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SCIENTIFIC SUPPORT ACTIVITY IN THE FIELD OF STRUCTURAL STABILITY OF CIVIL ENGINEERING WORKS
SNOW LOADS

Contract n° 500990 dated December 12th 1997

FINAL REPORT

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0. Executive Summary

The scientific work carried out under EC Contract n° 500990 is aimed at improving the scientific knowledge and models for the determination of snow loads on buildings by producing a sound common scientific basis which can be accepted by all European countries involved in the drafting of Eurocodes.

The research programme is in two consecutive phases. Phase I, concluded on March 1998, provided methods and techniques for the determination of ordinary and exceptional snow loads on the ground finalised in the production of a new European ground snow load map. Phase II investigated methods and techniques for determination of ordinary and exceptional snow loads on roofs and defined appropriate criteria for determining the serviceability loads on such roofs. This contract covers only Phase II.

The Final Report is a deliverable required by the contract (Annex III). It describes the work carried out and the results obtained.

The work has reviewed current practice in codes for snow loads concerning the definition of criteria to be adopted in serviceability load verifications and, starting form snow data acquired during phase I of the research, has identified the statistical techniques for determining ψ values and has suggested a set of values to be used in different climatic regions of Europe, as they were defined in phase I, for their implementation in the Eurocode for snow loads. This work is discussed in more detail in Chapter 3.

Shape coefficients for the conversion of the Phase I mapped ground snow loads into roof now loads, , were also investigated both with application of existing models, mainly developed in cold climates, and with data collected from an extensive measuring campaign in nature, undertaken in Switzerland, Italy, United Kingdom and Germany.
Results obtained from the above measuring campaign were integrated with those obtained from a wind tunnel test programme carried out at CSTB.
Details of this work are presented in Chapter 4.
Whilst there have been problems in setting up measurement stations in nature from a temporal viewpoint the work progressed satisfactorily. Results have not indicated any need to alter the objectives of the contract nor to adjust further the contract’s timetable.

Under this contract refinements and improvements to the European Ground Snow Loads Map, produced under phase I of the research, were also investigated. The methodology adopted and examples of the results achieved are illustrated in Chapter 5, with the updated version of the map being included in Annex B for completeness.

1. Introduction

The scientific work carried out under the present research is concerned with the design specifications of civil engineering works and supports the development of the structural Eurocodes. In particular it is aimed at improving the scientific knowledge and models for the determination of snow loads on buildings by producing a sound common scientific basis which can be accepted by all European countries involved in the drafting of Eurocodes. This should eliminate inconsistencies that could prevent Member States from reaching agreement on the relevant European Standards.

The research programme is divided into two consecutive phases. Phase I, concluded on March 1998, provided methods and techniques for the determination of ordinary and exceptional snow loads on the ground in order to produce a new European ground snow load map. Phase II investigated methods and techniques for determination of ordinary and exceptional snow loads on roofs and defined appropriate criteria for determining the serviceability loads on such roofs. A wide range of roof types common throughout the European countries were examined. Snow loads on roofs are needed because ground snow loads alone do not take into account roof geometries and their effects on snow eg local drifting.

This contract covers Phase II only. The research is focused on two tasks:

Task IIc: Definition of criteria to be adopted for serviceability loads

Task IId: Analytical study for the definition of shape coefficients.

The contract requires an interim report, already submitted, and this final report at the end of the Phase.

This final report includes: Chapter 2 which outlines administrative matters relevant to the contract, Chapters 3 and 4 which describe results obtained in Tasks IIc and IId respectively and several Annexes illustrating the procedures and calculations performed in detail. Chapter 5 and Annex B are dedicated to the illustration of the activity carried out under the present contract in relation to necessary modifications of the European Ground Snow Loads Map, developed under phase I of the research. Improvements and further refinements of the map were done, by introducing new data or modifying locally the definition of the regions, leading to a slightly

changed final map, examples of which are enclosed, together with the relative validation procedure.

2. Administrative matters

The contract n° 500990 for this phase of the research was signed on 12/12/1997, with a duration of 14 months. The interim report and final report were required to be sent to the Commission within 9 months and 12 months respectively. As a consequence of the need to perform at least one whole winter of measurements (1998/99) and to elaborate the relative results for task IId, the Co-ordinator, on behalf of the Partners, asked DGIII for an extension of six months to the contract duration. This was approved in the letter to the Co-ordinator from the Commission dated 8 June 1998 and article two of the contract was amended as follows:

"La tâche confiée au contractant devra être accomplie au plus tard 20 mois à compter de la date de signature du contrat (phase II)".

Therefore the timetable for the deliverables is as follows:

- interim report 12th September 1998;
- draft final report 12th June 1999;
- final report 12th August 1999.

The following meetings of the Partners have taken place,

in Nantes on 5-6 May 1998;
in Pisa on 20-21 July 1998 (with the presence of Mr. Chaboussant from DGIII-D/3);
in London on 14-15-16 September 1998;
in Bergamo on 16-17 November 1998;
in Davos on 25-26 January 1999;
in Florence 19-20 April 1999;
in Paris on 4 June 1999.

Additionally a restricted meeting was held in Zurich on 15 March 1999, between those partners directly involved in the collection of data on snow loads on roofs, for the determination of shape coefficients for task IId.

The same information and communication protocol between Partners as used in Phase I was adopted ..
For this research work liaison with CEN/TC 250/SC1 has been established. This liaison was approved by SC1 in resolution n° 76 dated May the 23rd 1997. Reports on the research group’s activity were presented, by Prof. Sanpaolesi, to the CEN/TC/250/SC1 meeting held in London on 8 May 1998 and discussed during the meeting of CEN/TC 250/SC1 held in Florence on 22-23 April 1999.

3. Investigation on Snow Loads for Verification of Serviceability Limit States

3.1 Introduction

The present study is concerned with procedures for derivation of load combination factors in relation to the serviceability limit state. This is performed as Task II(c) of the present Snow Load Research Project.

For the two basic background documents, i.e. *CEN-ENV 1991-1 Basis of Design* and *ISO/FDIS 2394: 1998 General Principles*, three different basic combinations are proposed. These are the Characteristic Combination, the Frequent Combination and the Quasi-permanent Combination. These combinations are introduced in order to cover different types of consequences in relation to exceeding a given serviceability criterion. However, there seems to be some differences between the two documents as to distinction between the three combinations.

For the *CEN-ENV 1991-1: Basis of Design*, p. 31, the purpose of each combination is stated as:

- *Combination values* for irreversible serviceability limit states
- *Frequent values* for reversible serviceability limit states.
- *Quasi-permanent values* for reversible serviceability limit states and for calculation of long term effects

The purpose of the combination formats according to *ISO/FDIS 2394: 1998 General Principles,* Appendix G, last page, are classified as:

- *Characteristic combinations* when exceeding a limit state causes serious permanent damage
- *Frequent combinations* when exceeding a limit state causes local damage, large deformations or vibrations which are temporary.
- *Quasi-permanent combinations* when long term effects are determinative

Furthermore, there are differences between the structure of the combination formats themselves (for the Serviceability Limit State, while this is not necessarily the case for the Ultimate Limit State). This applies in particular to the Characteristic combination. However, for the quasi-permanent combination, the two documents are in much more harmony. Accordingly more than three different load combinations, have to be addressed. Table 3.1 below contains the combinations relevant to the present task

Table 3.1 List of Relevant Serviceability Load Combinations in ISO/ENV 1991 documents

Combination	Design values			Type of limit state
	Permanent	Variable		
		Dominating	Not Dom.	
Characteristic (ISO) Characteristic(CEN)	γ_G γ_G	γ_Q γ_Q	-- $\gamma_Q\psi_0$	Serious Perm.Dam. Irreversible
Frequent (ISO) Frequent (CEN)	γ_G γ_G	$\gamma_Q\psi_1$ $\gamma_Q\psi_1$	$\gamma_Q\psi_2$ $\gamma_Q\psi_2$	Loc. dam., transients Reversible
Quasi-permanent (ISO/CEN)	γ_G	$\gamma_Q\psi_2$	$\gamma_Q\psi_2$	Long-term effects

It is implicitly understood that the characteristic value of each load effect is to be applied in the load combination. This characteristic value is generally to be taken as that corresponding to a return period of 50 years, i.e. with a probability of exceedance of 0,02 when referring to the cumulative distribution of the annual maxima.

The values of the partial coefficients γ_G and γ_Q are typically equal to 1.0 for the serviceability limit state. Accordingly, the basic load effects which enter the design checks are equal to their characteristic values.

An introduction to relevant design formulations and practical application of serviceability limit state criteria is given in Section 3.2 of the present report. Procedures for derivation of the combination factors are mainly different for ψ_0 versus ψ_1 and ψ_2 . Accordingly, procedures for derivation of the different combination factors are organised in the two main Chapters 3.3 and 3.4:

- *Chapter 3.3:* The Characteristic Combinations which deals with the combination factor ψ_0 . Three different procedures for derivation of this combination factor are described. One of the methods has been applied extensively to snow data from a number of European meteorological regions. Results obtained by application of the different methods are subsequently compared.

- *Chapter 3.4:* The Frequent and Quasi-permanent Combinations are investigated by consideration of cumulative probability levels for the short-duration maxima (e.g. one-day, one-week)

A summary of the proposed procedures for derivation of the combination factors and calculated values of the coefficients for different climatic regions is provided in Chapter 3.5. More details on the procedures and examples of results are given in Annexes I-V.

3.2 Treatment of load combination in the Eurocodes' system

3.2.1 Treatment of serviceability problems in system of Eurocodes

Serviceability limit states correspond to conditions beyond which specified service requirements for a structure or structural element are no longer met.
Serviceability requirements are concerned with (see [ENV 1991-1, 1994]):

- the functioning of the construction works or parts of them;
- the comfort of people;
- the appearance.

A distinction between reversible and irreversible serviceability limit states should to be made.

The following serviceability limit states require consideration:

- deformations and displacements which affect the appearance or effective use of the structure (including the functioning of machines or services) or cause damage to finishes or non-structural elements;
- vibrations which cause discomfort to people, damage to the structure or to the materials it supports, or which limit its functional effectiveness;
- damage (including cracking) which is likely to affect appearance, durability or the function of the structure adversely;
- observable damage caused by fatigue and other time-dependent effects.

3.2.2 Verification of serviceability limit states

It shall be verified that:

$$E_\mathrm{d} \leq C_\mathrm{d}$$

where:

C_d - is a nominal value or a function of certain design properties of materials related to the design effects of actions considered,

E_d - is the design value of the action effect (e.g. displacement, acceleration), determined on the basis of one of the combinations given below.

The combination of actions to be considered for serviceability limit states depends on the nature of the effect of actions being checked, e.g. irreversible, reversible or long term. Three main combinations should be considered:

3.2.3 Combinations of actions

Characteristic (rare) combination:

$$\sum_{j \geq 1} G_{kj} + P_k + Q_{k1} + \sum_{i > 1} \psi_{0i} Q_{ki}$$

Frequent combination:

$$\sum_{j\geq 1} G_{kj} + P_k + \psi_{11} Q_{k1} + \sum_{i>1} \psi_{2i} Q_{ki}$$

Quasi-permanent combination:

$$\sum_{j\geq 1} G_{kj} + P_k + \sum_{i\geq 1} \psi_{2i} Q_{ki}$$

Other combination can be also used, e.g. infrequent combination from [ENV 1991-3, 1994]:

$$\sum_{j\geq 1} G_{kj} + P_k + \psi_1^{'} Q_{k1} + \sum_{i>1} \psi_{1i} Q_{ki}$$

where:

G_{kj}	is the characteristic value of permanent actions;
P_k	is the characteristic value of a prestressing action;
Q_{k1}	is the characteristic value of the dominant variable action;
Q_{ki}	is the characteristic value of the variable action i;
ψ_0	coefficient for calculation of combination value of the variable action;
ψ_1	coefficient for calculation of frequent value of the variable action;
ψ_2	coefficient for calculation of quasi-permanent value of the variable action;.
$\psi_0\ Q_k$	is the combination value of the variable action for Seviceability Limit State;
$\psi_1\ Q_k$	is the frequent value of the variable action;
$\psi_2\ Q_k$	is the quasi-permanent value of the variable action;
$\psi_1^{'}\ Q_k$	is the infrequent value of the variable action;

3.2.4 Description of serviceability limit states in structural Eurocodes

According to the structural Eurocodes ENV 1992 - ENV 1995 the following serviceability limit states should be verified under the following combination of actions:

Table 3-2: Serviceability Limit States to be verified in Eurocodes

	Rare combination of loads	Frequent combination of loads	Quasi-permanent combination of loads
ENV 1992: Design of concrete structures	stress limitation to avoid the longitudinal cracks	limitation of the crack width or decompression limit for prestressed members	stress limitation to avoid non-linear creep
	stress limitation in the steel to avoid inelastic deformation		limitation of the crack width
			limitation of the deflections
ENV 1995: Design of timber structures		- limitation of displacements of joints - limitation of deflections - vibration control	
ENV 1993: Design of steel structures	limitation of deformations and displacements	Control of dynamics effects	
ENV 1994: Design of composite structures	limitation of displacements		limitation of the crack width

It can be mentioned that excepting the specific situation with timber structures (see above) only in two situations the frequent combination is on the interest:

- limitation of the crack width or decompression limit for prestressed members by design of concrete structures;

- control of dynamics effects by design of steel structures.

The last one is not relevant for snow load therefore only the first one (for example by design of large prestressed roofs, e.g. membranes for stadium) can be taken into account.

Specific situation with ENV 1995 "Design of Timber Structures"

For all SLS only one (frequent) combination is proposed:

$$\sum_{j\geq 1} G_{kj} + Q_{k1} + \sum_{i>1} \psi_{1i} Q_{ki}$$

This combination deviates from the one given in ENV 1991 but no clear explanation for it can be found.

The duration of actions is taken into account by means of the coefficient k_{def} which appears on the resistance side of the equation and has different values for effects of different loads.

It is possible that in the future developments of ENV 1995 the SLS combinations will be reconsidered to be in accordance with ENV 1991 rules. Then the quasi-permanent value of load will be used in design situations including the long-term effects. But it is questionable whether the frequent value will be used for verification of different SLS in the design of timber structures.

Specific conditions of glass structures

In recent years the use of glass as a structural element in buildings has become more popular. Compared to other materials, glass is extremely brittle and imminent breakage will not necessarily be announced by increasing deformations. The resistance of glass panes in bending depends considerably on the duration of previous loading.

For the moment the verification of glass elements is not yet adjusted to the system of the European Standards (e.g. ENV 1991-1). Therefore design engineers should follow the traditional way of comparing the stresses and deflections to upper limit values, fixed cautiously in order to cover all the uncertainties by a global safety factor. By attributing the safety exclusively to the resistance value, it is not possible to take into account the influence of different variable loads, e.g. wind pressure and snow load. In Germany sometimes more detailed verifications of glass structures are made, supposing the duration of the characteristic snow load on a glass roof to be one month.

3.2.5 Conceptual definitions of ψ factors

Considering all limit states in ENV-1991-1 "Basis of Design" it is possible to conclude where the ψ factors are used:

Combination values:

- verification of Ultimate Limit States
- verification of irreversible Serviceability Limit States

Frequent values:

- verification of Ultimate Limit States involving accidental actions
- verification of reversible Serviceability Limit States

Quasi-permanent values:

- verification of Ultimate Limit States involving accidental actions
- verification of reversible Serviceability Limit States
- calculation of the long-term effects of Serviceability Limit States

Combination factor ψ_0

The combination value $\gamma_Q\ \psi_0\ Q_k$ takes into account a reduced probability of simultaneous occurrence of the most unfavourable values of several independent actions. The combination value is determined in such a way that the probability of combined action effect values being exceeded is approximately the same as when a single variable action only is present.
Eurocode 1 and other documents establish the procedures for the calculation of the factor ψ_0 for the Ultimate Limit State and then use this factor in consideration of the Serviceability Limit States. This is the reason that the combination value $\gamma_Q\ \psi_0\ Q_k$ contains the partial safety factor γ_Q which is equal to 1,5 for ULS and equals 1,0 for SLS.

The combination factor should be calculated for all pairs of combined loads (for example for snow the most important combination is snow with wind). The actions are normally considered as stochastic processes (Borghes-Castanheta, pulse-process etc). This requires essential computational effort due to numerical integration of probability functions or the use of the First Order Reliability Method.

The ENV 1991-1 and ISO 2394 also propose to the use of simplified procedures which consider only the load itself (for example snow load). In this case the combination factor can be defined as:

$$\psi_0 = Q_{\text{non dom}} / Q_{\text{dom}}$$

where $Q_{\text{non dom}}$ design snow load value when snow is the non-dominating action

Q_{dom} design snow load value when snow is the dominating action.

(Possibly replace the definitions with the ones in red, if I have interpreted them correctly)

The probability of exceeding the design value of a variable action when it is the dominant one:

$$\Phi\ (-\ 0{,}7 \times \beta\ ) = 1 - 0{,}996 = 0{,}004$$

where Φ ( ) standard normal distribution function

β target reliability index, set equal to 3,8 for design working life of structure (see ENV 1991-1)

The probability of exceeding the design value of a variable action when it is the non-dominant one (the combination value of variable action):

$$\Phi\ (-\ 0{,}4 \times 0{,}7 \times \beta\ ) = 1 - 0{,}856 = 0{,}144$$

The combination coefficient ψ_0 can be defined either by means of Turkstra's rule or by means of the Design Value Method (see Section 3.4).

Factor for frequent value ψ_1

According to ENV1991-1, the frequent value is determined such that:
1. the total time, within a chosen period of time, during which it is exceeded for specified part; OR
2. the frequency with which it is exceeded

is limited to a given value.

The part of the chosen period of time or the frequency should be chosen with due regard to the type of construction works considered and the purpose of the calculations. Unless other values are specified the part may be chosen to be 0,05 or the frequency chosen to be 300 times per year for ordinary buildings.

For snow the duration of load above given thresholds should be used as the only criterion. For simplicity, it is also suggested that only the total (rather than continuous) duration during a year should be considered. The purpose is to establish "duration-over-the-threshold" curves (curves showing the total time related to one year, during which the load is above a specified threshold). The frequent value is determined such that the fractile of time during which it is exceeded is chosen to be 0,05 (a base case). Additionally fractiles ranging from 0,01 to 0,10 may also be relevant.

Factor for quasi-permanent value ψ_2

The quasi-permanent value is determined such that the time during which it is exceeded, is a considerable part of the reference period of time. The time during which it is exceeded may be set as 0,5 of the reference period. The quasi-permanent value may also be determined as the value averaged over the reference period of time.

3.3 Snow Loading in different climatic Regions

Combination coefficients ψ depend essentially on the frequency and the duration of the variable load. Consequently any evaluation of ψ coefficients for snow loads has to start from the time series observed at a typical station.

Due to the wide variety of climatic regions within Europe, modelling and statistical analyses of fine resolution snow measurement time series becomes a challenging task. A fundamental distinction can be made between continental climates (where the snow builds up more or less continuously throughout the winter months, without the snow cover melting away between snowfalls) and maritime climates (where the snow does melt between each snow falls from different weather systems).

As an example of snow data from a continental climate, the snowdepth at Susendal in Norway (Latitude: 65.36 Longitude: 14.26 Altitude: 498m) is shown in Figure 3.1. The record length is from October 1 to the end of May. As can be observed, after the initial two snowfalls between which some melting takes place, a continuous build-up of snow occurs. However, some intermediate melting implies that the maximum snow depth occurs before the end of the winter. After a certain time, no further snow is accumulated and a continuous melting process during the spring takes place.

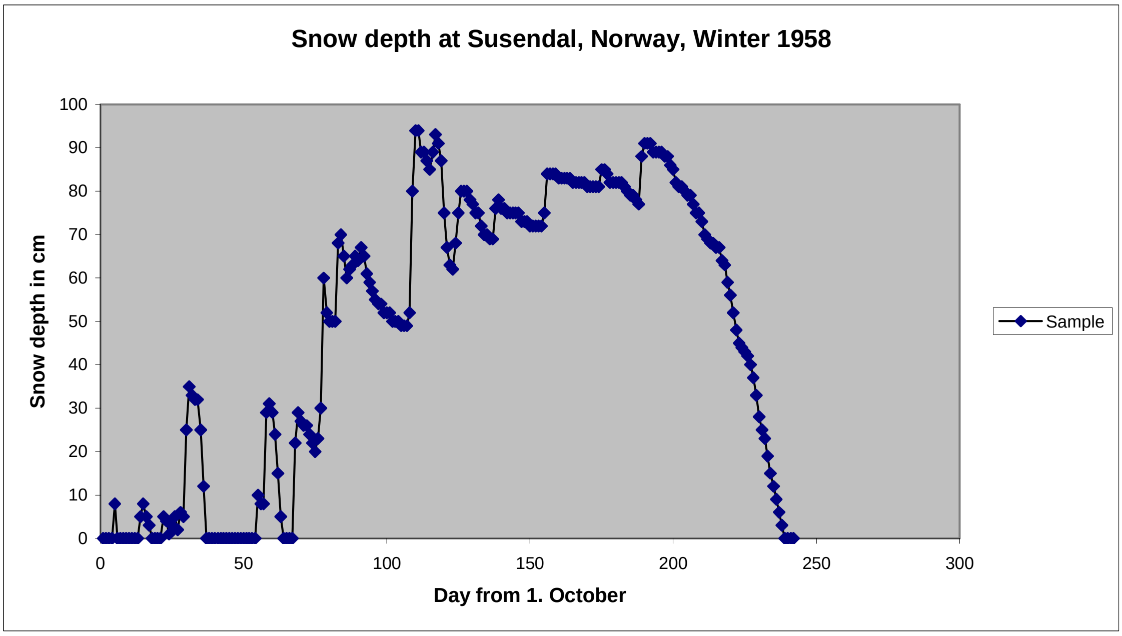


Figure 3.1 Example time series of measured snow depth for a continental climate. Susendal, Norway, winter 1958.

As an example of a time series for snow data from a maritime climate, a record from the station Ilfracombe (Latitude: 51.2, Longitude: –4.1 Altitude: 8m) located on the north coastline of Devon in Southwest England is shown in Figure 3.2. The snow data available for this station are records from twenty winters. During this period there have only been five winters with recorded snowfall, and a total of ten events, with only two of these lasting more than one day.

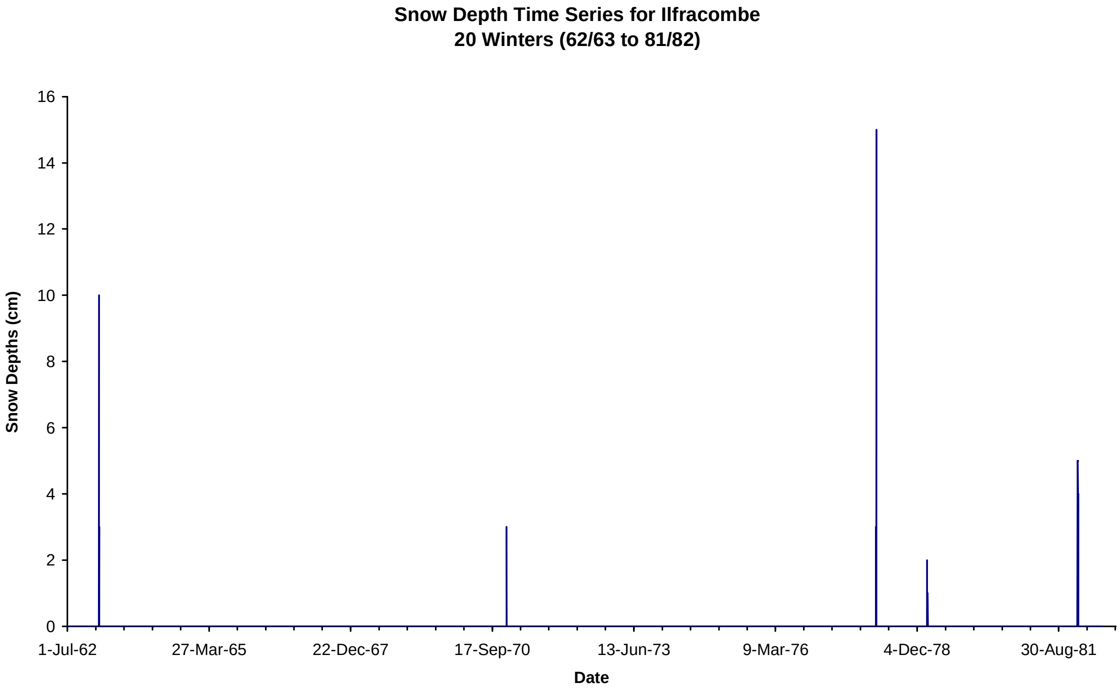


Figure 3.2. Example time series of measured snow depth for a maritime climate. Ilfracombe, UK, 1962-1982

As a third example, snow measurements from a station with a mixed climate are given in Figures 3.3 and 3.4. This station is located at Leinefelde in central Germany, in the North - West of the province Thuringia (latitude - 10^{o}19' north, longitude - 51^{o}24' east, altitude - 356 m above sea level)

The starting point of the time series is set at the 1st November and the end point at April (180 days).

This mixture between a maritime and continental (or mountain) climate represents a common snow behaviour in Germany. Generally, this produces difficulties for investigations related to snow loading. The variation of the process of snow accumulation and depletion from winter to winter is illustrated by the two selected measurement records. In Figure 3.3 (the winter of 78/79), a continental type of behaviour is observed for most of the snow season, and in Figure 3.4 (the winter of 79/80) a more “maritime” behaviour occurs except for a section at the mid-part of the snow season.
More examples of time series are given in Annex I, i.e. for Glenlivet (Banff, Scotland) and Madrid, Barcelona and Articutza in Spain.

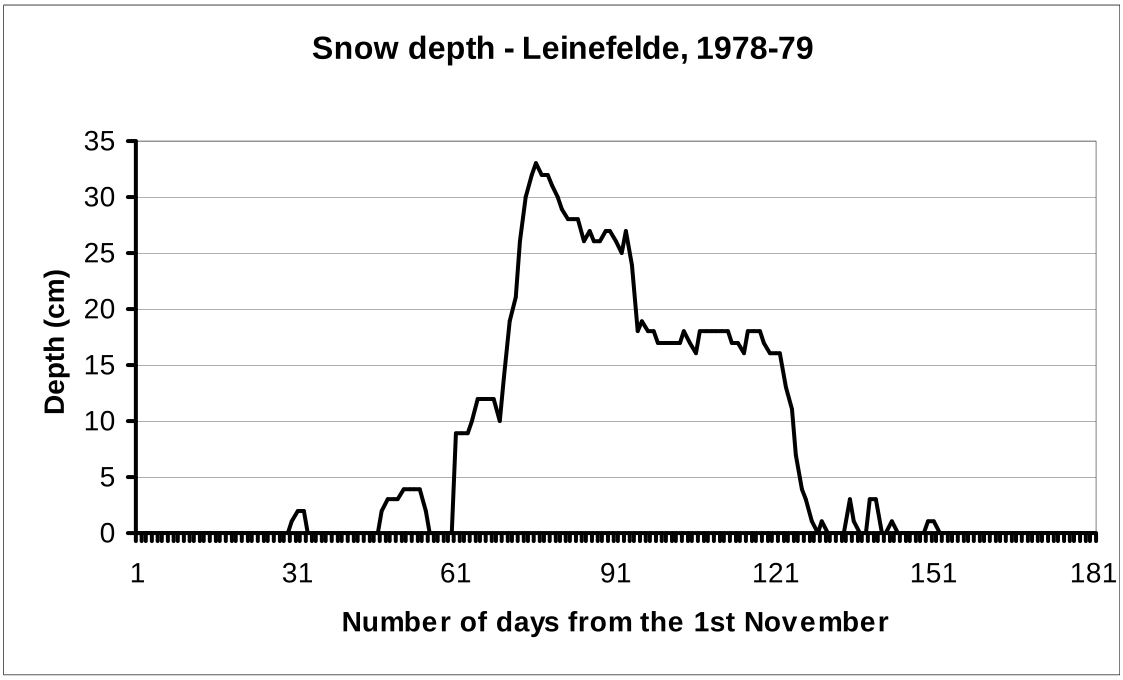


Figure 3.3. Snow depth at Leinefelde, winter 1978-79

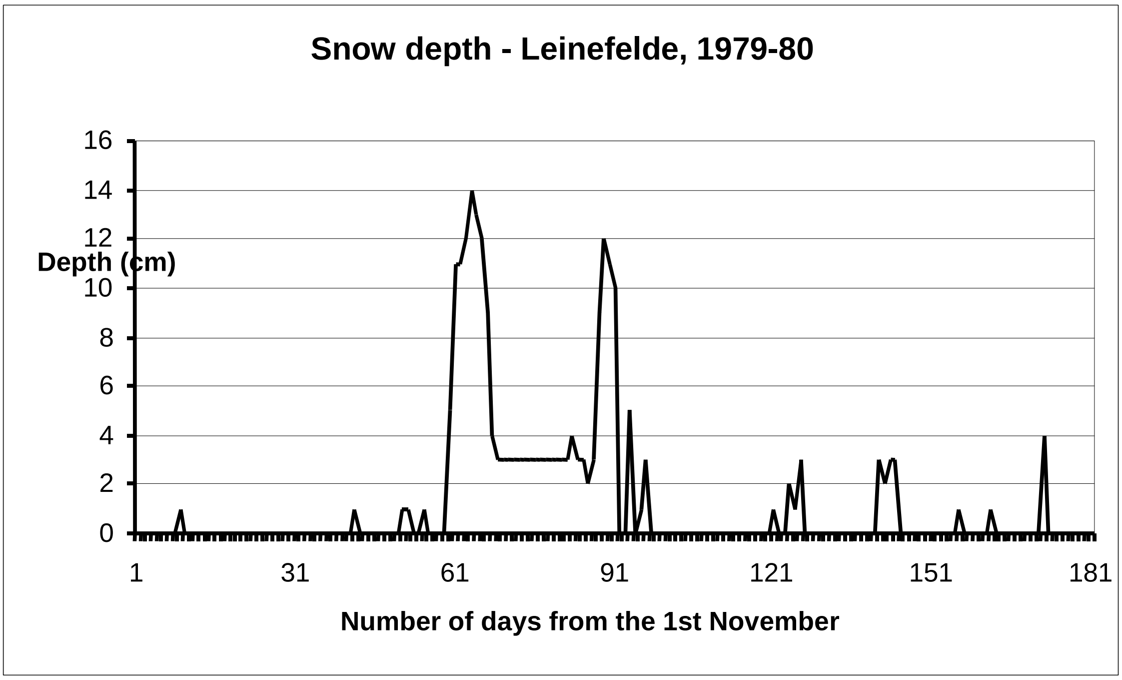


Figure 3.4. Snow depth at Leinefelde, winter 1979-80

3.4 Derivation of combination factor ψ_0

3.4.1 Introduction

The combination factor ψ_0 is applied to the snow load effect when the dominating load effect is due to some other external load, such as wind. Accordingly, a derivation of this combination factor strictly requires a refined modelling of both the snow and wind including the modelling of their variation with time. However, procedures based on such a refined model are typically time consuming both with respect to collection of input data, numerical algorithms and computation time. As a consequence, simplified procedures are described in the ENV 1991/ISO 2394 background documentsfor the derivation of this combination factor.

