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Experimental study on fire safety of chimneys in real use and actual site conditions

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A B S T R A C T

In recent years, numerous building fires have occurred in Finland where the fire has started due to the ignition of flammable materials in the vicinity of metal chimney penetrations through floors, roofs and walls. Based on onsite observations and experimental studies, one possible reason for the ignition is that the actual flue gas temperatures in real use in buildings are higher than those assumed for chimney design. An experimental study has been conducted in the TUT Fire Laboratory at Tampere University of Technology to determine the actual site conditions, identify the difference between the actual site conditions and the EN standard test conditions and assess whether the differences affect the fire safety of chimney penetrations. This paper describes the results of five site tests conducted in four different residential buildings and a sauna. The results revealed that the actual use of fireplaces and site conditions may differ significantly from the test conditions of EN standards. The site tests demonstrated higher flue gas temperatures and stronger draughts than what specified for the EN standard tests. The flue gas temperatures measured onsite were 134° to 278 °C higher than the mean temperature indicated in the CE marking of the tested fireplaces. The results indicate that the flue gas temperatures given in the CE markings of fireplaces may be too low for the designing of chimneys. This may cause a fire hazard at chimney penetrations.

1. Introduction

Increasing attention has been given to sustainable and energy-efficient buildings which require efficient biomass-fired heating systems, insulation materials with better thermal properties and thicker thermal insulation layers over the building envelope. Sustainable development has also increased the use of biomass fuels, such as firewood and pellets, in the production of warmth energy for the heating and hot water supply of residential one- and multi-dwelling buildings. In advanced systems, biomass installations are a part of a fully integrated system, including solar power and geothermal heating. With this development, interest to fireplaces has increased in many countries. In Finland, for example, approximately one fifth of all detached, semi-detached and terraced houses have wood-fired heating. Almost all new one-family houses have a fireplace that is generally used as a secondary heat source. The use of firewood and pellets has increased 20% in 15 years, and they provided approximately 40% of the heating energy consumed by detached houses in 2007–2008 [1]. In Sweden, biomass fuels have also accounted for a large increase, and consumption was approximately 35% in 2013 [2].

The use of fireplaces affects buildings' fire safety. Despite mandatory certification procedures, a high number of fires due to the presence of chimneys has been reported in some European countries. For example, in Finland, 700–900 building fires caused by fireplaces and chimneys have been reported annually [3–5]. Similar fire-safety problems have been reported in other European countries [6]. In the United States, the majority of residential fires involve solid-fuelled equipment, and fires are caused by the ignition of structural-frame components [7]. Prefabricated metal chimneys are relatively new products in Finland, and the majority of the metal chimneys in Finland are less than 10 years old. Based on a study by Leppänen [8], the number of fires caused by metal chimneys in Finland was high from 2004 to 2009. In 2012, metal chimneys caused over 70% of all chimney-induced fires in residential buildings in Finland [9]. The safety issue with metal chimneys is important, as they represent only 10% of all chimneys in Finland [10,11].

The new energy regulations have increased the thickness of thermal insulation materials in buildings and the air tightness of structures, which has increased the temperatures and risk of overheating the wood framing or other combustible materials adjacent to fireplaces and chimneys. Critical details for fire safety are where chimneys pass through floors, roofs and walls. Several reasons for chimney

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Fig. 1. Chimney roof penetration after fire.

penetration–induced fires have been identified: higher actual flue gas temperatures onsite than those assumed in chimney design, incomplete or insufficient chimney installations and the smouldering combustion of rockwool insulation [12]. Fig. 1 shows a site-survey picture from a roof space where the heat of a metal chimney has caused a fire. Thermal insulation of this roof consisted of 300 mm thick layer of sawdust overlaid by an additional 100 mm thick layer of blown cellulose insulation. A 100 mm thick penetration insulation of mineral wool was used to isolate flammable materials from the hot surface of the chimney. In this particular case, the penetration insulation was not sufficient and the cellulose insulation ignited and started a fire.

