# Iron Age houses in flames

## Testing house reconstructions at LEJRE

*Edited by Marianne Rasmussen*

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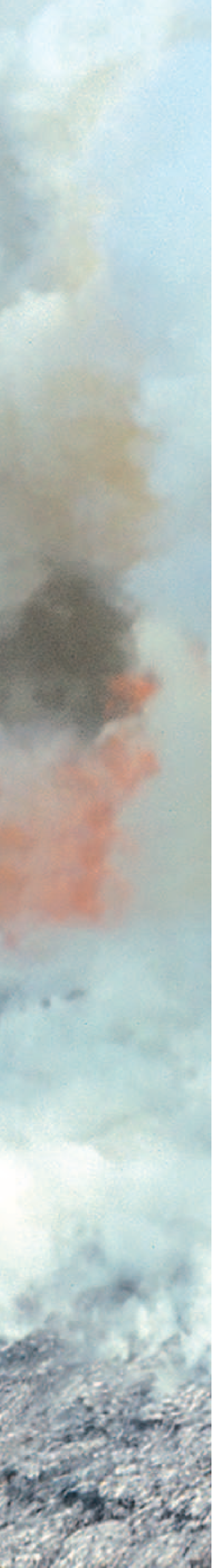

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*DVD*
1. Jernalderhus i flammer, 2007
   (main film, Danish version, 9 min)
2. Iron Age houses in flames, 2007
   (main film, English version, 9 min)
3. Building Iron Age houses, 1965
   (black and white, no sound, 27 min)
4. Original record of the experimental fire 1967,
   (colour, no sound, 6 min)
5. Spoken comments by Hans-Ole Hansen
   during the experimental fire, 1967,
   (original full length recording with
   complementary slides, 48 min).
   Danish version
6. Interview with Linda Boye, 1993
   (full length, 12 min). Danish version

Film recordings and editing by Ole Malling

Film recordings and editing 1965 and 1967 by
Arne Abrahamsen

Total length 1 hour and 51 minutes

# Contents

4 Preface

*Marianne Rasmussen*
6 Building houses and building theories – archaeological experiments and house reconstruction

*Jens N. Nielsen*
16 The burnt remains of a house from the Pre-Roman Iron Age at Nørre Tranders, Aalborg

*Hans-Ole Hansen*
32 The fire we started

*Lars Bjarke Christensen, Sofie E. Jensen, Anne Louise Lund Johansen, Pernille R. Johansen & Sara Lerager*
42 House 1 – experimental fire and archaeological excavation

*Anna Severine Beck, Lehne Mailund Christensen, Jannie Ebsen, Rune Brandt Larsen, Dyveke Larsen, Niels Algreen Møller, Tina Rasmussen, Lasse Sørensen & Leonora Thofte*
134 Reconstruction – and then what? Climatic experiments in reconstructed Iron Age houses during winter

*Nicolai Garhøj Larsen*
174 Virtual reconstruction – a tool for the future?

# Reconstruction – and then what?

## Climatic experiments in reconstructed Iron Age houses during winter

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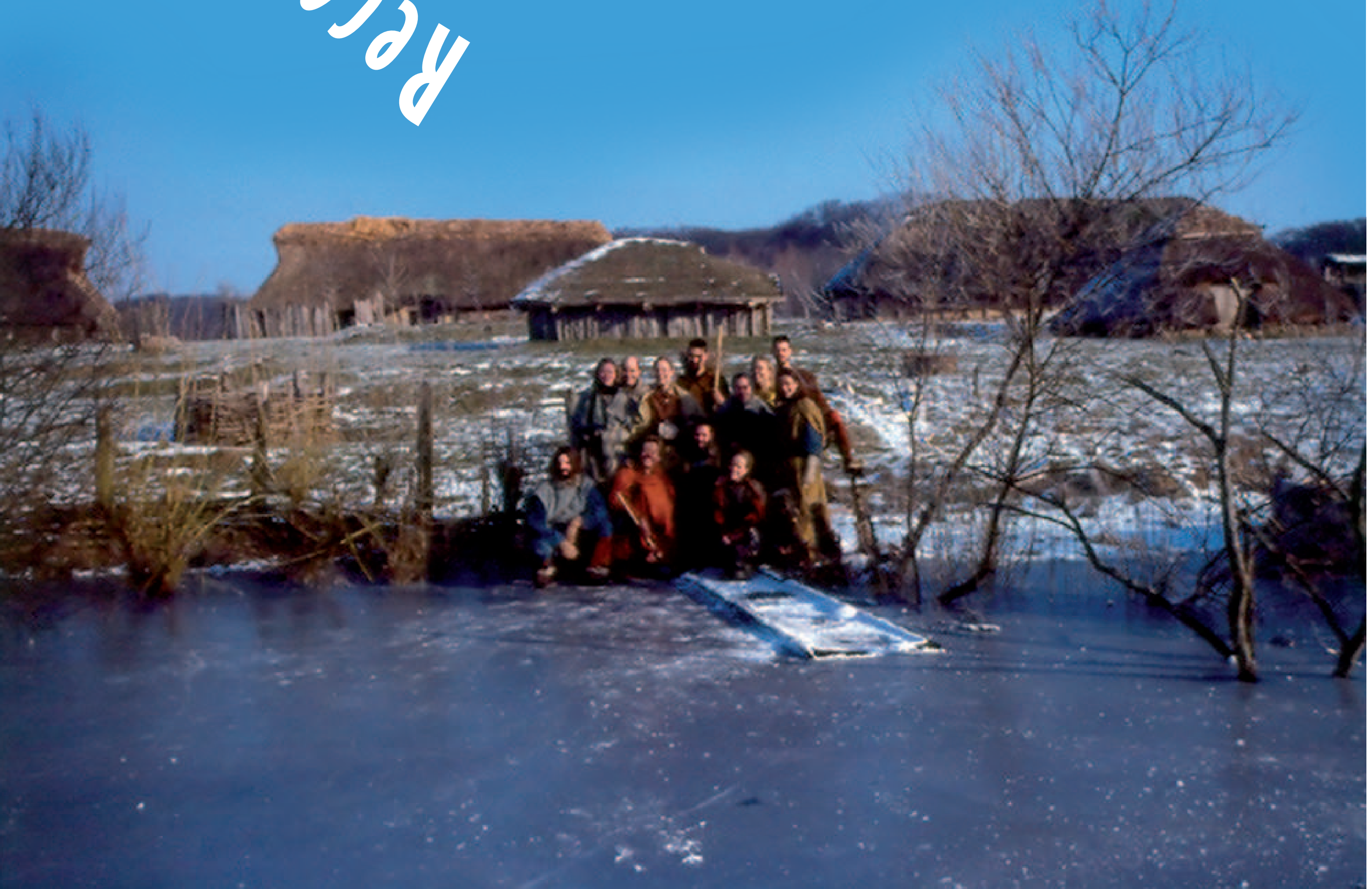


Figure 1
The experimental team involved in the 1999 experiments.

An Iron Age house can be used as a research tool in many different ways. It can be excavated, dated, fitted into typologies, analysed, reconstructed – and it can also be lived in as people did in the Iron Age. It can be difficult for modern people to picture how a house of this type functions in practice; one way to achieve this is to try living in the house for oneself.

Klima-X is the name of a series of habitation experiments carried out by a group of students from the Department of Prehistoric Archaeology, University of Copenhagen. The experiments took place during one week in February 1997, ten days in February 1998 and two weeks in February 1999. The aim of these experiments was to investigate the indoor climate and living conditions during winter in the reconstructed houses from the Early Iron Age built at Lejre Experimental Centre (figure 1, 2 & 3)[1].

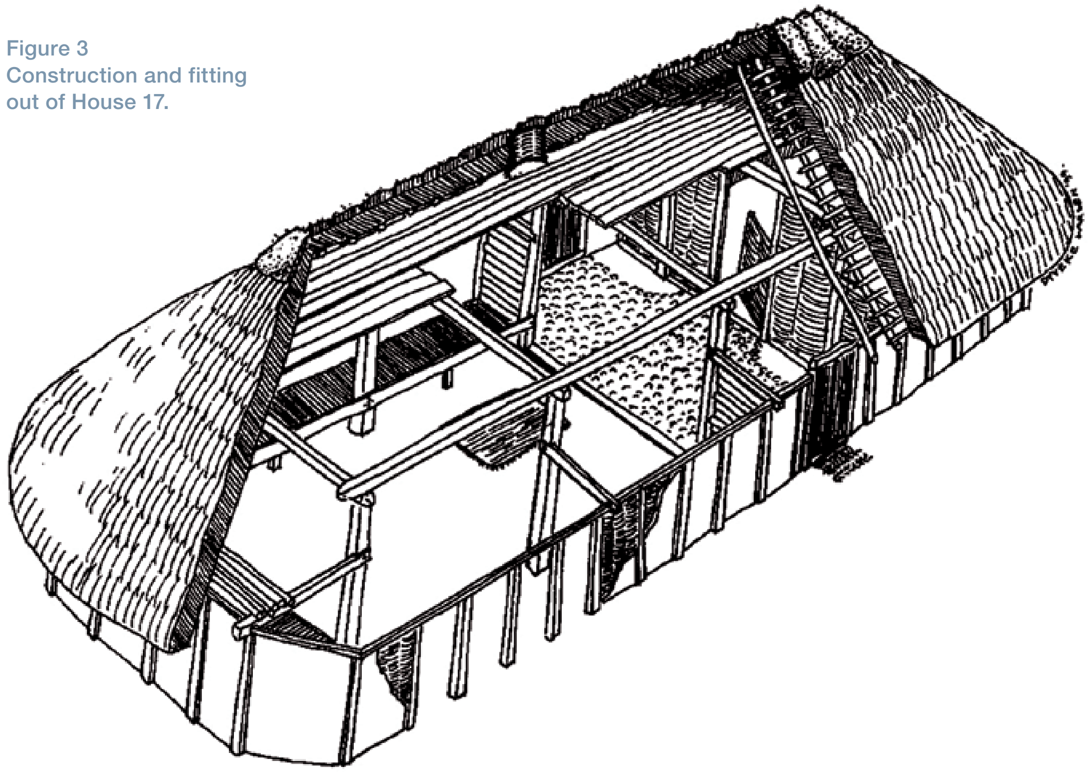
The reconstructions are used for living in and for activities every summer and therefore a good deal is known about how they function in warm and light conditions. But how do the reconstructions work in winter? Are they habitable, what is the indoor climate like and are they at all reasonable approximations to domestic buildings in the Iron Age? It was decided to carry out the experimental series as a contextual experiment in which as many factors as possible corresponded with the accepted interpretation of authentic Iron Age conditions. The aim was not, however, to recreate Iron Age life in all its variety. In this article, the applicability of this form of experiment will be argued for in greater depth.

The aims of this series of experiments relate to several problems and objectives at various levels of abstraction and in the following an attempt will be made to include as many of these as possible. The focus of this article will, however, primarily be on the reconstructions at Lejre Experimental Centre and only relevant results will be included. The article will give a comprehensive description of the indoor climate of the houses on the basis of both objective measurements and subjective evaluations. At a more general level, the empirical data will be used as the basis for a discussion of the reconstructed houses as they appear after their construction, periodic use and a few temporary changes. An experimental evaluation of the house of this kind is, in the opinion of the authors, a natural part of scientific studies involving archaeological reconstructions.

The point of departure for the series of experiments was some of the thoughts, ideas and assumptions that ordinarily occur with regard to Iron Age houses and conditions within them. None of us (for good reasons) has personal experience of life in the Iron Age, but most of us have some perceptions of it – perceptions originating from a broad spectrum of museums, archaeological theme parks, reconstructions, books – both fact and fiction, school teaching materials and various forms of more-or-less factual and objective archaeological communication and education. If these perceptions are formulated and repeated an adequate number

Figure 2
The Iron Age village at Lejre Experimental Centre. The two houses used in the experimental series are marked with their respective registration numbers.

Figure 3
Construction and fitting out of House 17.



of times, they can end up taking on the character of "truths", which become incorporated as an integrated and indisputable part of people's picture of the past; house reconstructions can also be influenced by this. In some instances they can also come to form the basis of scientific work and hereby further cement possible erroneous assumptions.

Examples of this include the widespread perception that livestock functioned as the house's heat source (Andersen 1999:33) and that the house was effectively lit by the fire in the hearth (Hvass 1980:40). Prior to the experiments, the authors were themselves convinced that the clay floor and the walls would retain heat when the house had been warmed up.

Ideas such as these should, of course, be tested against empirical observations in the source material – not just to discredit loosely founded perceptions but also to provide material for new hypotheses and ideas for the improvement of reconstructions.

By living in the reconstructed houses the authors have achieved a better understanding of living conditions and the indoor climate in an Iron Age house, as well as how various structural elements in the houses function. The following is an attempt to pass on this understanding.

## The houses at Lejre

When the first reconstructed Iron Age longhouses were built at Lejre Experimental Centre in 1964-65, one of the aims was to investigate important questions concerning building techniques and construction in the Iron Age. At the same time it was the intention that the houses should be used and tested so that Iron Age life in the buildings could also be investigated and presented. Accordingly, from the start both research and education were the basis for construction (Hansen 1964).

Very early in the history of Lejre Experimental Centre, teaching of school children about Iron Age life began to take place in the longhouses. The houses were also used as the physical framework for informing about Iron Age life and for practical tasks such as cooking on the hearth, looking after the livestock etc. The Centre still functions in the same way today and the houses also provide the setting for communication with, and activities for, the visiting public.

In the summer of 1970, the first so-called "prehistoric families" moved into the houses. Ordinary families volunteered to spend a week or more of their summer holiday "going back in time". This is still a popular way of holidaying for many families, and in the process a great body of knowledge has been accumulated about how the houses function during the summer. Throughout the life of the Experimental Centre, the houses have been used conscientiously and a great body of practical experience has been accumulated which today is invaluable. This practical experience feeds back into the reconstructions and often contributes to providing a frame of reference for the next building to be constructed.

## Habitation experiments – an historical perspective

Throughout the history of Lejre Experimental Centre the reconstructed Iron Age houses have also provided a framework for actual living experiments. In these, there has been a desire, by way of "objective measurement", to quantify and describe that which was "felt" and experienced practically (Hansen 1974:18).

Experiments were carried out in 1967 (Hansen et al. 1967), 1972 (Månsson 1972), 1975 (Hansen 1975a; Hansen 1975b), 1976 (Varmose 1976), 1990 (HAF 1990) and, most recently, the Klima-X series of experiments in 1997-99 (Klima-X 1997, 1998, 1999). Most of the experiments were carried out while people were living in the houses and, accordingly, created an "Iron Age situation" within the building. Some of the experiments were carried out in winter when the houses were challenged more, due to the extreme weather conditions.

The habitation experiments in the winters of 1967 and 1972 are almost directly comparable with the Klima-X experiments, where the aim was to measure temperatures and the influence of the weather on the house. In 1967, measurements were

taken over the course of about a week in January, and in 1972 measurements were taken over a period of 2½ months (January-April). The houses were, however, not inhabited during the whole of this period.

During both experiments there were animals in the byre and, as a rule, also a fire in the hearth when the measurements were taken. Both experiments produced a great deal of data which, unfortunately, have not yet been fully analysed. However, the preliminary results and conclusions correspond well with those from the Klima-X experimental series.

Common to all the early experiments is the fact that the results have not been published in detail. This was one of the main reasons that these results had virtually been forgotten at Lejre Experimental Centre when the Klima-X experiments began. As a consequence, the latter started almost from square one. When they began, in 1997, the experiments were, accordingly, a kind of pilot project in which procedures, problems and methods were to be clarified. In the subsequent years (1998 and 1999), the experiments were simplified by focussing on specific problems and reducing the number of variables. One of the main aims was to process and analyse the results thoroughly and to publish them such that they were accessible to a broader group of both professionals and laymen and could, in this way, form a basis for further experiments with the houses.

## The “contextual experiment” as a term

The way in which we chose to carry out the experiments is known as “contextual experiment”, an experimental approach which has been described by Marianne Rasmussen (Rasmussen 2001:6ff). In a contextual experiment there are, in contrast to a controlled experiment, many variables which all influence the experiment simultaneously. We chose, for example, to use the existing reconstruction, let it be influenced by the weather and live in the house in order to create as authentic an interior situation as possible as the basis for our experiments. The many variables were, therefore, in our case, wind and weather, open and closed doors when people entered or left the house, fires of various sizes for cooking, with and with out animals, with and without a loft etc.

The aim of contextual experiments is not to deliver a finished result but, on the contrary, to function as an “eye-opener” and as a source of inspiration, with practical experience being gained in the process. The reconstruction and the contextual experiment force choices to be made and new approaches to be adopted through their physical presence (Petersson 2003:271). Often these choices and approaches are so unexpected that they probably would not have emerged for a desk-based archaeologist.

A traditional experimental-archaeological experiment is, furthermore, often perceived as the testing of a hypothesis, i.e. a purely inductive method, whereas a contextual experiment has the primary aim of proposing new hypotheses on the basis of the experience gained, i.e. a more deductive method.