In the present investigation, three different categories of methods have been employed:

(i) Simplified methods based on assumed values of the "importance weighting" for the snow load effect. This weighting is different for the cases when the snow load is dominating versus non-dominating.

(ii) Modelling of the time variation for the two load effects by means of step-wise constant values. The characteristic time intervals for the two load effects are generally different from each other. In the ENV 1991/ISO 2394 background documents, this model is referred to as the Borghes-Castanheta Model.

(iii) Modelling of both load effects as stochastic time-processes with continuously changing intensity. This model is here referred to as upcrossing-rate analysis

Results obtained by application of these three methods are presented in Sections 3.4.2, 3.4.3 and 3.4.4, respectively. A comparison between results from the three methods is made in Section 3.4.5. Further details related to the different methods are given in Annexes 2, 3 and 4.

3.4.2 Derivation of combination factor based on simplified formulas in ENV 1991-1 and ISO 2349

3.4.2.1 Turkstra's Rule

According to ISO 2394 "General Principles on reliability of Structures" (Annex F) the combination factor based on Turkstra's rule may be written as:

$$\psi_0 = \frac{F_{Q_{\max}}^{-1}\left\{\Phi\left(-0{,}4\alpha_s\beta\right)^r\right\}}{F_{Q_{\max}}^{-1}\left\{\Phi\left(-\alpha_s\beta\right)\right\}}$$

where α_S- sensitivity factor for actions (equals -0.7 according to

ISO 2394 and ENV 1991)

β - reliability index (equals 3.8 for design life of 50 years according to ENV 1991)

Φ - Gaussian normalised distribution

r - the number of an independent load repetitions during the reference time

$Q_{\max}$ the maximum value of action Q during the reference time

$F_{Q\max}$ probability distribution function of $Q_{\max}$

Extreme value distribution, type I for maxima (Gumbel)

$$\psi_0 = \frac{1 - 0,78V\{0,577 + \ln[-\ln(\Phi(-0.4\alpha_s\beta))] + \ln r\}}{1 - 0,78V\{0,577 + \ln[-\ln(\Phi(-\alpha_s\beta))]\}}$$

where V - coefficient of variations of the action

Extreme value distribution, type III for minima (Weibull)

$$\psi_0 = \left\{\frac{Ln\left(1 - \Phi(-0,4\alpha_s\beta)^r\right)}{Ln\left(1 - \Phi(-\alpha_s\beta)\right)}\right\}^{1/c}$$

where c - parameter of Weibull distribution (another parameter is u):

$$F(x) = 1 - \mathrm{Exp}\,[-(x/u)^c]$$

with inverse function

$$x = F^{-1}(P) = u\,[-\mathrm{Ln}\,(1 - P)]^{1/c}$$

Parameter c can be found by the solution of a non-linear equation relating to the coefficient of variation of the action.

Log-normal distribution

$$\psi_0 = Exp\left\{B\left\{\Phi^{-1}\left(\Phi(-0,4\alpha_s\beta)^r\right) - \Phi^{-1}\left(\Phi(-\alpha_s\beta)\right)\right\}\right\}$$

where B - parameter of Log-normal distribution (another parameter is A):

$$F(x) = \Phi\,[(\mathrm{Ln}\,(x) - A)/B]$$

with inverse function

$$x = F^{-1}(P) = \text{Exp}(A)\ \text{Exp}[B\,\Phi^{-1}(P)]$$

Parameters A and B are:

$$B = \sqrt{Ln\left(1 + V_x^2\right)}$$

$$A = Ln(m_x) - \frac{B^2}{2}$$

3.4.2.2 Design Value Method

According to ISO 2394 "General Principles on Reliability of Structures" (Annex F) and ENV 1991, Part 1 "Basis of Design" (Annex A) the combination factor based on the design value method may be written as:

$$\psi_0 = \frac{F_{Q_{\max}}^{-1}\left\{\Phi(0{,}4\beta_c)^r\right\}}{F_{Q_{\max}}^{-1}\left\{\Phi(\beta_c)^r\right\}}$$

where $\beta_c = -\Phi^{-1}[\Phi(\alpha_S\beta)/r]$ - modified reliability index

The procedures of Turkstra's rule and design value method were extended for three different types of distributions: extreme value distribution type I for maxima and type III for minima, and log-normal distribution. The results can be seen here.

Extreme value distribution, type I for maxima (Gumbel)

$$\psi_0 = \frac{1 - 0{,}78V\left\{0{,}577 + \ln\left[-\ln\left(\Phi(0{,}4\beta_c)\right)\right] + \ln r\right\}}{1 - 0{,}78V\left\{0{,}577 + \ln\left[-\ln\left(\Phi(\beta_c)\right)\right] + \ln r\right\}}$$

Extreme value distribution, type III for minima (Weibull)

$$\psi_0 = \left\{\frac{Ln\left(1 - \Phi(0{,}4\beta_c)^r\right)}{Ln\left(1 - \Phi(\beta_c)^r\right)}\right\}^{1/c}$$

Log-normal distribution

$$\psi_0 = Exp\left\{B\left\{\Phi^{-1}\left(\Phi\left(0{,}4\beta_c\right)^r\right) - \Phi^{-1}\left(\Phi\left(\beta_c\right)^r\right)\right\}\right\}$$

Values for combination factor for different distributions, depending on the coefficient of variation *V* and the number of repetitions *r*, can be seen in Annex 2.

3.4.2.3 Analysis of statistical data from 10 different climatic regions

For derivation of the combinations factor ψ_0 , the design value method gives results which are slightly conservative in comparison with Turkstra's rule (see corresponding values in Annex 2). Furthermore, the extreme value distribution Type I (Gumbel) is generally a well-suited fitting distribution for most climatic regions Therefore it was decided to calculate the combination factor by means of the Design Value Method (which is based on the Borghes-Castanheta model) and extreme value distribution Type I (Gumbel).

In different parts of Europe the climatic conditions are different. Hence, the combination factor should also be different for these geographical regions. In order to calculate the ψ_0 factors, the coefficient of variation for the annual maximum snow load (which is denoted by CoV in the following) is required in addition to the number of load repetitions according to the Borghes-Castanheta model (which is denoted by *r in the following*) . These should be based on snow data collected during Phase I and Phase II. tThese values frequently depend on the altitude, and therefore the ψ_0 factor-s can also be a function of altitude within each region.

In ENV 1991 - 1 only one value of ψ_0 is given for the whole are of CEN members. This value is equal to 0,6.

The information about values of CoV and *r* for different regions can be found in Annex 3.

The results are summarised in Table 3-3 below. It is important to note that value of the present combination factor may increase by selection of a different probability distribution than the Gumbel. As an example, the Gaussian model is found to give the best fit to the measured samples for some of the measurement stations. If the number of load repetitions is set equal to 1 (i.e. r=1), the corresponding distribution of annual maxima also becomes Gaussian. For a CoV equal to 0,3, the derived combination factor based on the Gaussian model becomes 0,73 instead of 0,6 which corresponds to the Gumbel model. If a Weibull model was found to apply to the same case, an even higher value of 0,75 would be the result.

Table 3-3: ψ_0 values for different regions in CEN members area

	Region	**ψ_0**	**Additional information**
1	Alpine	0,65 0,5	altitude: > 1000m <= 1000m
2	UK and Eire	0,4	
3	Iberian	0,5 0,4	altitude: > 500m <= 500m
4	Mediterranean	0,5	
5	Central East	0,55 0,4	altitude: > 500m <= 500m
6	Central West	0,4	
7	Greece	0,5	
8	Norway	0,7 0,6	altitude: > 300m < 300m
9	Finland-Sweden	0.65 0.6	altitude: > 250m < 250m
10	Iceland	0,6	

In ENV 1991 – 1, only one value of ψ_0 (equal to 0,6) is given for the whole area of CEN states.

3.4.3 Derivation of combination factor based on Borghes – Castanheta model

3.4.3.1 Basic modelling assumptions

The specific load combination related to snow in conjunction with wind is considered. In order to apply the Borghes-Castanheta model, some degree of simplification of the load models is required. In particular, the length of the characteristic time scale for the snow loads must be a multiple of the scale for the wind load. Setting the latter e.g. equal to 3 days and the former equal to 15 days, a factor of 5 is obtained. Furthermore, the extreme dynamic wind load is assumed to act constantly throughout the characteristic wind interval.

The dynamic wind component is for simplicity represented by a single gust factor. This represents an approximation on the conservative side. However, for the purpose of load combinations it is believed to be sufficiently accurate.

The basic time varying load (or load effect) to be analysed can then be expressed as:

$$S(t) = a_1 * Q_{snow}(t) + a_2 *(Q_{wind(static)} (t) + Q_{wind(dyn)}(t)) \qquad (1)$$

where a_1 and a_2 are fixed constants, the ratio of which determines the relative scaling of the snow and wind loads. The corresponding design format ascertains that the resulting design load effect is properly selected in relation to the statistical properties of the load effect S(t).

In addition to the intrinsic time scales, cumulative distribution functions of the loads are also required in order to perform a load combination analysis. For the static wind load, a Weibull distribution is frequently employed. The extreme dynamic wind load referred to stationary wind conditions is represented by a single gust factor.

For the snow load, it is generally found that Gaussian, Gumbel, Weibull or exponential models can be employed for daily snow-loads. In the present example, a Weibull model is employed.

The Borghes-Castanheta model is based on a simplified time variation of the load processes. The properties of the following simplified expression is investigated:

$$S = a_1 *(Q_{snow}) + a_2 * \max_{n=nref} (Q_{wind(static)} + Q_{wind(dyn)}) \qquad (2)$$

where $n = n_{ref}$ is the number of repetitions of characteristic wind load “time intervals” within each characteristic snow load “time interval” (E.g. n=5 if the snow interval is two weeks and the wind interval is 3 days , as discussed above). A normalisation of this expression is subsequently performed as described in Annex 4.1

3.4.3.2 Analysis Methodology

Given the present simplifications, numerical integration is performed to obtain the relevant probability functions. The reason is that closed form expressions cannot be obtained. The computational procedure can be described in terms of the following four steps:

Step 1: Establish cumulative distribution functions for the snow and wind loading for the basic reference periods.

Step 2: Compute the cumulative distribution function for the maximum value corresponding to n= n_{ref} repetitions of the compound variable from Step 1

Step 3: Compute the distribution function for the total sum of the two main terms assuming independence between snow and wind loads. This involves calculation of a convolution integral.

Step 4: Compute the distribution function for the maximum value of the sum (S) obtained in Step 3, corresponding to a given number of repetitions. The number of repetitions corresponds to the chosen reference period for evaluation of the combined load effect.

In step 4, the reference period is here chosen as one year. Two different reference periods for the snow load are considered here: One is 15 days, and the other is 90 days. The number of repetitions of the "snow interval" during one year is then equal to 12 for the first case an 2 for the second case if the snow season is set to 6 months (which is a representative value for a continental climate).

The basic scheme for derivation of the combination factor itself (i.e. ψ_0) can subsequently be formulated as:

Select normalised values for the snow and wind load effects for the 50 year return period.

Compute the value of the combined load effect corresponding to the 50 year return period based on the cumulative probability distribution obtained from Step 4 above.

This value of this combined (and reduced) load effect is compared to the sum of the normalised values from (a), and the resulting combination factor is computed.

As an example, if the wind load effect is normalised to 1.0 and the snow load effect to 0.5, the sum of these values becomes 1.5. If the reduced value of the combined load effect from Step 4 e.g. is equal to 1.2, the combination factor obtains the value such that $1+0.5*\psi_0 = 1.2$. Hence, the resulting value of ψ_0 becomes 0.4.

Steps (a), (b) and (c) are accordingly repeated for each new set of values for the normalised load effects. The value of the combination factor will accordingly also vary as a function of the ratio between the normalised wind and snow loads. For code checking purposes, a representative high value or an upper bound should generally be employed.

3.4.3.3 Numerical Examples

The combination factor has been computed for a range of values of the normalised load effects. Cases where the wind load effect is dominating while the snow load effect is secondary has been addressed. This implies that the derived combination factor applies to the snow load.

The cumulative distribution function for the snow load is calculated by employing the fitted Weibull function. The shape coefficient for the characteristic interval is varied between 1.0 to 3.0 in order to cover a range of cases.

For convenience, the normalised 50-year wind load effect is set to 1.0. The normalised snow load effect is varied at levels 0.25, 0.50, 0.75 and 1.0. The first case hence represents negligible snow loads, while for the last case the snow load is of equal magnitude to the wind load.

Results for the case with a characteristic snow period of 15 days and a characteristic wind period of 3 days are given in Table 3.4. The number of wind load repetitions for each basic snow period is accordingly 5. The number of repetitions of the combinded load effect per year becomes 12. The Weibull shape factor for the snow load is varied at the levels 1.0, 2.0 and 3.0.

Table 3.4 Combination factor for snow load as a function of normalised 50-year value. 50-year wind load is normalised to 1.0. Characteristic time scale for snow load is 15 days.

Weibull Shape factor	Normalised Snow Load Effect			
	0.25	0.50	0.75	1.00
3.0	0.30	0.40	0.50	0.55
2.0	0.15	0.30	0.40	0.50
1.0	0.00	0.15	0.30	0.40

Corresponding results for a case with the characteristic snow period set equal to 90 days (i.e. 3 months) are given in Table 3.5. The number of repetitions of the wind load effect per characteristic snow period accordingly becomes 30. The number of repetitions of the combined load effect per year becomes 2. Two values of the Weibull shape factor are given for this case, i.e. 3.0 and 1.0, since they represent upper and lower bounds as compared to a shape factor of 2.0 (which is similar to the trend observed in Table 1.)

Table 3.5 Combination factor for snow load as a function of normalised 50-year value. 50-year wind load is normalised to 1.0. Characteristic time scale for snow load is 90 days.

Weibull Shape factor	Normalised Snow Load Effect			
	0.25	0.50	0.75	1.00
3.0	0.30	0.50	0.60	0.65
1.0	0.08	0.35	0.45	0.50

3.4.3.4 Observations

From the above, the following observations are made:

- The combination factor increases for increasing values of the Weibull shape factor (which implies a decreasing value of the Coefficient of Variation)

- The combination factor increases for increasing values of the normalised snow load relative to the normalised wind load effect

- The combination factor increases for increasing length of the characteristic snow time scale (relative to the characteristic wind time scale of 3 days)

In relation to the last observation, it is also noted that increasing length of the snow time scale implies a reduced number of repetitions of the combined load effect per year. For particular examples of the probability functions involved in the various steps of the calculations, reference is made to Annex 4.

3.4.4 Derivation of combination factor by outcrossing rate analysis

3.4.4.1 Basic Modelling Assumptions

The following basic modelling assumptions are employed:

- The wind and snow load effect processes are both non-stationary (slowly-varying) processes which are mutually independent

- A long term period can be considered as a sequence of short-term conditions (duration in the range of 1 to 3 hours) for which the wind load process can be considered stationary, and during which the snow load is constant

- The wind velocity process is assumed to be Gaussian for each short term stationary condition.

- Weather systems with a time separation of three to four days are considered independent from each other

Furthermore, since high levels of the combined and single processes are considered, the extreme value distributions are determined by the up-crossing rates for given levels.

3.4.4.2 Analysis Methodology

The extreme value distribution for the combined process is estimated by application of the up-crossing rate for the wind process, conditioned on a given level of the snow load-effect. Subsequently, integration with respect to the probability distribution of the snow process is performed.

The extreme value distributions for the individual processes are obtained by computation of the average up-crossing rate (for the total duration considered and for each given extreme value level)

The combination factor is finally found as the combined extreme load effect (with a given return period) divided by the sum of the individual extreme values corresponding to the same return period.

3.4.4.3 Numerical Example

Representative parameters for the wind and snow load processes corresponding to a given location (i.e. Blindern, Oslo) are employed. A Rayleigh distribution is employed for the hourly mean wind speed. For the snow load, the monthly maxima are modelled by a Weibull distribution with scale parameter 685 and shape parameter 1,3. The distribution of daily maxima is subsequently back-calculated from these parameters. For these calculations, a return period of 20 years was employed (However, similar results are expected for a return period of 50 years).

First, a situation where the wind load effect is approximately half the snow load effect is studied. The 20 year characteristic value of the long term wind load effect becomes 1054, and for the snow load effect the corresponding value is 2125. The 20 year characteristic value of the combined process is obtained as 2700 (based on the upcrossing-rate analysis). The corresponding value of the combination factor to be *applied* ***for the wind load effect*** becomes [(2700 – 2125)/(1054)] = **0.55 .**

Secondly, a case with approximately equal load effects is considered. This is achieved by adjusting the Weibull scale parameter such that the 20 year extreme value for the snow load becomes 1064. The 20 year extreme value for the combined process in this case becomes 1730 (based on the upcrossing rate analysis). The resulting combination factor to be *applied for the snow load* effect in this case becomes
[(1730–1054)/ (1064)] = **0.63**

Thirdly, the wind load effect is taken to be the dominating contribution. The snow load in this case is about half that of the wind load effect, i.e. with a 20 year value of 532. The 20 year value of the combined process in this case is equal to 1255 based on the upcrossing analysis. The combination factor applied for the snow load for this case is accordingly [(1255-1054)/(532)] = **0.37**.

3.4.4.4 Observations

The following observations were made from the numerical calculations:

- It is necessary to account for the dependence of a sequence of upcrossings for the wind process.

- The combination factors to be applied for the non-dominating load effects are reproduced in Table 3.6 below. The numbers in the last column correspond to rounded values.

Table 3.6 Combination factor for snow load as a function of dominating load effect based on upcrossing-rate analysis.

Dominating load effect	**Combination factor for non-dominating load effect**	**Rounded factor**
Snow	0.55 (applied to wind load effect)	0.55
Snow and wind of equal magnitude	0.63 (applied to snow load effect)	0.65
Wind	0.37 (applied to snow load effect)	0.40

Obviously, similar results need to be derived also for other snow load distributions than the Weibull (and with other shape parameters) to generalise these observations.

3.4.5 Comparison of results obtained by the different methods and conclusions

Here, focus is set on comparison between results obtained by the different methods as such. Accordingly, for comparison of results obtained for different geographical regions, reference is made to section 3.2.

A summary of results referring to a Weibull model for the snow load is provided by Table 3.7. Since the number and types of parameters for the different models are different, particular choices related to some of them are made. For the Borghes-Castanheta and the upcrossing-rate models, the ratio between the snow and wind load effects enter the analysis. It is here assumed that a snow load effect value of 50% relative to the wind load effect is representative when comparing to the simplified method.

Table 3.7. Comparison between combination factors ψ_0 obtained by application of three different methods.

Method	Snow load effect ratio			
	0.25	0.5	0.75	1.0
* Simplified		** 0.51/0.53		
*** Borghes-Castanheta	0.08	0.35	0.45	0.50
Upcrossing-rate		0.37		0.63

* *Results are upper bound which are based on a Coefficient of Variation for annual maxima equal to 0.5 (corresponds roughly to a Weibull exponent for annual maxima of 2.0). For a CoV of 1.0 (corresponding to a Weibull exponent of 1.0), the resulting combination factor becomes 0.24/0.26.*

** *First number refers to Turkstra rule, second refers to Design value method*

*** *Results are lower bound values corresponding to a Weibull exponent of 1.0*

The number of snow load effect repetitions for the first two methods are set equal to 2. The exponent of the Weibull distribution for the second method is set equal to 1.0, which is somewhat too low. For the third method, the corresponding value is 1.3 which refers to monthly maxima. Accordingly, the reported results for the second method represent lower bound values of the combination factor. For the first method, the Coefficient of Variation of annual maximum snow load is set equal 0.5, which corresponds to a Weibull exponent of 2.0 for the annual maxima. This value is somewhat high as compared to the Weibull exponent for the other methods.

A comparison between results from the simplified procedure and the Borghes-Castanheta model is provided by Table 3.8. As observed, the results agree quite well for the case that the snow and wind loads are of comparable magnitudes. (However, note that the annual maxima model of the simplified method strictly should have an exponent that is somewhat less than 3.0 to be directly comparable.)

Table 3.8 Comparison between combination factors obtained by the simplified and Borghes-Castanheta models. Characteristic time scale for snow load is 90 days. Weibull exponent is 3.0 for both models

Model	Normalised Snow Load Effect			
	0.25	0.50	0.75	1.00
Simplified	0.64/0.66 *			
Borghes-Castanheta	0.30	0.50	0.60	0.65

* *First number refers to Turkstra rule, second refers to Design value method*

From these results, the following observations can be made:

- The factors obtained from the Borghes-Castanheta and Upcrossing rate models agree fairly well. This is based on accounting for the fact that the values reported for the former method correspond to lower bound values due to the smaller value of the Weibull exponent. For the case that the snow and wind load effects are of comparable magnitude, the Upcrossing rate method gives the highest value.

- The results for the simplified method gives results that are higher than those obtained from the other methods for a snow load effect equal to 50% of the wind load effect. A snow load effect of 75-80% seems to be more relevant. However, for the case that the wind and snow load effects are of equal magnitude, the combination factor for the simplified method is somewhat smaller than for the upcrossing-rate method.

- The simplified method and the Borghes-Castanheta model agree well for the highest values of the Weibull exponent and for cases where the snow and wind load are of comparable magnitude.

Finally, it is noted that an upper bound value for the present combination factor should be of the order of 0.7 accounting for the highest values of the Weibull exponent. This is based on the Borghes-Castanheta model, also accounting for the corrections implied by the Upcrossing-rate method This value would apply to continental climates where the snow load during the winter season is mostly non-zero. For maritime climates where the snow loading is equal to zero most of the time, a much lower value will apply. Results from the simplified method indicates that this value should be of the order of 0.5.

3.5 Derivation of combination factors ψ_1 and ψ_2

3.5.1 Introduction

Snow load on the ground (or on a roof) may be considered as a process in time. Introducing an appropriate resolution of the time scale (e.g. daily measurements) the observed load values may be taken as a sample, which allows an empirical distribution of the (daily) snow load to be obtained. For some climatic regions the probability of occurrence of high snow loads is not constant during the whole winter season due to non-stationarity of the process of snow loading (e.g. mountain or continental climate). Combining all load values measured during several winters in one single histogram irrespective of the date of occurrence means a certain simplification for these types of climate.

The corresponding cumulative distribution function of daily snow loads makes it possible to obtain the load level having a certain probability *P* of not being exceeded. The ψ_1 and ψ_2 coefficients are the relation between these fractiles of *P* probability and the characteristic value of the snow load. The probability *P* may be interpreted as part of the entire time, during which the snow load is equal or less than the given load level.

The investigation may be based directly on the empirical cumulative distribution function representing the observed short-term snow loads or on an appropriate theoretical distribution, adjusted by choosing the best fitting parameters.

The time of action is taken as the sum of all days when a certain load level was not exceeded. Some materials have the possibility to recover from long-term detrimental effects if the loading is removed or interrupted. In those cases only the longest period of continuous loading is important for the serviceability check. Such special problems are not dealt with in the present report.

In most parts of Europe snow is present only during some months of winter season. The rest of the time the snow load has zero values, which often requires a special treatment of the data in statistical calculations. This can be taken into account by means of different statistical procedures (see next section).

The ψ_1 and ψ_2 values have been investigated for different climatic regions. The frequent and quasi-permanent values of the snow load are based on time series of daily snow loads, whereas the derivation of the characteristic values was performed in the first phase of the present research programme and based on annual maximum of the snow load (by using the statistics of extremes).

3.5.2 Derivation of ψ_1 and ψ_2

3.5.2.1 Factor for frequent value ψ_1

In according to section 3.2, the duration of snow load above given load levels should be considered.

The "duration-over-the-threshold" curves can be established either by the use of one of three methods, these methods have been called Model 1, Model 2 and the Hybrid method. The main difference between these methods is that Model 1 produces a CDF of snow days and proportion of days with snow lying; Model 2 produces a CDF of all the days in the year and the Hybrid model considers a specific snow season.
The development of Models 1 and 2 is described in more detail in Cook 1999 [17].

Model 1

Available:
- the record period of N years for snow depth (load);
- the total number of days k per N years when snow covers the ground (number of snow days)
-

Method of order statistics

All k values of snow depth (load) should be ranked in order and the probability plot for k points (Cumulative Distribution Function) can be obtained (i.e. P_k - probability of non exceedance of each snow value is calculated)
The probability of exceedance is:

$$Q_k = 1 - P_k \tag{1}$$

Designating the continuous distribution function corresponding to P_k by F(x), the probability distribution function can then be then obtain as:

$$P = q + p \cdot F(x) \tag{2}$$

where: $p = k / 365N$ - probability of snow present
$q = 1 - p$ - probability that no snow is present

To obtain the t-fractile of non-exceedance corresponding to the fractile of the CDF (corresponding to the left-hand side of Eq(2)), the following relation is applied:

$$P_t = (t - q) / p \tag{3}$$

For example for t = 0,95 (corresponding to a probability of exceedance of 5%):

$$P_{0,95} = (0,95 - q) / p \qquad (4)$$

where $P_{0,95}$ now is the corresponding fractile to be applied for the cumulative distribution F(x).

The Bins method

The maximum value of snow depth (load) which occurs during the period of observation should be subdivided into *m* bins, and the probability that snow exceeds each of *m* levels is calculated. The difference from the method of order statistics is only that CDF is not based on *k* observed values but consists of *m* steps (corresponding to the number of bins) and represents the probability of non exceedance of each of the *m* levels.

The equations from (1) to (4) are valid in this case.

Model 2

According to this method the probability plot is based on all the days the recordincluding days without snow ie 365N.

The method of order statistics

All values of snow depth (load) should be ranked in order, and the corresponding probability plot (Cumulative Distribution Function) can be obtained. However, only *k* values are non-zero ones. The other (*365N* - *k*) values are equal to zero. Therefore the CDF begins with the value (1 - k / 365N) at point x=0. The *t*-fractile is calculated directly from the obtained probability plot (i.e. *P* - probability of not exceedance)
The probability of exceedance is:

$$Q = 1 - P \qquad (5)$$

It is possible that the value (1 - k / 365N) can be greater than 0,95 (especially for maritime and mixed climate). This implies that the frequent value is equal to zero in this case.

The Bins method

This method is described above in section 3.5.2.1 and is applied here, but based on all *365N* values. The probability of non exceedance of the first level (which is equal to maximum of snow divided by number *m*) is the probability that no snow is present and is equal to (1 - k / 365N).

Model1/Model2 Hybrid model

It is also possible to consider a hybrid of Model 1 and Model 2 in which a specific snow season is assumed. This hybrid model is based on the number of days per year *n* when snow cover is possible due to the climatological conditions. In this model, the probability of snow being present is given by

P = k/nN

The method of order statistics and the bins method can be applied as given for the models above.

Calculation of factor ψ_1 for frequent value

The frequent value can be obtained directly as the 0,95-fractile (based on Model 2) or with the help of eq. (4) (based on Model 1or the Hybrid model). The other fractiles from 0,9 to 0,99 can be also considered as appropriate.

The ratio of this fractile to the characteristic value of snow load for given station is the coefficient ψ_1 for calculation of the frequent value of snow load.

3.5.2.2 Factor for quasi-permanent value ψ_2

Model 1

Again both the method of order statistics and the bins method can be used.
Using the same probability plot as in chapter 3.5.2.1 and eq. (3), the fractile for model 1 which corresponds to the 0,5-fractile of non-exceedance of a given snow load (depth) for model 2 can calculated based on the expression:

$$P_{0,5} = (0,5 - q) / p \quad (6)$$

This fractile is the quasi-permanent value of the snow load.
The ratio of this fractile to the characteristic value of snow load for a given station is the coefficient ψ_2 for calculation of the quasi-permanent value of snow load.

Model 2

Both the method of order statistics and the bins method can be used.
Using the probability plot obtained above the 0,5-fractile of non-exceeding of given snow loads (depths) can be calculated directly.
This fractile is the quasi-permanent value of the snow load.
The ratio of this fractile to the characteristic value of snow load for given station is the coefficient ψ_2 for calculation of quasi-permanent value of snow load.

Value of snow load averaged over the chosen period of time

If all the days in the year are considered (Model 2 or *n*=365 days in the Hybrid model) then the 0,5-fractile is automatically equal to zero if the snow is laying less than 180 days per year (6 months). In this case a different procedure for calculation of ψ_2 can be used: the quasi-permanent value is determined as the value averaged over the chosen period of time. This reference period is normally chosen as one year (365 days).
The ratio of this averaged value to the characteristic value of snow load for a given station can be also be considered for the coefficient ψ_2 for calculation of the quasi-permanent value for the snow load.