Fireplaces and chimneys are tested in accordance with EN standards. The standard tests are conducted in predefined laboratory conditions. The actual conditions onsite may be very different from the laboratory conditions. Site conditions vary, for example, due to fuel type and chimney-draught conditions, which depend on site, time, draught controls and the chimney's length and installation method. Chimney design based on EN standard tests should lead to a fire-safe solution. However, previous research on fireplaces has demonstrated that the flue gas temperature given in the CE marking of a fireplace may not always lead to a safe solution and should therefore not be used for the designing of a chimney [11]. Studies by Neri [13], Neri et al. [14–17] and Leppänen et al. [18] have shown that the standard test set-up and conditions are often different from the site installations.

To improve the fire safety of metal chimneys, an extensive research program was conducted in the TUT Fire Laboratory at Tampere University of Technology between 2010 and 2016. As part of the program, site tests were conducted to obtain better information on the actual flue gas temperatures and draught levels in real use in households. The aim of the research was to measure the actual flue gas temperatures and draught levels onsite, to determine the difference between the site and standard test conditions and to assess whether standard tests always lead to a fire-safe metal chimney penetration. In this paper, the results of five site tests conducted in four different residential buildings and a sauna are reported.

2. Testing in accordance with EN standards

CE marking of fireplaces is mandatory in European countries, and under the regulations, manufacturer's products are required to demonstrate compliance with laboratory tests by a notified test laboratory. Fireplaces are subjected to two different test: a nominal heat-output test and temperature-safety test in accordance with EN standards [19–22]. In the nominal heat-output test, the properties of the fireplace, such as efficiency, heat output, flue gas temperatures and emissions of the fireplace are determined. For the slow heat release appliances the test is called burning rate performance test. The temperature-safety test is used to demonstrate that the temperatures of the surfaces and structures nearby the fireplace do not exceed given limit values or ignition temperatures. Also for chimneys, two tests are required. Metal chimneys are tested in accordance with standard EN 1859 [23], which prescribes the heat stress test and thermal shock test to verify the safety distance between the outer face of the chimney and combustible materials. The purpose of the tests is to avoid overheating the materials in the chimney penetration area. In the chimney design, the temperature class based on the chimney tests must be equal or higher than the mean flue gas temperature recorded in the CE marking of the fireplace connected to the chimney.

The nominal heat-output test is performed at constant flue draught pressure following the manufacturer's recommendations regarding the test fuel, the burning rate and the combustion controls settings to be used to achieve the claimed nominal heat output during the test. The appliance is refuelled in accordance with manufacturer's instructions. Flue gas temperatures are measured during the test. The mean value of the flue gas temperatures measured is recorded to CE-marking to assist chimney design. In the temperature safety test higher draft level and a larger amount of firewood are used. The fire load of the temperature-safety test is specified by the standard either based on the size of the firebox [21,22] or on the fire load used in the nominal heat-output test [19,20]. In the temperature-safety test, a fireplace's flue draught is set to a constant value, 3 Pa higher than in the nominal heat-output test. Flue gas temperatures and draught levels are measured from a point approximately 1.4 m above the fireplace. Flue gas temperatures are not required in the temperature-safety test. The test arrangement is shown in Fig. 2a). The burning rate performance test and temperature-safety test results of a slow heat release appliance are shown in Fig. 3a. Fig. 3b shows the measured flue draught levels in the same tests.

In the heat stress test of metal chimney, hot gas is fed into the chimney. The temperature of hot gas depends on the temperature class specified for the chimney. The test structure consisting of two walls at right angles and two floors through which the test chimney passes. Temperatures within the floor construction are measured during the test and the test is maintain until an equilibrium is reached in the floor temperatures. It must be demonstrated that the surface temperatures at a safety distance specified by the manufacturer do not exceed 85 °C. The safety distance is measured from the outer surface of the chimney. In the thermal shock test, flue gas temperatures are kept at 1000 °C for 30 min. In the test criteria, the maximum surface temperatures measured inside the floor construction are limited to 100 °C. The manufacturer shall declare the minimum distance to combustible material and the performance need to be demonstrated by tests. The heat stress test is repeated after the thermal shock test. Test arrangement for metal chimneys is shown in Fig. 2b).

3. Previous research

3.1. Laboratory tests

Leppänen et al. [11] have studied the flue gas temperatures of fireplaces in laboratory conditions. Their study included a nominal heat-output test, a temperature-safety test, and extra heating, in which firewood batches larger than the recommended size were used to