127'	'FG-U'	'GB-0.0191'
1673	'OSB-0.0127'	'FG-U'	'GB-0.0254'

1674	'OSB-0.0127'	'FG-U'	'PW-0.0064'
1675	'OSB-0.0127'	'FG-U'	'PW-0.0095'
1676	'OSB-0.0127'	'FG-U'	'PW-0.0127'
1677	'OSB-0.0127'	'FG-U'	'PW-0.0159'
1678	'OSB-0.0127'	'FG-U'	'PW-0.0175'
1679	'OSB-0.0127'	'FG-U'	'OSB-0.0095'
1680	'OSB-0.0127'	'FG-U'	'OSB-0.0111'
1681	'OSB-0.0127'	'FG-U'	'OSB-0.0127'
1682	'OSB-0.0127'	'FG-U'	'OSB-0.0159'
1683	'OSB-0.0127'	'FG-U'	'OSB-0.0191'
1684	'OSB-0.0127'	'FG-K'	'GB-0.0064'
1685	'OSB-0.0127'	'FG-K'	'GB-0.0079'
1686	'OSB-0.0127'	'FG-K'	'GB-0.0095'
1687	'OSB-0.0127'	'FG-K'	'GB-0.0127'
1688	'OSB-0.0127'	'FG-K'	'GB-0.0159'
1689	'OSB-0.0127'	'FG-K'	'GB-0.0191'
1690	'OSB-0.0127'	'FG-K'	'GB-0.0254'
1691	'OSB-0.0127'	'FG-K'	'PW-0.0064'
1692	'OSB-0.0127'	'FG-K'	'PW-0.0095'
1693	'OSB-0.0127'	'FG-K'	'PW-0.0127'
1694	'OSB-0.0127'	'FG-K'	'PW-0.0159'
1695	'OSB-0.0127'	'FG-K'	'PW-0.0175'
1696	'OSB-0.0127'	'FG-K'	'OSB-0.0095'
1697	'OSB-0.0127'	'FG-K'	'OSB-0.0111'
1698	'OSB-0.0127'	'FG-K'	'OSB-0.0127'
1699	'OSB-0.0127'	'FG-K'	'OSB-0.0159'
1700	'OSB-0.0127'	'FG-K'	'OSB-0.0191'
1701	'OSB-0.0127'	'RW-B'	'GB-0.0064'
1702	'OSB-0.0127'	'RW-B'	'GB-0.0079'
1703	'OSB-0.0127'	'RW-B'	'GB-0.0095'
1704	'OSB-0.0127'	'RW-B'	'GB-0.0127'
1705	'OSB-0.0127'	'RW-B'	'GB-0.0159'
1706	'OSB-0.0127'	'RW-B'	'GB-0.0191'
1707	'OSB-0.0127'	'RW-B'	'GB-0.0254'
1708	'OSB-0.0127'	'RW-B'	'PW-0.0064'
1709	'OSB-0.0127'	'RW-B'	'PW-0.0095'
1710	'OSB-0.0127'	'RW-B'	'PW-0.0127'
1711	'OSB-0.0127'	'RW-B'	'PW-0.0159'
1712	'OSB-0.0127'	'RW-B'	'PW-0.0175'
1713	'OSB-0.0127'	'RW-B'	'OSB-0.0095'
1714	'OSB-0.0127'	'RW-B'	'OSB-0.0111'
1715	'OSB-0.0127'	'RW-B'	'OSB-0.0127'
1716	'OSB-0.0127'	'RW-B'	'OSB-0.0159'

1717	'OSB-0.0127'	'RW-B'	'OSB-0.0191'
1718	'OSB-0.0127'	'C-B'	'GB-0.0064'
1719	'OSB-0.0127'	'C-B'	'GB-0.0079'
1720	'OSB-0.0127'	'C-B'	'GB-0.0095'
1721	'OSB-0.0127'	'C-B'	'GB-0.0127'
1722	'OSB-0.0127'	'C-B'	'GB-0.0159'