Provocatively, it could be said that whereas a traditional experiment will give the answer to a question, a contextual experiment will uncover and ask many new questions. Furthermore, a contextual experiment can act as continuous evaluation of generally accepted archaeological interpretations or “truths”.

### Scientific experiment

Scientific experimental archaeology comprises three basic aspects: an archaeological problem, a clearly formulated aim and thorough recording and documentation of the experiment. All are of great importance in ensuring that the result of the experiment is scientifically valid.

The starting point for the Klima-X experiments comprised the interminable problems concerning interpretation of Iron Age houses and the conditions within them. Some conditions are taken for granted without having any basis in practical experience; others are unknown to us today because the archaeological record is so incomplete. The many aspects of this problem resulted in the aims of the Klima-X experiments being somewhat multi-facetted.

As already mentioned, there were both specific questions and more general aims associated with the experiments. On a more general level, we wanted to carry out the experiments in order to gain experience of life in a reconstructed Iron Age house; experience that could be used as inspiration for new questions and hypotheses concerning the archaeological record. A more specific aim was to describe, in as much detail as possible, the situation and the indoor climate in a reconstructed Iron Age house in a given situation. This was to form the basis for a discussion of the standing reconstruction and, accordingly, produce ideas concerning how further work could be carried out on the reconstruction of Iron Age houses and the fitting out of these. The intention was to test in practice some of the generally accepted perceptions concerning life in an Iron Age house. Part of the energy behind the Klima-X experiments did, however, also come from a certain spirit of adventure emanating from all the participants (cf. Petersson 2003:101).

Through contextual experiments such as the Klima-X series – and virtually all other experimental-archaeological activities – data are produced which must be recorded. This includes metric data, but also subjective and personal experiences. All three are important aspects of the experimental results. Unfortunately, it is often the case that subjective experiences are overlooked when the data are recorded, documented and analysed. In the Klima-X experiments, efforts were made to record as much as possible of all three types of data, on the premise that the data should be seen as a whole, i.e. objective, measurable data and subjective descriptions of experiences complement each other. All the metric data constituted a recording of the interior conditions within the reconstructed Iron Age house, described through measurement of scientifically manageable parameters such as temperature, relative humidity etc. We carried out this recording in order to be able to describe and map the situation that provided the framework for our subjective experiences, such that these could be put in context. The recording cannot be said to give an objective picture of the situation in the house but it gives an objective measurable view of the conditions we have chosen to describe.

Subjective experiences and personal impressions were also recorded, i.e. the experience of living in a reconstructed Iron Age house in winter, how the indoor climate was perceived and the project participants’ well-being and health. Personal experience and impressions of how the house’s constructional elements functioned and were used were similarly recorded. It was important for us to document this aspect of the experiment, as personal experience, acquired through experimentation, will always form part of the conclusions that are drawn from the results – intentionally or unintentionally. It was, therefore, our opinion that this was a field it was very important to articulate as expressively as possible, such that the way in which we reached our conclusions, through a combination of experience and metric data, became more transparent.

It should always be remembered that we are not describing how conditions were in the Iron Age. This applies to both metric and subjective data; metric data because we cannot be sure that the houses were constructed and fitted out in exactly this way, and the subjective data because we are modern people who have been placed in a very different situation. After a period of adaptation to the conditions, we will still perceive the conditions on the basis of our modern frame of reference and not as an Iron Age person. Therefore, it was not one of the aims of the experiments to describe exactly how conditions were in the Iron Age.

## Framework for the experiment

### The reconstructed houses

The three-year series of experiments took place in the latest of the Iron Age village’s series of reconstructed longhouses (House 17), completed in 1989. In addition to this, one of the earlier houses (House 10), built in 1975, was used in the last of the three experimental periods (figure 2). The houses are both so-called schematic models, i.e. they are composed of features from several house remains found at several different archaeological sites from the Early Roman Iron Age (Draiby 1991:105ff). In other words, the orientation of the houses, their construction and the materials used reflect the broadly accepted archaeological conven-

tions for three-aisled longhouses from the Early Roman Iron Age; these show a great degree of standardisation. Since the first house remains from the Iron Age were excavated in the beginning of the 20th century, numerous excavations have contributed both large and small details to the picture of this "standard house". Similarly, there has been much consideration of how the poorly preserved parts of the building, such as the roof, were constructed (Lund & Thomsen 1982:188ff).

House 17 has two load-bearing structural elements: five sets of roof-bearing oak posts with heads (longitudinal beams) which, together with the walls, form a three-aisled compartment. The gables are oriented towards the southeast and northwest, respectively, and the two side walls are both broken approximately in the middle by entrances which create a straight transverse passage (the entrance area) and divide the house roughly into two halves (figure 3).

House 10 has a very similar groundplan which does, however, distinguish itself by only having four pairs of roof-bearing posts. This makes the western end one bay shorter than in House 17. Both houses have walls of spaced posts with a c. 20 cm thick layer of wattle and daub, although the walls at the eastern end of House 10 are constructed of vertically-set planks with a worn outer turf wall. The roofs of both houses have a relatively steep pitch of rafters and are thatched with reed, but at the gables the two houses again differ. On House 17, the roof continues around the gable (full hip) whereas House 10 has louvres located in the gables so the roof is divided into a gable triangle and under hip. In House 17 it was decided instead to place a louvre in the ridge between the 2nd and 3rd sets of roof-bearing posts seen from the west (figures 5 & 15).

The floors of the houses are of hard-packed clay, while the entrance sections are cobbled. This further underlines the division into an eastern and a western end.

The western ends of both houses are fitted out as living quarters with a slightly raised hearth located more-or-less in the centre of the floor: in House 17 in the 2nd bay and in House 10 in the 1st bay from the west. Sleeping places have been established at the west gable and along the walls; in House 17 along the north wall and in House 10 along the south wall. House 17 has also the hint of a partition wall between the living quarters and the entrance, in that the side aisles at the 3rd set of roof-bearing posts are blocked by a loosely-assembled board partition. The nave (i.e. central aisle) is, on the other hand, open to the entrance area.

A byre has been constructed in the eastern end of both houses. In House 17 it is separated from the entrance area by a lightly-constructed open partition wall that extends right up to the loft. The byre in this house has been shortened relative to archaeological examples (figure 3). The byre of House 10 has more correct dimensions and is separated from the entrance area by a lightly-constructed wattle partition wall extending halfway up to the loft.

## Fittings and additional features

As we presumed that the reconstructed houses would be difficult to heat, various interior constructions were added with the aim of dividing up and isolating the inhabited space. In addition to making the actual conditions during the experiment more bearable for the participants, it was also our aim to investigate the effect of these additions – a subject which will be returned to later.

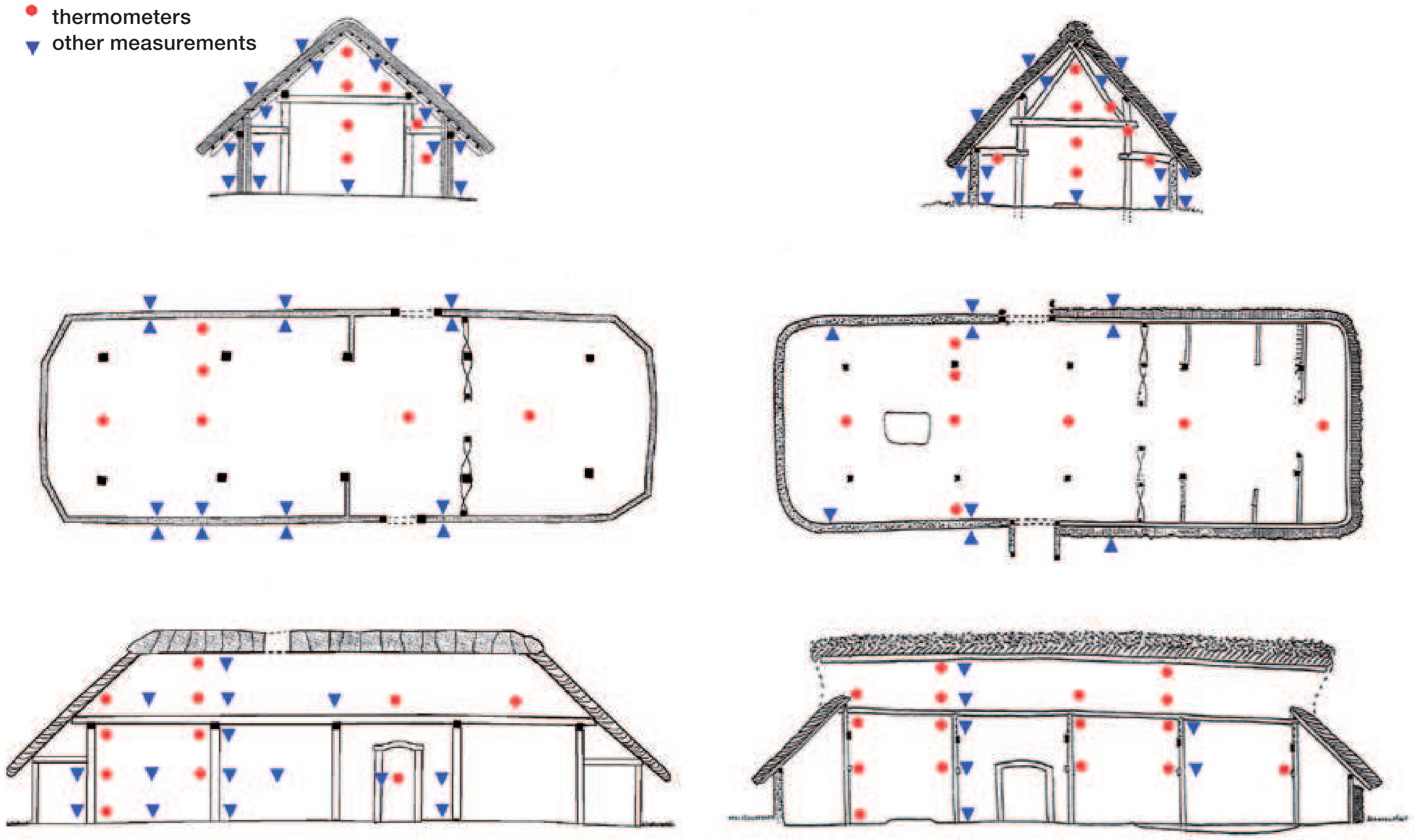
One of the interior constructional elements added was a dividing wall of thick felted woollen blankets between the living quarters and the entrance area at ground level. We chose to use blankets rather than a fixed wall in order for it to be more flexible and moveable and also easier to construct. At loft level, we retained the original undivided space running along the whole length of the house.

Further to this, thin straw mats were attached to all the walls – made of clay daub – in the living quarters in an attempt to insulate them, and the door at the north side of the entrance area was blocked off. A "porch" of blankets was put up just inside the southern door. Finally, we chose to block up the windows at the western end of House 17 in order to limit the number of parameters being investigated.

The most extensive addition to the construction was the insertion of a loft made of poles in House 17. This was laid transversely on top of the heads over the whole of the living quarters, with the exception of the area above the hearth. A layer of hay was placed in the loft to represent one form of stored fodder (figures 3 & 17). At times, this loft was taken down so that we could register the difference in the

Figure 4
Organization of the rearmost section of House 17 with beds, loft, wall coverings and household items. The hearth is located in the middle of the floor immediately outside this picture.

Figure 5
House 17 and House 10. The blue and red symbols indicate where the manual measurements were carried out during the experiment in 1999. House 17 has a ridge louvre and House 10 has two gable louvres.



indoor climate with and without it (figure 4).

The additions to the living quarters were all devices which contributed to creating a roughly realistic situation as a basis for the experiment. The byre was populated with animals in order to investigate the consequences their presence had for the indoor climate. We also wore Iron Age costumes, which affected our subjective perception of the conditions. Finally, we cooked food on the hearth, which was lit both during the day from 7.00 and in the evening until 21.30 in order to create a daily rhythm of activities and a source of heat that affected the house's indoor climate (figure 22).

## Indoor climate in the reconstructed Iron Age houses

### Recording the indoor climate

Under winter conditions there are a series of basic requirements that a house must meet. It must, first and foremost, ensure that the inhabitants can gain shelter from the weather and maintain their body temperature and it should also, as far as possible, provide a comfortable environment even under the worst winter conditions. But what is the nature of the indoor climate, the thermal situation, lighting conditions and, accordingly, the comfort level of the inhabitants in a reconstructed Iron Age house?

As mentioned previously in the section on contextual experiment, we chose to collect both objective data and subjective observations and experience in order to shed light on these factors.

The objective data comprised measurements of air temperature, relative humidity and air quality as well as draughts, surface temperature and thermal comfort. Thanks to our collaboration with various institutions and organisations, these measurements were taken using specialised monitoring equipment[2]. Data on temperature and air quality were registered automatically, whereas air humidity, draughts and surface temperatures were recorded manually at selected locations in the houses every four hours around the clock in the course of the experimental period (figures 5 & 6). The subjective perspective for the metric data was, first and foremost, provided by the participants filling out of questionnaires concerning their actual experience of the indoor climate. These questionnaire surveys were, just like the manual measurements, carried out every four hours, although not at night (1-7 am). As a supplement to the questionnaires, experiences and more general observations were written down in shared diaries and recorded *via* individual interviews. Finally, situations and activities were documented by photographs.

With this recording as a fixed basis, the effect of the heat sources was evaluated relative to the fixed and additional elements of the reconstructions. This was a balancing act, where we attempted only to change one parameter at a time. The data gathered can, therefore, be perceived as a description of the indoor climatic conditions in a reconstructed Iron Age house during the experimental periods[3].

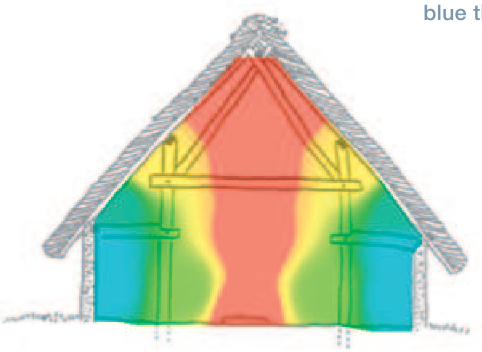
In the following description, primary use will be made of the results from the experiments carried out in 1999, unless otherwise stated.

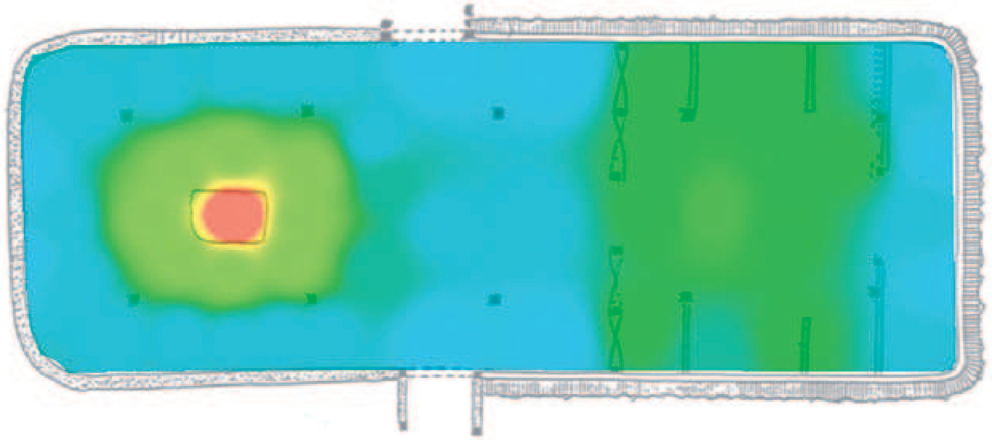
### Temperature

The temperature in a house can best be described as a result of the interaction between the weather, the insulative effect of the house and the heat sources present inside the house. The better the house is insulated, the greater the significance of the indoor heat sources. Correspondingly, with increased insulation, the weather, an external factor, is of less consequence for the temperature.

In the daytime, the fire on the hearth was the most important heat source in the house, but the heating effect across the whole house was uneven (figure 7). The heat from the fire ascended so that under the roof ridge directly above the fire the temperature was on average about 25° C. Whereas, on a day with an outdoor temperature of about 0° C, the temperature a metre above the floor just by the hearth was, at the same time, only about 12° C. At the same height in the byre, with the animals in place, the temperature during the day was 8-10° C, i.e. on average about 3° C lower than in the living quarters. The temperature by the fire was at times 6° C

Figure 6
Measurement of draughts at floor level.