This procedure is to be preferred in particular for regions with heavy snow (e.g. mountains) where it gives more realistic results than the 0,5-fractile method.

Results of calculations for ψ_1 and ψ_2 for different stations in different climatic are summarised in the next section.

3.5.3 Summary of results for ψ_1 and ψ_2

The above described procedures for the calculation of coefficients ψ_1 and ψ_2 were applied for 53 meteorological stations across the whole CEN members area in Europe. The stations were chosen to represent as much as possible all climatic regions in CEN area (including the different levels of altitude a.s.l.).

For most of the stations the Model 2 and bins method were used for calculation of the 0,95-fractile (for ψ_1) and 0,5-fractile (for ψ_2) for the duration-over- -threshold distribution. But as was already discussed above, the 0,5-fractile will automatically be equal to zero if snow lays for less than 180 days per year. Thus these results can deviate from the real ones, particularly for stations with heavy snow (e.g. with high altitude). In this case, the averaging procedure may be more preferable for calculation of ψ_2 . The method used for each station for the calculation of ψ_2 can be seen from the last column in Table 3-8.

The results obtained from these 53 stations are summarised in the Table 3-9 for the Alpine region and in Table 3-10 for all regions in the CEN members area. Within some regions, additional categories have been adopted for different altitudes or even between different geographical parts within the region (e.g. for Iceland).

In ENV 1991-1 (table 9.3) the factor ψ_1 is specified as 0,2 and the factor ψ_2 = 0,0, but it is written that modification for different geographical regions may be required. The results from the tables in this chapter show clear the necessity of this differentiation. In particular, the difference between the maritime and continental (and/or mountain) climates can be identified by means of these values. The factor ψ_1 has a maximum in the Alpine region of 0,45, in Norway of 0,5 and in Iceland of0,4, i.e. in regions of continental/mountain climate. Also ψ_2 values in these regions deviate from zero (the maximum is in Norway and equals 0,2). For areas of a maritime climate (UK, Mediterranean, Iberian, Central West, Greece) the ψ_1 values are very small (maximum 0,10 in the Mediterranean) and ψ_2 values are equal to zero.

Table 3-8: ψ_1 and ψ_2 values for different climatic stations in different climatic regions

N	Region	Country	Station	Altitude (m)	Period of observation	ψ_1	ψ_2	Method to obtain ψ_2
1	Alpine	Switzerland	Andermatt	1440	1995-1996	0,19	0,05	average
2	Alpine	Switzerland	Braunwald	1340	1995-1996	0,19	0,05	average
3	Alpine	Switzerland	Saas Fee	1790	1995-1996	0,29	0,08	average
4	Alpine	Italy	Villa Santina	363	1940-1961	0,21	0,00	0,5-fractile
5	Alpine	Italy	Coritis	641	1940-1961	0,14	0,00	0,5-fractile
6	Alpine	Italy	Sappada	1217	1940-1961	0,27	0,00	0,5-fractile
7	Alpine	Italy	Trafoi	1548	1940-1961	0,35	0,00	0,5-fractile
8	Alpine	Italy	Passo Tonale	1777	1940-1970	0,41	0,00	0,5-fractile
9	Alpine	Italy	Lago Baitione	2258	1940-1970	0,39	0,00	0,5-fractile
10	Alpine	Italy	Courmayer	1220	1940-1970	0,40	0,00	0,5-fractile
11	Alpine	Italy	Gressoney la Tr.	1631	1940-1970	0,44	0,00	0,5-fractile
12	Alpine	Italy	Lago della Rossa	2716	1940-1970	0,45	0,06	0,5-fractile

13	Alpine	Italy	Pascomonti	380	1940-1970	0,17	0,00	0,5-fractile
14	Alpine	France	Embrun	876	1968-1997	0,13	0,00	0,5-fractile
15	Alpine	France	Bourg Saint Maurice	868	1968-1997	0,27	0,00	0,5-fractile
16	Central East	Germany	Leinefelde	356	1957-1993	0,20	0,03	average
17	Central East	Germany	Fichtelberg	1213	1951-1993	0,39	0,08	average
18	Central East	Germany	Potsdam	81	1893-1993	0,12	0,02	average
19	Norway	Norway	Blindern	94	38 winters	0,42	0,10	average
20	Norway	Norway	Kruta	594	23 winters	0,48	0,17	average
21	Norway	Norway	Susendal	498		0,59	0,17	average
22	UK & Eire	UK	Bradford	134	1959–1994	0,03	0,00	0,5-fractile
23	UK & Eire	UK	Dyce	65	1957–1996	0,04	0,00	0,5-fractile
24	UK & Eire	UK	Huddersfield	232	1957-1986	0.002	0,00	0,5-fractile
25	UK & Eire	UK	Prestwick	16	1958–1992	0,00	0,00	0,5-fractile
26	UK & Eire	UK	Ronaldsway	16	1958–1995	0,00	0,00	0,5-fractile
27	UK & Eire	UK	Saint Mawgan	103	1958–1994	0,00	0,00	0,5-fractile
28	UK & Eire	UK	Stansted	101	1958–1996	0,00	0,00	0,5-fractile

29	UK & Eire	UK	Wick	36		0,00	0,00	0,5-fractile
30	Mediterranean	Italy	Lodi	80	1951-1990	0,00	0,00	0,5-fractile
31	Mediterranean	Italy	Mignano	342	1950-1990	0,02	0,00	0,5-fractile
32	Mediterranean	Italy	Parma	56	1950-1990	0,00	0,00	0,5-fractile
33	Mediterranean	Italy	Vedriano	590	1950-1990	0,08	0,00	0,5-fractile
34	Mediterranean	Italy	Pavullo	682	1950-1990	0,13	0,00	0,5-fractile
35	Mediterranean	Italy	Livorno	3	1940-1990	0,00	0,00	0,5-fractile
36	Mediterranean	Italy	Acerenza	833	1950-1990	0,00	0,00	0,5-fractile
37	Mediterranean	France	Marignane	36	1968-1997	0,00	0,00	0,5-fractile
38	Mediterranean	France	Perpignan	48	1968-1997	0,00	0,00	0,5-fractile
39	Iceland	Iceland	Reykjavík	52	1965-1997	0,21	0,00	0,5-fractile
40	Iceland	Iceland	Stórhöfði	118	1965-1997	0,07	0,00	0,5-fractile
41	Iceland	Iceland	Forsæti	10	1965-1997	0,17	0,00	0,5-fractile
42	Iceland	Iceland	Hólar í Hjaltadal	160	1965-1997	0,28	0,00	0,5-fractile
43	Iceland	Iceland	Lerkihlið	170	1965-1997	0,42	0,11	0,5-fractile
44	Iceland	Iceland	Staðarhóll	42	1965-1997	0,36	0,00	0,5-fractile

45	Central West	France	Agen	60	1968-1997	0,00	0,00	0,5-fractile
46	Central West	France	Nantes	27	1968-1997	0,00	0,00	0,5-fractile
47	Central West	France	Alencon	11	1968-1997	0,00	0,00	0,5-fractile
48	Central West	France	Belfort	423	1968-1997	0,05	0,00	0,5-fractile
49	Central West	France	Clermont Ferrant	332	1968-1997	0,00	0,00	0,5-fractile
50	Central West	France	Lille	52	1968-1997	0,00	0,00	0,5-fractile
51	Iberian	Spain	Barcelona Fabra	420	1926-1991 63 winters	0,00	0,00	average
52	Iberian	Spain	Articutza	305	1938-1997 47 winters	0,00	0,00	average
53	Iberian	Spain	Madrid Cuatro Vientos Aerodromo	687	1961-1996 36 winters	0,00	0,00	average
54	Sweden and Finland	Finland	Eno	126	1990-1997	0,53	0,15	average
55	Sweden and Finland	Finland	Hanko	2	1990-1997	0,20	0,03	average
56	Sweden and	Finland	Hutsisuonoja	85	1990-1997	0,54	0,13	average

	Finland							
57	Sweden and Finland	Finland	Inari, Ivalon Matti	266	1990-1997	0,58	0,03	average
58	Sweden and Finland	Finland	Kaukolanpuro	177	1990-1997	0,67	0,18	average
59	Sweden and Finland	Finland	Kiikoinen	70	1990-1997	0,31	0,06	average
60	Sweden and Finland	Finland	Konnevesi, Tutkimusasema	100	1990-1997	0,30	0,06	average
61	Sweden and Finland	Finland	Lappajarvi	80	1990-1997	0,30	0,06	average
62	Sweden and Finland	Finland	Tuusula	60	1990-1997	0,26	0,05	average
63	Sweden and Finland	Finland	Ylitornio, Haapakoski	60	1990-1997	0,50	0,13	average

Table 3-9: ψ_1 and ψ_2 values for different countries in Alpine region and proposed values for whole region

	Country	**ψ_1**	**ψ_2**	**Additional information**
1	Switzerland	0,30 -	0,10 -	altitude: > 1000m < 1000m
2	Italy	0,45 0,30	0,10 0,00	altitude: > 1000m < 1000m
3	Germany	0,40	0,10	
4	Austria	-	-	
5	France	0,30	0,00	
	Region	**0,45** **0,30**	**0,10** **0,00**	**altitude:** **> 1000m** **< 1000m**

Table 3-10: ψ_1 and ψ_2 values for different regions in CEN members area

	Region	ψ_1	ψ_2	**Additional information**
1	Alpine	0,45 0,30	0,10 0,00	altitude: > 1000m <= 1000m
2	UK and Eire	0,04	0,00	
3	Iberian	- 0,00	- 0,00	altitude: > 500m <= 500m
4	Mediterranean	0,10	0,00	
5	Central East	0,40 0,20	0,10 0,00	altitude: > 500m <= 500m
6	Central West	0,05	0,00	
7	Greece	0,00	0,00	
8	Norway	0,50 0,40	0,20 0,20	altitude: > 300m < 300m
9	Finland-Sweden	0,70	0,20	
10	Iceland	0,20 0,40	0,00 0,10	Area: South-West North-East

3.6 Conclusions and summary of recommended procedure

3.6.1 Combination factor ψ_0

Three different procedures of varying complexity for derivation of the combination factor ψ_0 are outlined. These are: (i) A simplified procedure based on expressions given in the background CEN/ISO documents (ii) A model representing the snow load time history as a sequence of piecewise constant levels. This is referred to as the Borghes-Castanheta model in the background documents (iii) An upcrossing-rate procedure based on non-stationary stochastic process models.

For methods (ii) and (iii), the specific load effect combination corresponding to wind and snow is considered. The following observations are made:

- The three procedures give comparable results. However, for the latter two models the combination factor increases as a function of the ratio between the snow load versus the wind load. For the first method, a single factor is obtained which is constant for all load ratios

- The simplified method typically gives an upper bound for the combination factor except for cases where the wind and snow load effects are of comparable magnitude. Accordingly, this procedure can be employed for a convenient assessment of representative design values for the combination factor, due to the limited amount of statistical data required.

- The upcrossing rate method gives a somewhat higher value than the two other methods for magnitudes of the snow load comparable to the wind load. However, a more systematic comparison for a wider range of parameter combinations is required in order to substantiate this observation.

Representative values for various climatic regions have been obtained by the simplified method, and these are summarized in the table below:

Table 3-11 ψ_0 values for different regions in CEN members area

	Region	ψ_0	**Additional Information**
1	Alpine	0,6 0,5	altitude: > 1000m <= 1000m
2	UK and Eire	0,4	
3	Iberian	0,5 0,4	altitude: > 500m <= 500m
4	Mediterranean	0,5	
5	Central East	0,55 0,4	altitude: > 500m <= 500m
6	Central West	0,4	
7	Greece	0,5	
8	Norway	0,7 0,6	altitude: > 300m < 300m
9	Finland-Sweden	0.65 0.60	altitude: > 250m < 250m
10	Iceland	0,6 0,6	Area: South-west North-east

3.6.2 Combination factors ψ_1 and ψ_2

Two mainly different approaches for normalisation of the probability distributions for derivation of these combination factors are considered. One is based on normalisation by the total time (i.e. all days in each year), and the second is based on normalisation by a subset of the total time (e.g. only days with non-zero snow depth). Basically, the two approaches give the same values of the combination factors when proper corrections are applied for conversion of fractiles between the models. However, it is found that the relative ranking between different types of fitted probability distribution functions can be different for the two approaches for some cases. For measurement stations where sufficiently long records are available, derivation of these factors should be based on the sample itself rather than fitted probability distributions.

A summary of representative values of these coefficients for various climatic regions is provided by the table below. These are mainly based on the sample values themselves rather than fitted probability distribution functions.

Table 3-12 ψ values for different regions in CEN members area

	Region	**ψ_1**	**ψ_2**	**Additional Information**
1	Alpine	0,45 0,3	0,10 0,0	altitude: > 1000m <= 1000m
2	UK and Eire	0,04	0,0	
3	Iberian	- 0,0	- 0,0	altitude: > 500m <= 500m
4	Mediterranean	0,10	0,0	
5	Central East	0,4 0,2	0,10 0,0	altitude: > 500m <= 500m
6	Central West	0,05	0,0	
7	Greece	0,0	0,0	
8	Norway	0,5 0,4	0,2 0,2	altitude: > 300m < 300m
9	Finland-Sweden	0,7	0,2	
10	Iceland	0,2 0,4	0,0 0,1	Area: South-west North-east

4. Investigation on Roof Snow Loads for the definition of Shape Coefficients

4.1 Introduction

In many areas of Europe the structural design of roofs is governed by the snow load which can be expected to accumulate on the roof. The structure should be capable of withstanding the severest load which will be imposed upon it during its lifetime. On the other hand economics dictate that the building should not be grossly overdesigned.

The procedure to determine the roof snow load, s, in the CEN/TC250/SC1-Code, most national codes on snow loads as well as the ISO-Code 4355 is to multiply the characteristic ground snow load s_k with certain "shape coefficients" μ which take into account some of the effects influencing the roof snow load. To emphasise the importance of these coefficients in design, their values generally range from 0.8 to 1.6 and occasionally even higher.

In order to provide further information towards the harmonisation of roof shape coefficients through Europe, task IId - analytical study for the definition of shape coefficients - was included in the programme of work. The details of this task are given in the next section.

4.2 Description of task

The following steps were performed during the research activities:

- Selection of a sufficient number of reference roof shapes for the basis of drift models

  Flat, mono- and duo-pitched roofs were selected in different climatic regions such as in the Italian Apennines and Alps, in Scotland, Germany and Switzerland. The selected roof shapes are the most relevant and common to all the European countries.

- Selection of methods for direct measurement of the snow loads on roofs

  Different measuring methods are available from field tests and measurement programmes carried out in U.S.A., Canada, Norway and United Kingdom.

  During the research the existing methods were compared and – according to the capabilities and preferences of the partners involved – methods for direct measurements were selected and used.
  During an initial phase in the 1997/98 winter measurements were performed in the Italian Apennines and in the United Kingdom. These measurements were used primarily to improve the measurement techniques. Unfortunately owing to little snow during this first phase only few data could be collected.

- Development of a drift, metamorphism and ablation model

  From existing research work carried out in the field and in wind tunnels on snow drifting, a drift, metamorphism and ablation model was selected and validated in order to know as much as possible about the general phenomenon of the snow processes on roofs.

- Collection of data on snow loads on roofs and on the ground and other meteorological data

  Initially a collection of data on snow loads on roofs during at least two or three years had been proposed in order to consider snow loading processes for several years and to consider also the possibility of not having (enough) snow during some winters.

  For some measuring stations the relevant meteorological data such as ground snow load, wind speed and direction and air temperature are available from the meteorological offices.

  In addition to the field measurement program, a large experimental campaign was undertaken in the Climatic Wind Tunnel at CSTB, Nantes. The experimental models are calibrated using the available data from the in situ measurements.

- Statistical analysis of the data according to a pre-established probabilistic method

  Following the data collection both in the field and in the wind tunnel, a probabilistic method is used for the analysis of the data from both these studies and the drift and depletion model.

  Based on the collected data, a multiple regression analysis for the different parameters is performed.

The investigation is still in progress to study the following problems on a statistical basis:

- Probabilistic distribution of the roof shapes coefficients
- Probabilistic distribution of the density of snow on roofs and the ground

Due to the lack of meteorological data and insufficient events during 1998/99 it is not possible to study the influence of rain falling into snow. The influence of the different climatic regions on roof shape factors can not be investigated due to the lack of snow and also due to there being insufficient roofs available for testing in all regions.

- Study of economical impact of the adopted criteria

Initially studies on the economic impact of the new roof shape coefficients had been planned. In particular, the following investigations had been foreseen:

- Collection of data related to collapses due to heavy snow falls
- Statistics of collapses
- Effect of different code provisions with respect to the reliability of the structures
- Cost/benefit-considerations
  - stronger structures against smaller insurance benefit
  - estimate the financial damage for several code provisions

Due to late receipt of the last-mentioned data the economical aspects are still under investigation. The results of which will be used for future code work.

- Aspects of load combination, especially wind - and earthquake loads

The effects of load combinations with wind and earthquake loads will have to be investigated within the cost/benefit-considerations mentioned above. Coordination with the other tasks of the European snow load program will be necessary.

- Shape coefficients for the Eurocode

Based on the statistical analysis of the data a possible code version for the treatment of the shape coefficients will be proposed for the elaboration of the EN-Code on snow loads.

4.3 Models

Snow layers consist of three components: air, ice and liquid water when the snow is wet. Drifting covers the horizontal transport of snow by wind from initial deposition to another place either on the same roof or a lower roof or the floor. Metamorphism describes the changes inside the snow pack, ablation is the process of melting.

4.3.1 Snow drift models

Phenomenology

During stormy weather conditions the mass of transported snow will significantly increase. The snow drift will reduce after warming of the snow surface when the uppermost part of the snow pack becomes wet. The forces of bonding between the snow grains are too strong for an uplift due to the drag of the wind.

Falling snow is deposited on roofs in uniform layers only if the wind speed is low. It is known that with wind speeds in the range of 4 to 5 m/s, much of the snow is deposited in areas of ’aerodynamic shade’. If the wind velocity increases above this range snow particles can be picked up from the snow cover, leading to depletion of the snow cover in areas of high wind speed and re-deposition of the snow on the lee sides of peaked or arched roofs, on lower roofs in the lee of higher roofs, or behind obstructions on the roof. The depletion and re-deposition of snow may result in overloading and possible collapse of the roofs.

Types of transportation

Depending on the velocity of the wind the transportation processes of the snow flakes are different, as shown in table 4.3-1.

Table 4.3-1: Types of transportation

Transportation	Threshold velocity in m/s (dependent on snow surface)	Comment
Creep	3 - 5	Gentle rolling of snow grains, mass transport is of minor interest
Saltation	6 - 8	“jumping” of snow particles, transport of snow is of interest for snow loads
Turbulent diffusion (suspension)	7 - 10	Mixture of air and snow, high transport rates - very important for calculation of snow loads

Height of snow drift

The following table shows the height of snow surface with drift phenomenon.

Table 4.3-2: Height of snow drift for different types of mass transport

Type of mass transport	Maximum height of snow above snow surface (m) dependent on the roughness of the snow surface
Creep	0.02 - 0.04
Saltation	0.30 - 0.40
Turbulent diffusion	1.50 - 2.50

The transport of snow from the ground to the roof for buildings higher than 3 m is not observed. Only for the following roof shapes does the ground snow layer influence the roof snow layer:

- Cylindrical curved roofs (snow load on the ‘walls’)
- Small buildings with gable roofs (eaves touch the ground)

Relevance of snow drift

Snow drifting is only relevant for mass transport on roofs which cause asymmetric loads.

Mass of drifted snow

The amount of transported snow is a function of:

- Wind velocity
- Duration of the high wind velocity
- Composition of the snow surface
- Depth of snow at the source (i. e. upper roof)
- Topographic relief
- Exposure
- Size of snow grains
- Temperature and humidity of the wind

General remark on drift models

Several models exist for the determination of the mass of drifted snow. However none of them can be applied directly for the determination of roof snow load.

Empirical models for the mass of drifted snow

Several mathematical expressions exist in order to calculate the mass of drifted snow. In these investigations snow drift measurements in flat homogenous terrain with undisturbed surface windward of 800 to 1000 m and a fetch at the end of this surface are analysed. The functions deduced from the snow drift measurements are only valid for the special test area. There is no possibility of using these functions without any modifications for the snow load calculation on roofs due to drifting.

Different equations for calculating the snow transport as a function of wind velocity are noted in table 4.3-3. The empirical expressions were derived from measurements in flat homogenous areas in Japan, USA and Russia or from wind tunnel tests.

To calculate the snow drift with the equations in table 4.3-3 the logarithmic law of wind velocity is used (i.e. a velocity of 15 m/s at a height of 10 m, 12 m/s at 1 m and 8 m/s at 0.2 m). The calculated snow drift masses show the huge difference between those resulting from the equations for homogenous snow surfaces [Cold Regions Hydrology and Hydraulics, 1990] and [Pomeroy & Gray, 1990].

Table 4.3-3: Empirically derived equations to calculate snow drift as a function of wind velocity. Wind velocity (u) in m/s measured at the height indicated by subscript U_x. The transport rate q is defined as the mass of snow (kg) per width (m) perpendicular to the wind direction per time (s) totalled over the indicated heights h (m).

Author	Height h (m)	Equation	Snow drift (kg/m^2 s)	Diff. (%)
Kobayashi (1972)	salt.[a]	$q = 0.00003\ (u_1 - 1.3)^3$	0.0367	100 %
Dyunin & Kotlyakov (1980)	0-2	$q = 0.00034\ (u_{0.2} - 3)^3$	0.0425	116 %
Dyunin & Kotlyakov (1980)	0-2	$q = 0.000077\ (u_{10} - 5)^3$	0.077	210 %
Takeuchi (1980)	0-2	$q = 0.0002\ u_1^{\ 2.7}$	0.164	447 %
Pomeroy & Gray (1990)	salt.[a]	$q = (u_{10}^{1.295} / 2118) - (1 / 17.37 u_{10}^{1.295})$	0.014	38 %

[a] The height of saltation h_s can be calculated using $h_s = u_*^2 / 12.25$ and $u_* = u_{10}^{\ 1.295} / 44.2$

The deciding factor for snow transport is the friction velocity (u*) at the snow surface. Assuming an undisturbed wind field with a wind velocity of 15 m/s at 10 m the friction velocity will be 0.7 m/s. For this condition the mass transport is mainly caused by turbulent diffusion (92 %), only 8 % is due to saltation. The part due to saltation increases if the friction velocity is lower. The transport rate depends strongly on the surface roughness and hardness.

Finite area element method (FAE)

Snow drift formations are highly dependent on the detailed wind velocity patterns over the roof which are in turn a function of wind direction and duration, roof geometry, and the local surroundings near the building. In areas of decelerating wind, snow will accumulate.

The finite area element (FAE) method [Irwin et al. (1995)] superimposes a grid onto the roof thus dividing it into a large number of small finite area elements. Values for the wind velocity at a small reference height (1 m) above the roof at the four corners of each elemental area are used to compute the snowdrift fluxes through the sides of the element. Empirical relationships based on field data are used to relate drift rate to wind velocity. To obtain the required wind velocities at each grid node, wind tunnel tests are usually undertaken in which the local velocities are measured as a fraction of some selected reference value, e.g. high above the building. When the results of the wind tunnel tests are combined with the hourly meteorological wind records, a set of velocities over the roof corresponding to any particular date and time can be established.

The wind turbulence in towns could be modelled using commercial fluid dynamic software (FLOW-3D) based on Navier-Stokes equations. The knowledge of digital terrain models is combined with computer-aided drawings (CAD) of buildings and computational fluid dynamics (CFD) models. FLOW-3D is a general purpose computer program for transient fluid phenomena. It can handle two-fluid flows and uses finite differences and finite volume approximations to solve the equations of motion. In the models the diffusion theory is most significant to the drift process. Snowdrift may then be considered as a two-phase problem where the phases are strongly coupled. Snow represents the dispersed phase and wind the continuous phase. A generalised drift-flux model based on low relative velocities between the phases is used, which means neglecting the saltation process [Bang et al. (1994)]. Narvik Institute of Technology has elaborated a computer simulation of snow drift and snow loads with the programme SNOW-SIM based on FLOW-3D [Bang et al. (1994)].

These methods have not yet been developed sufficiently to allow them to be used directly for the determination of snow loads on roofs. Considerable investigations will be necessary to develop and improve the method.

4.3.2 Metamorphism

Metamorphism starts immediately after the accumulation of snow flakes. After a short time the small needles and points of the flakes are rounded due to the transport of water vapour. The result is an increase of density and a decrease of snow depth. The time for this process depends on the air temperature and the temperature gradient in the snow pack. The temperature gradient could induce a transfer of heat and water vapour in the snow column. Destructive metamorphism becomes apparent with a gradient less than 0.1 °K/cm. There is a growth of rounded grains with a development of bonds between the grains. The number of grains increases. The snow cover is compact and stable.

With a temperature gradient higher than 0.2 °K/cm constructive metamorphism takes place. This gradient builds new facettes without any bonds and the snow cover is mechanically very weak.

The metamorphism of a snow cover is an important process for the transformation of the snow surface, in particular for the shape and characteristic of this surface. A frequent thaw-freeze cycle will transform the new fallen fluffy snow of the surface to a hard and icy crust, which after some cycles may cause the surface to be too hard for snow transport by wind.

4.3.3 Ablation

Introduction

The process of ablation is controlled through energy transfer from the atmosphere to the snow cover. The main energy input is from radiation and heat fluxes although additionally the energy input from rain should be considered.

There are two basic approaches to the prediction of the rate of snowmelt: the degree-day model and the full energy balance method. Both of these methods contain some empiricism; however the degree-day model is entirely empirical and generally site specific, whereas the physical basis of the energy balance approach allows the parameters found by experiment to be widely applicable.

Degree-day model

Most operational procedures for snowmelt prediction rely on air temperature as the index of the energy available for melt. A review of the expressions presented in the literature show that no single, universally applicable temperature index of snowmelt exists. Each index is unique to a geographical location. The magnitude varies depending on the prevailing atmospheric conditions (clear, cloudy, rain) and the time of the year. Such variability is not surprising, if one realises that the air temperature is only one factor influencing melt rates and other factors such as wind velocity, atmospheric moisture content and albedo of the snow are not directly related to air temperature. The simplest and most common expression relating snowmelt to the temperature index is:

$$M = M_f \, T_i \qquad \text{(equ. 4.1)}$$

where M = melt produced in cm of water in a unit time,
M_f = melt factor or degree-day factor (cm °C^{-1} d^{-1})
T_i = index air temperature (daily mean temperature or $(T_{min} + T_{max}) / 2$), measured near the buildings

The melt factor M_f varies, dependent on location, vegetation, etc., between 0.35 and 0.60 cm °C^{-1} d^{-1}. However, it is not recommended that a temperature index be used to predict the maximum rate of snowmelt over a short time period.

The melt factor could be calculated as a rough approximation from Gray & Male (1981):

$$M_f = 1.1 \, \rho_s / \rho_w \qquad \text{(equ. 4.2)}$$

where ρ_s = density of snow
ρ_w = density of water

The degree-day method should be used to determine the ablation on roofs and the degree-day factor should be determined for every region. The results on different roofs could differ significantly caused by the aspect and slope of the roofs. This should be considered in the determination of the degree-day factor.

Energy balance method

The components of the energy balance of a snow pack are as follows:

$$Q_m = Q_{SW} + Q_{LW} + Q_H + Q_E + Q_G + Q_P + dU/dt \qquad \text{(equ. 4.3)}$$

where Q_m = energy content of the snow pack
Q_{SW} = short wave radiation
Q_{LW} = long wave radiation
Q_H = sensible heat flux
Q_E = latent heat flux
Q_G = heat flux from the ground / roof
Q_P = energy of precipitation
dU/dt = energy change of the snow pack

It is possible to measure all of the components with expensive devices or to determine the different parts of the energy balance by equations. The most important terms are the following:

- short wave radiation (especially when the snow on the roof is patchy)
- sensible heat flux (transport of 'warm' air to the snow)
- precipitation (depends on the climatic region)

In order to determine these terms the following possibilities can be followed:

- The approximation of the shortwave balance by equations is very rough. Therefore the incoming and outgoing shortwave radiation should be measured.
- The longwave balance could be calculated using the temperature of the snow surface and of the atmosphere at different heights. The real emissivity of the atmosphere depends on the height and type of clouds and the water content.
- The sensible heat flux is an important term of the energy balance because the energy input could exceed 40 % of the total available energy. The derivation of the sensible heat flux using meteorological measurements at different heights might be impossible in towns due to turbulence.
- The contribution of latent heat flux (condensation and evaporation) is minor. The derivation might be impossible, also due to turbulence.
- The heat flux from the roof to the snow cover could reach 10 % of the total energy. It depends on the insulation of the roof and heating of the building.
- The energy input by precipitation could be important for areas of maritime climate. The available energy is

$$Q_P = \rho \, C_P \, (T_r - T_s) P_r / 1000 \qquad \text{(equ. 4.4)}$$

where
Q_P = energy supplied to the snow cover by rain
ρ = density of water
C_P = heat capacity of water
T_r = temperature of the rain
T_s = snow temperature
P_r = amount of precipitation

using average values for the parameters ρ = 1000 kg/m^3, C_P = 4.20 kJ/(kg °C), and T_s = 0°C

$$Q_P = 4.2 \, T_r \, P_r \qquad T_r \approx T_{air} \qquad \text{(equ. 4.5)}$$

The energy balance approach is the more exact method but requires some measurement devices and a good knowledge of the local micro turbulence.

4.3.4 Conclusions for the model for the roof snow load

In the sections 4.3.1 to 4.3.3 the three processes of the roof snow load are described: drifting, metamorphism and ablation. In order to determine the roof snow load all three influences are treated as additive load parts.