1723	'OSB-0.0127'	'C-B'	'GB-0.0191'
1724	'OSB-0.0127'	'C-B'	'GB-0.0254'
1725	'OSB-0.0127'	'C-B'	'PW-0.0064'
1726	'OSB-0.0127'	'C-B'	'PW-0.0095'
1727	'OSB-0.0127'	'C-B'	'PW-0.0127'
1728	'OSB-0.0127'	'C-B'	'PW-0.0159'
1729	'OSB-0.0127'	'C-B'	'PW-0.0175'
1730	'OSB-0.0127'	'C-B'	'OSB-0.0095'
1731	'OSB-0.0127'	'C-B'	'OSB-0.0111'
1732	'OSB-0.0127'	'C-B'	'OSB-0.0127'
1733	'OSB-0.0127'	'C-B'	'OSB-0.0159'
1734	'OSB-0.0127'	'C-B'	'OSB-0.0191'
1735	'OSB-0.0127'	'SPF-OC'	'GB-0.0064'
1736	'OSB-0.0127'	'SPF-OC'	'GB-0.0079'
1737	'OSB-0.0127'	'SPF-OC'	'GB-0.0095'
1738	'OSB-0.0127'	'SPF-OC'	'GB-0.0127'
1739	'OSB-0.0127'	'SPF-OC'	'GB-0.0159'
1740	'OSB-0.0127'	'SPF-OC'	'GB-0.0191'
1741	'OSB-0.0127'	'SPF-OC'	'GB-0.0254'
1742	'OSB-0.0127'	'SPF-OC'	'PW-0.0064'
1743	'OSB-0.0127'	'SPF-OC'	'PW-0.0095'
1744	'OSB-0.0127'	'SPF-OC'	'PW-0.0127'
1745	'OSB-0.0127'	'SPF-OC'	'PW-0.0159'
1746	'OSB-0.0127'	'SPF-OC'	'PW-0.0175'
1747	'OSB-0.0127'	'SPF-OC'	'OSB-0.0095'
1748	'OSB-0.0127'	'SPF-OC'	'OSB-0.0111'
1749	'OSB-0.0127'	'SPF-OC'	'OSB-0.0127'
1750	'OSB-0.0127'	'SPF-OC'	'OSB-0.0159'
1751	'OSB-0.0127'	'SPF-OC'	'OSB-0.0191'
1752	'OSB-0.0127'	'SPF-CC'	'GB-0.0064'
1753	'OSB-0.0127'	'SPF-CC'	'GB-0.0079'
1754	'OSB-0.0127'	'SPF-CC'	'GB-0.0095'
1755	'OSB-0.0127'	'SPF-CC'	'GB-0.0127'
1756	'OSB-0.0127'	'SPF-CC'	'GB-0.0159'
1757	'OSB-0.0127'	'SPF-CC'	'GB-0.0191'
1758	'OSB-0.0127'	'SPF-CC'	'GB-0.0254'
1759	'OSB-0.0127'	'SPF-CC'	'PW-0.0064'

1760	'OSB-0.0127'	'SPF-CC'	'PW-0.0095'
1761	'OSB-0.0127'	'SPF-CC'	'PW-0.0127'
1762	'OSB-0.0127'	'SPF-CC'	'PW-0.0159'
1763	'OSB-0.0127'	'SPF-CC'	'PW-0.0175'
1764	'OSB-0.0127'	'SPF-CC'	'OSB-0.0095'
1765	'OSB-0.0127'	'SPF-CC'	'OSB-0.0111'
1766	'OSB-0.0127'	'SPF-CC'	'OSB-0.0127'
1767	'OSB-0.0127'	'SPF-CC'	'OSB-0.0159'
1768	'OSB-0.0127'	'SPF-CC'	'OSB-0.0191'
1769	'OSB-0.0127'	'XPS'	'GB-0.0064'
1770	'OSB-0.0127'	'XPS'	'GB-0.0079'
1771	'OSB-0.0127'	'XPS'	'GB-0.0095'