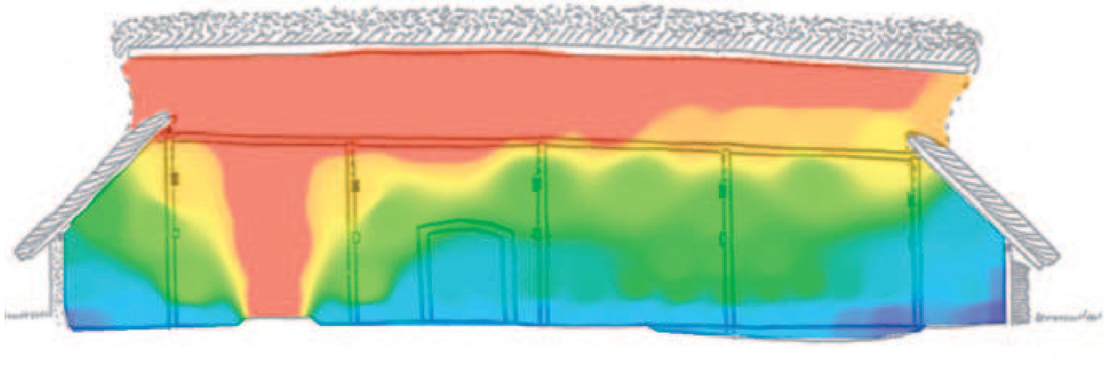
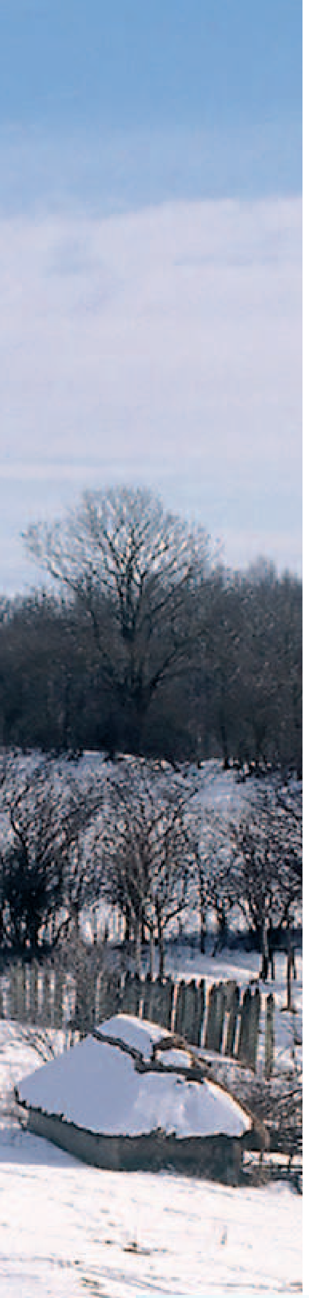


Figure 7
The heat distribution in House 10. Red denotes the warmest areas and blue the coldest.



higher than in the entrance area. In the living quarters themselves, the temperature was completely dependant on distance from the fire and from the walls. Whereas the temperature in the middle of the room was about 12° C, it decreased towards the side walls of the house and towards the byre, to about 7° C. At floor level, in the vicinity of the fire, the temperature was as low as about 5° C. In the middle of the living quarters, a lit fire resulted in a temperature about 5° C higher than if no fire was burning. This effect was significantly less along the walls, where the temperature increase from the fire was probably closer to 2-3° C. In the entrance area and the byre the effect of the fire on the temperature was not much more than an increase of a single degree celcius. The fire had, therefore, an exceptionally local heating effect. This was also the conclusion reached after the experiments in 1972 (Hansen 1974:18f).

As already mentioned, the effect of the fire was greatest up under the roof. Here, the temperature was over 20° C with the fire lit, even when the external temperature fell to below freezing point and the heat distributed itself along the whole length of the loft. The temperature under the roof did, however, fall rapidly when the fire went out and draughts and heat reduction together led to the heat escaping. It was also observed during the experiment in 1972 how the temperatures up under the roof (2.5-3.5 m above floor level) were very high and evenly distributed (Hansen 1974:18f).

Figure 8
House 10 seen from the south. Note how the heat from the animals has melted the snow over the byre.

But the fire did not just warm up the air. Radiant heat also resulted in a heating up of the immediate surroundings and because the heated air, as is apparent from the above, quickly rose without being of great benefit. This radiant heat was the most important heat source for the inhabitants.

At night, the temperature in the house evened out. In the living quarters the temperature fell, whereas in the byre and the entrance area it remained more constant due to heat given off by the animals (figure 8). With an outdoor temperature of -2° C there was a room temperature in the living quarters of between 4° and 5° C, although it was a little warmer just around the benches used for sleeping, and a temperature in the byre of about 7° C.

In order to gain an impression of how the inhabitants, purely subjectively, perceived temperature conditions in the longhouses, the questionnaire asked if conditions in the house were: “very cold”, “cold”, “neutral”, “warm” or “very warm”. On the basis of the answers to this question it could be seen that the houses generally were perceived as relatively warm.

The perception of the heat was, however, very individual and depended, among other things, on the participant’s level of activity just prior to answering the questionnaire and on how many layers of woollen clothing they were wearing. Furthermore, the participants were often sat by the fire when they answered the questionnaires.

The most troubling problem was generally perceived as cold feet and many also experienced that their body was warm on the side facing the fire but cold on the side that faced away. The weather was, as already mentioned, of crucial significance for the temperature in the houses and there was a close relationship between temperature oscillations outside and inside the houses. Only in the area around the fire, the temperature was relatively unaffected by changes in outdoor temperature. The sun’s warming rays had no perceivable effect on the temperature indoors, despite the fact that one of the side walls faces south and, accordingly, is potentially exposed to the sun all day long.

The force of the wind was also of great importance for the temperature inside the house. On calm days it was easier to maintain a high temperature in the house, whereas a wind led to more rapid heat loss. The more rapid heat loss from the house was due to both the cooling effect of the wind on the roof and walls and the increased air circulation through the house, with a loss of warm air as a consequence. When the outdoor temperature fell this was also reflected in the questionnaires as the inhabitants felt that it was colder in the house.

## Draughts

Draughts are defined as an unwanted local cooling of the body caused by air movements, bringing about a feeling of discomfort (Toftum et al. 1997:7). Great turbulence, i.e. a large fluctuation in the speed of air movement, gives the greatest draught problems[4]. Rapid air movement can be due to gaps in the outer construction of the house, insufficient insulation, the form of the walls or cold coming from adjacent rooms. Rapid air movement can, for example, arise between two rooms with different temperatures, in that the warm air uppermost moves into the cold room and the cold air lowermost moves into the warm room (Valbjørn 1983:22).

The greater the difference in local temperature within a house, and between the indoor and outdoor temperatures, the greater the air circulation, and draughts will be created between the warm and the cold areas.

In a reconstructed Iron Age house, therefore, significant draughts are to be expected due to the uneven heat from the fire, gaps in the construction, the poor insulation and great differences in temperature between rooms. In order to investigate this, draughts were regularly measured at fixed monitoring points during the course of the experiment (figures 5 & 6). The points by the fire were intended to simulate draught conditions at foot and shoulder height for a person sitting by the fire. The draught monitoring in the byre in House 10 shows the air movements away from the fire. In House 17 it was not possible to measure the draughts because of the presence of the animals and the fact that the byre was also separated from the living quarters by blankets. Accordingly, the sleeping quarters were chosen, as these were approximately as far from the fire as the byre was in House 10. The draught measurements were carried out using a draught monitor, which records

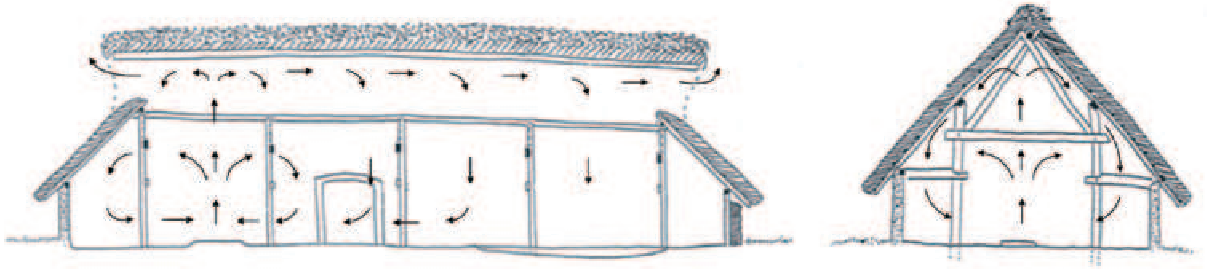


Figure 9
Model of the air circulation in House 10.

temperature and the speed of air movements over a given period[5].

The draughts in the reconstructed longhouses proved generally to be very substantial. On a calm day, draughts were measured of between 0.10 and 0.51 m/s in the living quarters (figure 9). In comparison, air movements in a modern building do not normally exceed 0.15 m/s. As the primary heat source for the houses was the fire, a great continual draught was presumably created along the floor, starting in the more distant parts of the house and moving in towards the hearth. The draughts were generally also greatest in House 17 just above the floor, i.e. at a height of 10 cm, by the fire and the bench. Here, the air movement was almost always greater than 0.15 m/s, giving an average speed for air movements in the house of 0.27 m/s. The greatest draught readings were, however, registered next to the fire at a height of 80 cm. This was perhaps because the heating effect of the fire created the most rapid air movements at this height.

On the basis of the subjective questionnaires, the participants in the experiment generally perceived the draughts in the houses as a very great source of discomfort. This feeling was probably accentuated by the reconstructed Iron Age costumes – these were woollen and were, therefore, not wind resistant – and by the fact that we, as modern people, are used to present-day levels of comfort.

It was probably external factors (the weather), in particular, which determined the magnitude of the draughts felt within the house. In very windy weather the inhabitants of both houses felt more of a draught.

## Air humidity

It can be difficult for a person to judge the humidity of the air. If the temperature is low or moderate, air humidity has only a slight influence on a person's thermal comfort and perception of heat. This could be seen from the very variable answers to the questionnaire. The air humidity can, however, be of significance for the lifetime of a house construction. In order to gain a picture of the air humidity in the reconstructed Iron Age houses, the relative humidity was regularly measured at selected points within both houses (figure 5). The relative air humidity (RH) is a measure of the water content of the air expressed as a percentage of the maximum possible water content at that temperature (Valbjørn 1993:83). In general, the relative humidity indoors should not be too high as this can lead to condensation which, among other things, can lead to fungal growth and rot in organic materials. During the experiment, the relative humidity in both Iron Age houses was, however, relatively high, with an average value of more than 60%. Despite this, the temperature at occupation level was so low that the water content of the air did not exceed the recommended limits for modern buildings. Under the roof, at loft level, the temperature was such (over 17° C) and the conditions so damp (over 60% RH), that these limit were often exceeded. Fluctuations in air humidity in both houses generally followed the same trend as the outdoor measurements, but the relative humidity was often greater inside the house, possibly due to water vapour given off by people and animals, and during cooking etc. The weather had a decisive effect, but internal factors in each house also exerted a certain influence.

Figure 10
The reconstructed clay lamps.

## Light sources

Light is the reason we can see what is going on around us. Sight, based on the presence of various kinds of light-sensitive cells in the retina of the eye, is the most dominant of senses. Our perception of the world depends on the way in which we see or, more precisely, the way in which we see light. In the literature it is sometimes described how the hearth lit up the whole house in the Iron Age and there was sufficient light to permit various tasks to be carried out (Hvass 1980:40). During the experiments, the house's light sources comprised daylight from the louvres and doors as well as light from the fire and the reconstructed Iron Age lamps[6] (figure 10). The small windows, which were built into the walls of both House 10 and House 17, were closed by choice during the winter occupation to reduce cold and draughts.

The light conditions in the house were evaluated solely on the basis of the subjective questionnaires. In general, the participants were of the opinion that at 9 am and 1 pm there was enough light in both houses to allow cooking and other activities to be carried out without difficulty. The light became poorer at 5 pm and even worse at 9 pm. House 17, with the louvre in its ridge, was judged to have the most light, probably because the gable louvres in House 10 largely only let in light in the mornings and, on certain days, were also closed with a flap. In House 17, the ridge louvre was always open and functioned incredibly well as a light source, even though in the daytime it could be dark in the far corners of the house, beyond the reach of light from the fire and the louvre. In the evening, when the daylight disappeared, the quality of light was most dependent on the intensity of the fire. We therefore spent most of our time around the hearth, and this area functioned as an activity area for cooking and minor craftwork, because the participants migrated towards the heat and light. Even here, however, it was so dark in the evening that it was difficult to do any work that could not be carried out by touch. For example, it was virtually impossible to read a book in the evening, even close to the fire. Reading was, of course, not something Iron Age people did but presumably it requires the same amount of light to weave a fine pattern or perform other detailed craftwork where it is necessary to see detail. Although it seems likely that people then must have been accustomed in a completely different way to managing in the dark. It also became clear over the course of the experimental period that the fire was not such a strong light source that it could illuminate the whole of the house. There was only sufficient light to permit work in the area immediately around the hearth. Furthermore, the lighting conditions in the reconstructed Iron Age houses appear to be influenced by the fact that the inner surface of the roof is very dark and sooty and that the walls are relatively dark. Even if they had been whitewashed, investigations show that the reflected light would probably have been scant as very little light reached this far from the fire (Larsen 2003:44).

## Air quality and smoke

The quantity of smoke depends on the type of wood used, how dry it is and how the fire is tended. During the experiment we used fairly dry split ash and elm wood. We could also have used brushwood, coal or peat, but restricted ourselves to just trying one type of fuel in order to, as mentioned previously, limit the number of variables in the experiment.

The fires in the reconstructed Iron Age houses produced large quantities of smoke, leading to pollution of the air in the house. The smoke followed the hot air from the fire, moved upwards and lay after a while like a thick blanket at a height of about 1.5 m above the floor and upwards towards the roof. The greatest smoke concentration was measured in the loft. On the basis of observations of the route taken by smoke out of the house, it seemed that the roof construction and the louvres played an important role with regard to the quantity of smoke in the two houses (see the section on *Constructional elements, activity areas and indoor climate, e.g.* figure 17).

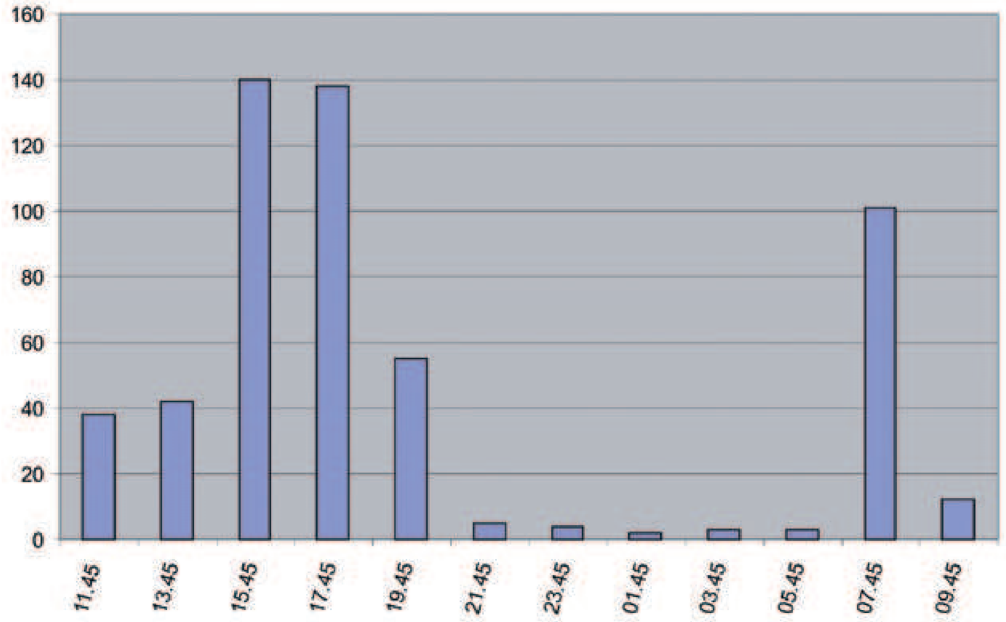
One of the investigations we carried out in order to gain an impression of the quantity of smoke in the two houses was measurement of the $CO_2$ (carbon dioxide) content of the air. In House 17 (ridge louvre) very high $CO_2$ values were measured. On windy days, the house was, however, fairly free of smoke but on calm, especially damp days being in the house was sometimes unbearable. In

Figure 11
Experiment participant with a nitrogen dioxide $NO_2$ sampler which measures the amount of smoke the person is exposed to.

Figure 12
Discomfort levels for nitrogen dioxide $NO_2$. Pulmonary oedema: Seepage of fluid into the lungs leading to dyspnoea, blue colouration and rapid and rasping respiration with a cough and frothy, possibly bloody phlegm. After www.kemikalieberedskab.dk
It is possible to compare the ratio between ppm and ug/m$^3$, because Âµg/m$^3$ is comparable with ppb and mg/m$^3$, which again is comparable with ppm. By using a conversion factor from the ideal gas law, which states that this particular law is depended on absolute temperature, pressure and mass of the molecule it is possible to calculate their ratio. The calculation factor is given, if you assume that 237 K and 1 atm; for $NO_2$ corresponds to 1 ppb to 2.05 Âµg/m$^3$ or 1 ppm to 2052 Âµg/m$^3$. For Benzene 1 ppb corresponds to 3.48 Âµg/m$^3$. Oral communication from Henrik Skov, DMU.

| parts per million - ppm | symptoms |
|---|---|
| **10-20 ppm** | **irritation of eyes and respiration** |
| **20 ppm** | **concentration that is immediately dangerous to life and health** |
| **100 ppm** | **pulmonary oedema, perhaps deadly after 60 min.** |
| **250 ppm** | **pulmonary oedema, deadly after 5 min.** |

Figure 13
Hourly average for the concentration of benzene measured in House 17 between 10th and 11th February 1999. After Skov et al. 2000:3003.