According to ISO 4355 the snow load on the roof is given by:

$s = s_b + s_d + s_s$ where s_b = balanced, s_d = drift, s_s = slide (equ. 4.6)

The multiplicative approach takes into account the physical behaviour of snow loads

$s = s_k * \mu = s_k * C_e * C_t * \mu_b * \mu_d$ (equ. 4.7)

where s_k = characteristic value of the snow load on the ground
C_e = exposure factor, which usually has the value 1.0
C_t = thermal coefficient, which usually has the value 1.0
μ_b = balanced factor, describes the differences between windward and lee
μ_d = drift factor

These two approaches, one additive and one multiplicative, are used in civil engineering design but from the scientific point of view the equations are only a rough approximation to the natural conditions. The application of regression analysis is used to improve the results. The linear regression may have the following form:

$s = s_k * \mu$ (equ. 4.8)

where $\mu = a + b * \alpha_1 + c * T_{env} + d * T_{env} + e * T_{build} + f(u\text{-}x)^3 * t$ (equ. 4.9)

and
$b * \alpha_1$ = term for the slope α_1
$c * T_{env}$ = term to take into account the metamorphism using the temperature of the environment
$d * T_{env}$ = term to take into account the ablation using the temperature of the environment
$e * T_{build}$ = term to take into account the insulation of the roof
$f(u\text{-}x)^3 * t$ = term for the snow drift with wind velocity u during the time t

The logarithmic regression differs in the following way

$\mu = m * \alpha_1^{n1} * T_{env}^{n2} * T_{env}^{n3} * T_{build}^{n4} [(u\text{-}x)^3 * t]^{n5}$ (equ. 4.10)

and
α_1^{n1} = term for the slope α_1
T_{env}^{n2} = term to take into account the metamorphism using the temperature of the environment
T_{env}^{n3} = term to take into account the ablation using the temperature of the environment
T_{build}^{n4} = term to take into account the insulation of the roof
$[f(u\text{-}x)^3\ t]^{n5}$ = term for the snow drift with wind velocity u during the time t

Only the second approach was used to determine the snow loads on roofs using the measurements obtained during the 1998/99 winter.

4.3.5 Implications for the measurement campaign

From the investigation of the different models to treat drift, metamorphism and ablation the following implications are relevant for the measurement campaign:

- The buildings for the measurement campaign should be near to meteorological stations. Additional automatic weather stations may be helpful for further investigations.
- The location of the buildings and their neighbourhood should be described precisely. The dimensions of the buildings (incl. height) should be determined.
- For continental climates the depth of the snow cover and the density of the snow volume should be measured at least every 2 weeks on the roofs and near to the building in an undisturbed area.
- Some of the buildings on which the roof snow loads are measured should be used for verification of the simulation of snow drift in the wind tunnel. It is important that the recorded meteorological parameters should be used as an input for the investigations in the wind tunnel.

4.4 Measuring documentation

The forms for the data collection are shown on the next page. Relevant information on the measurements themselves is described in annex A.7.

Table 4.4-1: Building information form (example)

Location (Name):
Building (Name, Address):
Observer:
Date:

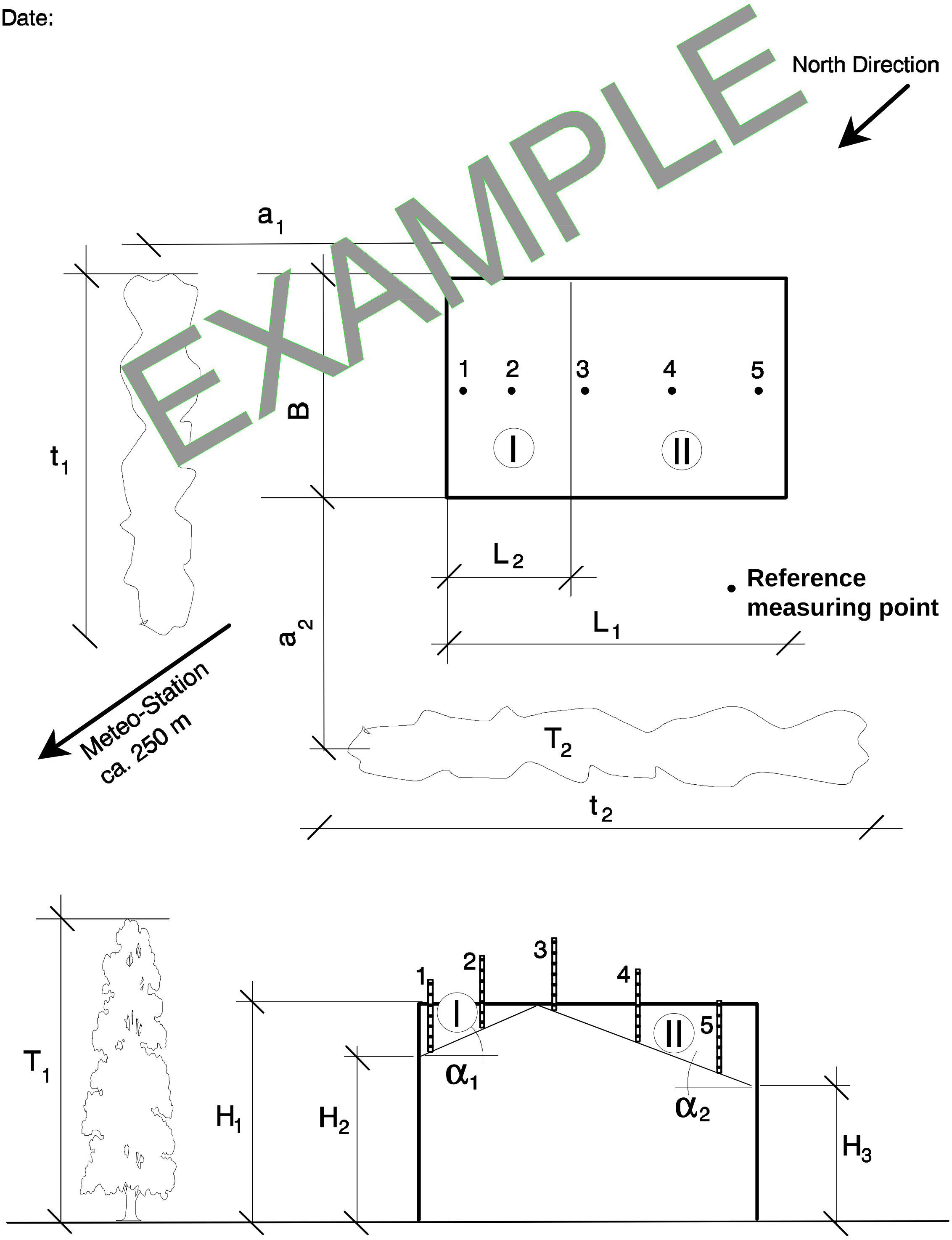


Table 4.4-2: Data collection form

European Snow Load Research Programme

Measuring Documentation

			Dimensions of the Building [m]:			
Location:	Name: No:		H_1 H_2 H_3		T_1 T_2 T_3 T_4	
Environment:	Exposure: Main wind direction: Mean windspeed:		α_1 α_2 α_3 α_4		t_1 t_2 t_3 t_4	
Building:	Name/Address: No: Type: Roof type: Heating (0:no, 1:yes): Type of heating: Insulation (0:no, 1:yes): Type of insulation: K-value:		B L_1 L_2		a_1 a_2 a_3 a_4	

Observations			**Max Roof shape coeff. μ_{max}**	**1**	**2**	**3**	**4**	**5**	**6**
Date Time Observer									
Handnotes sheet(s) No Photograph(s) No									
Weather Conditions									
Avg. Temperature		[°C]							
Avg. wind speed >4m/s		[m/s]							
Duration of high wind speed		[h]							
Main wind direction									
Cloud cover		[%]							
Ground snow data									
Average hight		[cm]							
Density		[kg/m^3]							
Water equivalent		[mm]							
Global roof snow data									
% of roof covered		[%]							
Relevant μ per roof side									
		μ_1	**0.00**						
		μ_2	**0.00**						
Detail roof snow data									
Point No 1	hight	[cm]							
	density	[kg/m^3]							
	water eq.	[mm]							
	shape coeff.	[-]							
Point No 2	hight	[cm]							
	density	[kg/m^3]							
	water eq.	[mm]							
	shape coeff.	[-]							

4.5 Measuring campaign

4.5.1 Requirements for the site selection

The following requirements for the site selection are considered:

- The sites have been selected such that snow falls can be expected during the winter period 98/99 to sample realistic relevant data (e.g. Great Britain has 2 sites with probably 10 snow falls per year). It was also decided to select sites at different altitudes (e.g. for the Italian Apennines between 100 and 1'400 m a.S.L. or Switzerland at 600 m, 1’000 m, 1'300 m and 1'600 m a.S.L.).
- The sites for measurements have to be near meteorological stations where the following meteorological parameters are, at least partly recorded:
  - Wind speed: hourly 1 Minute wind speed, averaged over 10 minutes, measured at an elevation of 10 m
  - Wind direction: hourly or daily predominant wind direction
  - Air temperature: mean daily temperature, maximum and minimum daily temperatures
  - Air humidity: mean humidity, maximum and minimum daily humidity
  - Solar radiation: duration and maximum intensity
  - Rain precipitation: daily height

  In general it is more important to know the type of meteorological data available than to have exactly the type of data mentioned above. Detailed information is included in the site description.
- At a site, several buildings (e.g. 2 to 4 up to 6) with flat and gabled roofs should be measured.
- Important roof configuration parameters are as follows:
  - Roof shape, roof angle(s): flat roof, gabled roof with 20° and 40°, no canopies or measurements not to be taken in areas under the influence of a canopy, no upper roof
  - Roof dimension(s): at least 10 m x 10 m
  - Roof material: normal roughness, e.g. normal tiles
  - Usage/heating of space below roof: if possible unheated structure to reduce the effect of heating
  - Roof insulation: irrelevant if no heating, otherwise very high insulation
  - Roof height above the ground: at least higher than any snow drifting influence from the ground snow
- Environmental parameters
  - Wind exposure of the building: normal exposure, not in a forest nor on wide open flat plane
  - Solar exposure: exposed to normal sun, if possible throughout the whole day

4.5.2 Site selection in the United Kingdom

The following table 4.5-1 shows the site and relevant building information of the measurement campaign undertaken by BRE. As measurement tools they used both the depth measurement poles and the pressure pads described in detail in annex A.6.

Table 4.5-1: Sites for roof snow load measurements of BRE in the United Kingdom

	SITE	BUILDING TYPE	ROOF SHAPE	SLOPE	ROOF MATE-RIAL	ALTI-TUDE A.S.L (M)	MEASUREMENTS				
							Snow Load (BRE pads)	**Roof snow depth**	**Ground snow depth**	**Ground snow water eq.**	**Roof snow water eq.**
1	Cairngorm Mountain Railway Company, Aviemore (Ski Resort)	Workshop	FL	N/A	F	656	✗	✓	✓	See Note 1.	
		Main Building	FL	N/A	F,T						
		Base chairlift	M	10°	F						
			M	10°	F						
			FL	N/A	F		✓				
2	Glenmore Lodge, Aviemore	Garage	FL	N/A	F	345	✗	✓	✓	✓	See Note 1.
		Workshop/Garage	D	28°	PS						
		Chalet	D	23°	T						
		Accommodation block	D	21°	PS						
3	Glenshee Chairlift Company, Braemar	Café/ Accommodation	FL	N/A	C	650	✓	✓	✓	✓	See Note 1.
		Café/ Accommodation	FL	N/A	F						
		Ski Hire	D	16°	PS		✗				
4	The Spittal of Glenshee Hotel, Spittal of Clenshee	Leisure room	D	25°	T	350	✗	✓	✓	✓	✓
		Main building	D	14°	F						✗
5	Glencoe Chairlift Company, Kingshouse	Main building	D	22°	PS	355	✗	✓	✓	See Note 1.	
6	Darvel	Bungalow	D	25°	T	220	✗	✓	✓	✓	✗
7	Eskdalemuir	Bungalow	D	38°	T	242	✗	✓	✓	✓	✗
		Storage block	FL	N/A	F						
8	Callander	Garage	D	26°	T	75	✗	✓	✓	✓	✗
		Forestry Com. Offices	D	30°	T	30					✗
		David Mar.Visitor centre	FL	N/A	F	90					✓
		Garage/shed	M	10°	T	75					✗
		Cottage	D	36°	T	135					✗
		Farm buildings (6)	D, DO	V	V	130					✗
9	Inverness	Storage shed	M	10/20 °	PS	5	Photographs only				
		School	D	40°	T						
10	Weardale, Co. Durham	Garage	D	25°	T	335	✗	✓	✓	✓	✗
11	Appleby, Cumbria	Farm buildings (5)	M/D	V	V	150	✗	✓	✓	✓	✗
12	Mole-y-Crio, Wales	Shed	D	35°	T	260	✗	✓	✓	✓	✗
		Car port	M	8°	PS						
13	Llanarmon DC, Wales	Bungalow	D	30°	T	280	✗	✓	✓	✓	✗
14	Velindre, Wales	House	D	30°	T	152	✗	✓	✓	✓	✗
15	Garston, Watford	Various	FL/D	V	T,F	78	✗	✓	✓	✓	✓
16	RAF Kinloss, Invernessshire	Various	V	V	V	5	BRE are to be informed when snow on roofs. BRE staff to make site visit to record data.				
17	RAF Leuchars, Fife	Various	V	V	V	10					
18	RAF Leeming, Northallerton	Various	V	V	V	32					

Key for roof materials:
F – Felt   T – Tiles   PS – Profiled steel
V – Various   C – Concrete

Key for roof shapes:
M – Mono-pitch   D – Duo-pitch   FL – flat roof

Note 1.: BRE are to be informed when snow on roofs. A decision will then be made on the feasibility of a site visit to record additional data.

__4.5.3 Site selection in the Italian Apennine__

The snow measurements performed by the University of Pisa for the different sites in the Apennine are shown in table 4.5-2.

Table 4.5-2: Sites for the roof snow load measurements of the University of Pisa in the Apennine, Italy

	SITE	ROOF SHAPE / SLOPE	ALTITUDE A.S.L (M)	NEAREST CLIMATIC STATION	LAT.	LONG.	REMARKS
1	Pistoia	Flat roof	88	Pistoia	43.56	14.01	Single snow events
2	CampoTizzoro	Flat roof	700	Pistoia	43.56	14.01	Single snow events
3	S. Marcello Pistoiese (school)	Gabled roof (slope ~ 25°)	620	San Marcello Pistoiese	44.03	14.09	Single snow events
4	S. Marcello Pistoiese (unused school)	Gabled roof (slope ~ 20°)	800	San Marcello Pistoiese	44.03	14.09	Single snow events
5	Cutigliano	Gabled roof (slope ~ 20°)	685	Cutigliano	44.06	14.12	Mainly single snow events
6	Pian degli Ontani	Gabled roof (slope ~ 25°)	1200	Pian di Novello	44.07	14.15	Snow accumulation
7	Abetone 1 (school)	Gabled roof (slope 10°)	1340	Abetone	44.08	14.16	Snow accumulation
8	Abetone 2 (ANAS)	Gabled roof (slope ~ 40°)	1340	Abetone	44.08	14.16	Snow accumulation
9	Abetone 3 (ski resort)	Gabled roof (slope ~ 20°)	1340	Abetone	44.08	14.16	Snow accumulation
10	Abetone 4 (Public Offices)	Gabled roof (slope ~ 30°)	1300	Abetone	44.08	14.16	Snow accumulation
11	Abetone 5 (forester's station)	Gabled roof (slope ~ 25°)	1300	Abetone	44.08	14.16	Snow accumulation
12	Abetone 6 (forester's station)	Gabled roof (slope ~ 20°)	1300	Abetone	44.08	14.16	Snow accumulation
13	Abetone 7 (ski resort)	Gabled roof (slope ~ 22-25°)	1340	Abetone	44.08	14.16	Snow accumulation

4.5.4 Site selection in Italy, Dolomites

The following sites had been selected:

- Passo del Tonale, Meteomont station and Alpine barracks
- Negritella refuge
- Fermeda Meteomont station and refuge
- Scotter refuge
- Varmost alpine hut

4.5.5. Site selection in Germany, Leipzig and Erzgebirge

The sites with snow roof measurements in Germany during the 1998-99 winter are summarised in table 4.5-3.

Table 4.5-3: Sites for roof snow load measurements of the University of Leipzig in Germany

Site	Altitude	Building	Roof slope	Meteorological station
Carlsfeld	880 m	Barn	45^{0}	Distance 500 m
Carlsfeld	880 m	Stable	30^{0}	Distance 500 m
Leipzig	141 m	Garage	18^{0}	near

4.5.6 Site selection in Switzerland

Table 4.5-4 shows the stations for snow load measurements on roofs during the 1998/99 winter. The roofs are all close to the stations of the two meteorological institutes measuring weather data in Switzerland, the Swiss Meteorological Institute (SMA) at Zurich and the Swiss Snow and Avalanche Research Institute (SLF) at Davos.

Table 4.5-4: Sites for the roof snow load measurements in Switzerland

Site	**Altitude**	**Institute**	**Roof measurements**		**Ground measurements**
			Gabled	**Flat**	
Davos	1560	SLF	4	2	2
Adelboden	1355	SLF	3	2	2
Braunwald	1340	SLF	2	1	1
Hinterrrhein	1620	SLF	1	1	1
San Bernardino	1628	SMA		1	
Disentis	1190	SMA	3	2	0
Robbia	1078	SMA	4	1	1
Bern	570	SMA	4	4	0
Total			**21**	**14**	**7**

4.5.7. Summary of selected sites

The following table 4.5-5 shows an overview of the locations of the roof measurements.

Table 4.5-5: Overview of all sites of roof snow load measurements

Participants	**Number of roofs**			**Material**	**Personnel**	**Met. Stations**
	Total	**Flat roofs**	**Gabled roofs**			
Switzerland	35	14	21	Wooden poles	Mainly employees of meteo stations	Yes
Italy	13	3	10	Poles	Dept. Personnel – local employees	Yes (Abetone)
Great Britain	25	9	16	Poles	Met. Office	Yes
ISMES	5	0	5	Pressure transducers	Automatic stations	Automatic stations, every 3 h per day
Germany Leipzig	3	0	3	Wooden poles	Geographic faculty	Yes
Total	81	26	55			

4.6 Data analysis

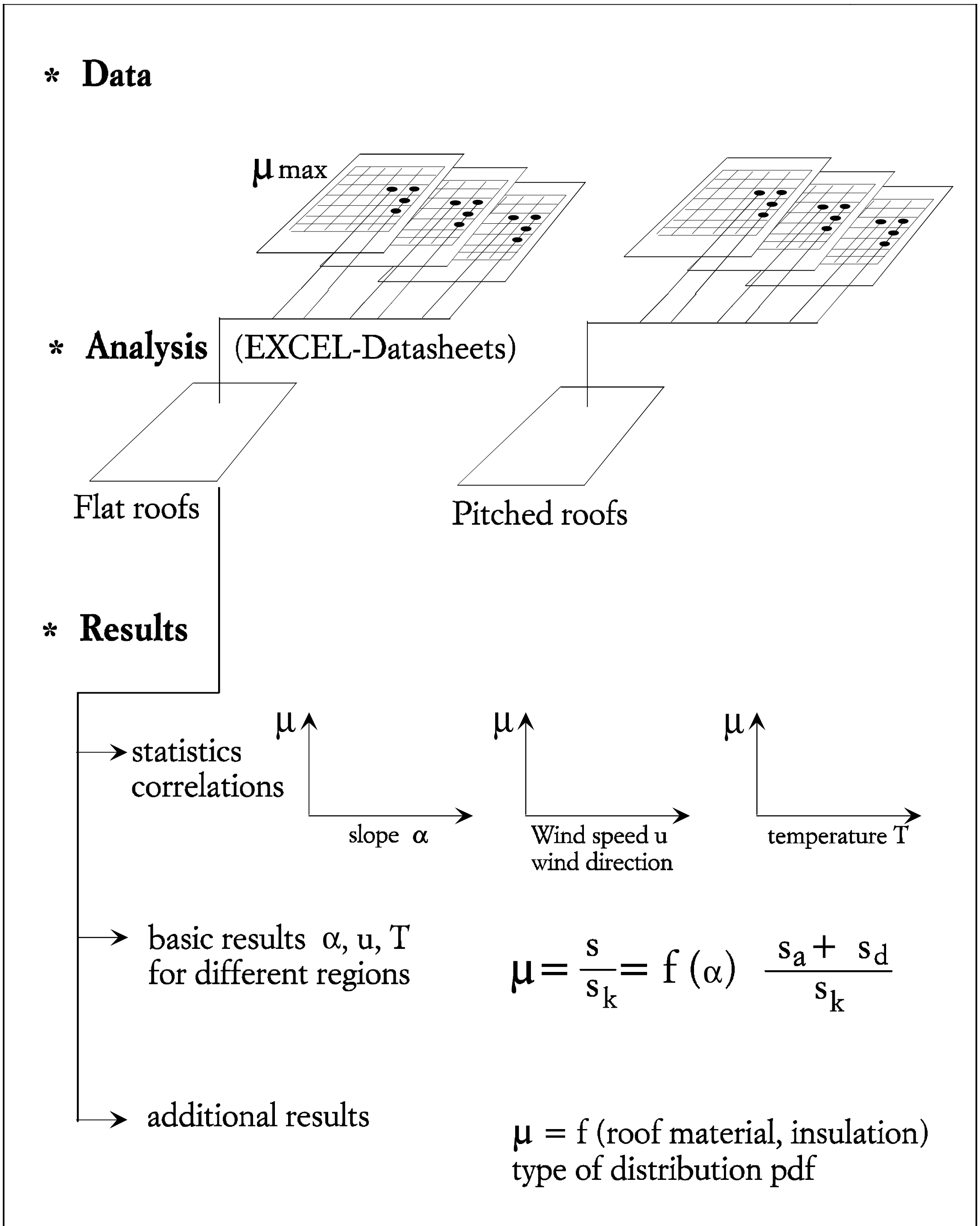
4.6.1 Principles for the data analysis

The principles for the data analysis are shown in figure 4.6-1. As far as possible regression analysis is performed on the data of every climatic region. From this analysis basic information on the shape coefficient can be drawn. In figure 4.6-2 the procedure to determine the maximum roof shape coefficient is described. The EXCEL-program to analyse the data uses simple and multiple regression analysis considering the mathematical expression of equation 4.10. The EXCEL-datasheet with information about the statistics used is treated in detail in Gruner, 1999.

The following coefficients are used in the regression analysis:

- T_{env} = Average temperature in Switzerland of an early morning hour (7 - 8 a.m.), others average daily values
- T_{build} = 20 °C if the construction is heated; T_{env} if the construction is not heated
- DD = The number of the days with temperatures higher than 0 °C since the previous observation resp. since start of snow (only if snow lying) will be multiplied by the number of degrees
- u = Average wind speed values in Switzerland of an early morning hour (7 - 8 a.m.), others average daily values
- u_{high} = Average high wind speed values above 4 m/s (if possible hourly mean values) since last observation [m/s]; data from meteorological station
- α = Roof slope

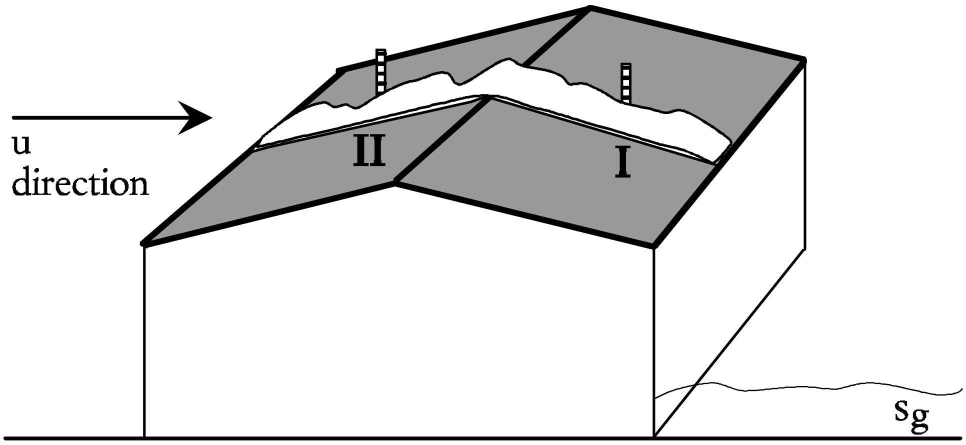
Figure 4.6-1: Roof snow load data analysis: principles



Legend:
μ = Roof shape coefficient
s = Snow load on the roof
s_k = Characteristic value of the snow load on the ground
s_a = Snow load on the roof due to ablation and metamorphism
s_d = Snow load on the roof due to drift

Figure 4.6-2: Roof snow load data analysis: selection of μmax

* **Measurements**



* **Selection**

- measurement point 1

measurements				
1	2	3	4	....
s_{11}	s_{12}	s_{13}	s_{14}	....
s_{k11}	s_{k12}	s_{k13}	s_{k14}	....
μ_{11}	μ_{12}	μ_{13}	μ_{14}	....

μ 1 relevant meas. of max s_{k1x})

- measurement point 2

measurements				
1	2	3	4	....
s_{21}	s_{22}	s_{23}	s_{24}	....
s_{k21}	s_{k22}	s_{k23}	s_{k24}	....
μ_{21}	μ_{22}	μ_{23}	μ_{24}	....

μ 2 relevant meas. of max s_{k2x})

4.6.2 Multiple linear regression analysis

The following tables 4.6-3, 4.6-6 and 4.6-9 and figures 4.6-4, 4.6-5, 4.6-7, 4.6-8, 4.6-10 and 4.6-11 show the results of the data analysis. Since the most measurements are for Switzerland and the meteorological data could be gathered quite completely the first analysis is performed for these data. If for one of the other climatic regions more than five, or at least more than three data sets (partly incomplete with respect to meteorological data) were available, a separate analysis is worked out. In addition reasonable combinations are performed to analyse the differences between the results for different climatic regions. Of particular interest are the possible differences between the continental continuous snow falls and the maritime single snow falls.

Flat roofs

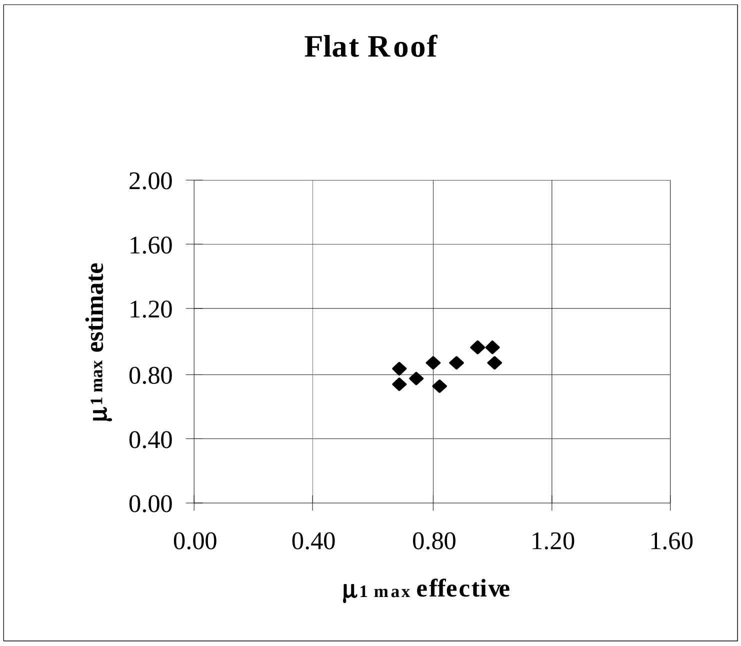
Table 4.6-3: Factors for the equation for the roof snow load on flat roofs

Climatic region	N° sites	Coefficients of the regression equation					Correlation coefficient R^2
		Intercept	Log T_{env}	Log T_{build}	Log DD	Log u	
Switzerland	10	-58.8	24.56	-	-	0.01	0.55
Italy Apennine	3	0.35	-	-	0.28	-	0.20
United Kingdom	2	Remarks see below					
Switzerland + Italy Apennine	13	Remarks see below					
Switzerland + United Kingdom	18	Remarks see below					

The following remarks can be made from these data analysis on flat roofs:

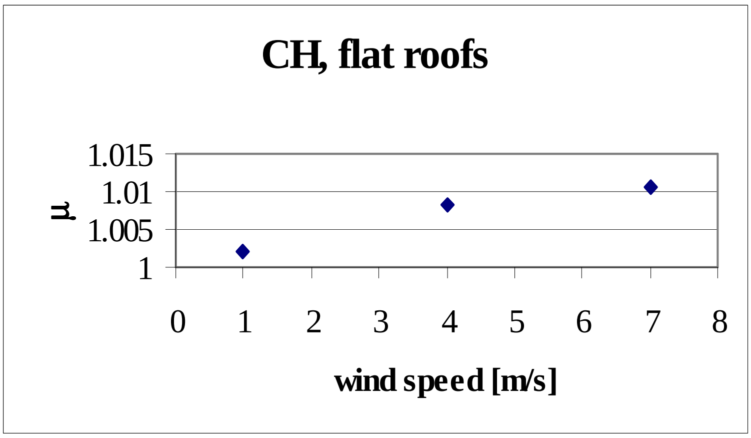
- The correlation factor for the Swiss data set with $R^2 = 0.55$ is quite high compared with other roof snow load measurements in the United States. The effective and estimated values are plotted in figure 4.6-4. From the t-test only the parameter T_{env} is shown to be sufficiently reliable to be used as a parameter in the regression analysis. This means that from a statistical point of view the data must be partly improved and additional investigations are necessary. Nevertheless important parameters to characterise the roof snow load can be determined.
- The correlation factor for the Italian data with $R^2 = 0.20$ is not as high as that for the Swiss measurements; this is probably due to the small quantity of data. From the statistical point of view three data sets are insufficient for reasonable analysis. To introduce all of the the available information into the analysis it was decided to use all the measured data.
- For two of the UK sites BRE has the required meteorological data and only on two flat roofs was there enough snow to be measured. This is not sufficient for a statistical treatment.
- The combination of the Swiss data with the data from the Apennines is not reasonable because the same meteorological data does not exist.
- The combination of the Swiss data, representative for a continental climate, with the data from United Kingdom is not reasonable due to few data from United Kingdom.