1772	'OSB-0.0127'	'XPS'	'GB-0.0127'
1773	'OSB-0.0127'	'XPS'	'GB-0.0159'
1774	'OSB-0.0127'	'XPS'	'GB-0.0191'
1775	'OSB-0.0127'	'XPS'	'GB-0.0254'
1776	'OSB-0.0127'	'XPS'	'PW-0.0064'
1777	'OSB-0.0127'	'XPS'	'PW-0.0095'
1778	'OSB-0.0127'	'XPS'	'PW-0.0127'
1779	'OSB-0.0127'	'XPS'	'PW-0.0159'
1780	'OSB-0.0127'	'XPS'	'PW-0.0175'
1781	'OSB-0.0127'	'XPS'	'OSB-0.0095'
1782	'OSB-0.0127'	'XPS'	'OSB-0.0111'
1783	'OSB-0.0127'	'XPS'	'OSB-0.0127'
1784	'OSB-0.0127'	'XPS'	'OSB-0.0159'
1785	'OSB-0.0127'	'XPS'	'OSB-0.0191'
1786	'OSB-0.0159'	'FG-U'	'GB-0.0064'
1787	'OSB-0.0159'	'FG-U'	'GB-0.0079'
1788	'OSB-0.0159'	'FG-U'	'GB-0.0095'
1789	'OSB-0.0159'	'FG-U'	'GB-0.0127'
1790	'OSB-0.0159'	'FG-U'	'GB-0.0159'
1791	'OSB-0.0159'	'FG-U'	'GB-0.0191'
1792	'OSB-0.0159'	'FG-U'	'GB-0.0254'
1793	'OSB-0.0159'	'FG-U'	'PW-0.0064'
1794	'OSB-0.0159'	'FG-U'	'PW-0.0095'
1795	'OSB-0.0159'	'FG-U'	'PW-0.0127'
1796	'OSB-0.0159'	'FG-U'	'PW-0.0159'
1797	'OSB-0.0159'	'FG-U'	'PW-0.0175'
1798	'OSB-0.0159'	'FG-U'	'OSB-0.0095'
1799	'OSB-0.0159'	'FG-U'	'OSB-0.0111'
1800	'OSB-0.0159'	'FG-U'	'OSB-0.0127'
1801	'OSB-0.0159'	'FG-U'	'OSB-0.0159'
1802	'OSB-0.0159'	'FG-U'	'OSB-0.0191'

1803	'OSB-0.0159'	'FG-K'	'GB-0.0064'
1804	'OSB-0.0159'	'FG-K'	'GB-0.0079'
1805	'OSB-0.0159'	'FG-K'	'GB-0.0095'
1806	'OSB-0.0159'	'FG-K'	'GB-0.0127'
1807	'OSB-0.0159'	'FG-K'	'GB-0.0159'
1808	'OSB-0.0159'	'FG-K'	'GB-0.0191'
1809	'OSB-0.0159'	'FG-K'	'GB-0.0254'
1810	'OSB-0.0159'	'FG-K'	'PW-0.0064'
1811	'OSB-0.0159'	'FG-K'	'PW-0.0095'
1812	'OSB-0.0159'	'FG-K'	'PW-0.0127'
1813	'OSB-0.0159'	'FG-K'	'PW-0.0159'
1814	'OSB-0.0159'	'FG-K'	'PW-0.0175'
1815	'OSB-0.0159'	'FG-K'	'OSB-0.0095'
1816	'OSB-0.0159'	'FG-K'	'OSB-0.0111'
1817	'OSB-0.0159'	'FG-K'	'OSB-0.0127'
1818	'OSB-0.0159'	'FG-K'	'OSB-0.0159'
1819	'OSB-0.0159'	'FG-K'	'OSB-0.0191'
1820	'OSB-0.0159'	'RW-B'	'GB-0.0064'
1821	'OSB-0.0159'	'RW-B'	'GB-0.0079'
1822	'OSB-0.0159'	'RW-B'	'GB-0.0095'