House 10 (gable louvres), lower $CO_2$ values were measured, both with closed and open gable louvres and on days both with and without wind. The subjective smoke investigations revealed that the participants in the experiment generally described the houses as rather smoky, but the inhabitants of House 10 had fewer smoke problems than those in House 17. Several of the inhabitants in the latter house experienced physical discomfort such as, red eyes, sore throat, headaches and nausea, as a consequence of the smoke. These symptoms are short-term side effects of carbon monoxide (CO) poisoning (Artursson 1994:21ff). This could indicate that the house was not very suited to habitation because the smoke stayed within it. On the other hand, a smoke concentration of this order could have been an advantage, being used to conserve food and also keeping pests away from the loft (see the section on *Constructional elements, activity areas and indoor climate*).

Assisted by Danmarks Miljøundersøgelser/DMU (National Environmental Research Institute/NERI), thorough investigations were carried out during the experiments on the quality of the air in House 17, which had a ridge louvre[7].

The measurements arising from this revealed alarmingly high amounts of various toxic pollutants produced as a consequence of burning wood. These included: carbon monoxide, nitrogen dioxide ($NO_2$), benzene ($C_6H_8$), toluene ($C_6H_5CH_3$) and O-xylene ($C_6H_4(CH_3)$).

Nitrogen dioxide is known to irritate mucous membranes and the respiratory system and also to cause chronic lung disease (Jacobsen 2004:2894ff).

The quantity of nitrogen dioxide was measured over the course of a week with the aid of four passive $NO_2$ samplers attached to a test person, as well as at three monitoring points within the house. The test person carried out indoor activities most of the time and was, in total, only outside the house for about one to two hours a day (figure 11).

The measurements showed that the test person was exposed to a $NO_2$ level of about 61.6µg/m$^3$ over the course of a week (expressed as a weekly average), when there was a concentration of 9.9µg/m$^3$ outdoors and of about 110µg/m$^3$ in the house's living quarters. In comparison, the concentration of $NO_2$ in the reconstructed houses was at least twice as high as that registered *via* the uptake of $NO_2$ by children in the heavy traffic of Copenhagen in 1994-95 (Nielsen & Skov 1997:964ff) (figure 12).

The concentrations of benzene, toluene and O-xylene were also measured over the course of a single day with the aid of stationary sampling equipment which performed active sampling of particles in the air (Skov et al. 2000:3801ff).

Benzene proved to be the most dominant of the three substances. It is also the most damaging, being known as a strongly carcinogenic substance which can, among other things, cause leukaemia.

The highest concentrations of benzene were, not surprisingly, measured during cooking on the hearth, and the lowest were measured at night when the fire was out. A 24-hour average for the measurements gave a concentration of 45.8µg/m$^3$ (figure 13). The recorded benzene level would therefore constitute a serious health risk to people experiencing such conditions over a lifetime. In comparison, the concentration of benzene in the house was around five times greater than on one of the most heavily-used roads in Copenhagen (Jagtvej). Furthermore, the levels that the participants were exposed to were more than twice those experienced by people who live and work in Copenhagen (Skov et al. 2000:3803). The recorded benzene level of 45.8µg/m$^3$ was, on the other hand, only a third of the concentrations that women living in country areas in the Third World are typically exposed to (Zang & Smith 1996:147ff).

In another study of people's exposure to smoke from open fires in Third World countries, very high concentrations of carbon particles in the air were also observed (Smith 1988:16ff). On the basis of these ethnographic observations it is therefore to be expected that use of an open fire leads to a high concentration of airpolluting particles within the house. This was also confirmed visually during the Klima-X experiments with the great quantities of smoke seen in the houses. There could, therefore, have been other dangerous substances in the smoke which, collectively, constituted an even greater health risk than the substances which were measured in the course of our experiments.

It should, however, be emphasised that the measurements were taken at a time of calm weather which led to an extreme situation in which House 17 became exceptionally smoke-filled. Furthermore, it should be pointed out that these smoke problems could be due to the facilities for smoke extraction constructed in House 17 (ridge louvre) (see section *Constructional elements, activity areas and indoor climate*). It is therefore desirable that, in the future, similar smoke monitoring should be carried out in a reconstructed house with a different roof and louvre construction, for example House 10. The results of these measurements of exposure to and concentration of air-polluting substances in the houses could, perhaps, contribute to an insight into living conditions in the Iron Age and other periods for that matter. The levels of various substances could have resulted in people in the Iron Age being exposed to extreme air pollution in their houses, which could have affected their general state of health and average life expectancy.

Even with levels of smoke less than those measured, it is possible that continual exposure over a lifetime of about 40 years would leave some traces in the body.

If we turn to the archaeological record, it is very rare to find indications that people have been exposed to high levels of air pollution. In a very few cases there have, however, been finds of frozen, dried or mummified lung tissue from prehistoric individuals which have been exposed to air pollution (Brimblecombe 1987:1ff). Lung tissue showing the effects of air pollution was, for example, found in an Irish bog body dated to the period 1050-1410 AD. It was concluded that the presence of carbon in a cross-section of the lung indicated that the individual had been in smoky surroundings which presumably originated from open hearths used for heating and cooking (Delaney & Floinn 1995:128ff). In this respect, it would be very interesting to investigate lung tissue from the many bog bodies from Northern Europe in order to ascertain whether they too had been exposed to similar air pollution.

## Constructional elements, activity areas and indoor climate

The aim of contextual experiments is, as described above, to function as an "eye-opener" and a source of inspiration, while at the same time building up practical experience. The sum of these can then be applied to conventional archaeological interpretation. The many results, experiences and thoughts we have accumulated during winter occupation of the reconstructed Iron Age houses can, accordingly, be used as a starting point for a discussion of the constructional elements of the houses. This discussion focuses on both static and moveable features, the various activity areas provided by the byre, the entrance area and the living quarters, as well as the general fitting out of an Iron Age house. It is based on evaluations of functionality in winter and is rooted in measurements of temperature, smoke, damp, draughts and light. Furthermore, there is a subjective judgement as to whether the various indoor conditions that were measured and experienced appeared acceptable, working from the basic premise that smoke, draught and cold are three factors that it is desirable to minimise in a house. The problem is, however, that these three factors constantly work against one another. We want to remove smoke from the house but we want to retain the heat. We also want to allow light into the building but not draughts. Neither do we know what was considered acceptable in the Iron Age: How much smoke was tolerated, how warm – or cold – was it in the houses, or how much light did people think was necessary? Nor do we know the extent to which house construction and fitting out was controlled by these factors. This is very difficult for modern people to judge, especially on the basis of modern habits in this respect, which we take very much for granted. Also, must we not forget that the construction, fitting out and use of houses in the Iron Age was very probably also conditional on non-functional factors such as beliefs, traditions and social norms. These are factors about which it is very difficult to obtain knowledge today (Edblom 2004; Lund 2003:67). As a result, we are not able to arrive at final conclusions or determine whether the house reconstructions and their component parts are true or perfect solutions.

The following sections are, conversely, a presentation and discussion of our experiences with various structural elements and activity areas relative to the indoor climate. They are intended to give others an insight into the combined functioning of the construction, materials and areas under the conditions which were tested. In addition, some of the questions and considerations that arose during the course of the experiment are considered. These deliberations and discussions will, hopefully, inspire others in future experiments involving new reconstructions and, possibly, also open up new evidence in the archaeological record.

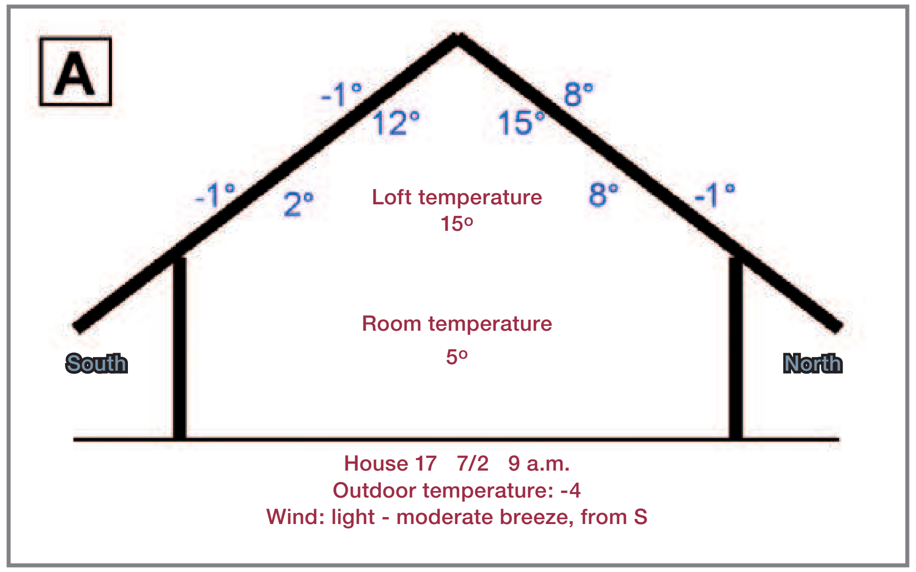
### Roofing material and influence on the indoor climate

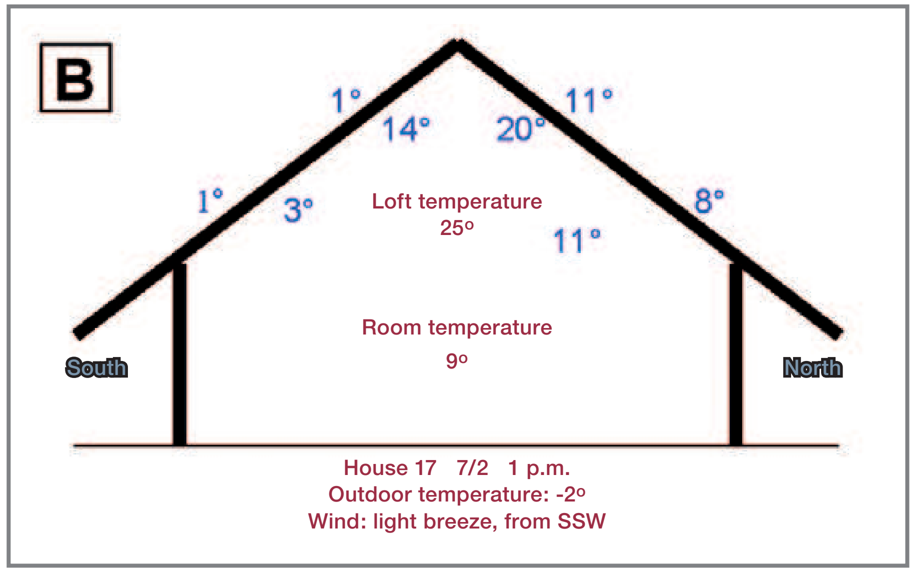
The thatched roof of reconstructed Iron Age houses such as Houses 10 and 17 constitutes more than half of the house's external surface and has a volume greater than the walls. The roofing material proved to be of great significance for the indoor climate of the houses during the Klima-X experiments.

Despite the fact that no definite evidence has yet been found for thatched houses in the Iron Age, all the reconstructed dwelling houses at Lejre Experimental Centre, and reconstructed houses in many other places, are thatched with reed as *"it is presumed…that in Southern Scandinavia and also in Northwestern Europe, where the three-aisled longhouse extends far back in time, there were lighter roofs of a relatively steep angle"* (Draiby 1991:111). One of the reasons for the choice of reed is that in many places reeds and rushes were available and abundant (Lund & Thomsen 1981:200). The few archaeological traces that have been found so far provide, however, evidence for the use of turf as a roofing material, for example the ash layer in the house remains from Ginderup[8] (Kjær 1928:16; Kjær 1930:23; Hatt 1957:37; Lund 1979:118; Lund & Thomsen 1981:200).

One evening during the experiments we carried out a study of the movement of smoke out of the houses using large spotlights. In the backlight from the spotlights it could be clearly seen how the smoke seeped out of the actual roof surface of both houses. Where the smoke exited, we presume that warm air accompanied it (figures 5 & 9). Measurements of the temperature of the inner and outer surfaces of the roof also confirmed this heat loss (figure 14). The wind penetrated the roof and during strong winds it was, on occasions, almost as cold on the inner surface of the roof as on the outer (figure 14F). However, at other times little or no heat loss through the roof was recorded, especially from House 10 (figures 14C & 14E). This is probably due either to the modest wind strength at these times or that the heat disappeared out through the roof somewhere other than where the surface temperature was measured, for example *via* the gables. Particularly in House 10, it seems very likely that the heat escaped through the large gable louvres, especially with an easterly or westerly wind. The reeds in the roof allowed air to penetrate and, therefore, contributed to a great turnover of air in the house, even though the wind or draught could not be felt directly up in the loft. It is presumed, therefore, that the greatest heat loss from the house took place out through the roof, as the same heat loss could not, for example, be recorded from the walls where the daub did not allow the air to penetrate (see section *Walls – insulation and influence on indoor climate*).

Apart from this heat loss, the thatched roof can be said to have functioned as intended: It prevented rain, snow and direct wind from entering the house and was, at the same time, permeable to air so the smoke could more-or-less escape. The roof had also a certain insulative effect, despite the heat loss. For example, the temperature under the roof ridge at night was, on average, 8º C during the whole of the experimental period, whereas the average night temperature outdoors during the same period was –8.8º C. During the experiment in 1967 it was suggested that the reason for the house's internal temperature being so low was that the thatched roof was so thin (Ritzau 1969). We do not know the thickness of the roof in these previous experiments, but during the Klima-X experiments the roofs on Houses 10 and 17 were relatively new and about 20 cm thick. Even today this is a fairly normal thickness for a thatched roof. Even so, the indoor temperature was also low during the Klima-X experiments. The roof's thickness must, therefore, have been of less significance as the heat escaped anyway and the low temperature in the house should probably rather be explained in terms of the roofing material's permeabil-





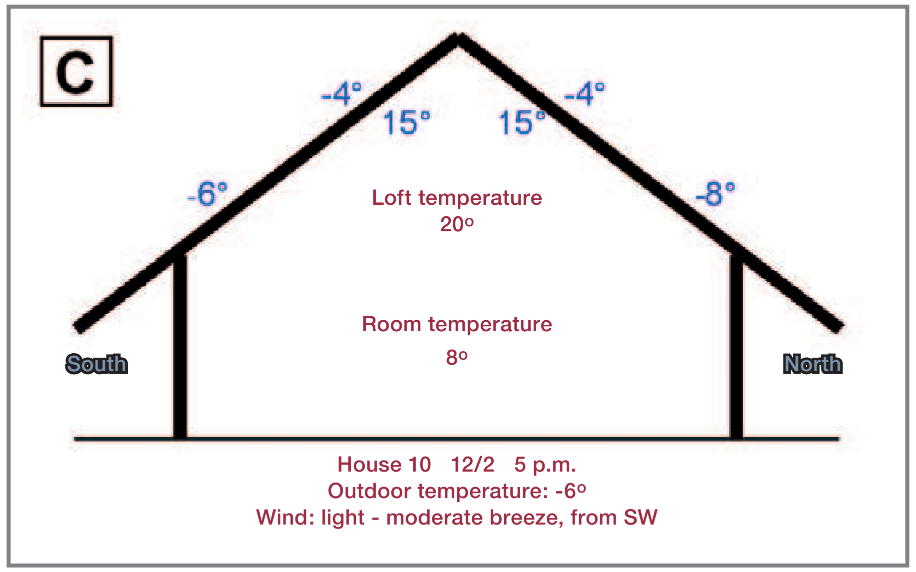


Figure 14
Technical diagram of surface temperature at selected times. The measurements were taken approximately at the middle of the roof on the house's longitudinal axis. Values in blue denote surface temperatures. Values in red show air temperatures at the level of the loft and living quarters.

A. Measurements taken immediately after the fire was lit in the morning. There is an immediate heat loss through the roof uppermost on the north side.