Figure 4.6-4: Effective and estimated roof shape coefficients for the roof snow load on flat roofs for Swiss data



In figure 4.6-5 the roof shape coefficients for different wind speeds are calculated using the regression equation with the coefficients in table 4.6-3.

Figure 4.6-5: Calculated roof shape coefficients for the roof snow load on flat roofs for Swiss data for different wind speed



Gabled roofs side I (lee)

Table 4.6-6: Factors for the equation for the roof snow load on gabled roofs side I (lee)

Climatic region	No sites	Coefficients of the regression equation						Correlation coefficient R^2
		Intercept	Log α	Log T_{env}	Log T_{build}	Log DD	Log u	
Switzerland	17	-14.63	-0.68	6.77	-	-	-0.03	0.12
Italy Apennine	4	2.86	-1.34	-	-	-0.51	-	-
Italy Dolomite	5	-206.30	4.08	84.69	-1.63	-	0.24	-
Germany	3	27.00	0.62	-4.57	-	-	24.84	-
United Kingdom	2	-	-	-	-	-	-	-
Switzerland + Italy Dolomite + (Alps)	22	-8.8	-0.36	4.17	-	-	-0.003	0.04
Switzerland + Italy Apennine	21	0.8	-0.02	-	-	-	-	0.0001
Switzerland + Italy Dolomite + Germany (Continental)	25	-11.57	-0.63	5.46	-	-	-0.01	0.12
Switzerland + Italy Dolomite + Italy Apennine	26	0.78	-0.02	-	-	-	-	0.0001
Switzerland + Italy Dolomite + Italy Apennine+ Germany	29	1.11	-0.27	-	-	-	-	0.02
Switzerland + Italy Dolomite + Italy Apennine + Germany + United Kingdom	31	1.07	-0.24	-	-	-	-	0.01

From the analysis of the roof snow load data for the leeward side of the gabled roofs (side I) in table 4.6-6 the following conclusions can be drawn:

- The correlation coefficient R^2 = 0.12 for the Swiss data is low (table 4.6-6 and figure 4.6-7). The reasons for this fact might be bad data collection or not considering all the relevant influences. To eliminate the first reason several improvements of the data were performed, such as elimination of data that was gathered after snow removal due to extremely heavy snow falls or wrong measurements after discussion with local observers. The t-test shows values with an unusually high probability of 15 to 20 % for a wrong decision (5 % is normal). All the parameters therefore are only of limited use for the determination of the roof shape coefficients.

  In figure 4.6-8 the roof shape coefficients for different slopes of the roof are given, using the regression equation with the coefficients in table 4.6-6. As shown in this figure the shape coefficient is reduced remarkably for higher slopes whereas different wind speeds play only a minor role for the shape coefficient.

Figure 4.6-7: Effective and estimated roof shape coefficients for the roof snow load on gabled roofs side I (lee) for Swiss data

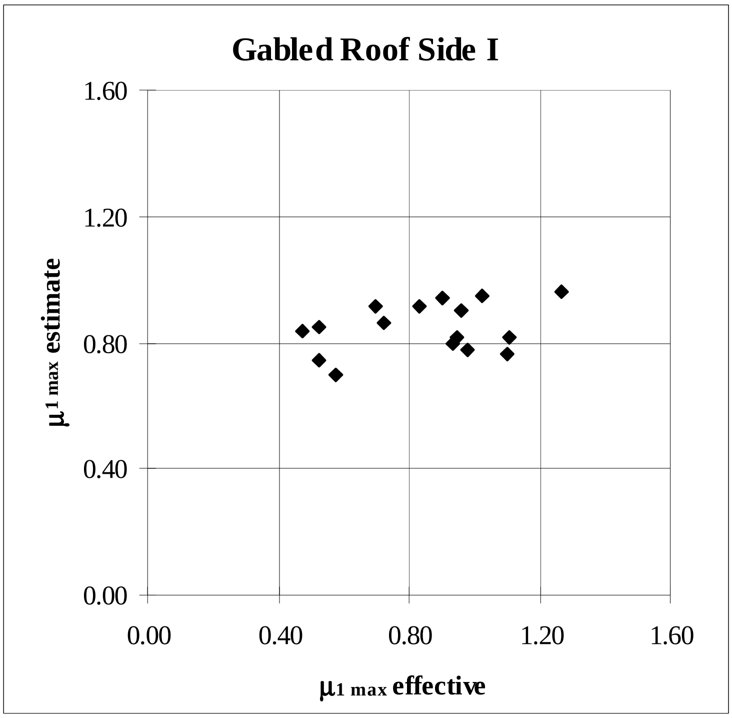
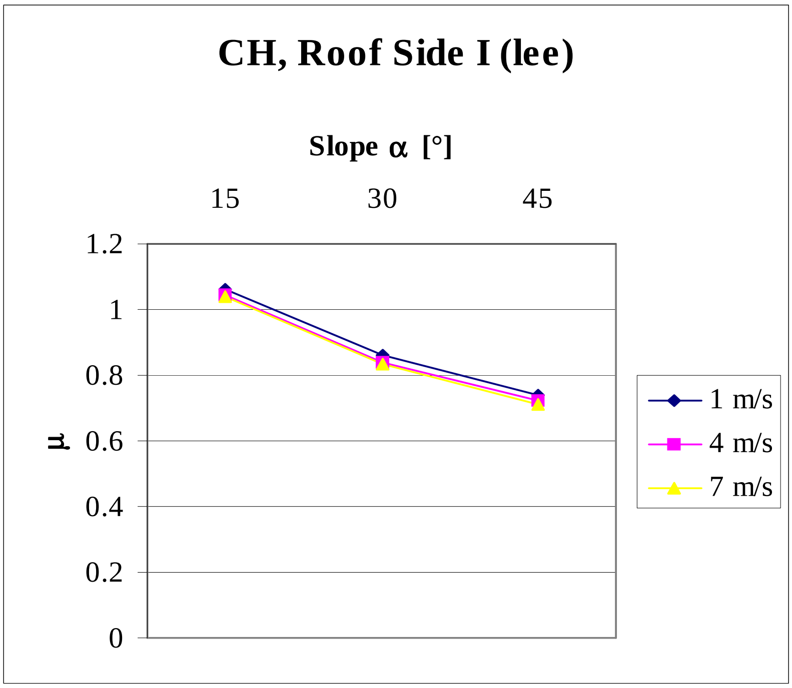


Figure 4.6-8: Calculated roof shape coefficients for the roof snow load on <u>gabled roofs side I (lee)</u> for Swiss data for different slopes of the roof and different wind speeds

Matrix of μ values (with Intercept -14.63; log α = - 0.68
log T_{env} = 6,77; log u = - 0.03)

α [°] / u [m/s]	1	4	7
15	1.063079	1.045017	1.037726
30	0.858379	0.840317	0.833026
45	0.738637	0.720575	0.713284



- There was an insufficient number of data sets for Germany and for the Italian Apennines and Dolomites in order to calculate reasonable correlation coefficients. The number of data sets is approximately equal to, or smaller than, the number of independent variables of the multiple linear regression analysis, therefore correlation coefficients of 0.75 and 1 result.
- The same correlation coefficient for the Swiss data as for the combination of the Swiss, German and Italian Dolomites data might be a hint that for these climatic regions – all with continuous snow fall and a build up of the snow layer during several weeks and months – the same regression equation might be valid. Unfortunately there are insufficient data for this to be a final conclusion.
- The combination of the Swiss data and the Italian Dolomites with the data from the Italian Apennine shows an extremely low correlation coefficient. This might be sign that the Italian Apennine follows a different law for shape coefficients than continental regions.
- The combination of the continental data with the data from United Kingdom again seems to have no correlation. If this data is significant from a statistical point of view cannot be judged due to few data.

Gabled roofs side II (windward)

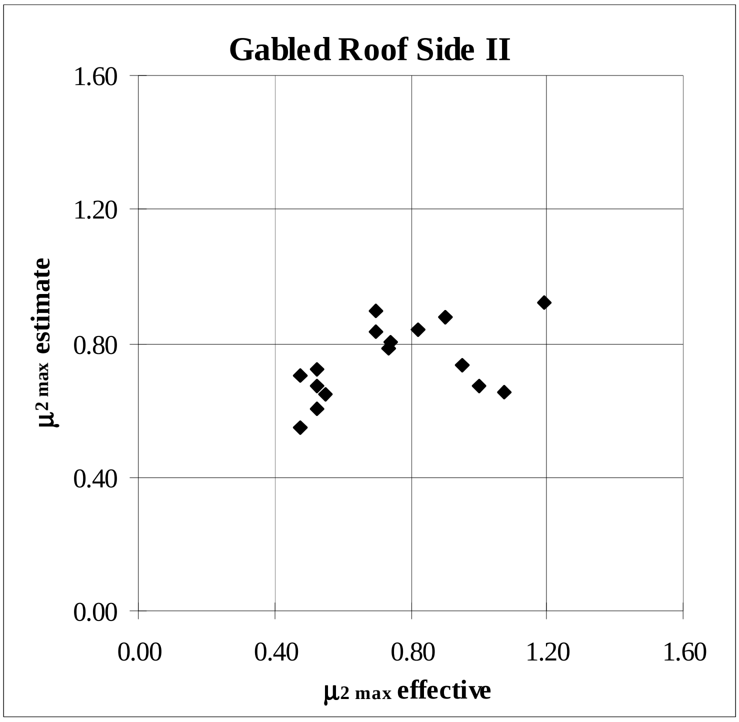
Table 4.6-9: Factors for the equation for the roof snow load on gabled roofs side II (windward)

Climatic region	No sites	Coefficients of the regression equation						Correlation coefficient R^2
		Intercept	Log α	Log T_{env}	Log T_{build}	Log DD	Log u	
Switzerland	18	-49.80	-0.57	21.16	-	-	-0.10	0.27
Italy Apennine	4	2.49	-0.95	-	-	-0.54	-	
Italy Dolomite	5	-206.30	4.08	84.69	-1.63	-	0.24	
Germany	3	39.94	0.52	-7.19	-	-	-35.00	
United Kingdom	1	-	-	-	-	-	-	
Switzerland + Italy Dolomite (Alps)	23	-30.22	0.00	12.74	-	-	-0.06	0.13
Switzerland + Italy Apennine	22	0.68	0.02	-	-	-	-	0.0001
Switzerland + Italy Dolomite Germany (Continental)	26	-41.46	-0.45	17.61	-	-	-0.08	0.19
Switzerland + Italy Dolomite + Italy Apennine	27	0.56	0.09	-	-	-	-	0.002
Switzerland + Italy Dolomite + Italy Apennine + Germany	30	1.13	-0.34	-	-	-	-	0.02
Switzerland + Italy Dolomite + Italy Apennine + Germany + United Kingdom	31	0.9	-0.22	-	-	-	-	0.01

From the analysis of the roof snow load data for the windward side of the gabled roofs (side II) the following conclusions can be drawn:

- The correlation coefficient R^2 = 0.27 for the Swiss data is higher than for the leeward side but is still not satisfactory (table 4.6-9 and figure 4.6-10). The reason can be the same as described above. The t-test shows better values than for the leeward-side. The probability of an erroneous decision is for wind speed less than 5 % and for the other two parameters, slope of the roof and temperature, approx. 15 %.
- In figure 4.6-11 the roof shape coefficients for the different slopes of the roof are given, using the regression equation with the coefficients in table 4.6-9 again for the Swiss data. As shown in this figure the shape coefficient is reduced remarkably for the higher slope values whereas different wind speeds play only a minor role for the shape coefficient. Comparing these values with figure 4.6-8 the values for the lee side of the roof are about the same as for the windward side, this is not expected. Other investigations have always shown a remarkable difference between the two roof sides.

Figure 4.6-10: Effective and estimated roof shape coefficients for the roof snow load on gabled roofs side II (windward) for Swiss data

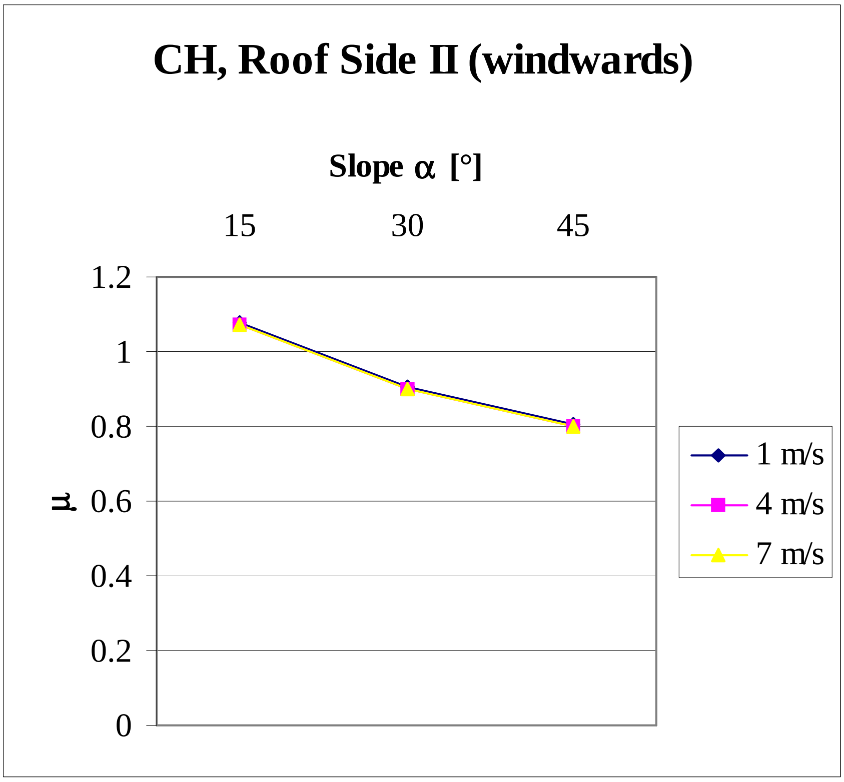


- The combination of the continental data shows a smaller correlation coefficient, R^2 = 0.19, than for the Swiss data. The reason for this fact can not be determined from the existing data basis.
- The combination of the Swiss data with the data from the Apennine follows the same pattern as for the leeward side.
- The combination of the continental data with the data from United Kingdom shows again a low correlation.

Figure 4.6-11: Calculated roof shape coefficients for the roof snow load on <u>gabled roofs side II (windward)</u> for Swiss data for different slopes of the roof and different wind speeds

Matrix of μ values (with Intercept - 49.8, log α = - 0.57, log T_{env} = 21.16, log u = -0.10

α [°] / u [m/s]	1	4	7
15	1.07883	1.072809	1.070379
30	0.907242	0.901222	0.898792
45	0.80687	0.80085	0.798419



4.6.3 Simple linear regression analysis

Since the multiple linear regression analysis in section 4.6.2 shows only partially satisfactory results, the influence of each single parameter on the roof shape coefficient is investigated in this section. The following table gives details of the simple linear regression analysis.

Flat roofs

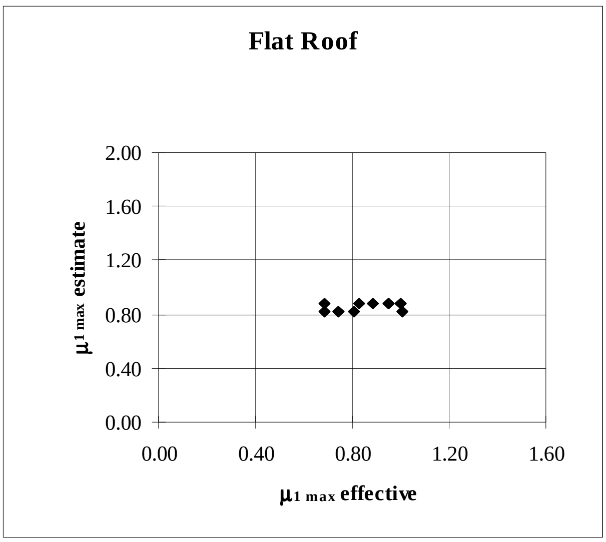
Table 4.6-12: Simple linear regression analysis for the parameters with influence on the roof shape coefficient of <u>flat roofs</u>

Climatic region	No sites	Inter-cept	Env. Temp		Wind Speed			High Wind Speed			Degree Days		
			Log T_{env}	Corr. Coeff. R^2	Inter-cept	Log u	Corr. Coeff. R^2	Inter-cept	Log u_{high}	Corr. Coeff. R^2	Inter-cept	Log DD	Corr. Coeff. R^2
Switzerland	10	-61.01	25.46	0.54	0.86	0.025	0.08	1.75	-1.23	0.69	-	-	-
Italy Apennine	3	-	-	-	-	-	-	-	-	-	0.35	0.28	0.20
Italy Dolomite	0	-	-	-	-	-	-	-	-	-	-	-	-
Germany	0	-	-	-	-	-	-	-	-	-	-	-	-
United Kingdom	2	-	-	-	-	-	-	-	-	-	-	-	-
Switzerland + United Kingdom	12	-4.3	2.14	0,004	-	-	-	-	-	-	-	-	-

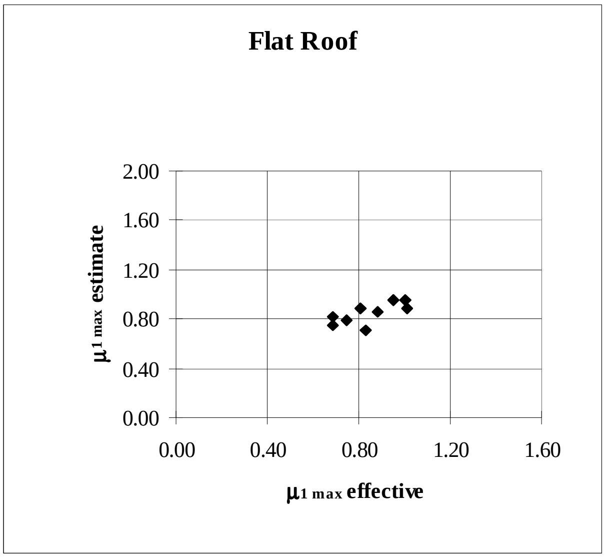
The correlation between measured and calculated shape coefficients can be seen from figure 4.6-13:

Figure 4.6-13: Correlation for measured and calculated shape coefficients for <u>flat roofs</u> for Swiss data

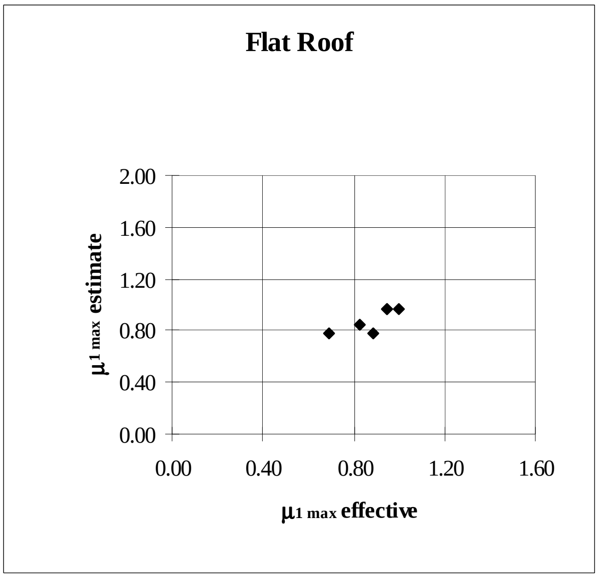
- Wind speed (all data)



- Environmental temperature



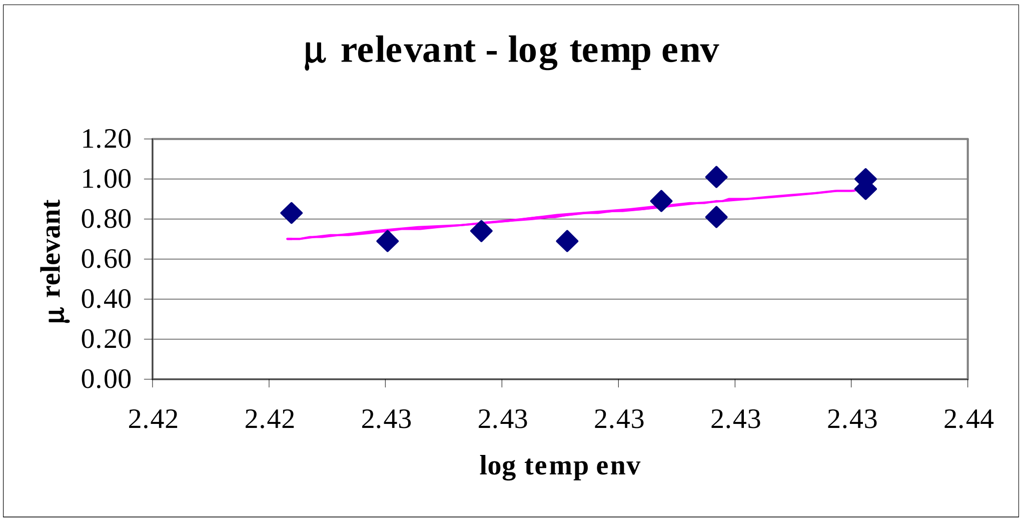
- High wind speed (> 4 m/s)



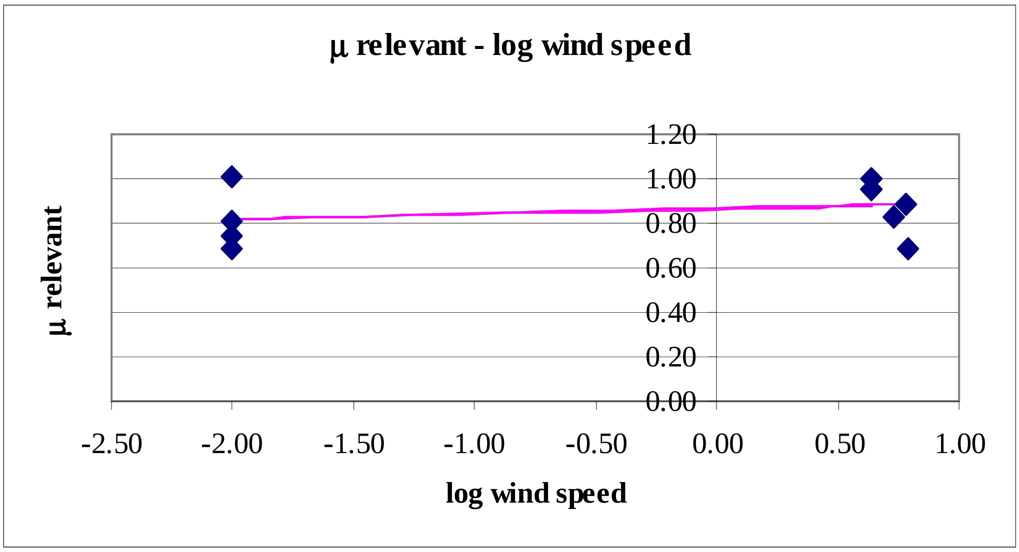
From the following figures the fit of the data for the different parameters can be seen.

Figure 4.6-14: Shape coefficient for flat roofs depending only on singular parameters for Swiss data

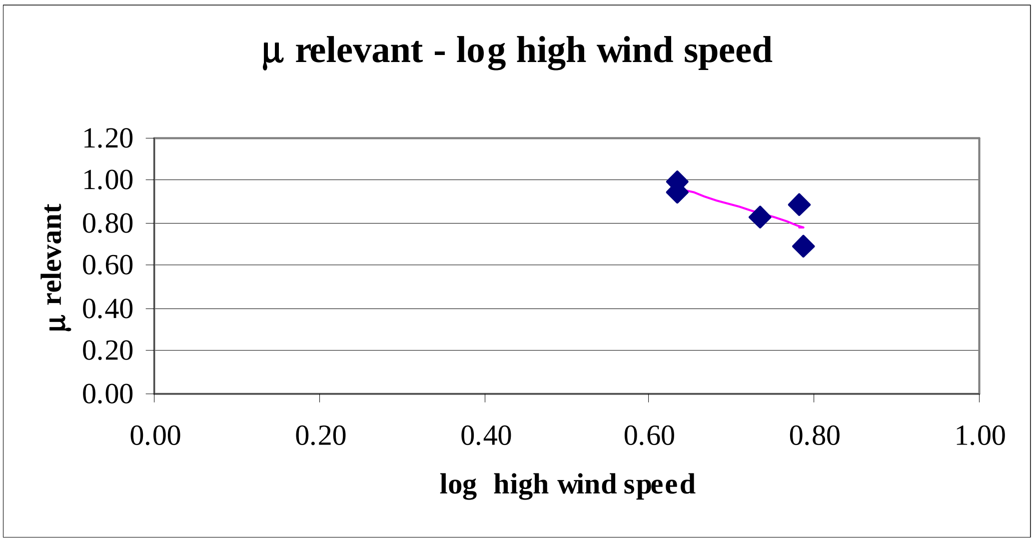
- Environmental temperature



- Wind speed (all data)



- High wind speed (> 4 m/s)



From these results the following conclusions can be drawn:

- For the Swiss data the high wind speed parameter with a correlation coefficient $R^2 = 0.69$ and environmental temperature with $R^2 = 0.54$ describe quite well the influences on the shape coefficient. The t-test gives normal results; the probability of an erroneous decision is normally small. This correlation is coherent with the discussion of the influencing parameter for drift, metamorphism and ablation in section 4.3.
- The correlation coefficient for the degree days parameter of the data from Italy Apennine is with $R^2 = 0.20$ not as high as the R^2-value for the environmental temperature parameter of the Swiss data. Further investigations would be necessary to conclude from a statistical point of view the significance of the differences.