1823	'OSB-0.0159'	'RW-B'	'GB-0.0127'
1824	'OSB-0.0159'	'RW-B'	'GB-0.0159'
1825	'OSB-0.0159'	'RW-B'	'GB-0.0191'
1826	'OSB-0.0159'	'RW-B'	'GB-0.0254'
1827	'OSB-0.0159'	'RW-B'	'PW-0.0064'
1828	'OSB-0.0159'	'RW-B'	'PW-0.0095'
1829	'OSB-0.0159'	'RW-B'	'PW-0.0127'
1830	'OSB-0.0159'	'RW-B'	'PW-0.0159'
1831	'OSB-0.0159'	'RW-B'	'PW-0.0175'
1832	'OSB-0.0159'	'RW-B'	'OSB-0.0095'
1833	'OSB-0.0159'	'RW-B'	'OSB-0.0111'
1834	'OSB-0.0159'	'RW-B'	'OSB-0.0127'
1835	'OSB-0.0159'	'RW-B'	'OSB-0.0159'
1836	'OSB-0.0159'	'RW-B'	'OSB-0.0191'
1837	'OSB-0.0159'	'C-B'	'GB-0.0064'
1838	'OSB-0.0159'	'C-B'	'GB-0.0079'
1839	'OSB-0.0159'	'C-B'	'GB-0.0095'
1840	'OSB-0.0159'	'C-B'	'GB-0.0127'
1841	'OSB-0.0159'	'C-B'	'GB-0.0159'
1842	'OSB-0.0159'	'C-B'	'GB-0.0191'
1843	'OSB-0.0159'	'C-B'	'GB-0.0254'
1844	'OSB-0.0159'	'C-B'	'PW-0.0064'
1845	'OSB-0.0159'	'C-B'	'PW-0.0095'

1846	'OSB-0.0159'	'C-B'	'PW-0.0127'
1847	'OSB-0.0159'	'C-B'	'PW-0.0159'
1848	'OSB-0.0159'	'C-B'	'PW-0.0175'
1849	'OSB-0.0159'	'C-B'	'OSB-0.0095'
1850	'OSB-0.0159'	'C-B'	'OSB-0.0111'
1851	'OSB-0.0159'	'C-B'	'OSB-0.0127'
1852	'OSB-0.0159'	'C-B'	'OSB-0.0159'
1853	'OSB-0.0159'	'C-B'	'OSB-0.0191'
1854	'OSB-0.0159'	'SPF-OC'	'GB-0.0064'
1855	'OSB-0.0159'	'SPF-OC'	'GB-0.0079'
1856	'OSB-0.0159'	'SPF-OC'	'GB-0.0095'
1857	'OSB-0.0159'	'SPF-OC'	'GB-0.0127'
1858	'OSB-0.0159'	'SPF-OC'	'GB-0.0159'
1859	'OSB-0.0159'	'SPF-OC'	'GB-0.0191'
1860	'OSB-0.0159'	'SPF-OC'	'GB-0.0254'
1861	'OSB-0.0159'	'SPF-OC'	'PW-0.0064'
1862	'OSB-0.0159'	'SPF-OC'	'PW-0.0095'
1863	'OSB-0.0159'	'SPF-OC'	'PW-0.0127'
1864	'OSB-0.0159'	'SPF-OC'	'PW-0.0159'
1865	'OSB-0.0159'	'SPF-OC'	'PW-0.0175'
1866	'OSB-0.0159'	'SPF-OC'	'OSB-0.0095'
1867	'OSB-0.0159'	'SPF-OC'	'OSB-0.0111'
1868	'OSB-0.0159'	'SPF-OC'	'OSB-0.0127'
1869	'OSB-0.0159'	'SPF-OC'	'OSB-0.0159'
1870	'OSB-0.0159'	'SPF-OC'	'OSB-0.0191'
1871	'OSB-0.0159'	'SPF-CC'	'GB-0.0064'
1872	'OSB-0.0159'	'SPF-CC'	'GB-0.0079'