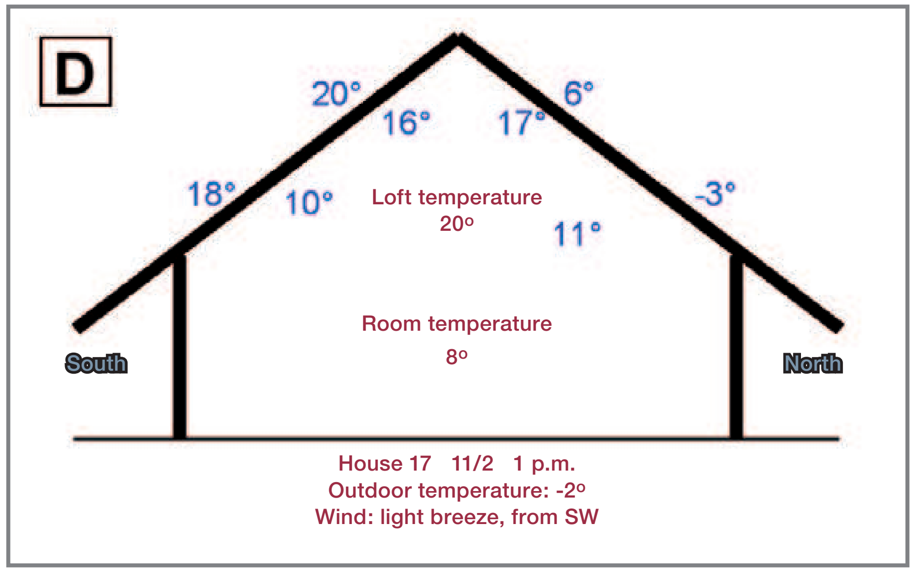
B. Heat loss out through the roof on the north side due to wind from the south. The wind penetrates the roof so the temperature on the inside of the roof is 3-14° C in the south, but 11-20° C in the north.

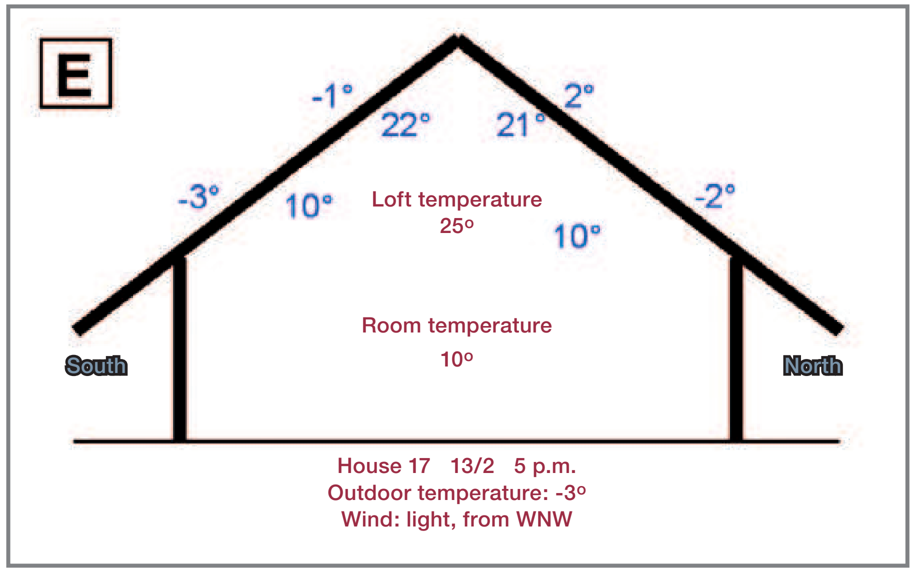
C. Virtually no heat loss out through the roof. Perhaps the heat disappears primarily through the gable louvres at this time.

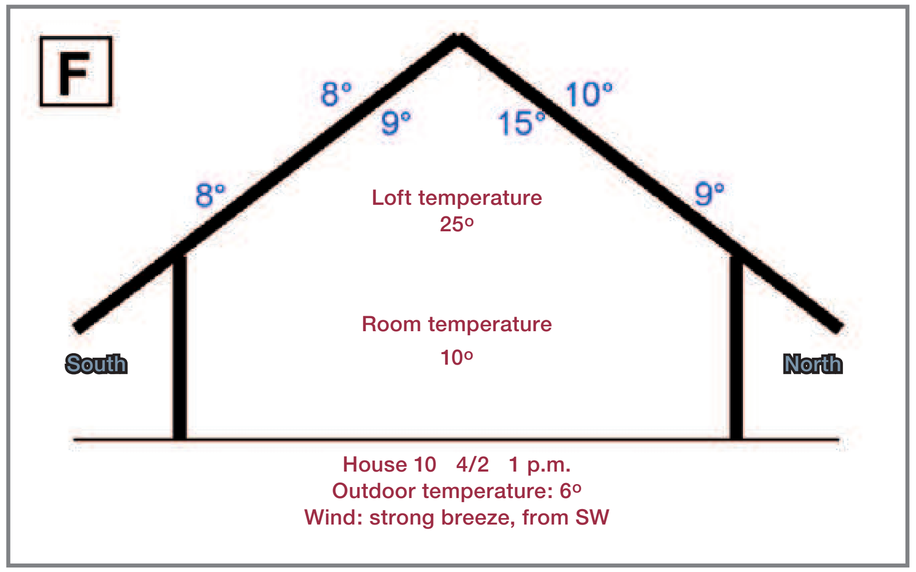
D. The sun affects the roof in the south, but has no influence on the inner surface where the temperature is lower in the south than the air temperature.

E. Virtually no heat loss out through the roof, possibly due to the light wind from WNW. Perhaps the heat seeps out in other places due to the wind direction, for example at the gables?

F. Here it can be seen how the wind has forced hot air out of the roof so that there is almost the same temperature on both inner and outer surfaces.







ity to air and the influence of the weather on the house, as mentioned above (see section *Temperature*).

During the experiment we had the idea that it would be possible to clad the inner surface of the thatched roof with a thick layer of clay, making it more air-tight and therefore able to retain the heat. This idea has not, however, been tested on dwelling houses and, as far as we know, no archaeological traces have been found of daub with impressions of reeds, suggesting a covering such as this.

A turf roof would similarly be less permeable to air and therefore retain more of the heat. The insulative effect of turf is known, for example, from cooking in pits and as wall insulation on the outer surface of houses (Hvass 1988:60). The difference in density and compactness of the two materials was also illustrated by the spotlight study. Here, it could clearly be seen that smoke seeped out through the ridge of House 10, which has a straw covering, whereas there was virtually no visible smoke penetration through the ridge of House 17, which was of turf (see the section on *Louvres – smoke outlet and/or light source?*).

An Iron Age dwelling house was once reconstructed with a turf roof at Bognæs (Hansen 1964:56ff). Unfortunately, no description exists of the indoor climate of this house. It would be both significant and interesting to be able to compare, for example, the heat-retaining capacity of a thatched roof with the insulative effect of a turf roof on a house of the same type. There is, therefore, a need to build several reconstructed Iron Age houses of the South Scandinavian type where the roof consists of a material other than thatch/straw – for example turf. This would be consistent with the few known archaeological finds of possible roof remains.

The Klima-X experiments also show that a thatched roof is not necessarily the best solution as it allows air to penetrate and, as such, contributes to there being greater heat loss from the house. However, the experiments cannot be said to discount thatch as a roofing material.

## Louvres – smoke outlet and/or light source?

There is no direct evidence in the archaeological record of the construction and location of eventual openings to allow smoke to escape through the roofs of Early Iron Age houses. Discussions in the literature, and in connection with the building of various reconstructions, have therefore dealt with the extent to which gable louvres, ridge louvres or no louvres at all are the most probable and effective solution relative to the weather, wind, smoke, heat and roof construction. The arguments are based, in particular, on analyses of ethnological evidence, written sources from the Nordic Middle Ages, technical and mathematical calculations based on the location of the postholes and the archaeological evidence (Hansen 1964:23f; Lund & Thomsen 1982:198; Näsman 1982; Draiby 1991:112; Edblom 2004:208). In Sweden, experimental investigations have also been carried out into louvres and the distribution of smoke in some reconstructed Iron Age settlements, including the ring-walled castle of Eketorp, as well as Gene Fornby from the 5th century, which comprises a c. 40 m longhouse with a bark and turf roof. Both investigations were, however, carried out using house reconstructions that are not directly comparable with Danish houses from the Early Iron Age, as represented by the house reconstructions at Lejre Experimental Centre (Näsman 1982; Edblom 2004).

During the Klima-X experiments we investigated both gable and ridge louvres (figure 15). The triangular gable louvres in House 10 measure 120 cm at the base and are 85 cm high. The ridge louvre in House 17 is made from a cylinder of woven willow withies, 40 cm in length and with a diameter of about 30 cm. As outlined above, both the $CO_2$ measurements and the subjective descriptions revealed that the quantity of smoke was greater in House 17, with a ridge louvre, than in House 10, with two gable louvres. The gable louvre construction appeared, on the face of it, to function most effectively. However, it remained unclear to us for some time where and how the smoke left the houses and, accordingly, the actual significance of the louvres as a smoke outlet relative to the roof itself.

As already mentioned, we carried out an investigation of the movement of smoke out of the houses using a spotlight as backlighting. It could be clearly seen how a great amount of smoke escaped through the louvres relative to other parts of the roof. In this way, we gained an impression of the efficiency of the louvres (figure 15). These observations were carried out on nights with frost and only a very light westerly wind.

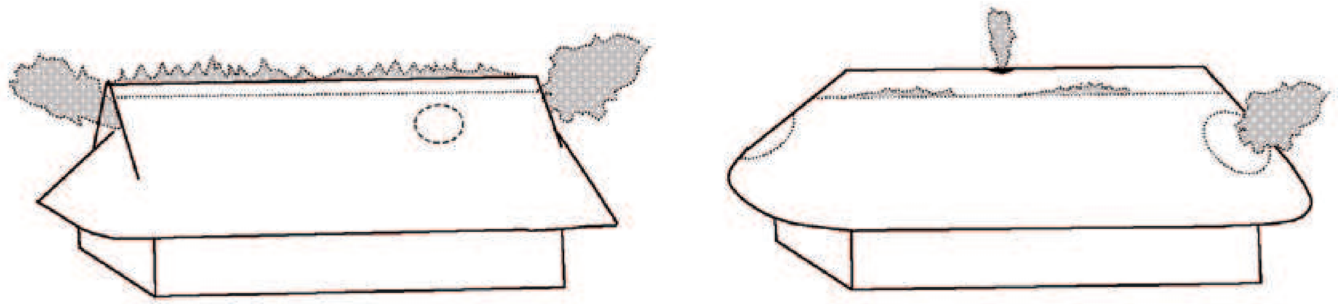


Figure 15
The route taken by smoke out of House 10 (left) (seen from the north looking south) and House 17 (right) (seen from the south looking north) as it appeared in the spotlight observations. The smoke became visible against the dark night sky in the backlight from the large spotlight. The stippled lines denote dry areas on the roof.

Regarding House 10 (gable louvres), a great amount of smoke poured out through both louvres and a good quantity also seeped out through the thatch along the whole length of the straw-covered roof ridge. Further to this, a small amount escaped *via* the roof surfaces, especially when one or both louvres was closed.

Regarding House 17 (ridge louvre), only part of the smoke streamed out *via* the louvre and very little escaped *via* the turf-covered ridge. Conversely, a great proportion exited by way of the actual roof surface, especially through a small area at the east gable (the byre end) where the thatched roof was dry, in contrast to the remainder, which was damp or covered with frost. A similar dry area could also be seen at the west gable. However, smoke was not seen to escape here during these investigations.

An explanation for the behaviour of the smoke could be that when heat rises, and with it the smoke, it naturally ends up under the ridge. If all the smoke is not able to leave through the ridge and the ridge louvre, it naturally becomes forced out towards the ends of the house due to heat continually being added from the hearth and due to the house's elongated form. The temperature distribution in the house also showed that the heat distributes itself over the whole of the loft. At times it was even warmer at the gables than in the middle of the loft above the fire.

The ridge louvre in House 17 appears, therefore, not to be optimal as a smoke-hole relative to the house's elongated form, as the opening only makes up a very small proportion of the whole ridge. As a consequence, the smoke becomes distributed along the whole of the ridge and the roof out towards the gables. The investigation appears to show, therefore, the efficiency of the gable louvres.

These observations are not consistent with the arguments against gable louvres presented when House 17 was built and a ridge louvre chosen as a smoke hole: *"…the fact that gable louvres function poorly for smoke extraction has been demonstrated by many years of use in the Lejre village's longhouses. And the situation becomes even worse if lofts are inserted. Experiments in the Eketorp house reconstructions have also shown that these do not function satisfactorily"* (Draiby 1991:112). It is our opinion, against the background of our observations, that gable louvres function well as smoke vents and in the Eketorp houses it was, as the archaeologists behind the reconstruction project underlined, probably the house's location with one gable close up against the ring wall, which created the problems with smoke extraction (Näsman 1982:204).

It was, however, observed how small gusts of wind now and then entered the gable louvres in House 10. These could have caused turbulence in the smoke and disturbed smoke extraction. As already mentioned, the large gable louvres could also have led to some of the heat escaping (see the section *Roofing material and influence on the indoor climate*). The gable louvre probably did not need to be as big as was the case in House 10, as the smoke managed to escape through small gaps and leaks at the sides of the louvres, even though the latter were closed. Ethnographic parallels also often show smaller gable louvres and even small holes cut directly through the thatched roof (Michelsen 1976; Näsman 1982:206f; Uldall 1944:37).

But if the ridge louvre did not appear to function efficiently as a smoke vent it was, in contrast, very good as a light source. Due to the ridge louvre, it was light during all daylight hours in House 17, whereas the gable louvres in House 10 virtually only allowed light to enter in the morning (see also section *Light sources*).

Historical evidence for ridge louvres is available from several sources. The ethnologist Bjarne Stoklund writes, concerning old Danish farms, that the louvre in

the ridge functioned as a light source. With the advent of windows in the Late Middle Ages it lost some of its primary function. The introduction of windows also resulted in the hearth being moved from the middle of the floor out to one of the dividing walls and the louvre subsequently was used solely as a smoke vent (Stoklund 1969:63). In Norway, in the 17th and 18th centuries, so-called "røgstuer" (literally "smoke rooms") served as ordinary living accommodation and kitchens. "Røgstuer" were of a different construction and dimensions to the Iron Age houses in Denmark. However, just like the latter, they had an open hearth in the middle of the floor and a louvre located above it. This louvre functioned both as a light source and as smoke vent (Lærum & Brekke 1990:46ff). In the habitation experiments at Lejre in 1967 it was also remarked that: *"With the correct fuel and burning regime a smoke hole was unnecessary for the smoke. Perhaps for light."* (Hansen et al. 1967). Furthermore, the Danish term for louvre,"lyre", comes from the same word as "lyse", which means light[9].

It seems, therefore, that the ridge louvre could have had an important function as a light source. But it is also conceivable there was a ridge louvre located elsewhere so the light from the fire could be made use of in one place and the light from the louvre in another. The function of the louvre as a smoke vent would probably be neither improved nor worsened by this, as all the smoke from the hearth does not, in any case, rise directly up and out of the louvre.

The different positioning of the ridge louvre depends, however, on whether in the Iron Age there was a need for light elsewhere than by the hearth where various functions, including cooking, were carried out. Also whether there were other sources of light and whether it would be too cold to sit elsewhere than by the fire in the winter. If the distribution of finds in Iron Age houses from Denmark is considered, there are many indications that areas, other than that immediately around the hearth, were used for various activities. For example quernstones, mortar stones, pits, ovens, clay benches and various types of vessels have been found in other parts of the houses (Lund 2003:71f). There would also have been a need for light in the byre in order for the animals to be fed and watered. It is also possible to conceive of a roof construction which included both ridge and gable louvres. In this way it would be possible to achieve both better lighting and smoke extraction. But perhaps this would also mean a greater loss of heat?

In the 1960s, an Iron Age house was constructed at Lejre Experimental Centre with a ridge louvre in the middle of its roof, according to historical examples of houses from the heaths of Jutland. It was quickly concluded, however, that the ridge louvre allowed rather too much snow and rain to enter the house (Hansen 1964:24). In the course of our experiments in House 17 only a little snow and rain entered the house in this way; it also evaporated quickly in the heat from the fire. It would, furthermore, be easy to construct a flap, which could close the louvre hole in case of heavy rain. This would, perhaps, be particularly necessary should the ridge louvre be located in a place other than directly above the hearth. Archaeological excavations have, on occasions, revealed the presence of a few small postholes by the hearths of Iron Age houses which, perhaps, could arise from just such a flap construction (Lund 2003:70). The above-mentioned Norwegian "røgstuer" also had a flap construction that functioned with the aid of a freely-suspended rod with no attachment to the floor (Lærum & Brekke 1990).