Gabled roofs side I (leeward)

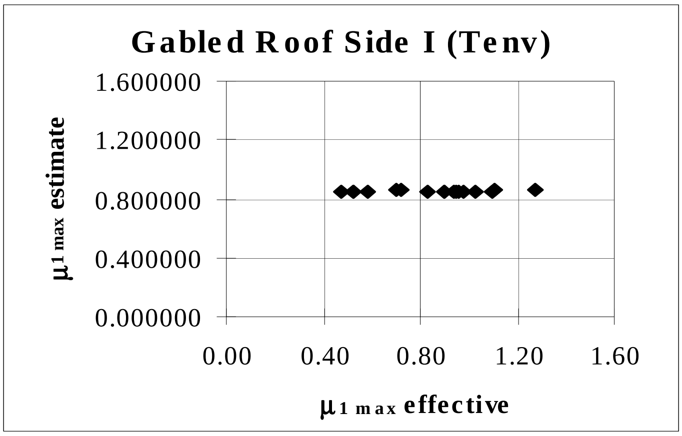
Table 4.6-15: Simple linear regression analysis for the parameters with influence on the roof shape coefficient of the leeward side of gabled roofs side I

Climatic region	No sites	Inter-cept	Env. Temp		Wind Speed			High Wind Speed			Roof Shape α		
			Log T_{env}	Corr. Coeff. R^2	Inter-cept	Log u	Corr. Coeff. R^2	Inter-cept	Log u_{high}	Corr. Coeff. R^2	Inter-cept	Log α	Corr. Coeff. R^2
Switzerland	17	5.76	-2.02	0.001	0.86	-0.03	0.02	1.93	-1.40	0.40	1.82	-0.68	0.10
Italy Apennine	4	-	-	-	-	-	-	-	-	-	2.58	-1.78	0.592
Italy Dolomite	5	-8.35	3.73	0.026	0.73	0.04	0.079	-	-	-	0.84	-0.09	0.006
Germany	3	-179.2	73.96	0.967	11.82	-17.25	0.967	-	-	-	2.28	-1.19	0.642
United Kingdom	2	-	-	-	-	-	-	-	-	-	-	-	-
Switzerland + Italy Dolomite (Alps)	22	-10.75	4.76	0.007	0.82	-0.01	0.001	-	-	-	1.35	-0.37	0.036
Switzerland + Italy Dolomite + Germany	26	-18.83	8.08	0.017	0.79	-0.02	0.007	-	-	-	1.75	-0.68	0.115
Switzerland + Italy Dolomite + Italy Apennine	26	-	-	-	-	-	-	-	-	-	0.78	-0.02	0.000
Switzerland + Italy Dolomite + Italy Apennine + Germany	29	-	-	-	-	-	-	-	-	-	1.11	-0.27	0.018
Switzerland + Italy Dolomite + Italy Apennine + Germany + United Kingdom	31	-	-	-	-	-	-	-	-	-	1.07	-0.24	0.014

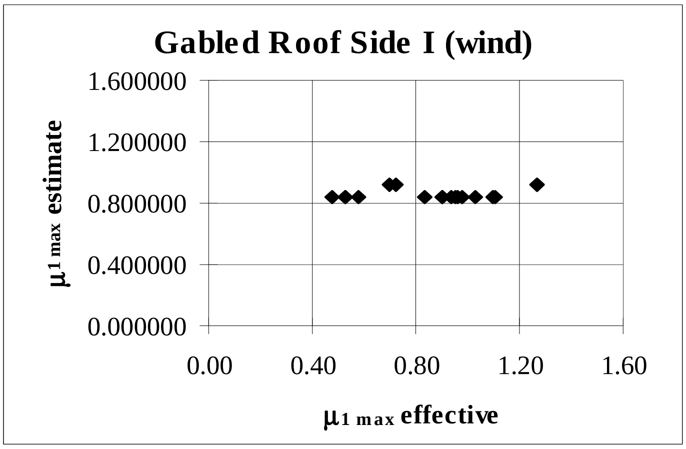
The correlation between measured and calculated shape coefficients can be seen from figure 4.6-16:

Figure 4.6-16: Correlation for measured and calculated shape coefficients for the leeward side of gabled roofs side I (Swiss data)

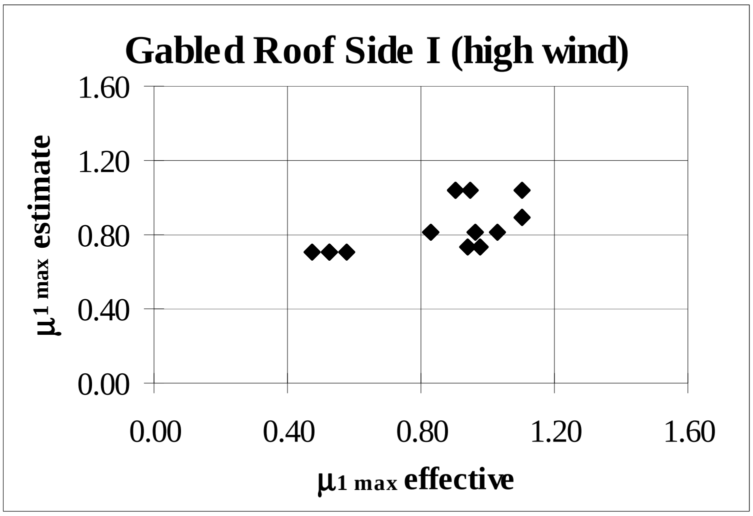
- Environmental temperature



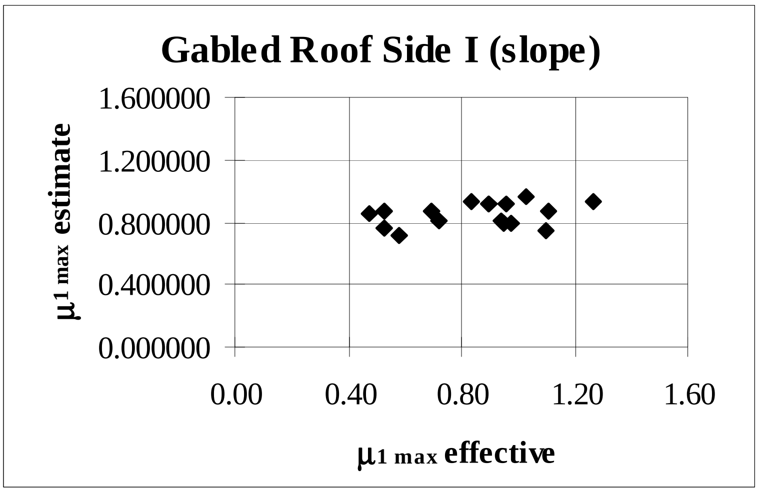
- Wind speed (all data)



- High wind speed (> 4 m/s)



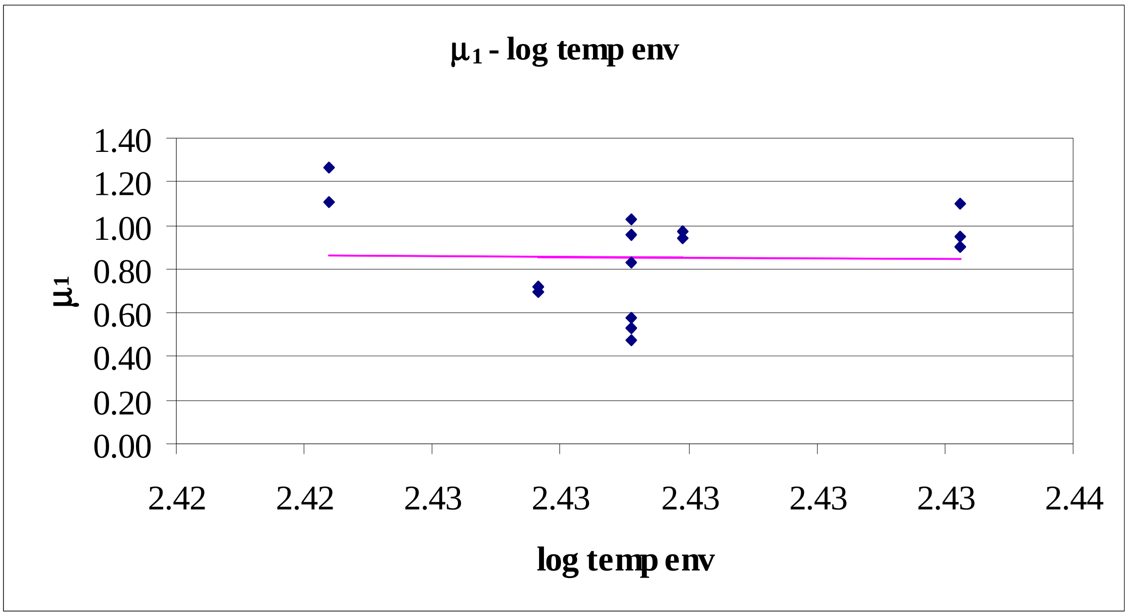
- Roof slope



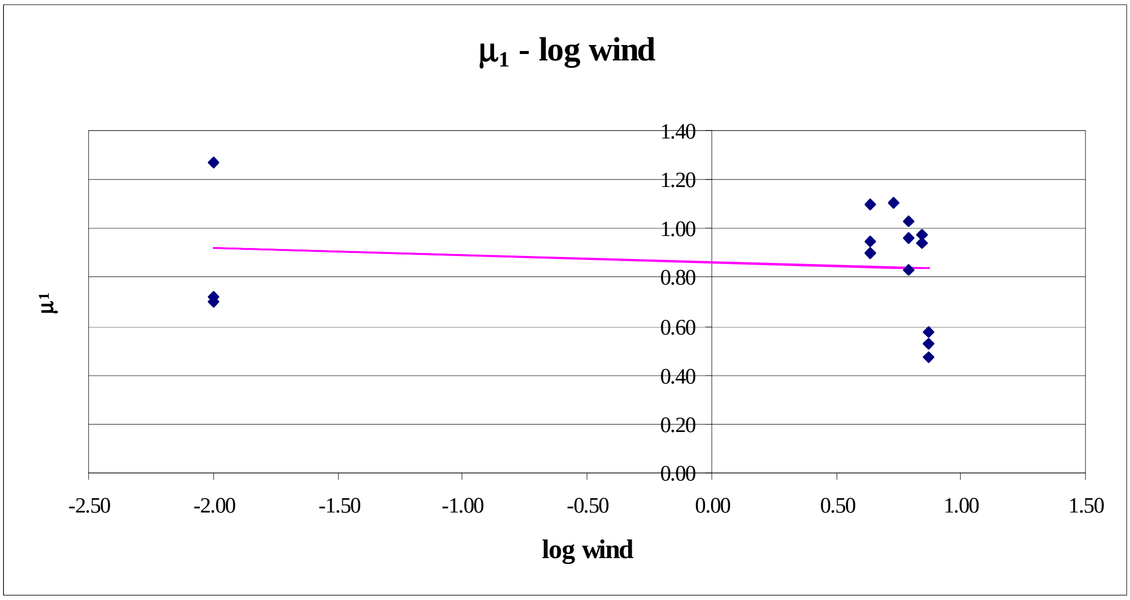
From the following figures the fit of the data for the different parameters can be seen.

Figure 4.6-17: Shape coefficient for the leeward side of gabled roofs side I depending only on singular parameters (Swiss data)

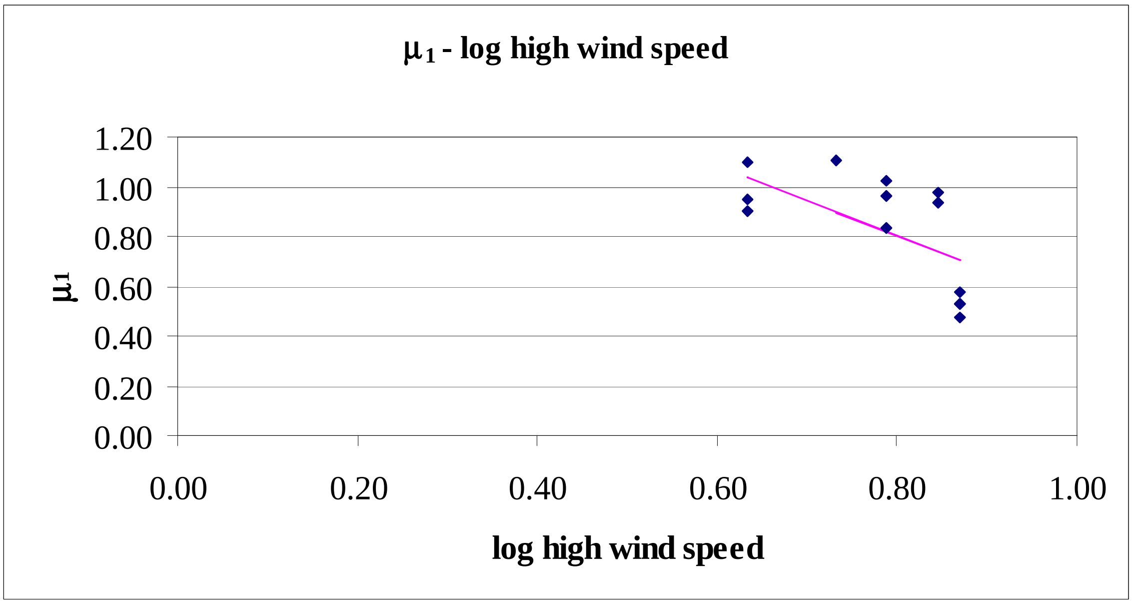
- Environmental temperature



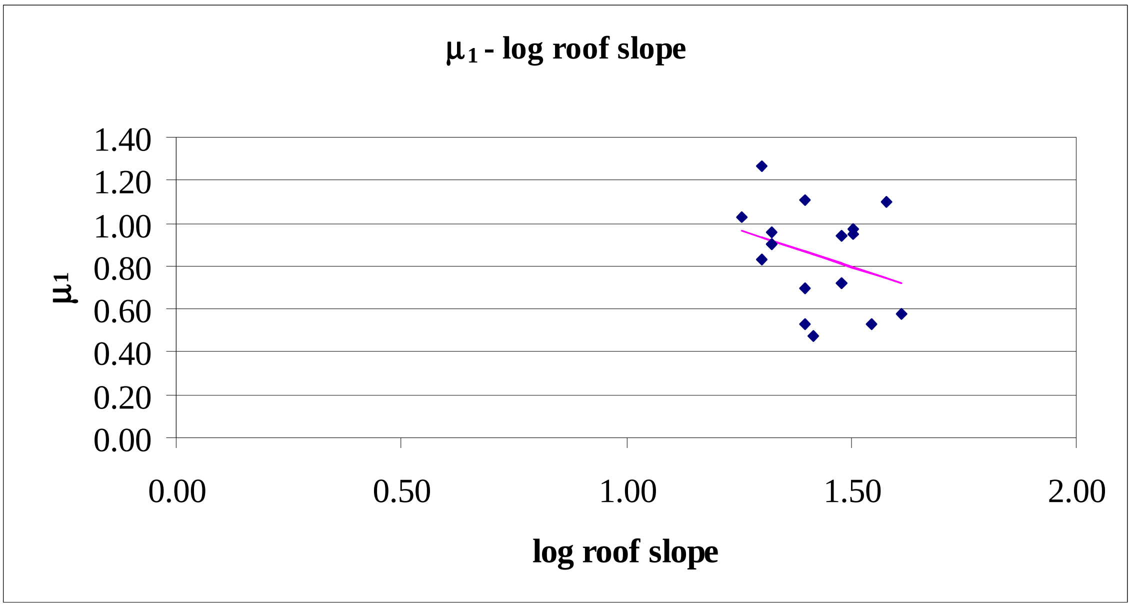
- Wind speed (all data)



- High wind speed (> 4 m/s)



- Roof slope



From these results the following conclusions can be drawn:

- The two parameters, environmental temperature and wind speed, have for the Swiss data no correlation with the shape coefficient. Whereas high wind speed and roof slope have similar effects from a statistical point of view on the determination of the roof shape coefficients with relatively high correlation coefficients of 0.4 and 0.1.
- From figure 4.6-17 no higher values for a slope between 30 ° and 45 ° can be observed.
- The Italy Apennine values show high correlation for the roof shape (R^2 = 0.59).
- High correlation coefficients for other data sets are mainly due to few data sets.
- All combinations show no relevant correlation or significant differences.

Gabled roofs side II (windward)

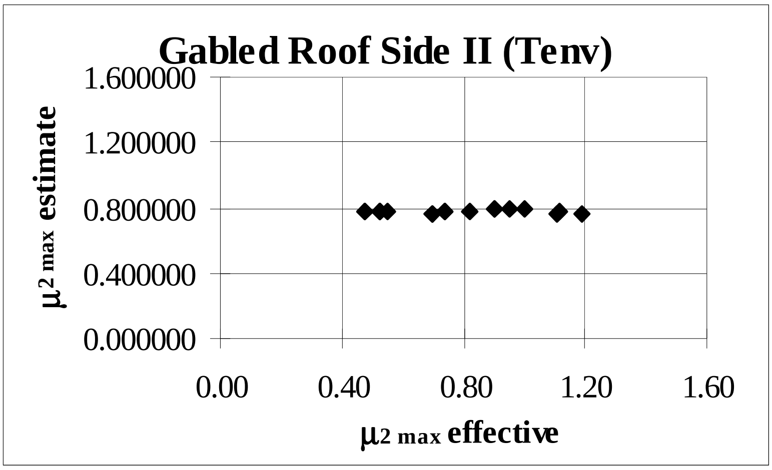
Table 4.6-18: Simple linear regression analysis for the parameters with influence on the roof shape coefficient of the windward side of gabled roofs side II

Climatic region	No sites	Inter-cept	Env. Temp		Wind Speed			High Wind Speed			Roof Shape α		
			Log T_{env}	Corr. Coeff. R^2	Inter-cept	Log u	Corr. Coeff. R^2	Inter-cept	Log u_{high}	Corr. Coeff. R^2	Inter-cept	Log α	Corr. Coeff. R^2
Switzerland	18	-7.76	3.51	0.002	0.81	-0.11	0.24	2.22	-1.93	0.77	1.27	-0.35	0.03
Italy Apennine	4	-	-	-	-	-	-	-	-	-	2.31	-1.49	0.305
Italy Dolomite	5	-7.54	3.34	0.093	0.58	0.01	0.02	-	-	-	0.69	-0.09	0.023
Germany	3	-289.33	119.18	0.991	18.52	-27.80	0.991	-	-	-	3.27	-2.01	0.723
United Kingdom	1	-	-	-	-	-	-	-	-	-	-	-	-
Switzerland + Italy Dolomite (Alps)	23	-22.09	9.39	0.025	0.73	-0.06	0.078	-	-	-	0.77	-0.03	0.41
Switzerland + Italy Dolomite + Germany	26	-36.61	15.35	0.043	0.7	-0.08	0.084	-	-	-	1.47	-0.56	0.063
Switzerland + Italy Dolomite + Italy Apennine	27	-	-	-	-	-	-	-	-	-	0.56	0.09	0.002
Switzerland + Italy Dolomite + Italy Apennine + Germany	30	-	-	-	-	-	-	-	-	-	1.13	-0.34	0.02
Switzerland + Italy Dolomite + Italy Apennine + Germany + United Kingdom	31	-	-	-	-	-	-	-	-	-	0.97	-0.22	0.01

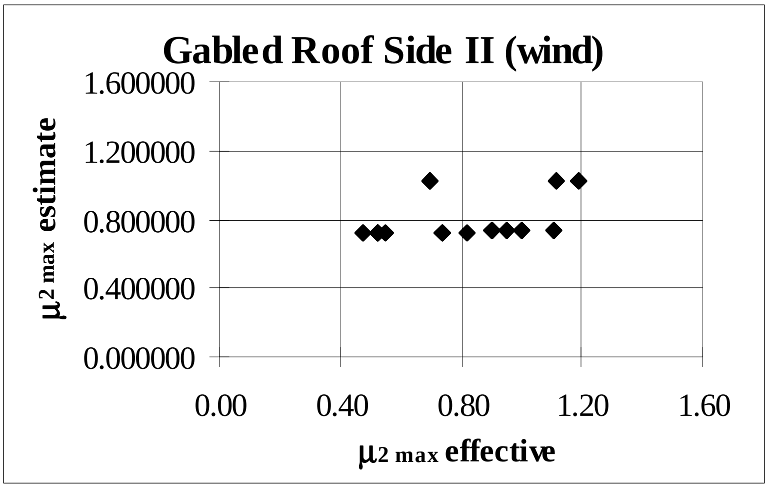
The correlation between measured and calculated shape coefficients can be seen from figure 4.6-19.

Figure 4.6-19: Correlation for measured and calculated shape coefficients for the windward side of gabled roofs side II (Swiss data)

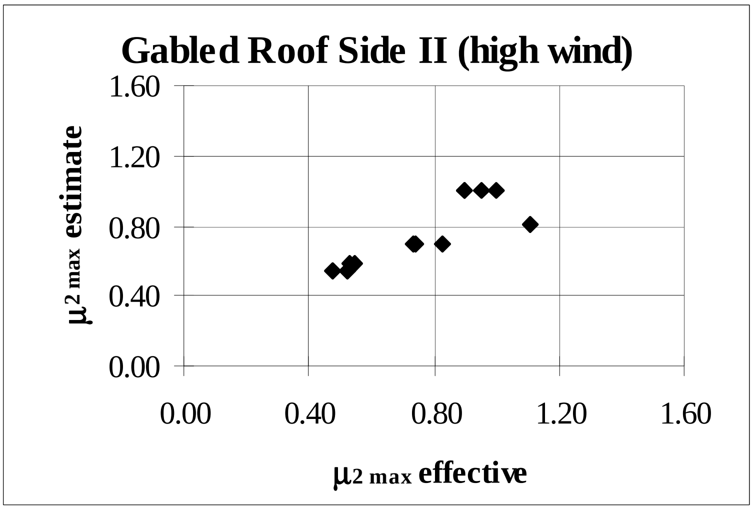
- Environmental temperature



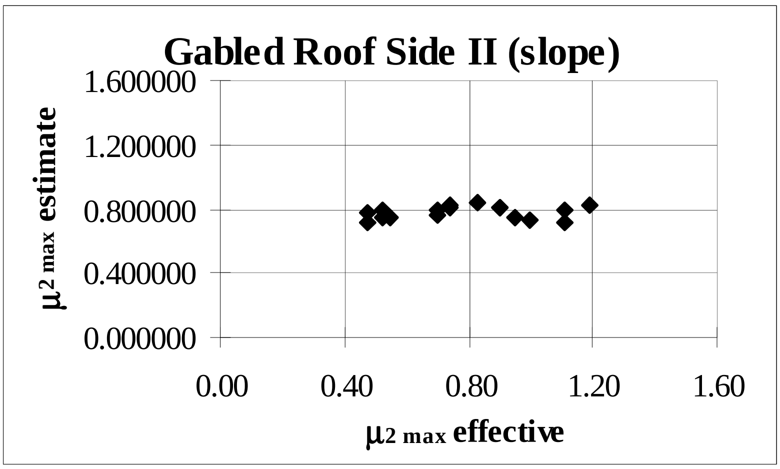
- Wind speed (all data)



- High wind speed (> 4 m/s)



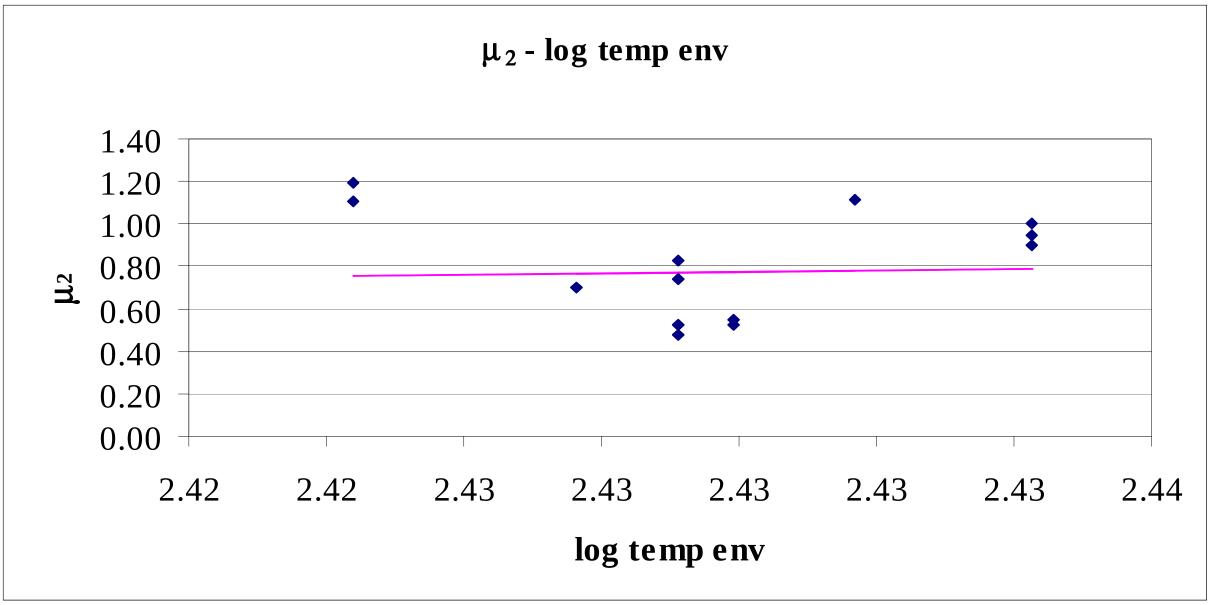
- Roof slope



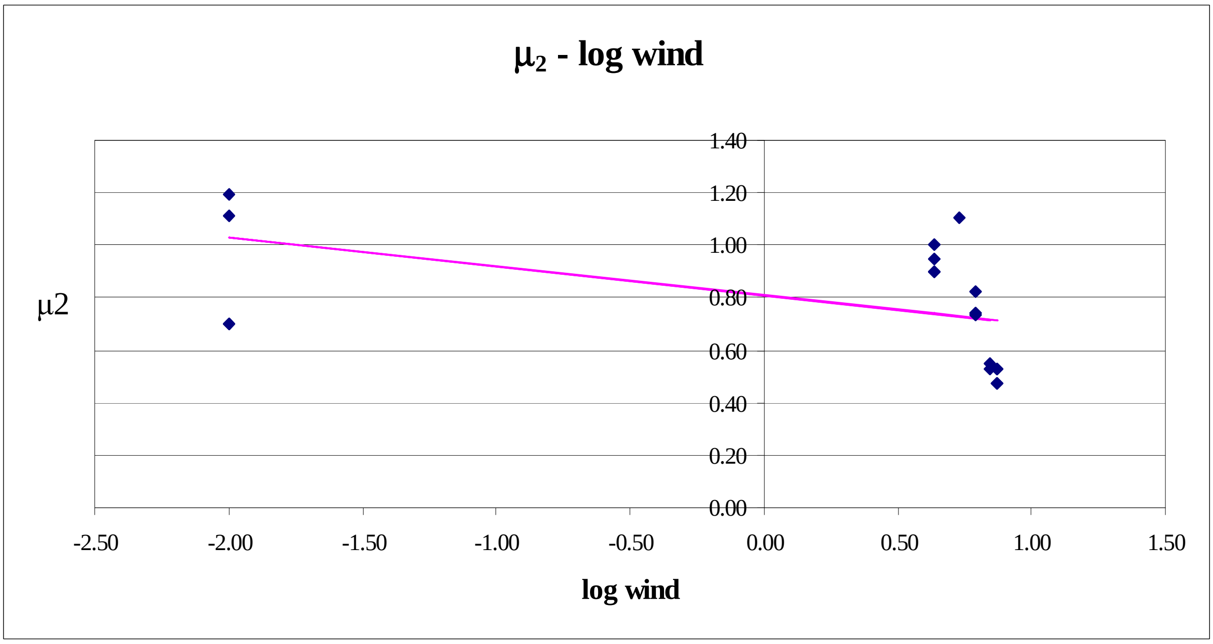
From the following figures the fit of the data for the different parameters can be seen.

Figure 4.6-20: Shape coefficient for the windward side of gabled roofs side II depending only on singular parameters (Swiss data)

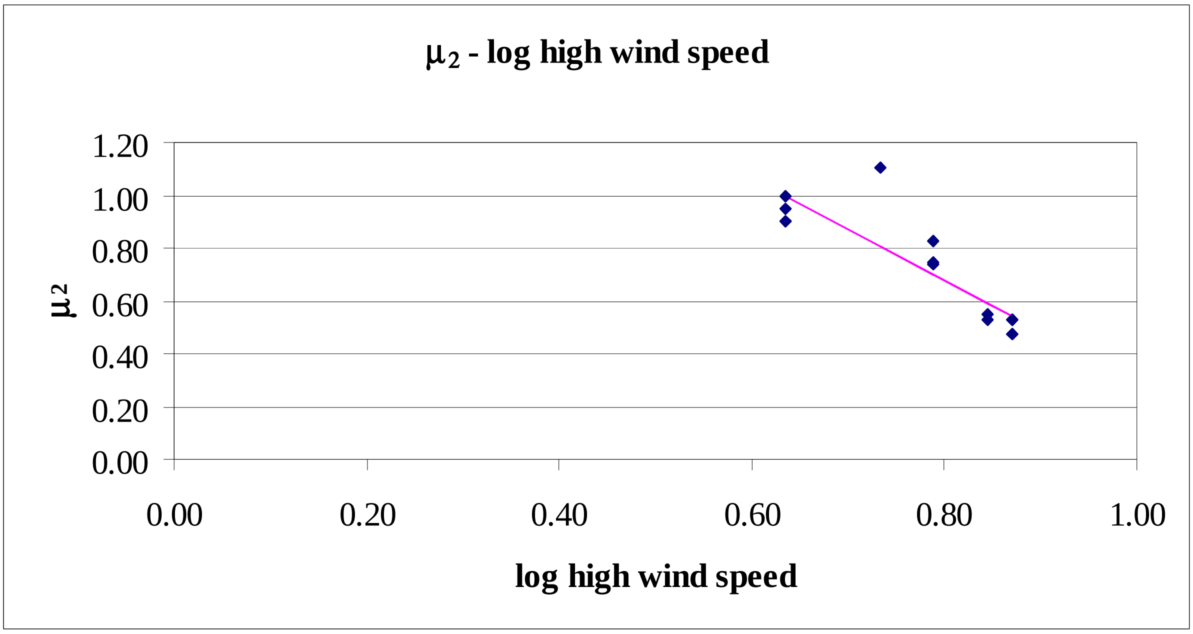
- Environmental temperature



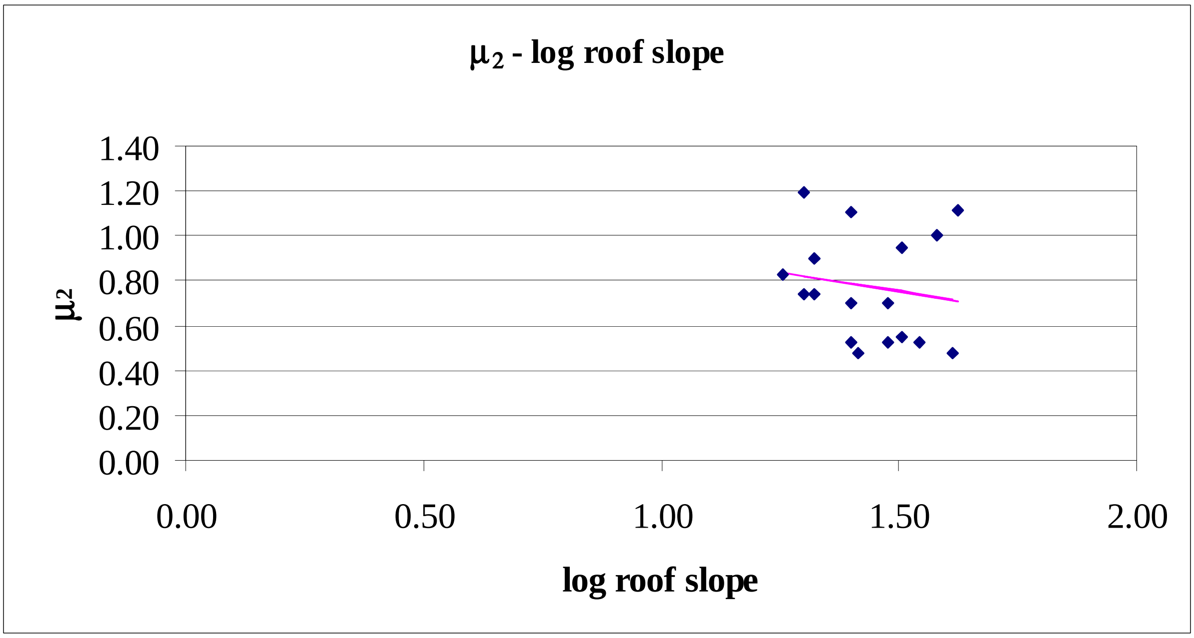
- Wind speed (all data)



- High wind speed (> 4 m/s)



- Roof slope



From this analysis the following conclusions can be drawn:

- As for the Swiss data on the leeward side of the roofs the parameter ‘environmental temperature’ has no correlation with the shape coefficient.
- For sites with low wind speeds far larger shape coefficients are determined than for sites with high wind speeds.
- The correlation coefficient for the roof slope of the Swiss data is only very small, for the Italy Apennine with $R^2 = 0.3$ small. The t-test values show a big probability for the Swiss data and an increased probability for the Italy Apennine data of an erroneous decision. It seems that the slope of the roof on the windward side does not have a dominant influence.
- High wind speed is strongly correlated to shape coefficients, the correlation coefficient of 0.77 as well as the t-test statistics support this fact for the Swiss data.
- Other comments are similar to the ones for the gabled roof side I (leeward).