1873	'OSB-0.0159'	'SPF-CC'	'GB-0.0095'
1874	'OSB-0.0159'	'SPF-CC'	'GB-0.0127'
1875	'OSB-0.0159'	'SPF-CC'	'GB-0.0159'
1876	'OSB-0.0159'	'SPF-CC'	'GB-0.0191'
1877	'OSB-0.0159'	'SPF-CC'	'GB-0.0254'
1878	'OSB-0.0159'	'SPF-CC'	'PW-0.0064'
1879	'OSB-0.0159'	'SPF-CC'	'PW-0.0095'
1880	'OSB-0.0159'	'SPF-CC'	'PW-0.0127'
1881	'OSB-0.0159'	'SPF-CC'	'PW-0.0159'
1882	'OSB-0.0159'	'SPF-CC'	'PW-0.0175'
1883	'OSB-0.0159'	'SPF-CC'	'OSB-0.0095'
1884	'OSB-0.0159'	'SPF-CC'	'OSB-0.0111'
1885	'OSB-0.0159'	'SPF-CC'	'OSB-0.0127'
1886	'OSB-0.0159'	'SPF-CC'	'OSB-0.0159'
1887	'OSB-0.0159'	'SPF-CC'	'OSB-0.0191'
1888	'OSB-0.0159'	'XPS'	'GB-0.0064'

1889	'OSB-0.0159'	'XPS'	'GB-0.0079'
1890	'OSB-0.0159'	'XPS'	'GB-0.0095'
1891	'OSB-0.0159'	'XPS'	'GB-0.0127'
1892	'OSB-0.0159'	'XPS'	'GB-0.0159'
1893	'OSB-0.0159'	'XPS'	'GB-0.0191'
1894	'OSB-0.0159'	'XPS'	'GB-0.0254'
1895	'OSB-0.0159'	'XPS'	'PW-0.0064'
1896	'OSB-0.0159'	'XPS'	'PW-0.0095'
1897	'OSB-0.0159'	'XPS'	'PW-0.0127'
1898	'OSB-0.0159'	'XPS'	'PW-0.0159'
1899	'OSB-0.0159'	'XPS'	'PW-0.0175'
1900	'OSB-0.0159'	'XPS'	'OSB-0.0095'
1901	'OSB-0.0159'	'XPS'	'OSB-0.0111'
1902	'OSB-0.0159'	'XPS'	'OSB-0.0127'
1903	'OSB-0.0159'	'XPS'	'OSB-0.0159'
1904	'OSB-0.0159'	'XPS'	'OSB-0.0191'
1905	'OSB-0.0191'	'FG-U'	'GB-0.0064'
1906	'OSB-0.0191'	'FG-U'	'GB-0.0079'
1907	'OSB-0.0191'	'FG-U'	'GB-0.0095'
1908	'OSB-0.0191'	'FG-U'	'GB-0.0127'
1909	'OSB-0.0191'	'FG-U'	'GB-0.0159'
1910	'OSB-0.0191'	'FG-U'	'GB-0.0191'
1911	'OSB-0.0191'	'FG-U'	'GB-0.0254'
1912	'OSB-0.0191'	'FG-U'	'PW-0.0064'
1913	'OSB-0.0191'	'FG-U'	'PW-0.0095'
1914	'OSB-0.0191'	'FG-U'	'PW-0.0127'
1915	'OSB-0.0191'	'FG-U'	'PW-0.0159'
1916	'OSB-0.0191'	'FG-U'	'PW-0.0175'
1917	'OSB-0.0191'	'FG-U'	'OSB-0.0095'
1918	'OSB-0.0191'	'FG-U'	'OSB-0.0111'
1919	'OSB-0.0191'	'FG-U'	'OSB-0.0127'
1920	'OSB-0.0191'	'FG-U'	'OSB-0.0159'
1921	'OSB-0.0191'	'FG-U'	'OSB-0.0191'
1922	'OSB-0.0191'	'FG-K'	'GB-0.0064'
1923	'OSB-0.0191'	'FG-K'	'GB-0.0079'