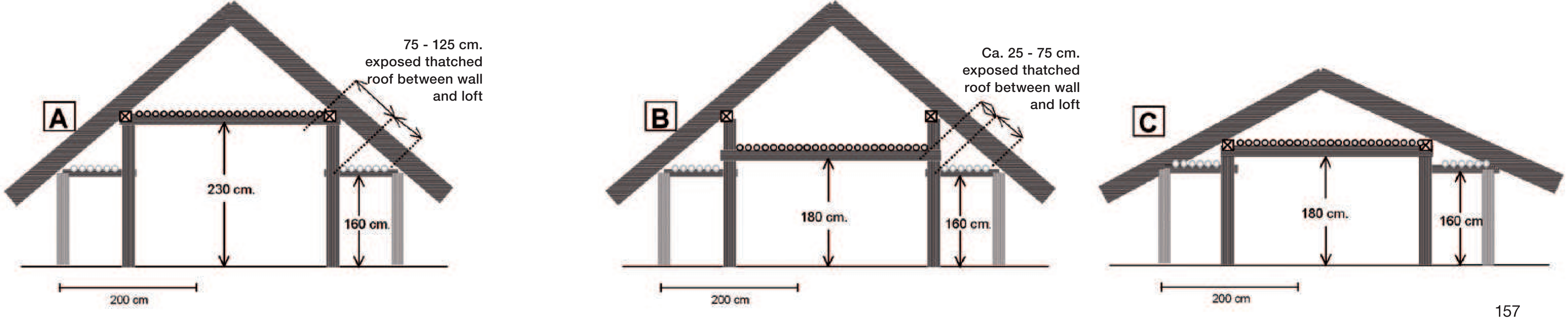


Figure 16

The tie-beam between the roof-bearing posts is an obvious place for the construction of a loft made, for example, of poles. A loft or shelves can also be laid on the tail-beam running between the roof-bearing posts and the walls. The higher the tie-beam and the possible loft are located, the greater the area of thatched roof that will be exposed directly at the level of the living areas (A and B). The size of exposed section also depends on whether there are poles on the tie-beams.

Situation A shows the situation in House 17 with a head(-beam)-construction (overremskonstruktion). Here, the loft is located very high up relative to activities around the low hearth.

By lowering the tie-beam between the roofbearing post making a wall plate construction (underremskonstruktion) as seen in situation B, the loft will also be lowered and the loft space increased accordingly.

The tie-beams and loft could, furthermore, be extended further out towards the roof insituation B and so reduce the exposed section of thatched roof.

Situation C shows a house with a shallower roof pitch – as would be the case with a turf roof. This has the same wall height, lower loft height than A and head (-beam) construction, but also less loft space. Here the exposed section of roof will be of less significance, as turf is not as permeable to air as a thatched roof. Account has not been taken of what would be most probable and practical on a purely constructional basis, but only of how the constructional changes would work functionally. For example, Bente Draiby is of the opinion that a wall plate construction such as B is unlikely (Draiby 1991:109).

The various investigations carried out in the course of the experiments suggest, accordingly, that gable louvres, generally, function more effectively as smoke vents than a ridge louvre and are efficient both in calm and windy conditions – in contrast to the latter.

This does not, of course, prove that there were no ridge louvres in Iron Age houses, it is impossible to know whether Iron Age people were used to smoke-filled rooms and just tolerated the situation. This was the case, for example, in the Norwegian "røgstuer", and in many Third World countries, people live in very smoky houses (Lærum & Brekke 1990; Zang & Smith 1996). Smoke and heat, as mentioned earlier, accompany each other, so when there is a lot of smoke it is also usually warm. Warmth was perhaps more important for Iron Age people. Both the Klima-X experiments and the historical sources also appear to show that the ridge louvre had an important role as a light source.

It is also possible that a ridge louvre of a different shape and size would function more efficiently. But until this has been tested under comparable conditions it is only possible to say that ridge louvres such as that in House 17 are, in our opinion, not very suitable for smoke extraction but they function very efficiently as a light source. It would therefore be interesting to test many aspects of louvre construction in future reconstructions – for example, small gable louvres, possibly cut directly through the thatched roof at the gable ends on a roof construction such as House 17, a roof construction that had a combination of gable louvres and ridge louvre, or one where the ridge louvre was located elsewhere than directly above the hearth.

Other important questions relative to an understanding of the significance of the louvres include whether they are at all necessary in a thatched roof in order for the smoke to escape and how a thatched roof functions with louvres relative to one without if the smoke is to be removed from the house while retaining heat.

## The loft – function and influence on the indoor climate

No definite archaeological evidence has been found showing the presence of lofts in Iron Age houses but a few burnt house sites contain timber remains which, in principle, could have belonged to loft constructions[10], especially over the byre (Kjær 1928; Kjær 1930; Hatt 1957).

At a burnt house site at Neder Hallum, from the Late Pre-Roman Iron Age, there were also fallen beams between which lay a compact layer of charred grain.

The latter is interpreted by the excavator as grain that had been stored on a loft constructed of beams (Nørgaard 1987:284).

The indications for the existence of lofts are, therefore, few but the way in which most three-aisled Iron Age houses are reconstructed – with tie-beams between the roof-bearing posts – creates an obvious opportunity to build a loft (figure 16).

Figure 17
Pole loft in House 17. The loft is sealed with "stores" comprising blankets and mattresses stuffed with straw. In the foreground the loft opening can be seen above the hearth.

This could have been used as a storage place for grain and other foods, fodder and various other materials. Another possibility would be to use the loft above the byre as a sleeping place. Here, one could lie in the rising heat from the animals regardless of how slight this may be (see section *Significance of the animals for the indoor climate*).

Further to these purely functional uses, we had the idea prior to the experiments that a loft could have an advantageous effect on the indoor climate by, for example, retaining smoke in the loft space and also raising the temperature and reducing draughts at the level of the living quarters. Similar thoughts were expressed when House 17 was built, but these were never tested (Draiby 1988). The loft which was constructed did not cover the area directly above the hearth out of a concern for fire hazards (figures 3 & 17). But it would of course be possible to construct a fireguard that would also function as a smoke flue up through the loft. It could be made of hide or wattle and daub, as known from ethnological examples (Näsman 1982:207f), but this was not tried out in practice. A cowhide was stretched out above the hearth in House 10 in order to screen the thatched roof from sparks and therefore reduce the risk of fire. There was no similar structure in House 17, with its ridge louvre, as this would also screen out the light. However, it became apparent that sparks from the fire disappeared before they reached the roof or were swept out of the ridge louvre without lodging on the thatched roof.

During the experiments, the loft did prove to have an effect on the temperature but this was modest. It was 1-2° C warmer on average in the living quarters with a loft above. The questionnaires also showed that the participants had the perception that it was warmer on the days when the loft was in place. When asked in interviews they did not think that they could feel a noticeable difference between the two situations. However, it was mentioned that it felt cosier and more "enclosed" with a loft. This factor could have had an influence on the experience and the subjective perception that it was warmer, rather than this actually being detectable by humans. Some participants were also of the opinion that they could feel draughts a little more on the days when the loft was not in place. This could be due to the fact that the living space was open to the thatched roof when the loft was removed and, as mentioned earlier, the roof appeared to allow air to penetrate. However, the thatched roof still constituted a large proportion of the surface in the living quarters when the loft was in place. This was due to the loft planks not lying at the same level as the junction between wall and roof when they were laid on the tie-beams. On the contrary, they lay about 1 m above the top of the wall and, as a consequence, did not cover the lowermost part of the thatched roof (figure 16). The question is, therefore, whether it is possible to place the loft lower down relative to the roof and the wall, and whether draughts would then be reduced and the heat easier to retain? If the loft were to lie on level with the wall-roof junction or, at least, such that the exposed piece of roof was reduced, then the walls would need to be higher and the tie-beams should possibly be placed some way lower down on the roof-bearing posts (figure 16).

Measurements of the $CO_2$ content of the air showed that, in general, it became slightly smokier in the living quarters when the loft was in position. $CO_2$ measurements from the loft space itself revealed generally very high values and it was virtually impossible to be up on the loft when the fire was lit. In our opinion, this excludes the idea of the loft as a dwelling area, e.g. sleeping quarters, for some time after the fire had been extinguished. Only if it were possible to construct a dense dividing wall extending from the floor and up to the roof ridge between the living quarters and the entrance area, or between the byre and the entrance area, would it perhaps be possible to screen off the smoke to such degree that it was possible to sleep above the byre. This idea has not, however, been tested in practice.

The thermometers mounted at loft level also became heavily coated in soot and tar in the course of the relatively short experimental period, as was also the case for the hay stored on the loft. This illustrates the great quantity of smoke present in the loft space. If the loft were used for storage over a longer period, the stored items would also become heavily affected in this way – a phenomenon known from historical times when chimneys began to be used and a new method had to be found of maintaining and conserving the woodwork (Steensberg 1977:12f). Against this background, the appropriateness of storing food or fodder on a loft is questionable. Would animals and humans even eat this if it had a tar-covered surface? Sources from the 18th century in Northern Friesland recount that cows preferred to eat smoked hay and straw and it was even thought that the hay was improved as a result. According to these sources, the hay was stored in the loft above the byre, which was in direct continuation of the living quarters (Michelsen 1976:56). The living quarters were heated by way of an open hearth on the floor, i.e. a situation corresponding fully to that in Iron Age houses, even though the house dimensions and construction are completely different. On this basis, it is easy to imagine loft space in the Iron Age possibly being used for the storage of fodder. Perhaps the great heat would also be advantageous for, for example, the storage of grain, as seen in the find from Neder Hallum. The grain would be kept warm, there would probably be fewer pests in the abundant smoke and smoke is also well known for its preservative qualities. However, the high humidity at loft level would presumably cause the grain to rot even though there would be considerable air renewal in the house, especially at loft level. Future experiments should aim to determine whether a loft in an Iron Age house is a suitable space for the storage of food and other items.

All in all, it must be concluded that a loft in an Iron Age house with a ridge louvre does not appear to be disadvantageous for the indoor climate. But neither does it give great advantages in this respect. It appears to have a psychologically important function, but when the loft was in place, the temperature in reality only rose slightly at the level of the living quarters and the air became a little smokier. With regard to light, a loft can in itself reflect light from the fire, especially if it is whitewashed or of light-coloured wood (Beck & Rasmussen 1999). But if light from a ridge louvre is required, then it is necessary to have a loft that only covers the area out towards the sides of the house, limiting the available loft space as a consequence.

At loft level it was generally very smoky and hot, something which could be an advantage for storage. However, storage of, for example, grain was not tested and exploitation of the great quantity of smoke at loft height does not in reality require

the construction of a loft floored with planks. The smoke and heat would anyway accumulate up under the roof where grain and other foodstuffs could, for example, be hung in sacks or other containers. This is, therefore, no indication that there were floored lofts in Iron Age houses. Due to the great amount of smoke in the loft, it appears unlikely that it was used as sleeping quarters.

## Walls – insulation and influence on indoor climate

Prior to the pilot experiment in 1997 we had the perception that the clay walls (and the floor) would be heated up and would retain this heat for a long time once a fire had been burning in the house for some time. This proved to be completely wrong. The clay walls did not become warm, at least no warmer than the air temperature in the house itself which was, of course, relatively low (see the section on *Temperature*). The inhabitants had a feeling that the walls virtually radiated cold – a cold which was, for example, unpleasant to sleep up against or sit close to. This could be because clay is a poor conductor of heat. For example, a clay pot which is used for cooking on a hearth becomes very hot on the side facing towards the fire, whereas the side which faces away becomes no warmer than it is still possible to touch it.

If the clay really were to be able to store and give off heat of any significance, it would be necessary for the air by the walls to be warm – and it was not. The warm air rose up to the loft and out through the roof and louvres, and the radiant heat did not reach the walls to a sufficient extent. The walls had, therefore, the same temperature as the air in the house, or were a little cooler. Similarly, the outer surface of the walls followed approximately the air temperature outdoors (figure 18).

We also thought that the sun would contribute to warming up the walls, and with them the house, but neither did this appear to be the case. On a sunny day the temperature of the outer surface of the walls on the southern side of the house could be as high as 23° C, where they were exposed to the sun, whereas the temperature of their inner surfaces was 5° C.

On average, over the course of the experimental period, there was a difference between the temperature of the southern wall's outer and inner surfaces of 6.5° C. The walls did not, therefore, allow the heat to dissipate in the same way as the roof appeared to do but at the same time they remained relatively cold. It was therefore obvious during the experiment to test ways of insulating the outer walls that could have been used in the Iron Age, and which should contribute to raising the temperature inside the house.

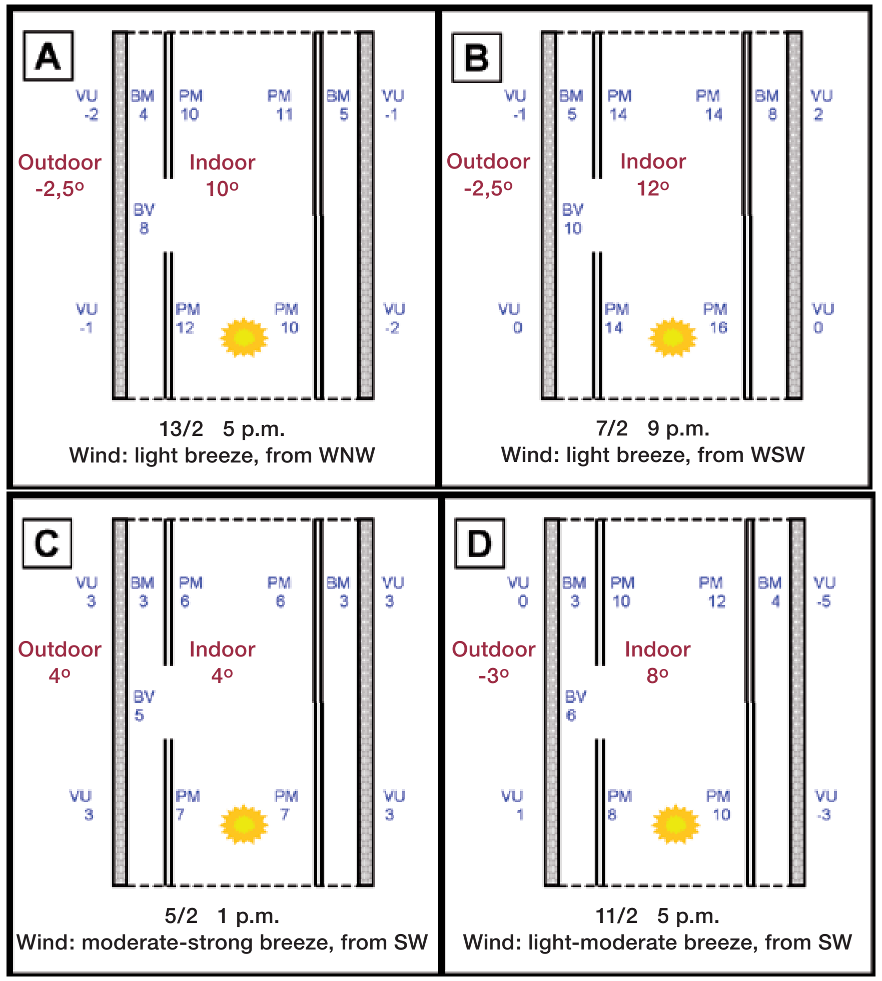
During the excavation of an Early Iron Age house from Nørre Fjand, finds were made of fallen pieces of woven straw, which the excavator interpreted as possible wall mats (Hatt 1957:14). The use of wall hangings is also known from, for example, Bayeux in France and the Oseberg site in Norway. These were probably hung up both to decorate large impressive halls as well as to reduce cold and draughts. Our idea was, therefore, that mats of straw or woollen blankets would have an insulative effect due to the body of static air formed between the mat and the wall as well as within the straw mat itself. Accordingly, we hung up straw mats made of 1-2 layers of rye straw on all the walls as an experiment (figures 19 & 4).

It quickly became apparent that it was much more comfortable to sleep up against a wall covered with mats than against a bare clay wall. As shown in figure 18, the mats also created a greater temperature difference between the inner and outer sides of the walls. The mats were usually about 3° C warmer on the surface than the bare walls and also 1-2° C warmer than room temperature.

The cavities within them and the porosity of the mats, as well as the straw's ability to take up heat, ensured that the inner surface of the mats remained warmer. The differences were, however, not great, but it seems likely that thicker mats would have produced an even better effect than these relatively thin examples.

We could not, however, register an actual increase in room temperature when the mats were in place, but perhaps more targeted experiments would be able to demonstrate this.

In modern buildings, the assumption is that internal insulation has a short-term effect whereas external insulation is more long term[11]. It therefore seems likely that turf around the house would contribute to insulating the walls and reducing wind cooling. At Lejre, turf has been stacked up experimentally against the walls



☀ : Hearth
▨ : Clay wall
═ : Straw mat
Red number: Air temperature in Celsius
Blue number: Surface temperature in Celsius
VU: Wall outside (outer side, in shadow)
BM: Behind mat (the mat pulled aside)
PM: On mat (side towards room)
BV: Bare wall (inner side, without mat)

Figure 18
The relationship between clay wall, straw mats and air temperature at selected times. The figures show the surface temperature of walls and mats in the living quarters in House 17 in either typical or more special situations (not to scale).
A. Typical situation where there is approximately the same temperature on the surface of the mats as the air indoors and where the outer surface of the wall has the same temperature as the air outdoors.
B. The temperature on the outer surface of the north wall is higher (2° C) than both the air temperature (-2.5° C) and the outdoor temperature elsewhere on the wall (0/-1° C). This shows perhaps some heat loss through the wall and that it may be possible to heat up the wall throughout its whole thickness, if only minimally. The fact that this happens precisely at this time could be due to the light wind or that, in the hours previous, there was a very active fire which led to accumulation of heat in the house. A similar situation could be observed on 11th February at 9 pm and 9th February at 9 pm.
C. Both the temperature of the inner surface of the walls and the air temperature outdoors are relatively low. This is most probably due to the strong wind creating air currents through the thatched roof and low temperatures in the living quarters rather than the wind penetrating the wall or cooling it. If the wind affected the wall there would probably be a difference in surface temperature between north and south due to the wind direction, but this is not the case.
D. It is relatively warm on the outer surface of the south wall relative to the air temperature. This is probably due to the sun having shone on the south wall all day and warmed it up, and that the heat has spread to areas which otherwise lie in the shade (the shown surface temperatures). The temperature further down the wall (outside the shaded area) is at the same time 5° C and earlier in the day (1 pm) it was 6° C. It appears, therefore, that heat can be stored in the wall under special conditions, although without this having a great influence on the house itself and indoor temperatures.