4.6.4 Analysis for wind exposure classification

This section treats the influence of the wind exposure on the shape coefficients. Similar investigations have been performed by O'Rourke, Koch, Redfield (1983) and by Ellingwood (1985). The following figures show the mean and standard deviation for all data from the different types of roofs. As expected the shape coefficients for windy sites are (much) smaller than for sheltered sites as are the coefficients of the windward side. The standard deviation of the data becomes larger for more windy sites.

There are no significant differences between the climatic regions. However it must be mentioned that since the statistical basis excludes Switzerland it is rather limited.

Compared to the investigation by O'Rourke, Koch, Redfield (1983), the European mean values are rather higher, and the standard deviation smaller than the American values.

Figure 4.6-21: Mean and standard deviation of the roof shape coefficient for flat roofs for Swiss, Italian Dolomites, United Kingdom

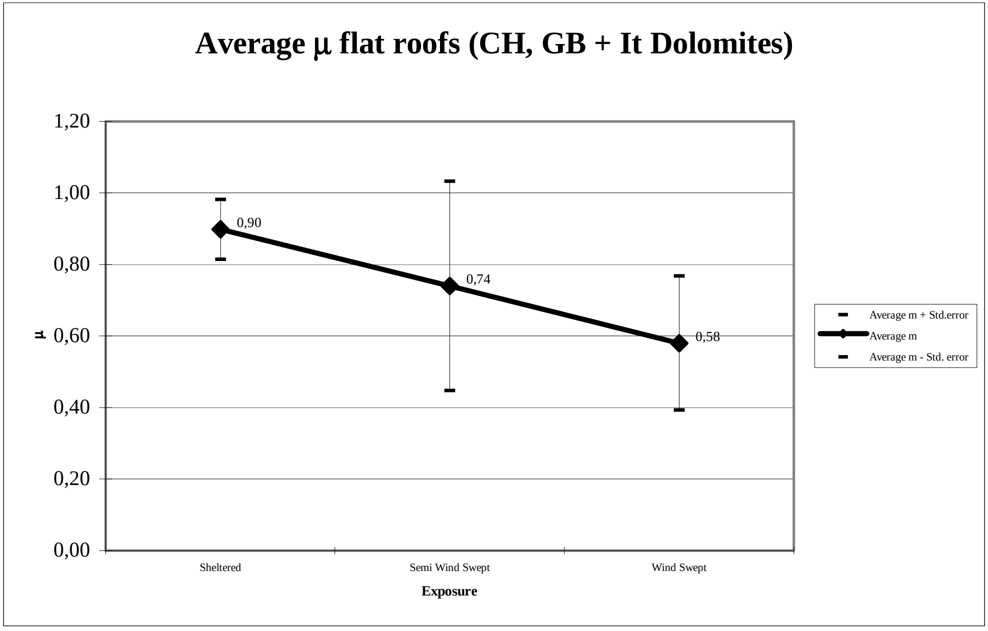


Figure 4.6-22: Mean and standard deviation of the roof shape coefficient for gabled roofs side I (lee) for Swiss, Italian Dolomites, United Kingdom and German sites

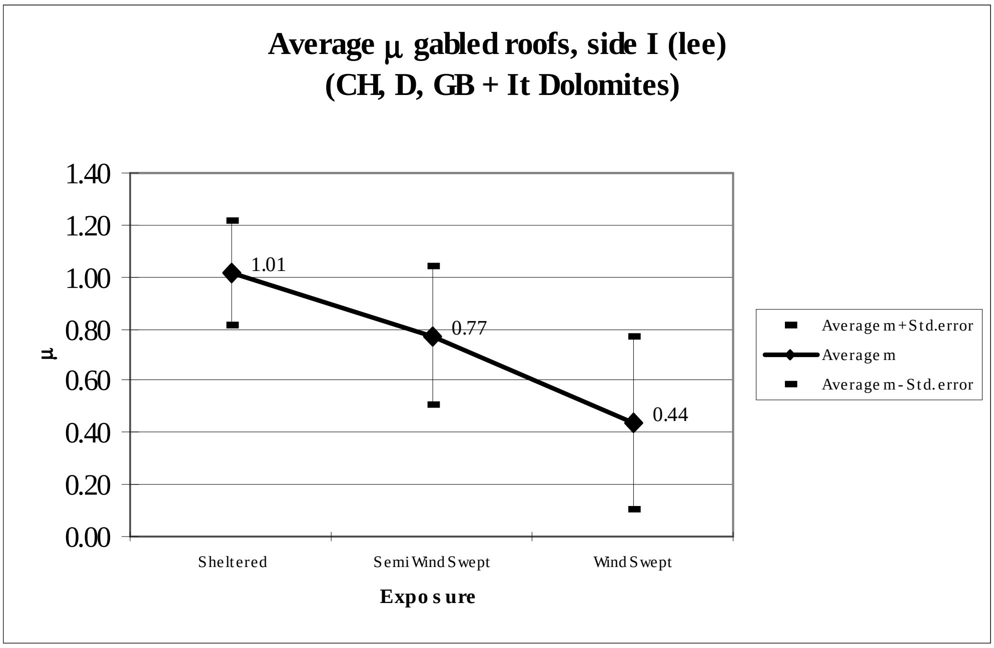
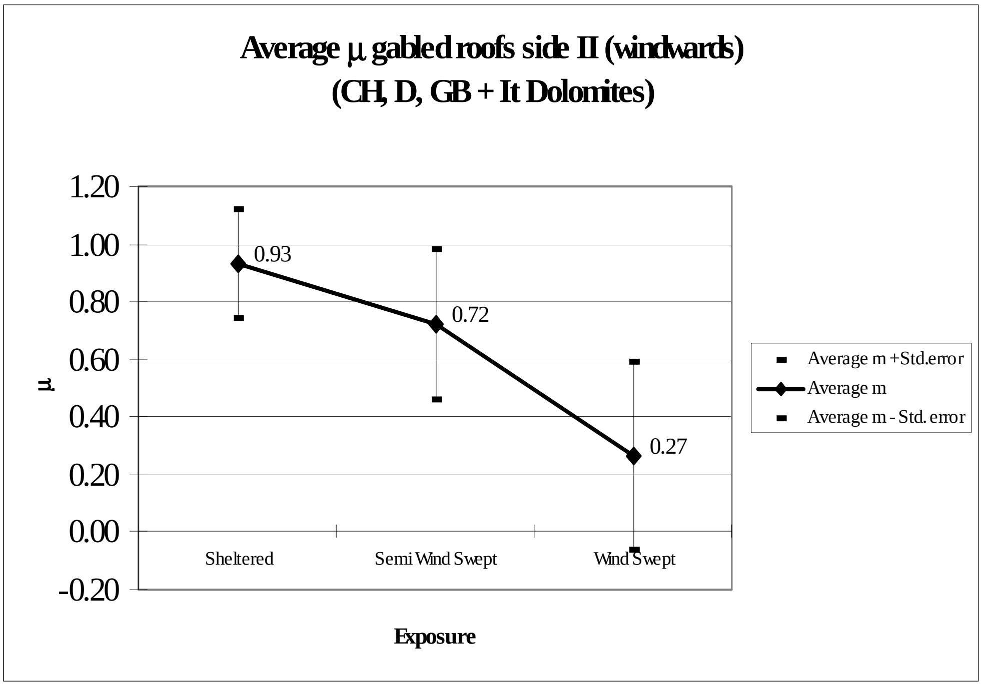


Figure 4.6-23: Mean and standard deviation of the roof shape coefficient for gabled roofs side II (windward) for Swiss, Italian Dolomites, United Kingdom and German sites



4.6.5 Analysis for roof slope classification

The roof shape coefficients are subdivided into the following categories:

- 0 – 7 °
- 8 – 22 °
- 23 – 37 °
- 38 – 52 °

From the following figures 4.6-24, 4.6-25 the shape coefficients for the different roofs dependent on the roof slope can be seen.

Figure 4.6-24: Mean and standard deviation of the roof shape coefficient for gabled roofs side I (lee) with different slopes for Swiss, Italian Apennine, Italian Dolomites, United Kingdom and German sites

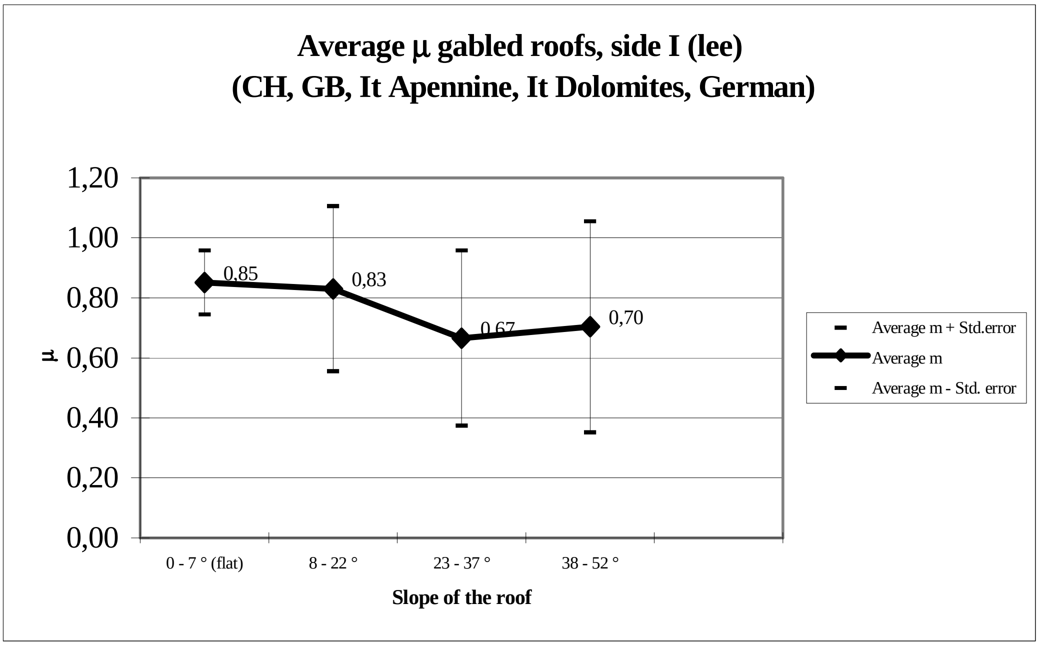
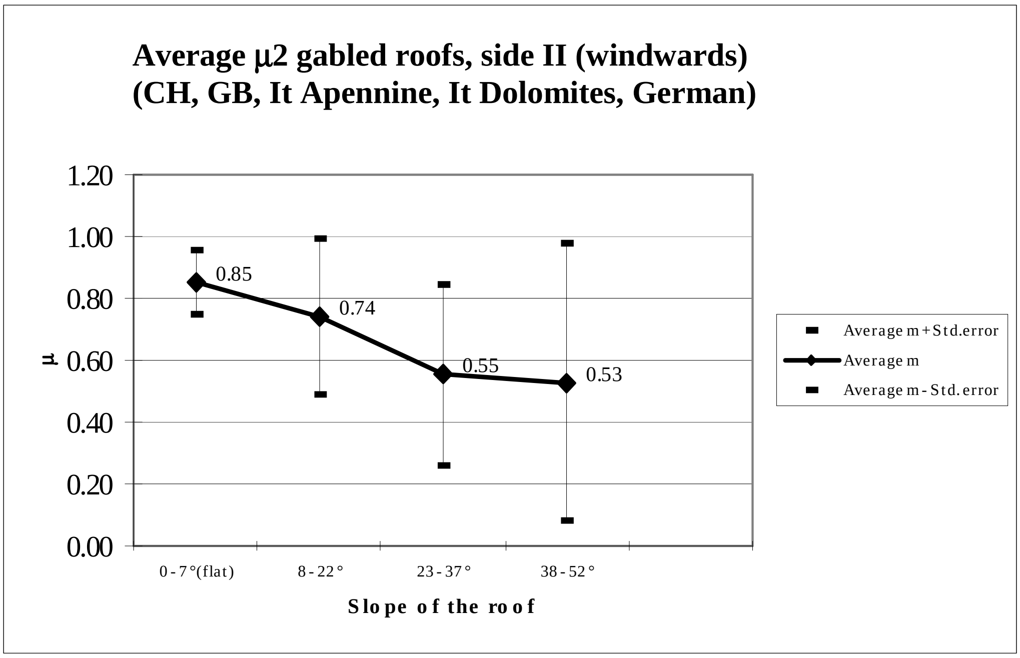


Figure 4.6-25: Mean and standard deviation of the roof shape coefficient for gabled roofs side II (windward) with different slopes for Swiss, Italian Apennine, Italian Dolomites, United Kingdom and German sites



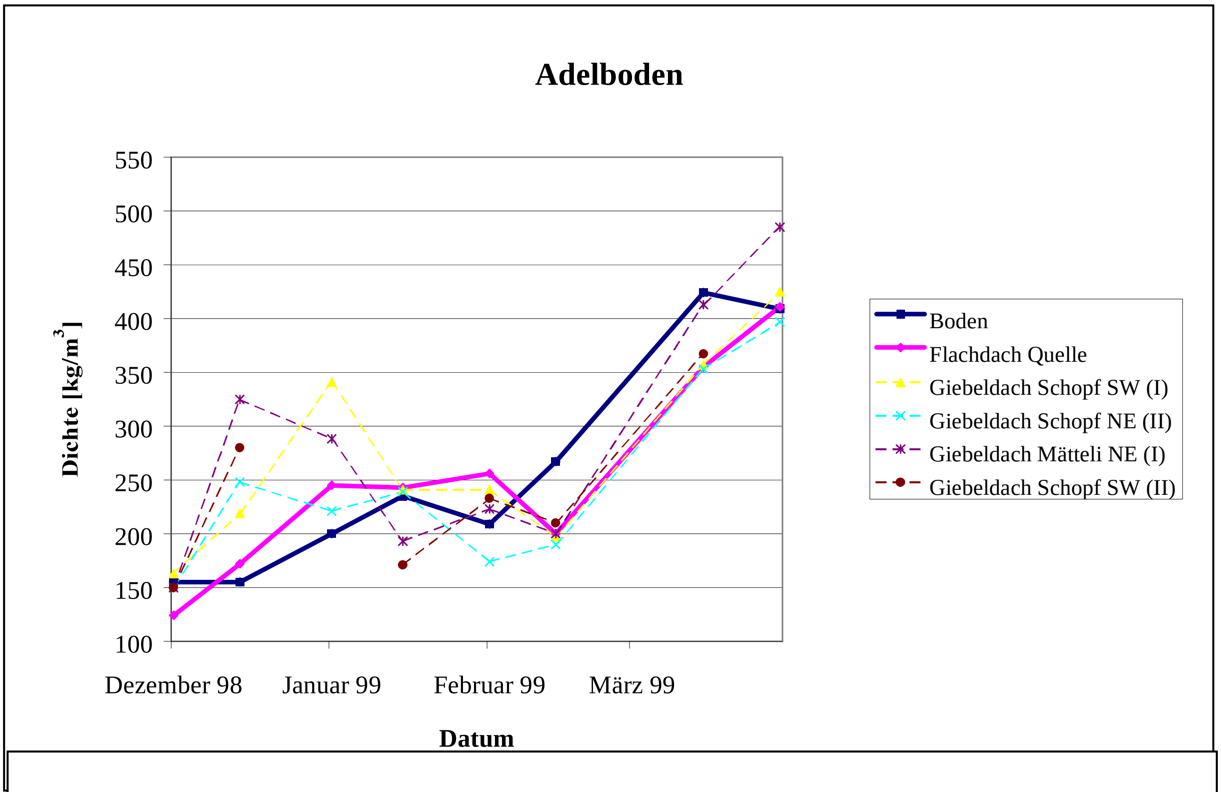
From these figures the following conclusions can be drawn:

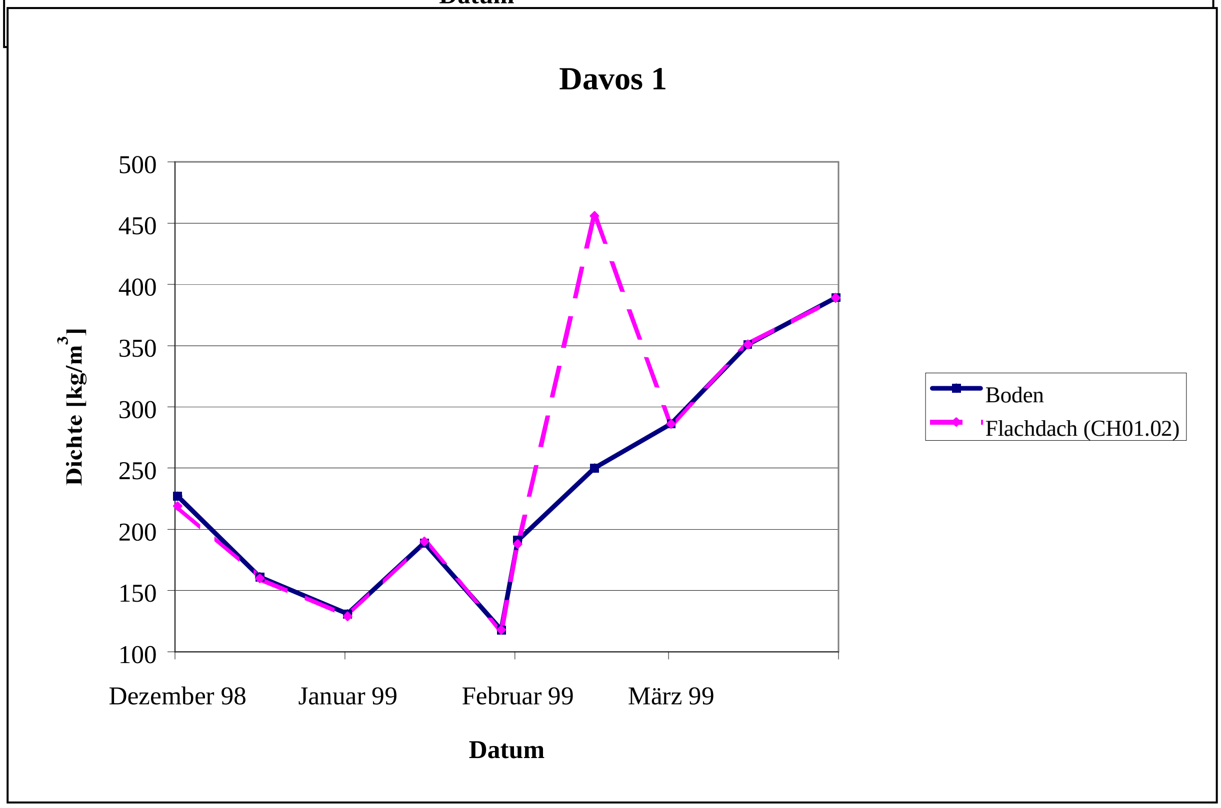
- A decrease of the roof shape coefficient with an increase in the slope of the roof is obvious, as expected.
- For the leeward side the shape coefficient is constant up to 30 °.
- The shape coefficients for the windward side are smaller than for the leeward side, as expected.
- For the leeward side no increase for 30 ° can be determined.

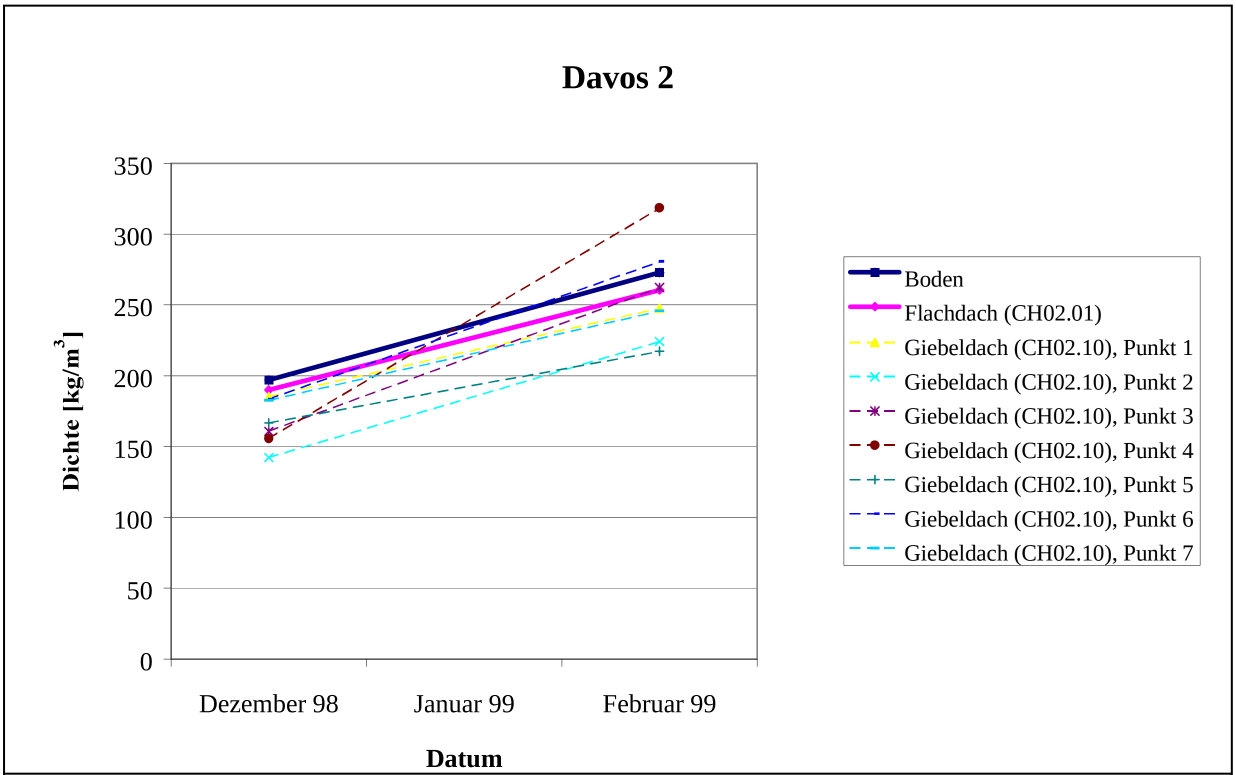
4.6.6 Density development during winter months

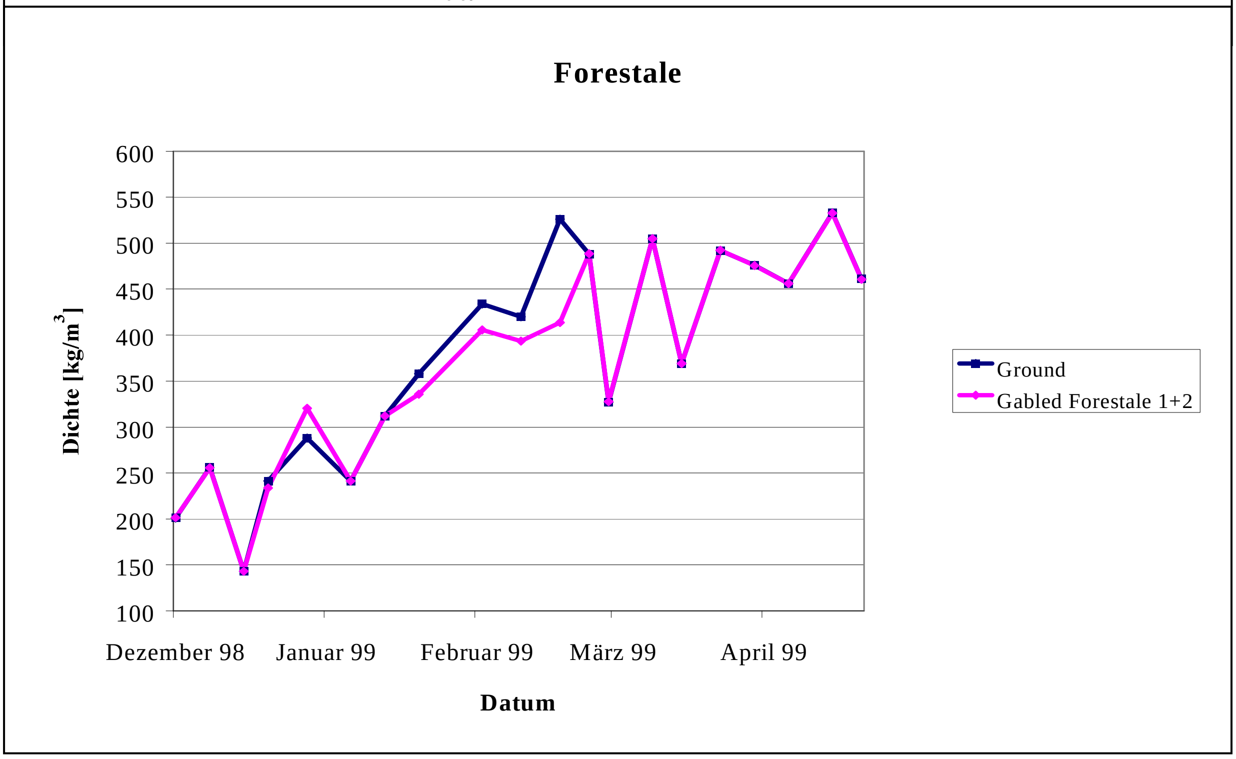
The figure 4.6-26 shows the development of the snow density on some sites measured during the 1998/99 winter .

Figure 4.6-26: Density development during winter 1998/99 in Adelboden (CH), Davos 1 and 2 (CH), Forestale (I)






Davos 2
Dichte [kg/m³]
350
300
250
200
150
100
50
0
Dezember 98
Januar 99
Februar 99
Datum
Boden
Flachdach (CH02.01)
Giebeldach (CH02.10), Punkt 1
Giebeldach (CH02.10), Punkt 2
Giebeldach (CH02.10), Punkt 3
Giebeldach (CH02.10), Punkt 4
Giebeldach (CH02.10), Punkt 5
Giebeldach (CH02.10), Punkt 6
Giebeldach (CH02.10), Punkt 7


Forestale
Dichte [kg/m³]
600
550
500
450
400
350
300
250
200
150
100
Dezember 98
Januar 99
Februar 99
März 99
April 99
Datum
Ground
Gabled Forestale 1+2

4.6.7 Influence of wind for drifting on gabled roofs

The influence of wind on the drifting of snow on gabled roofs is investigated, based on the data gathered in Switzerland during the 1998/99 winter. From these investigations the following conclusions can be drawn:

- The wind direction during snow storms influences directly the distribution of the snow on the gabled roof: the roof slope on the windward side has less snow than the leeward side, as the following summary shows:
  - 20 roofs with both roof slopes investigated
  - 5 roofs without wind during snow fall
  - 6 roofs with no difference between the shape coefficients of the two roof slopes
  - 8 roofs where the windward roof slope has the smaller shape coefficient and the leeward roof slope the larger shape coefficient, and 1 roof with reverse results to these.
- Two roof configurations were selected with the eaves directions at right angles: a one-storey office building in Bern-Liebefeld and a barn in Davos. The shape coefficients for the office building were equal due to little snow. The difference between the shape coefficients for the roof slopes of the barn perpendicular to main wind direction is slightly greater than the difference between the shape coefficients of the roof slopes in the main wind direction.
- For the results of the correlation analysis see section 4.6.2 and 4.6.3. From this analysis the higher velocity gusts (> 4 m/s) are shown to have a very important influence on the formation of the drift.

4.6.8 Conclusions for future snow measurements

The following aspects can be concluded from the roof snow load measurements during the 1998/99 winter:

- Satisfactory roof snow load measurements need time; measurements must be performed throughout several winters.
- For each climatic region at least 5 to 10 roofs of each type must be equipped and measured.
- A meteorological station or wind and temperature measurements in the vicinity of the roofs must be guaranteed.
- Close support for the observers of the measurements is necessary. Several visits to the sites, especially after the first snow falls, need to be planned. The observers should be as reliable as possible.

4.7 Wind Tunnel Tests

4.7.1 Introduction

The aim of the wind tunnel experiment is to determine the effect of wind on snow coverage on roofs (unbalanced roof loads) for a single snowfall. The programme is subdivided in two sub-tasks.

1st sub-task: Typical and simple roof shape tests dedicated to the calibration of the wind tunnel experiments.

The data obtained from the wind tunnel experiments were used to set-up influence relationships between experimental parameters.

2nd sub-task: Tests to collect data of reference building configurations (particular roof shapes, complex shapes, aerodynamic interaction) which might be of primary importance in the codes.

4.7.2 Experimental parameters

The tests were carried out in the climatic wind tunnel (figure 4.7-1) where airflow and temperature are controlled. Snow particles are created with snow guns similar to those used in ski resort. A description of the wind tunnel is given in annex A.13.1. A scale model of 1/10 was chosen for the test, its influence is discussed in 4.7.3.1, and two load cases are generated: uniform loading (simulation of a snow fall on the models without wind) and snowstorm with wind. In both load cases, experimental area covered by snow is about 4 m x 4 m.

Figure 4.7-1: duo-pitched roof 1/10 scale model in the wind tunnel

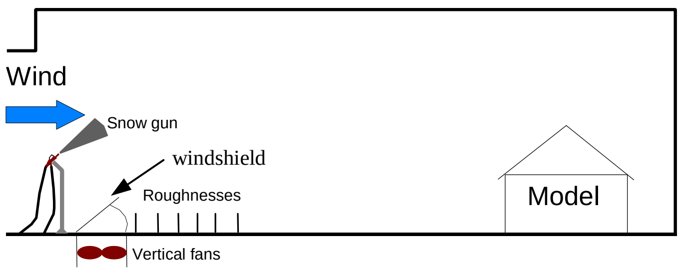
4.7.2.1 Uniform loading

Due to technical reasons, a snowfall without wind, which would have been required to simulate a uniform loading could not be performed in the facility. The snow making process actually needs a continuous heat exchange between the cold air of the wind tunnel and the water spray produced by the snow guns. Consequently, it is essential to keep a minimum air movement in the wind tunnel.