1924	'OSB-0.0191'	'FG-K'	'GB-0.0095'
1925	'OSB-0.0191'	'FG-K'	'GB-0.0127'
1926	'OSB-0.0191'	'FG-K'	'GB-0.0159'
1927	'OSB-0.0191'	'FG-K'	'GB-0.0191'
1928	'OSB-0.0191'	'FG-K'	'GB-0.0254'
1929	'OSB-0.0191'	'FG-K'	'PW-0.0064'
1930	'OSB-0.0191'	'FG-K'	'PW-0.0095'
1931	'OSB-0.0191'	'FG-K'	'PW-0.0127'

1932	'OSB-0.0191'	'FG-K'	'PW-0.0159'
1933	'OSB-0.0191'	'FG-K'	'PW-0.0175'
1934	'OSB-0.0191'	'FG-K'	'OSB-0.0095'
1935	'OSB-0.0191'	'FG-K'	'OSB-0.0111'
1936	'OSB-0.0191'	'FG-K'	'OSB-0.0127'
1937	'OSB-0.0191'	'FG-K'	'OSB-0.0159'
1938	'OSB-0.0191'	'FG-K'	'OSB-0.0191'
1939	'OSB-0.0191'	'RW-B'	'GB-0.0064'
1940	'OSB-0.0191'	'RW-B'	'GB-0.0079'
1941	'OSB-0.0191'	'RW-B'	'GB-0.0095'
1942	'OSB-0.0191'	'RW-B'	'GB-0.0127'
1943	'OSB-0.0191'	'RW-B'	'GB-0.0159'
1944	'OSB-0.0191'	'RW-B'	'GB-0.0191'
1945	'OSB-0.0191'	'RW-B'	'GB-0.0254'
1946	'OSB-0.0191'	'RW-B'	'PW-0.0064'
1947	'OSB-0.0191'	'RW-B'	'PW-0.0095'
1948	'OSB-0.0191'	'RW-B'	'PW-0.0127'
1949	'OSB-0.0191'	'RW-B'	'PW-0.0159'
1950	'OSB-0.0191'	'RW-B'	'PW-0.0175'
1951	'OSB-0.0191'	'RW-B'	'OSB-0.0095'
1952	'OSB-0.0191'	'RW-B'	'OSB-0.0111'
1953	'OSB-0.0191'	'RW-B'	'OSB-0.0127'
1954	'OSB-0.0191'	'RW-B'	'OSB-0.0159'
1955	'OSB-0.0191'	'RW-B'	'OSB-0.0191'
1956	'OSB-0.0191'	'C-B'	'GB-0.0064'
1957	'OSB-0.0191'	'C-B'	'GB-0.0079'
1958	'OSB-0.0191'	'C-B'	'GB-0.0095'
1959	'OSB-0.0191'	'C-B'	'GB-0.0127'
1960	'OSB-0.0191'	'C-B'	'GB-0.0159'
1961	'OSB-0.0191'	'C-B'	'GB-0.0191'
1962	'OSB-0.0191'	'C-B'	'GB-0.0254'
1963	'OSB-0.0191'	'C-B'	'PW-0.0064'
1964	'OSB-0.0191'	'C-B'	'PW-0.0095'
1965	'OSB-0.0191'	'C-B'	'PW-0.0127'
1966	'OSB-0.0191'	'C-B'	'PW-0.0159'
1967	'OSB-0.0191'	'C-B'	'PW-0.0175'
1968	'OSB-0.0191'	'C-B'	'OSB-0.0095'
1969	'OSB-0.0191'	'C-B'	'OSB-0.0111'
1970	'OSB-0.0191'	'C-B'	'OSB-0.0127'
1971	'OSB-0.0191'	'C-B'	'OSB-0.0159'
1972	'OSB-0.0191'	'C-B'	'OSB-0.0191'
1973	'OSB-0.0191'	'SPF-OC'	'GB-0.0064'
1974	'OSB-0.0191'	'SPF-OC'	'GB-0.0079'