Figure 19
Insulating straw mats along the south wall of House 17. The mat in the middle has been moved to one side in order to measure the temperature of the clay wall. See also figure 5.

of some of the reconstructed houses, extending up to the level of the eaves. Unfortunately, this does not include the houses used in the Klima-X experiments. Only House 10 had a thin, worn turf bank around the walls of the byre. Turf banks such as this would increase the distance between the external influences (wind and weather) and the living quarters. And if the turf is stacked up a short distance from the walls, perhaps a cavity would be formed in which the air was more or less static. This could possibly have a minor effect on the indoor temperature. The effect would, however, probably not be great because the radiant heat from the fire would not reach the walls and the warm air would disappear up and out of the house. Future experiments, in which houses of the same construction with and without turf banks could be compared under standard conditions, will hopefully be able to provide an answer to this.

Until this has been attempted it can be concluded from our experiments that the clay walls alone are not optimal for insulation. It is true that they provide a barrier to wind and rain but they remain just as cold as the air on the inside and outside. Neither the sun, nor the fire, appears to be able to heat them up as we previously thought they would.

The straw mats we hung up also gave only a very local effect. They were of the greatest importance when sitting or sleeping up against the wall, in that they were warmer on the surface than the bare wall. We were, however, not able to register an increase in temperature as a consequence of the presence of the mats.

## Partition walls – function and influence on the indoor climate

Structures which can be interpreted as the remains of partition walls have been found in several houses from the Early Iron Age[12] (Hatt 1957:30ff; Lund & Thomsen 1982:64; Hvass 1985:116; Nielsen 2002:5). However, they are not so common, or so easily recognisable, as they are in houses from the Early Bronze Age or Late Roman Iron Age where they can, furthermore, often be detected across the full width of the house (Näsman 1987:80; Hvass 1988:70; Rasmussen & Adamsen 1993:136; Rasmussen 1999:283f). In the Early Iron Age, these structures can, as was the case at the Hodde village, take the form of a line of posts set in the earth and extending about 1 m out from each side wall, and the roof-bearing post (figure 3). Or, as at Nørre Fjand, a 2.5 m long sill running across the house, on which a partition wall could have stood (Hatt 1957:30ff; Lund & Thomsen 1982; Hvass 1985:116). Very clear and straight boundaries between flooring materials, as often seen between clay floors in the living quarters and earthen floors in the byre, or between cobblestones in the entrance area and the flooring materials in the byre and the living quarters, have also been seen as an indication that partition walls existed between these areas (Hvass 1985:122; Kjær 1928:15; Lund 2003:69).

Partition walls are shown on several reconstruction drawings of houses from the Early Iron Age (e.g. Jensen 2003:403). Similarly, House 17 was originally intended to have a partition wall extending from floor to roof between the living quarters and the entrance area, but this was never installed (Draiby 1988).

It is not known whether these potential partition walls could have had a special function connected with the fitting out of the house and the demarcation of specific areas. Or whether they had a function relative to the indoor climate, e.g. for retaining heat and screening out draughts. We decided to investigate just such a possible function, and therefore, as previously described, a partition wall of blankets was hung up between the living quarters and the entrance area (see section *Fittings and additional features*) (figure 20). The blankets were not hung in place until the second day of the experiment so we had the opportunity to detect any possible difference in the temperature or draughts. The measurements from the two years of experiments in House 17 show that during the day, on days when the blanket partition wall was in place, it was 1.5° C warmer in the living quarters than in the entrance area. The partition walls contributed, therefore, to retaining the heat in the living quarters or, more probably, to screening out the cold from the entrance area.

Figure 20
Partition wall of blankets between the entrance area and living quarters in House 17.

At night it was, however, slightly warmer among the animals in the byre than in the living quarters which would argue against having a partition wall extending the full width of the house if the heat from the animals was to be exploited in the living quarters (see section *The byre – the significance of the animals for the indoor climate*). No great difference in draughts could be measured with or without the partition wall but the blankets did not quite fit snugly against the floor and walls. Even if the partition wall had been completely closed off it is possible that the participants would still have felt a draught in the living quarters because the partition wall only extended up to the tie-beam and, therefore, did not screen off possible draughts from the roof.

The dividing wall did result in the smoke from the fire being more or less excluded from the entrance area and the byre and remaining instead in the living quarters. This seems undesirable unless there was a wish to exploit the heat associated with the smoke and have a smoke-free environment in the entrance area and byre. On the other hand, the partition wall screened the air movements produced when the door was opened and, therefore, made the fire less agitated and smoky. It was also seen that the smoke rose more vertically after the partition wall had been erected in House 10. During the experiment in 1967 it was similarly established that "*…doors that are open or not shutting tightly destroy the finely-balanced heat and*

*smoke exchange system that becomes established in the static air in the house*" (Hansen 1974:18f).

Subjectively, all participants in the room thought they could perceive a difference when the blankets were hung up, even though there was agreement that there was still a draught from the entrance area, although this was now reduced. By moving from the entrance area to the living quarters some participants thought they could feel a real difference in temperature after the blankets were hung up.

Creating a partition wall is, however, not without its problems. For example, a partition wall means that the light from the door cannot be exploited in the living quarters in the summer. Furthermore, a partition wall across the full width of the house brings with it considerations of where or how there was an entrance leading to the living quarters. In the course of the experiments it was our experience that an opening directly in front of the fire was a disadvantage as, on entering, one walked almost directly into the hearth. An opening here also resulted in an agitated fire. It is known that houses from the Late Iron Age have a door in this position and it can be imagined that there was a threshold here consisting of a broad vertical plank which screened the fire to some degree, as seen in some reconstructions[13]. A door into the living quarters could perhaps also have been located to one side or the other. Resolution of this question would require a return to the source material in order to look for particular arrangements of posts or differences in the wear patterns of the floors in this region.

When a partition wall of blankets was hung up between the entrance area and the living quarters the latter seemed to become smokier, even though this difference was not pronounced and despite the fact that the fire seemed to burn more steadily. The measurements and the subjective observations showed, furthermore, a tendency towards slightly less draught and cold in the living quarters when the partition wall was in place. Perhaps more closely-fitting partition walls of, for example, wattle and daub, caulked planks or hide screens extending all the way up to the roof would amplify the tendencies we observed with regard to temperature, draughts and quantity of smoke. There is therefore a need for further experiments regarding the indoor climate in reconstructions with partition walls of more substantial construction.

## The byre – the significance of the animals for the indoor climate

From present day experience we know that a byre full of cows can feel warm when we step into it and that it is the animals that are the source of this heat. This knowledge has often been applied directly to conditions in a prehistoric byre. The general belief has been that the cows constituted the predominant heat source in an Iron Age house and that this, furthermore, was the reason why the tradition of building the living quarters and the byre as one, became so common in the Iron Age (Andersen 1999:33). But was this the case in the Iron Age houses at Lejre?

From the archaeological record we know about both the animals and the byre they stood in – at least for part of the year (Zimmermann 1999:302ff). A few well-preserved burnt house sites have proved to contain the remains of animals in the byre, giving a direct insight into Iron Age livestock. It is apparent from these finds that there could be a mixture of animals in a byre: cows, horses, sheep and pigs (Hatt 1928:219ff; Kjær 1928:7ff; Nielsen 2002:5ff).

The general assumption is that the animals were outside and grazed all summer and that some of them were housed in the byre when winter came and they were not taken out again before the spring (Zimmermann 1999:307ff).

In order to simulate an Iron Age winter situation, we chose therefore to have animals in the byre during the experiments. In House 10 we set up ten "artificial cows" which were to represent a byre full of animals. An "artificial cow" consisted of an oil drum containing a radiator which produced the same amount of heat as an Iron Age cow would produce in a relatively cold byre, i.e. 550W (Huld 1978) (figure 21). The surface area of the oil drum was approximately the same as that of an Iron Age cow, calculated on the assumption that the latter was of approximately the same size as a small modern Jersey cow[14].

The idea for the artificial cows came from The Royal Veterinary and Agricultural University in Copenhagen (KVL), where this method is used in investigations of indoor climate and experiments in modern byres.

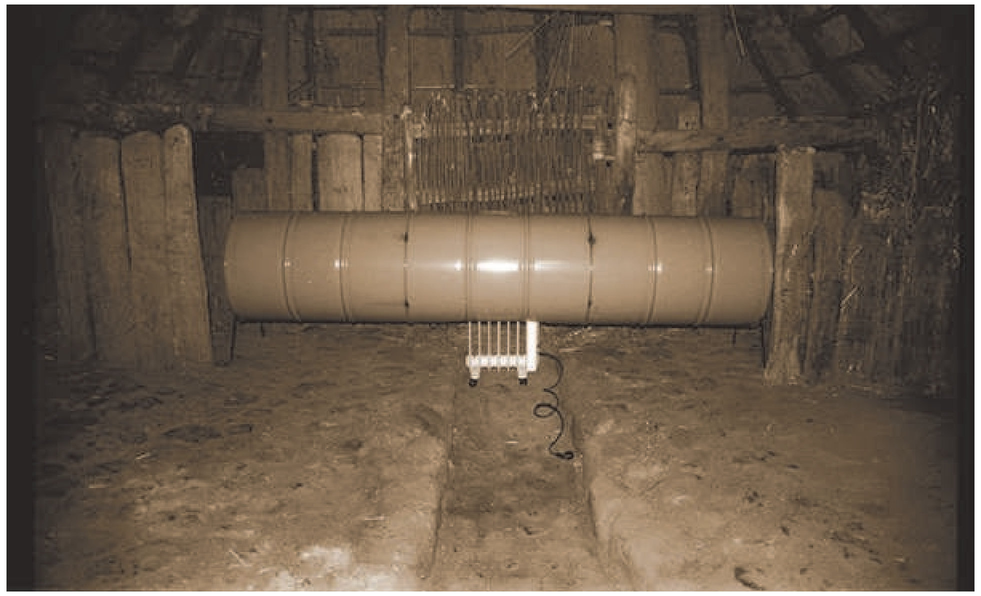


Figure 21
Artificial cows made of oil drums and electric radiators. These "cows" give off as much heat as ten real cows.

The artificial cows in House 10 were easier to "handle" than real animals and we could easily switch them on and off to represent whether they were in or out of the byre. It was necessary to be able to compare measurements on days with and without cows in the house.

On the advice of Bjarne Bjerg from KVL, we had no layer of manure in the byre as this would only have had a slight or no effect on the temperature in the byre and the house[15]. With respect to this, during the habitation experiments in 1967 and 1972, there was a large collection of living animals in the byre and at the same time a thick layer of manure. With the aid of temperature measurements it was discovered at the time that the temperature was about 40° C in the middle of the manure layer without this or the animals having any influence on the temperature in the actual living quarters (Hansen 1974). In House 17 we had living animals in the byre: three goats, two oxen and two horses. This mixture was, relative to the above, more representative of Iron Age conditions, even though the byre in House 17 is somewhat smaller than it should be according to the archaeological record, and with it the number of livestock it contained. In the following section, measurements from House 10 will be used to exemplify the influence the animals have on the indoor climate of a reconstructed Iron Age house.

The average temperature in the living quarters in House 10 in the daytime was 8.1° C on days with animals (i.e. with the radiators switched on). In the evening, the average temperature was 8.3° C.

On days without animals in the byre (i.e. with the radiators switched off) the average temperature in the daytime was 5.7° C and 5.5° C in the evening. The temperature difference in the living quarters on days with and without animals was therefore 2.4-2.8° C.

In the daytime there was, as mentioned previously, also a fire in the hearth, the heat production from which could, due to fluctuating size and intensity, have "disturbed" the measurements. In fact, the daytime temperature in the byre with animals was on average about 3° C lower than in the living quarters. Without a fire, i.e. at night, the picture proved, however, to be much the same as in the daytime, although on a smaller scale. On nights with animals in the byre there was an average temperature of 3.5° C in the living quarters. On nights without the animals the average was 2° C, i.e. a difference of 1.5° C.

In the interviews, the participants expressed the view that they could not detect a difference in temperature between when the animals were switched on and when they were switched off. But on the basis of the regularly completed questionnaires there seemed to be a tendency towards people being of the opinion that it was slightly warmer in the house when the cows were switched on relative to the days when they were switched off.

On the basis of our experiments we can therefore conclude that the animals con-

tributed some heat to the house and the living quarters, but in no way did they constitute the dominant heat source in the house – this role was fulfilled by the fire. Habitation studies in the Netherlands and those from 1969 and 1972 at Lejre also arrived at exactly the same results (Hansen 1974:18f; Zimmermann 1999:314ff). Accordingly, it is not possible, in the light of these results, to argue that the heat contribution from the animals was a decisive factor in having the living quarters and byre under the same roof, as was usual in the Iron Age.

## Fitting out and use of living quarters and entrance area

For many people who see or use reconstructed houses it is everyday tasks and the fitting out of the house that inspire the greatest interest as well as prompting numerous questions.

But when the houses are to be reconstructed and built it is primarily the building itself, and not the fitting out and contents, which interests researchers. Accordingly, the internal organisation of the house, apart perhaps from the byre with its stalls and, perhaps, also a dung channel, is not integrated into the actual building work. The houses are fitted out subsequent to the construction and experimental phases, but the sources used and arguments behind the chosen method are rarely described in publications. Furthermore, compromises are often entered into concerning the knowledge or the theories that are actually available concerning the internal organisation of Iron Age houses, relative to the function the reconstructed house is to have after it is built. The reconstructions at Lejre (and elsewhere) are examples of this, where considerations pertaining to the many school children and re-enactors are, to a great extent, allowed to determine how the houses are fitted out, dictating, among other things, the inclusion of long benches in the middle of the room and multiple sleeping places. The finished house reconstruction can also easily give a picture of Iron Age daily life that is either empty or impractical because no decisions have been made concerning how to make visible Iron Age people's many tasks and material needs. Or there are not the practical or economic means to enable the house to be filled with materials and artefacts.

The tendency to give fitting out too low a priority can also have its roots in the archaeological record; its quality and the state of preservation may not allow conclusions to be drawn concerning interior fittings. But there are some sources, not just archaeological but also anthropological, which together with experience and so-called *"sensible evaluation of what must have been needed"* (Hansen 1964:74), are used extensively. These should, therefore, always be presented and discussed such that the interior fittings can be included in scientific research into the function of Iron Age houses. Furthermore, it is important to be aware, in any attempt to evaluate the internal organisation of a reconstructed Iron Age house that due to the lack of evidence, we are showing how people at that time behaved in their houses influenced, to a very great extent, by how we as a modern people, use a house. During the Klima-X experiments, our perceptions of life in an Iron Age house, together with each participant's personal experiences, played a major role. Our choice of tasks and the pre-determined fitting out of the house were, to a great extent, decisive for how we used the house's living quarters and entrance area. We did not recreate, for example, *"ordinary Iron Age daily life"* with production and craftwork or work with the animals. This, of course, influenced our movements and observations in the house. As a result we probably spent disproportionately large amounts of our time indoors and around the fire. The number of occupants was also determined by the size of the Klima-X group. This was probably slightly too large relative to the presumed household size in the Iron Age. In the relatively small houses from the Early Iron Age with only one, perhaps two, rooms in addition to the byre, the living area is really quite small – about 30-50 $m^2$. The number of occupants is estimated at about 3-5 adults and a corresponding number of children. The living area in House 17 is about 32 $m^2$. In 1999 there were six people living in each experimental house and in the two previous experimental periods about ten people lived in House 17, i.e. the experiment in 1999 was more realistic with regard to the number of occupants. As a consequence, the evaluation of the internal organisation of House 17 builds primarily on the results from 1999. Unfortunately, like so many others, we had not considered in advance carrying out experiments with the fittings and contents, apart from partition walls, lofts and wall-covering mats. We therefore used the houses as they stood – already fitted out with beds, shelves, benches and quernstones – instead of researching the sources and the relevant archaeological debates (figures 3, 4, 19, 20 & 22). Even so, we have gained experience that can be used in a discussion of some aspects of the internal organisation of an Iron Age house. This applies in particular to the use of the hearth, the form and position of the beds, storage and the function of the entrance area.

Figure 22
Cooking around the fire in House 17 – seen from the entrance area.