1975	'OSB-0.0191'	'SPF-OC'	'GB-0.0095'
1976	'OSB-0.0191'	'SPF-OC'	'GB-0.0127'
1977	'OSB-0.0191'	'SPF-OC'	'GB-0.0159'
1978	'OSB-0.0191'	'SPF-OC'	'GB-0.0191'
1979	'OSB-0.0191'	'SPF-OC'	'GB-0.0254'
1980	'OSB-0.0191'	'SPF-OC'	'PW-0.0064'
1981	'OSB-0.0191'	'SPF-OC'	'PW-0.0095'
1982	'OSB-0.0191'	'SPF-OC'	'PW-0.0127'
1983	'OSB-0.0191'	'SPF-OC'	'PW-0.0159'
1984	'OSB-0.0191'	'SPF-OC'	'PW-0.0175'
1985	'OSB-0.0191'	'SPF-OC'	'OSB-0.0095'
1986	'OSB-0.0191'	'SPF-OC'	'OSB-0.0111'
1987	'OSB-0.0191'	'SPF-OC'	'OSB-0.0127'
1988	'OSB-0.0191'	'SPF-OC'	'OSB-0.0159'
1989	'OSB-0.0191'	'SPF-OC'	'OSB-0.0191'
1990	'OSB-0.0191'	'SPF-CC'	'GB-0.0064'
1991	'OSB-0.0191'	'SPF-CC'	'GB-0.0079'
1992	'OSB-0.0191'	'SPF-CC'	'GB-0.0095'
1993	'OSB-0.0191'	'SPF-CC'	'GB-0.0127'
1994	'OSB-0.0191'	'SPF-CC'	'GB-0.0159'
1995	'OSB-0.0191'	'SPF-CC'	'GB-0.0191'
1996	'OSB-0.0191'	'SPF-CC'	'GB-0.0254'
1997	'OSB-0.0191'	'SPF-CC'	'PW-0.0064'
1998	'OSB-0.0191'	'SPF-CC'	'PW-0.0095'
1999	'OSB-0.0191'	'SPF-CC'	'PW-0.0127'
2000	'OSB-0.0191'	'SPF-CC'	'PW-0.0159'
2001	'OSB-0.0191'	'SPF-CC'	'PW-0.0175'
2002	'OSB-0.0191'	'SPF-CC'	'OSB-0.0095'
2003	'OSB-0.0191'	'SPF-CC'	'OSB-0.0111'
2004	'OSB-0.0191'	'SPF-CC'	'OSB-0.0127'
2005	'OSB-0.0191'	'SPF-CC'	'OSB-0.0159'
2006	'OSB-0.0191'	'SPF-CC'	'OSB-0.0191'
2007	'OSB-0.0191'	'XPS'	'GB-0.0064'
2008	'OSB-0.0191'	'XPS'	'GB-0.0079'
2009	'OSB-0.0191'	'XPS'	'GB-0.0095'
2010	'OSB-0.0191'	'XPS'	'GB-0.0127'
2011	'OSB-0.0191'	'XPS'	'GB-0.0159'
2012	'OSB-0.0191'	'XPS'	'GB-0.0191'
2013	'OSB-0.0191'	'XPS'	'GB-0.0254'
2014	'OSB-0.0191'	'XPS'	'PW-0.0064'
2015	'OSB-0.0191'	'XPS'	'PW-0.0095'
2016	'OSB-0.0191'	'XPS'	'PW-0.0127'
2017	'OSB-0.0191'	'XPS'	'PW-0.0159'

2018	'OSB-0.0191'	'XPS'	'PW-0.0175'
2019	'OSB-0.0191'	'XPS'	'OSB-0.0095'
2020	'OSB-0.0191'	'XPS'	'OSB-0.0111'
2021	'OSB-0.0191'	'XPS'	'OSB-0.0127'
2022	'OSB-0.0191'	'XPS'	'OSB-0.0159'
2023	'OSB-0.0191'	'XPS'	'OSB-0.0191'