The hearth and its position comprise, as a rule, the only certain evidence that exists with regard to the internal organisation of the house. The hearth must therefore be the starting point for any consideration of the internal organisation. The fire proved to be clearly the most important focal point in the house where, in the light it gave off, along with that from the louvre, we cooked, carried out minor crafts and so on (figures 22 & 20). There was, however, very little free space in the area around the hearth and the bed that stood up against the north wall was often found to be awkward to use. It was too far from the heat of the fire and so high that one found oneself up in the smoke layer when sitting there. Smoke often settles out, as mentioned earlier, at a height of about 1.5 m, i.e. at head and chest height, so the nearer the floor one was the less smoke one encountered. This is perhaps why hearths are always found directly on, or only slightly raised above the floor and not at knee height or higher as in the kitchens and living rooms of later houses where there are chimneys.

During the experiments we discovered that by sitting on an animal skin on the floor, in addition to being down below the smoke, one also came into closer contact with the pots by the fire and light from the flames, which was an advantage when cooking. There were, however, also disadvantages of sitting on the floor. Clothes became very easily dirty and also exposed to sparks from the fire. It was also often cold and damp. Low stools that could be moved, like those from the Iron Age village of Feddersen Wierde in Northwestern Germany, were therefore found to be

the best compromise (Haarnagel 1979; Lund 2003:73f).

With thoughts of the terrible power of fire, its indispensability and its attractive effect on the participants in the experiment creating a central social sphere, it was easy – and almost blindingly obvious – that hearths had to be of more than just of functional importance for Iron Age people. This perspective is perhaps best reflected in the miniature vessels and other finds of possible offerings, which occasionally are found under hearths in Iron Age houses (Hatt 1938:182ff; Hatt 1957; Nielsen 1987:295).

Where and how people slept in Iron Age houses is something we know virtually nothing about. Only a few sources can, perhaps, give us a hint: At the tell sites in Northern and Western Jutland, several examples have been found of clay baulks constructed of stone and clad with clay that could be interpreted as sitting and sleeping benches. These clay benches are found at various locations in the houses. Sometimes they are in the gable area; others lie alongside the side walls (Kjær 1928:8; Kjær 1930:19; Hatt 1938:171ff; Jørgensen & Klingenberg 1988:10).

At a burnt house site at Ginderup, a structure made of wooden boards, measuring about 1.7 x 0.7 m, was found in the house's southwestern corner. This can be interpreted as the remains of a bed (Kjær 1930:25).

The probable location of the sleeping places could perhaps also be discovered by investigating where in Iron Age houses there are other finds which exclude the possibility that a particular area was used as a sleeping place. In the western end of some Iron Age houses, for example, large pots have been found which have been interpreted as being for grain storage or some kind of oven (Kjær 1928; Nielsen 1972). Similarly, pits in the floor or sunken pots are also often found at the west gable[16] (Lund 2003:71; Mikkelsen 1987:291). Several Iron Age houses have, for example, also quernstones and stone mortars in the rearmost bay (Hatt 1938:153ff; Hatt 1957:19f). Warp-weighted looms, pots and containers for water, food and various other materials would similarly require considerable space.

An investigation of the pottery distribution at selected burnt house sites from the Early Iron Age has shown that tableware and cooking pottery is concentrated in the southwestern part of the houses and that storage vessels and larger pots are mainly found in the west-northwestern area. These vessels are often intact and are therefore thought not to have stood on shelves, if this were the case they would have shattered as they fell down during the fire (see Christensen et al. in this publication). It is therefore unlikely that there were beds in this area. Conversely, this investigation, together with other finds from the western end of the houses, suggests that these areas along the side walls in the eastern part of the living quarters were available. Another solution to the sleeping place problem could be that people slept in or over the byre. The burnt remains of people in the byre of a house from the tell site of Nørre Tranders could perhaps be an example of this (Nielsen 2002:5). Sleeping in the loft over the byre is mentioned in several Nordic written sources (Edblom 2004:140f) and the Klima-X experiments also showed that the temperature was slightly higher in the loft above the animals at night. On the other hand, as mentioned earlier, large quantities of smoke were recorded in the loft when the fire was lit. If people were to sleep in the loft, care would need to be taken not to light a fire at the same time, as the quantity of smoke would quickly prove fatal. Otherwise it would be necessary to have a smoke-proof partition wall extending up to the roof between the byre and the entrance area or between the entrance area and the living quarters (see sections *Air quality and smoke and The loft – function and influence on the indoor climate*).

There are, therefore, various possibilities with regard to the location of the sleeping quarters. Theoretically, they could have been in all the places where there were beds in House 17, but it is unlikely that there were so many beds in the house at one and the same time. The space in Iron Age houses, judging from the many finds, appears to have been used for several other purposes, as described above, and in the course of the experimental period we discovered that the beds occupied a disproportionate amount of space. Unusable and damp corner areas developed at the western end of the house between the beds and household items, materials etc. had to be stored in the middle of the floor in front of the beds.

The beds in the house's northern aisle and at the west gable were, in both cases, constructed in conjunction with the roof-bearing posts and the dimensions were determined by the position and internal spacing of these posts. The beds in the side aisle were, therefore, about 80 cm wide and very narrow for more than one person to sleep on unless they slept head to toe and even then there was not much space. The side-aisle beds were also about 3 m long due to the distance between the pairs of roof-bearing posts. This was far too long for one person and the bed therefore occupied far too much unnecessary space. The large bed in the west gable, which measured 3 x 1.3 m, functioned well, however, because there was room for several people to sleep there at once. This also made it easier to keep warm under the animal skins; four to five people slept in this bed. During the experiment in 1998, the gable bed was fitted out as an alcove with felt blankets on all sides. As a result it was, on average, 2.4° C warmer at night in the alcove than outside it. Those who slept in the alcove were in agreement that it was warm to sleep in, but there was not felt to be a great difference relative to the open beds.

The question of the construction of the beds and their position in Early Iron Age houses is a difficult one. In order to make progress it is perhaps necessary to think unconventionally and test new ideas against the evidence. It is possible that the beds were short, almost square, and stood in the corners. Or that they had long legs so that pots and other similar items could be stored under them. In the latter case, they would be difficult to recognise archaeologically. Perhaps we should not assume that there were permanent constructions such as we are used to in this modern age (Edblom 2004:184).

In an Iron Age household it was necessary to store food, pots, skins, textiles, tools, provisions etc. But how and where were these things stored? Some could have been kept in the outhouses that apparently became common in the course of the Early Iron Age, or in the cellars found in the northern parts of the country (Hvass 1993:190; Lund 1979). But with the many different structures taking up space in the houses' living quarters[17] (Lund 2003:70f), for example ovens, pits, sunken pots, clay benches etc., it is a wonder that there was room for everything. It is not inconceivable that several different solutions, such as shelves, hooks and lofts, were employed (see section *Loft – function and influence on the indoor climate*). Tools and containers could also have been hung from the tie-beams or rafters or on hooks on the walls. It is also very likely that items were stored in the entrance area and byre.

During the experiments not much attention was paid to the storage of materials and food. Many things stood in baskets on the floor and on shelves above the beds. The shelves consisted of uneven poles, which rested on the tie-beams, on which the clay pots did not stand securely. If shelves were part of the fittings in an Iron Age house, these must have had more even surfaces so that pots and vessels were more stable. Finds of piles of pottery in small areas at a burnt house site at Ejstrup have led to the interpretation that the ceramics were either stored on shelves, which fell down during the fire, or that they stood on the floor and the roof collapsed on top of them (Nielsen 1987:295). Experiments on how pottery lands and breaks relative to its position on shelves or floors would perhaps aid a better understanding of the distribution of pottery finds at house sites and would also help with the fitting out of houses (see Christensen et al. in this publication).

The function of the entrance area has not been clarified and finds are rare from this part of the house. It has been suggested that it was used for cleaning threshed grain by winnowing, as a strong draught can develop between the opposing doors (Henriksen 1996:70f). Finds in houses from Feddersen Wierde of clay vessels containing grain and seeds in this area have led to a perception of the entrance area as a kind of scullery (Haarnagel 1979:119).

There is also the question of whether the entrance area should be perceived as part of the living quarters or as a separate room, at times separated from the living quarters by partition walls.

During the experiments we did not use the entrance area to any great extent, partly because it was cold and also because it was used for stabling horses. During the experiment, the entrance area functioned mostly as an entrance or porch and also as a kind of "covered patio" between the living quarters and the byre; this function was reinforced by the erection of the partition wall. There was very little light in the entrance area when the outer doors were closed against the winter conditions. However, if a more permanent and wind proof partition wall were to be set

up towards the living quarters, as mentioned above, the outer doors could be left open more and the room could function more readily as a work room. When the entrance area is not separated from the living quarters by a partition wall, which was the case in House 10, it must have been included as part of the living quarters and greater efforts were probably made to ensure the two outer doors closed more tightly. We discovered that the entrance area could still be used as a work area though it was very cold and dark when the two outer doors were closed.

Research into the fitting out of Iron Age houses is challenging and new finds, targeted investigations and further habitation experiments, firmly rooted in the archaeological record, are extremely important in order to investigate this subject further. A higher priority for the excavation of burnt house sites, houses with preserved culture layers and other particularly good conditions for preservation is therefore very necessary in the future, together with new and exhaustive analyses of the many well-preserved houses which were located in the middle of the 20th century.

## Summary

Through the Klima-X experiments we have obtained a thorough record of the indoor climate in the reconstructed longhouses. The houses proved to be relatively cold, with strong draughts and high relative humidity. The fire contributed heat but at the same time large quantities of smoke which at times made the air a definite health risk. Further to this, the houses were dark, especially after sunset. The picture obtained of the indoor climate was, however, complex. Wind and weather, in particular, were of crucial significance for conditions in the house. The fire was the all-determining heat source in the house.

This picture confirms some of the ideas we had before we started the series of experiments, but there were also some aspects about which we had to change our beliefs on the basis of our experiences. For example, it was not, as we thought at the beginning, the cold in the room which caused the greatest discomfort, but draughts and the cold floor. Our idea that the clay floor and walls became heated up and then helped to retain the heat in the room proved unfounded. Similarly, the fire was not the stable light source, capable of illuminating the whole house, which we had imagined. The fact that heat from the animals did not have any great effect on the temperature in the living quarters was also a surprising result which will probably prompt revision of some of the widespread perceptions held concerning conditions in Iron Age longhouses.

We can, however, not be sure if the indoor climate in Iron Age houses was exactly as we experienced and described through our experimental series. And in any case, seen from a modern point of view, the indoor climate would probably be judged to be extreme. An evaluation such as this can be used to arrive at two completely different conclusions of the standing reconstructions:

- Either the reconstructions are “too poor” relative to Iron Age standards and need to be improved. They need to be altered in some way, or new practical solutions need be sought to the practical problems concerning the houses, other than those available today.
- Or the reconstructions are “good enough” and Iron Age people accepted conditions which we would not today. Accordingly, the described situation was not perceived as extreme and we therefore do not need to change the reconstructions but rather our perceptions of what are acceptable living conditions. What is not possible, however, is to carry out a decisive evaluation of the reconstructions as “correct” or “incorrect”.

Even though the described situation in the houses does not necessarily reflect an exact picture of the indoor climate in the Iron Age, and we cannot carry out a final evaluation of the reconstructions, we believe that these experiments have produced many valuable results. These can be applied to ongoing work concerning archaeological interpretation, both relative to reconstructions of Iron Age houses at a practical level and relative to more over-arching interpretations of living conditions in the Iron Age. The habitation experiments were, therefore, a valuable way to investigate the past.

Through testing and discussion of the standing reconstructions we have learned a great deal about how various structural details do and do not function. Accordingly, a foundation of experience has been built up and new questions have been posed. These can provide a starting point when new reconstructions are to be built or when new investigations of the indoor climate are to be carried out.

The series of experiments can, furthermore, inspire new examinations of the archaeological record concerning, for example, partition walls, insulation or completely new and, as yet, undiscovered find groups. The experiments have also prompted new questions which, possibly, would not have arisen *via* traditional “desk-based” archaeology; because the experimental series presented the participants with some very real physical problems. With new interpretations of, and perspectives on, the archaeological record, the study can ultimately result in recognition that interpretations of life in the Iron Age need to be changed.

The experiments have also shown that one should not uncritically accept “common truths” and assumptions as being correct if there is no supporting practical experience and knowledge.

One of the most important objectives in the scientific process is to continue to ask questions and challenge generally accepted interpretations. Reconstructions and subsequent experimental habitation are important tools when travelling along this route. Reconstructions are otherwise perceived as the ultimate goal of research, but this is not the case. There are no absolute and complete answers concerning the past. Reconstructions are therefore not an ultimate aim but a means towards an end – hopefully a more complete picture of life in the past. Consequently, the story of life in the longhouses is far from over. After reconstruction comes experimental use!

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## NOTES

1 **The Klima-X group 1997-1999** comprised: Anna Beck, Claudio Casati, Jonas Christensen, Lehne Mailund Christensen, Christian A. Christiansen, Jannie A. Ebsen, Johan Frendrup, Rune Brandt Larsen, Dyveke Larsen, Niels A. Møller, Tina Rasmussen, Katrine Moberg Riis, Leonora Thofte, Nicolai Thye, Lasse Sørensen and Abigail Wheadon. All took part in the occupation experiment and in the processing of the large quantity of data that was produced. **Thanks to:** Bjarne Berg from KVL (Royal Veterinary and Agricultural University of Denmark), Arsen Milikov and Thomas Lund Madsen from DTU (Technical University of Denmark), and Henrik Skov, Jes Fenger and Carsten A. Christensen from DMU (National Environmental Research Institute) – for useful collaboration, loan of equipment and friendly guidance. Thanks to Bente Draiby for answering innumerable questions. Thanks to Lejre Experimental Centre for practical and economic support – especially to Merete Essenbæk for valuable help and good advice. The investigation results, by their very nature, are based on a long series of conversations with, and personal communications from, people who have helped in the course of the project and which, accordingly, form part of the source material. This applies in particular to: Bjarne Berg, KVL; various conversations in 1998, Bente Draiby, archaeologist and architect responsible for the construction of House 17; answering questions by telephone 1998 & 2004, DTU; conversations with various people from Department of Civil Engineering, DTU 1998, including Arsen Milikov and Thomas Lund Madsen; Tove Hatting, Zoological Museum; answers to questions by telephone in 1998, Jens N. Nielsen, museum curator, Aalborg Historical Museum; lecture at Copenhagen University 2001, J.E. Rasmussen, lecturer in Indo-European at the Department of Scandinavian Studies and Linguistics, Copenhagen University; answers to questions 1998, Mads Runge, museum curator, Odense City Museums 2004.

2 KVL: 18 instruments for measuring temperature (Tinytalk). DTU: 16 temperature sensors (Squirrel-meter), air humidity monitor (DeltaOhm), infra-red surface temperature monitor, air velocity monitor (Velocicalc), trace gas monitor (Kitagave), monitor of draught and heat radiation (SwemaAir 300), comfort monitor (Thermal Comfort Meter Type 1212), thermal mannequins. DMU: 3 stationary smoke meters with active collection on absorption tubes, smoke meter badges, radiello tubes or samplers. School of Conservation: Lux meter (Megatron D7-Lightmeter). Lejre Experimental Centre: Pyrometer, fish scales for weighing firewood, ten ordinary outdoor thermometers, photo lux meter.

3 In addition to the measurements mentioned, investigations were also carried out into firewood consumption for heating and cooking, the insulative properties of Iron Age costumes and the thermal comfort and light conditions in reconstructed houses.

4 Turbulence intensity is defined as the relationship between the standard deviation and the average velocity. The greater the standard deviation relative to the average velocity, the greater the turbulence.

5 The draught measurements were carried out with a SwemaAir 300 (SWA 03 S/N:361149) instrument which measures air velocity and temperature in a recommended monitoring period of three minutes.

6 Four types of reconstructed lamps were produced and used. They were all made of clay, had pig fat as fuel and rush (Juncus effusus) wicks.

7 The measurements were carried out in collaboration with the Department of Atmospheric Environment, DMU, Roskilde, Denmark.

8 Oral communication from Jens N. Nielsen.

9 The word ”lyre” (louvre) comes from the proto-Germanic *leuh-ran-, which is derived from the Indo-European root *leuk- (light); Leuh-ran meaning light or to shine (oral communication from J.E. Rasmussen). The Concise Danish Dictionary (Politikens Nudanske ordbog 14. udgave 1990) states that the word “lys” (meaning light) comes from the Old Nordic “ljós”. In Norwegian a ridge louvre is, furthermore, called a “ljore”.

10 Oral communication from Jens N. Nielsen.

11 Oral communication, DTU.

12 In the newly-excavated tell site near Aalborg there are several examples of traces of partition walls being found across the full width of the house in the form of rows of postholes or remains of planks across the floor. The partition wall is often seen between the entrance and the byre, but also between the entrance area and the living quarters. Oral communication from Mads Runge.

13 For example, a reconstructed Iron Age farm at ”Dejbjerg Jernalder” in Denmark, built according to groundplans from one of the Skjern-Egvad museum’s unpublished excavations in Tarm. The locality is called Engholmvej. Oral communication from Torben Egebjerg.

14 Oral communication from Tove Hatting

15 Oral communication from Bjarne Bjerg.

16 Oral communication from Jens N. Nielsen.

17 Oral communication from Mads Runge.