Various configurations were tested to simulate the uniform loading [ENV 1991-1, 1994] use of porous windshields in front of the building models, breaking of the wind flow pattern due to a vertical additional air flow, and mounting of the building model on a rotating structures.

Finally a compromise between technical difficulties and effectiveness was found. The cover of the vertical fan in the wind tunnel nozzle was used as a solid windshield while the model was kept steady during the experiments. The windshield horizontal angle was adjusted to create an averaged calm wind zone around the building model (see figure 4.7-2).

Figure 4.7-2: Side schematic representation of the test section for uniform loading configuration

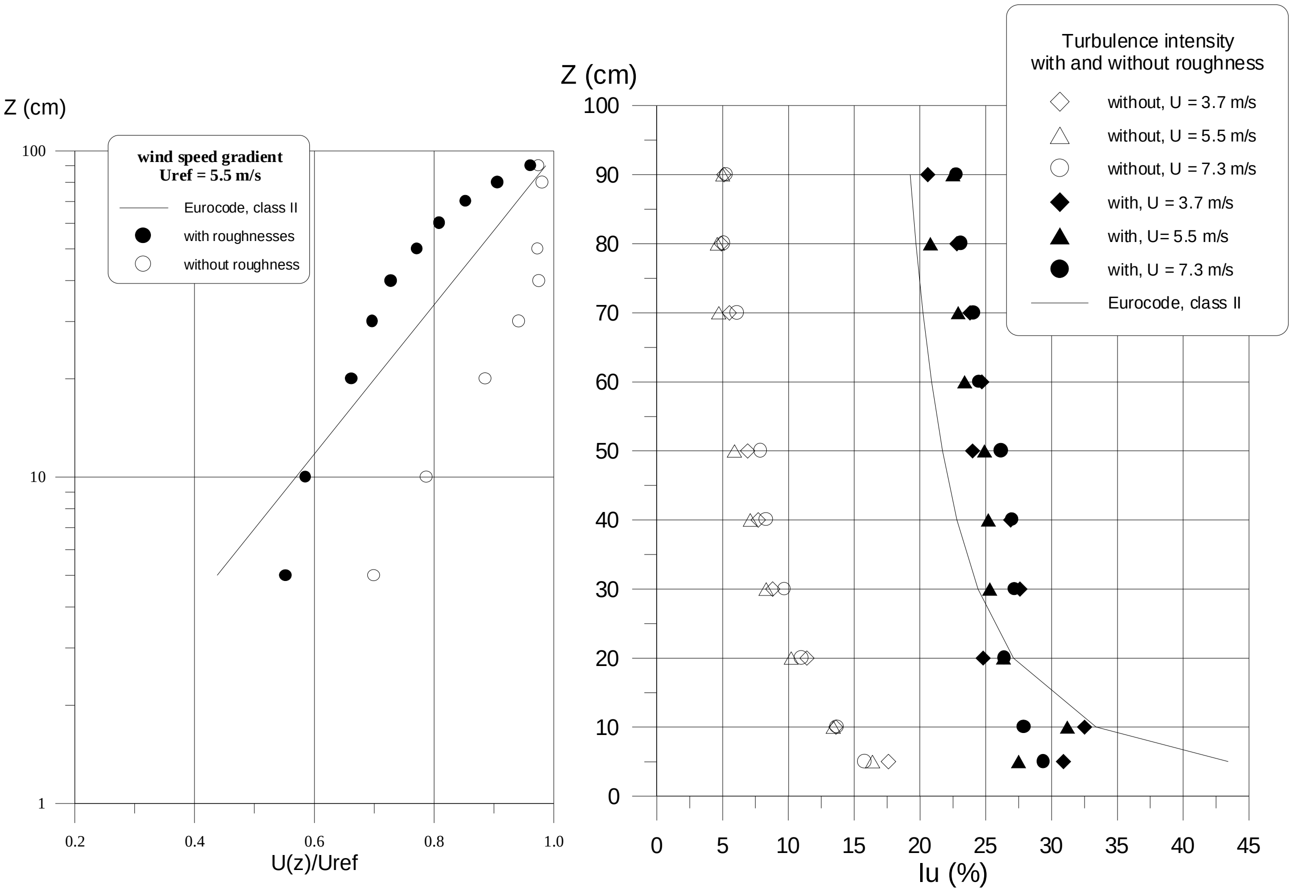


This simulation was not a truly no-wind situation and a residual wind speed lower than 1 m/s was observed at the model location in the opposite direction with respect to the usual wind direction in the wind tunnel.

4.7.2.2 Snow storm with wind

This snow event type was simulated at 4 m/s for all models. A realistic vertical wind speed gradient and turbulence rate was reproduced at the model scale (figure 4.7-3). This was done thanks to the investigation of the optimal location of roughnesses in the first part of the test section upwind the test models. The model location was set at about 16 m from the nozzle. The wind speed measurements were made by using the hot wire technique.

Figure 4.7-3: Wind speed gradient (left) and turbulence rate (right) initial state (without roughness) and with roughnesses



4.7.2.3 Type of snow

The snow type can be adjusted from "wet" to "dry". This characteristic of the snow produced in the wind tunnel is actually determined by the volumetric air/water ratio, injected in the snow gun for a particular wet bulb temperature.

The snow quality can be evaluated by a calorimeter, which was built especially for the measurements.

For the snow load experiments, the wind tunnel was operated by keeping the humidity regulation systems off and at rather low ambient temperature (-10 °C). Snow density is about 360 kg/m^3. The liquid water content measurements of the snow were made both on the floor near the building model and on the model itself.

The average liquid water content was 3.6 % for the uniform load experiments. This corresponds to an artificial "dry" snow. In section 4.6.6 actual measured densities over the winter period are shown.

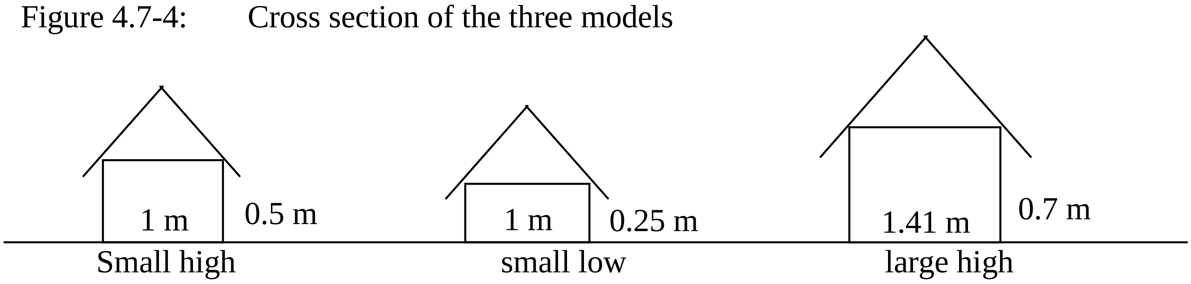
4.7.3 Influence of experimentation parameters

These tests were made with only one snow gun and for a duration of half an hour. So it is not possible to compare them with one-hour tests with two snow guns. The purpose is to analyse the influence of some experimental parameters such as geometrical aspect (effect of model scale and model height), experimentation duration and climatic condition in the wind tunnel (air temperature).

4.7.3.1 Influence of model size or height

Three wooden models of gabled roof with a pitch angle of 40° were used (figure 4.7-4). The first one is the model described in the calibration test, the second one is the same roof but for a single storey building and the third one is the first one with the lengths multiplied by 1.4, so that the surfaces areas double.

Figure 4.7-4: Cross section of the three models



As figures 4.7-5 and 4.7-6 show, dimensionless snow depth factors μ (average snow depth on the roof divided by average snow depth on the ground) for the three models, there is no significant difference between each model. Aerodynamic effects (difference between wind 4 m/s and 3 m/s) are more important.

Figure 4.7-5: depth factor with 3 m/s wind

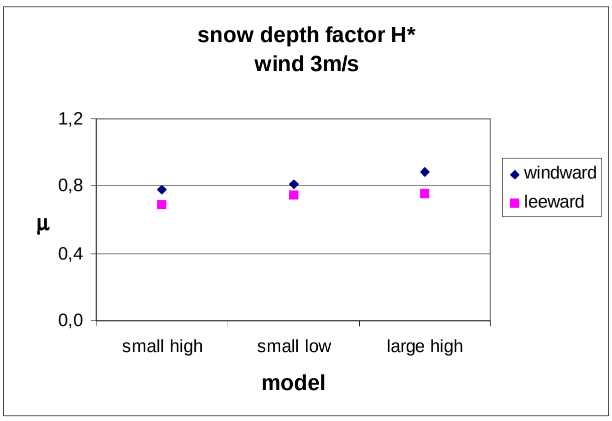
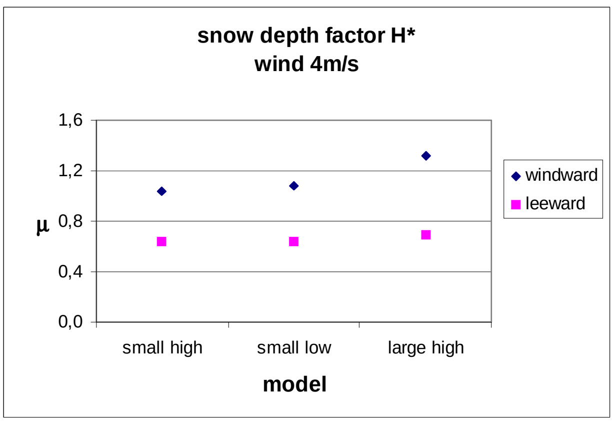


Figure 4.7-6: depth factor with 4 m/s wind



The first model, two storey building, scale 1/10, duo-pitched roof with pitch angle of 40° is used for the following influence tests.

4.7.3.2 Influence of test duration

Tests of snowstorm with wind were carried out with measurement of snow cover every 15 minutes. The results show, table 4.7-7, that the snow cover increases quite regularly with time. The ratio between the average depth of the windward and leeward snow cover decreases at the beginning of the test but is becoming constant after one hour (figure 4.7-8). It means that the loading reaches a stationary profile. For this reason the test duration was set at one hour.

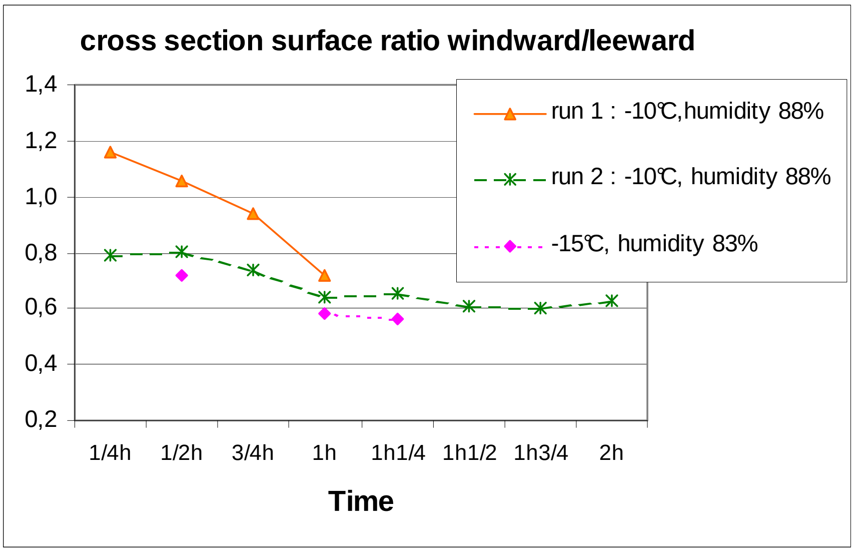
4.7.3.3 Influence of temperature conditions

Artificial snow can be created in the wind tunnel in cold air (negative temperature). Tests at –10 °C, humidity 88 % and –15 °C, humidity 83 % give close results. Snow density, measured at the end of each experiment, is higher at –15 °C, 390 kg/m^3, than at –10 °C, 370 kg/m^3 (table 4.7-7). Thus a test temperature of –10 °C was chosen to facilitate the experiments in the wind tunnel and produce the lower density for the artificial snow.

Table 4.7-7: Results of duration tests for two temperature conditions

Test conditions	Cross section surface ratio windward/leeward								Density on the ground Kg/m^3		Density on the roof Kg/m^3	
	Duration (h)											
	1/4h	1/2h	3/4h	1h	1h1/4	1h1/2	1h3/4	2h	windward	leeward	windward	leeward
-10°C,88%	1.16	1.06	0.94	0.72					360	374	400	334
-10°C,88%	0.79	0.80	0.74	0.64	0.65	0.61	0.60	0.63	371	366	400	310
-15°C,83%		0.72		0.59	0.56				390	390	418	352

Figure 4.7-8: Variation with duration test of snow cross section surface ratio windward/leeward on the roof



4.7.3.4 Conclusion about influence tests

Snowstorm simulations with a model scale of 1/10 and a test duration of 1h are relevant. The air temperature in the wind tunnel, about –10 °C, provides artificial "dry" snow (liquid water content less than 4 % in volume) with a density of 360 kg/m^3.

Wind tunnel test duration of 1 h represents a long real snowstorm event. The relation between wind tunnel test duration and real duration depends on wind velocity and snow particle characteristics. According to the similarity laws detailed in annex A.13.1 the extreme cases of unbalanced snow loads were simulated.

4.7.4 Snow load measurements

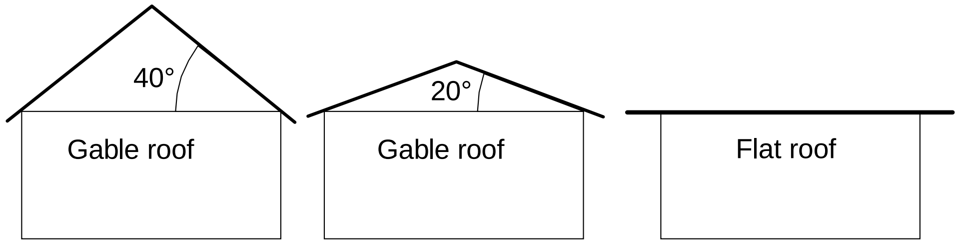
4.7.4.1 1st sub-task: snow loads on simple roof shape

In order to initiate the wind tunnel 1st sub-task, the following experimental modelling options are used (table 4.7-9): Double pitched roof, 20 ° and 40 ° slope roofs and 0 ° or flat roof (figure 4.7-10), main roof direction perpendicular to the wind direction, two wind speeds: <1 m/s (for uniform loading) and 4 m/s.

Table 4.7-9: characteristic of models for 1st sub-task

Model scale	1/10
Geometry of the building	Model of 2 storey buildings (g. floor + 1, i.e. ~ 0.5 m high), ground surface = 1.0 x 1.2 m.
Roof shape	Duo-pitched roof (pitch angle about 20 ° and 40 °) and flat roof. Roof with eaves length of 7.5 cm (0.75 m at full scale)
Roof roughness	Roof surface roughness due to tiles is modelled by thin plywood plates of about 3 mm (3 cm at full scale)
Building environment	Terrain category II (turbulence intensity ~ 20 %)
Simulation of single snow events	Uniform loading and snow storm.

Figure 4.7-10: The test models for 1st sub-task



The snow depth was measured on both sides of the roofs (windward and leeward side) by using a piece of cardboard on which to draw the snow layer profile (figure 4.7-11). The evolution of the snow depth with respect to the distance from the rooftop was evaluated from the drawing and plotted (figure 4.7-12). With the associated spreadsheet files it is possible to calculate the surface of the snow layer cross section in order to provide the average snow layer thickness on each roof side. The experimental snow layer profiles are given in annex A.13.2.

Figure 4.7-11: Snow depth measurements

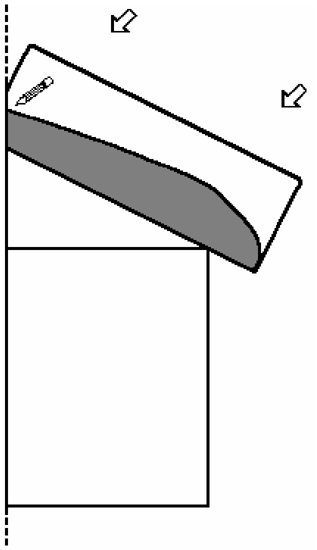
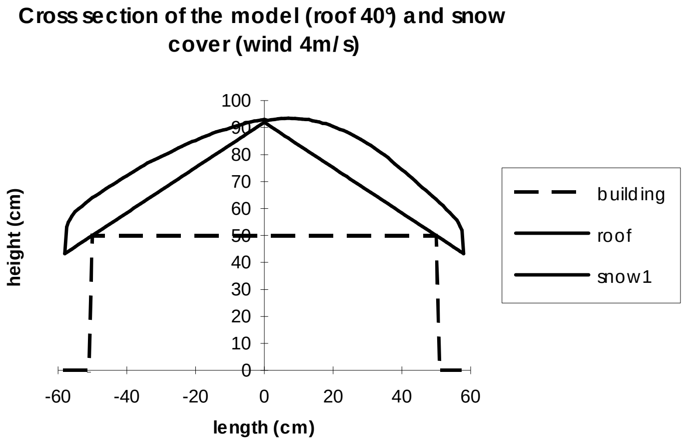


Figure 4.7-12: Example of snow depth plot (wind from the left-hand side)



As already mentioned the low speed experiments (<1 m/s) can not be considered as truly a no-wind situation on the gable roofs. Moreover, due to a large-scale eddy, the residual airflow at the model location is in the opposite direction with respect to the usual wind direction. Hence, it is sensible to take into account this local wind situation for the measurements.

At the end of the low speed experiments (<1 m/s) the thickness of the snow layer on the ground around the model is regular enough to provide a meaningful measurements using the same method as for the roof. Actually the snow layer thickness 1 m upwind the model and 1 m downwind the model are measured. These 2 values are averaged to assess the snow depth on the ground, which is about 15.5 cm.

At the end of the 4 m/s experiments, it did not seem relevant to measure the snow depth on the ground around the models, due to the irregular surface layer upwind and downwind the model. To assess the ground snow load in the windy conditions used for the experiments, the model is taken out the wind tunnel and an additional experiment was performed to measure the snow layer thickness at the model location: 10.5 cm.

Measurements of the snow density are carried out for all experimental conditions. Density variations were observed depending on the wind speed or on the location: ground, windward or leeward roof side (annex A.13.2).

The table 4.7-13 summarises the average snow depth measurements, l_{roof}, made during the experiments. The snow layer thickness on the roofs was divided by the measurements made on the ground to give a dimensionless "depth factor": $\boldsymbol{\mu_l}=l_{roof}/l_{ground}$.

Table 4.7-13: average snow depth on roof

Identification	Roof tilt angle	Wind velocity	l ($\boldsymbol{\mu_l}$) windw. Side	l ($\boldsymbol{\mu_l}$) leew. side
T20V0	20 °	< 1 m/s	17.4 cm (**0.89**)	21.0 cm (**1.08**)
T20V4	20 °	4 m/s	7.3 cm (**0.70**)	12.8 cm (**1.22**)
T40V0	40 °	< 1 m/s	17.1 cm (**0.88**)	22.0 cm (**1.13**)
T40V4	40 °	4 m/s	10.5 cm (**1.00**)	13.0 cm (**1.24**)
T0V0	0 °	< 1 m/s	15.3 cm (**0.99**)	15.5 cm (**1.00**)
T0V4	0 °	4 m/s	8.5 cm (**0.81**)	14.0 cm (**1.33**)

The table 4.7-14 summarises the snow loads calculated by taking into account the actual density of the snow layer measured locally during the experiments. The snow load on the roof, w_{roof}, was divided by the snow load on the ground to give the dimensionless "load factor": $\boldsymbol{\mu_w}=w_{roof}/w_{ground}$.

Compared with the "depth factors", the "load factors" are not modified in case of low wind speed. This is obviously due to the uniformity of the snow density on the roof and on the ground in that steady climatic situation.

In the case of 4 m/s wind, the snow density on the windward side is higher than the density on the ground. This is probably due to the packing of the snow by the wind. In the same wind condition, the snow density on the leeward side is lower than the density on the ground. This is probably due to the way the snow is packed on this roof side by local low speed airflow and eddies.

Although the uneven windward/leeward snow drifting is induced by highest wind speed, the snow density measurements tend to compensate the apparent unbalanced snow loads.

On the gabled roofs, the difference of "load factors" between windward and leeward side is actually lower than the difference of "depth factors" measured at the same locations.

Table 4.7-14: average snow loads on roof

Identification	Roof tilt angle	Wind velocity	w (**μ_w**) windw. side	w (**μ_w**) leew. side
T20V0	20 °	< 1m/s	63.5kg/m^2 (**0.89**)	77.1kg/m^2 (**1.09**)
T20V4	20 °	4m/s	28.0kg/m^2 (**0.74**)	42.1kg/m^2 (**1.11**)
T40V0	40 °	< 1m/s	62.4kg/m^2 (**0.88**)	80.3kg/m^2 (**1.13**)
T40V4	40 °	4m/s	40.3kg/m^2 (**1.06**)	42.8kg/m^2 (**1.13**)
T0V0	0 °	< 1m/s	62.3kg/m^2 (**0.99**)	63.2kg/m^2 (**1.00**)
T0V4	0 °	4m/s	30.2kg/m^2 (**0.80**)	50.7kg/m^2 (**1.33**)

Maximum snow depth location analysis is given in table 4.7-15. The distance of the maximum snow depth, D (H_{max}), is the horizontal distance from the windward edge of roof side (eaves edge for windward side and ridge for leeward side). Horizontal length of the roof, L_{roof}, is used to calculate the relative position of the maximum snow depth, D (H_{max})/L. Snow depth on the ground are used to calculate dimensionless snow depth factor $\mu_{H\ max}$.

Table 4.7-15: Results for maximum snow depth

Identification	H_{max} (cm)	D(H_{max}) (cm)	L_{roof} (cm)	D(H_{max})/L	l (cm)	$\boldsymbol{\mu_l}$	$\mu_{H\ max}$
T20V0 windward side	19.3	30	57.5	0.52	17.4	0.89	1.25
T20V0 leeward side	22.8	35	57.5	0.61	21	1.08	1.47
T20V4 windward side	8.7	21.5	57.5	0.37	7.3	0.70	0.83
T20V4 leeward side	17.4	44.5	57.5	0.77	12.8	1.22	1.66
T40V0 windward side	19	23.5	57.5	0.41	17.1	0.88	1.23
T40V0 leeward side	25	32	57.5	0.56	22	1.13	1.61
T40V4 windward side	14	11	57.5	0.19	10.5	1.00	1.33
T40V4 leeward side	17.4	31	57.5	0.54	13	1.24	1.66
T0V0	17	66	115	0.57	15.4	0.99	1.10
T0V4	14.7	86	115	0.75	11.1	1.06	1.40
T0V4 bis (length multiplied by 2)	15.9	152	230	0.66	11.8	1.13	1.51

A discussion of these results is given in annex A.13.3. Model scale experiments are achieved to work out the snow deposition on a basic gable roof model. The location and magnitude of snow load on the building models are identified.

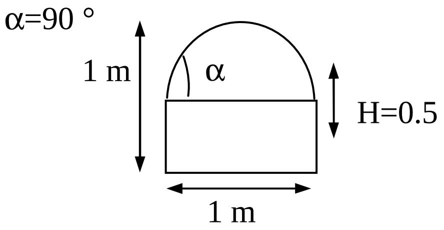
4.7.4.2 2nd sub-task: snow load on typical roofs

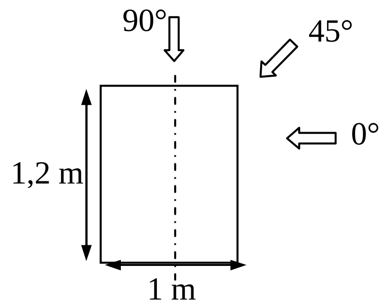
In order to enlarge the number of roof shape cases, various roof shapes are added to the duo-pitched roof: two-level flat roof, round roof and multi-pitch roof. The geometry of the models and wind direction are described in figure 4.7-16. The two-level flat roof model has five different step configurations (length or high of the step). The round roof model has the same lower part as duo-pitched roof. One of the multi-pitch roofs is symmetrical with a pitch angle of 30 °, the other is non-symmetrical with pitch angles of 60 ° and 30 °.

These roofs are tested in a snowstorm with a wind velocity of 4 m/s.

Figure 4.7-16: roof shapes and wind directions for 2nd sub-task

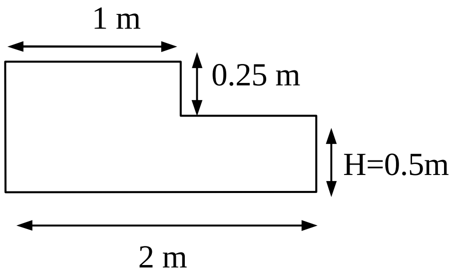
Round roof, 3 wind directions (RR)

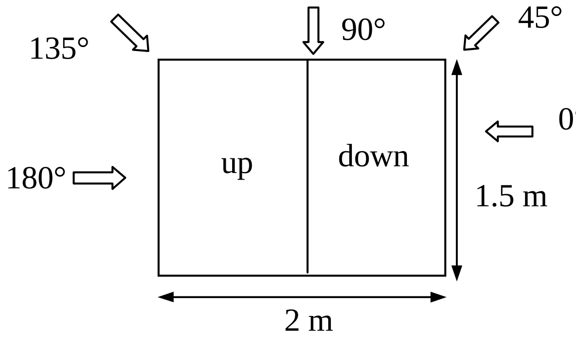




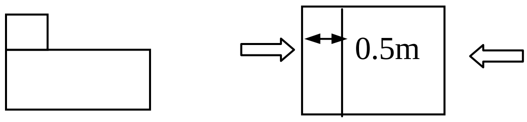
Two-level flat roof: various shape and wind direction (TL)

Shape n°1 (S1), 5 wind directions

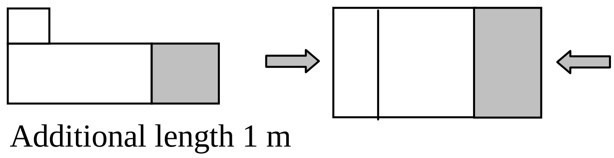




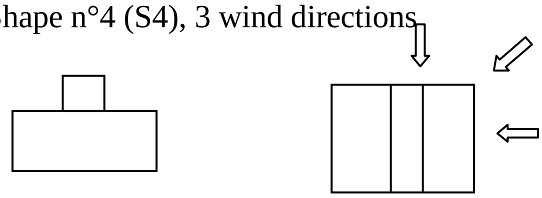
Shape n°2 (S2), 2 wind directions



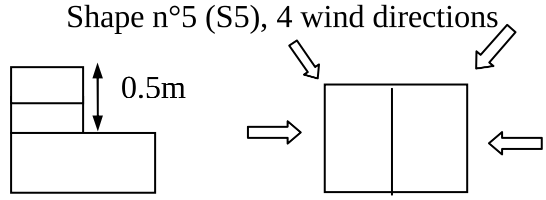
Shape n°3 (S3), 2 wind directions



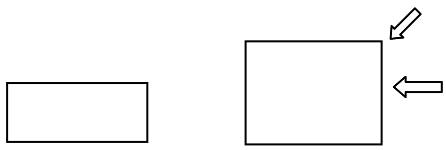
Shape n°4 (S4), 3 wind directions



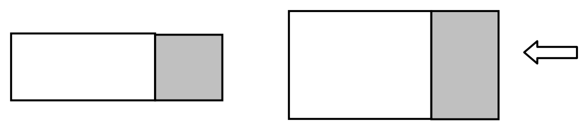
Shape n°5 (S5), 4 wind directions



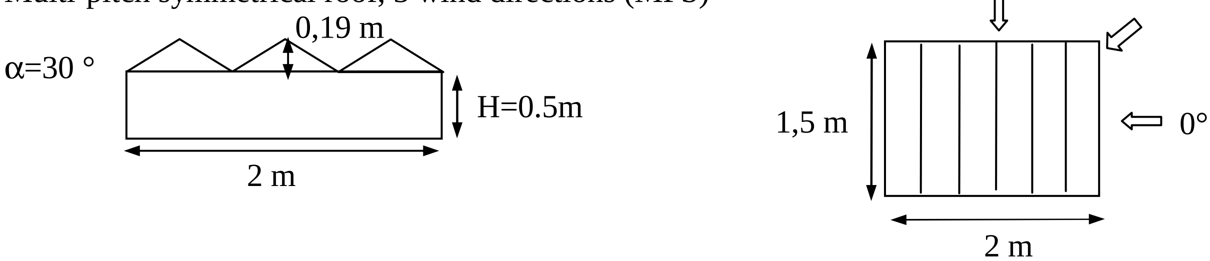
Shape n°7 (S7), 2 wind directions (reference flat roof)



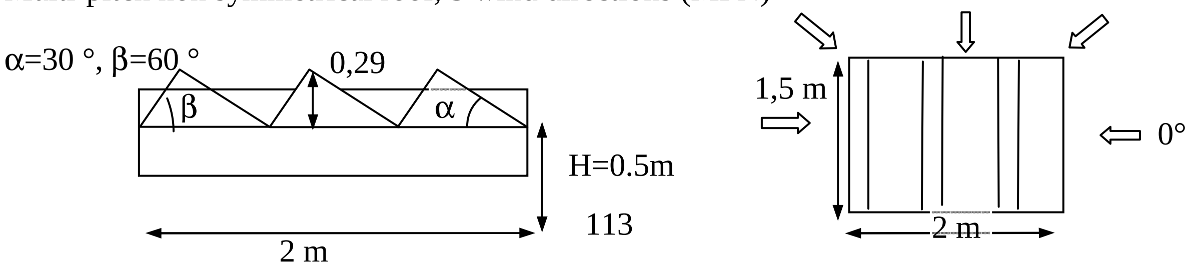
Shape n°8 (S8), 1 wind direction
(n°7with additional length)



Multi-pitch symmetrical roof, 3 wind directions (MPS)



Multi-pitch non symmetrical roof, 5 wind directions (MPN)



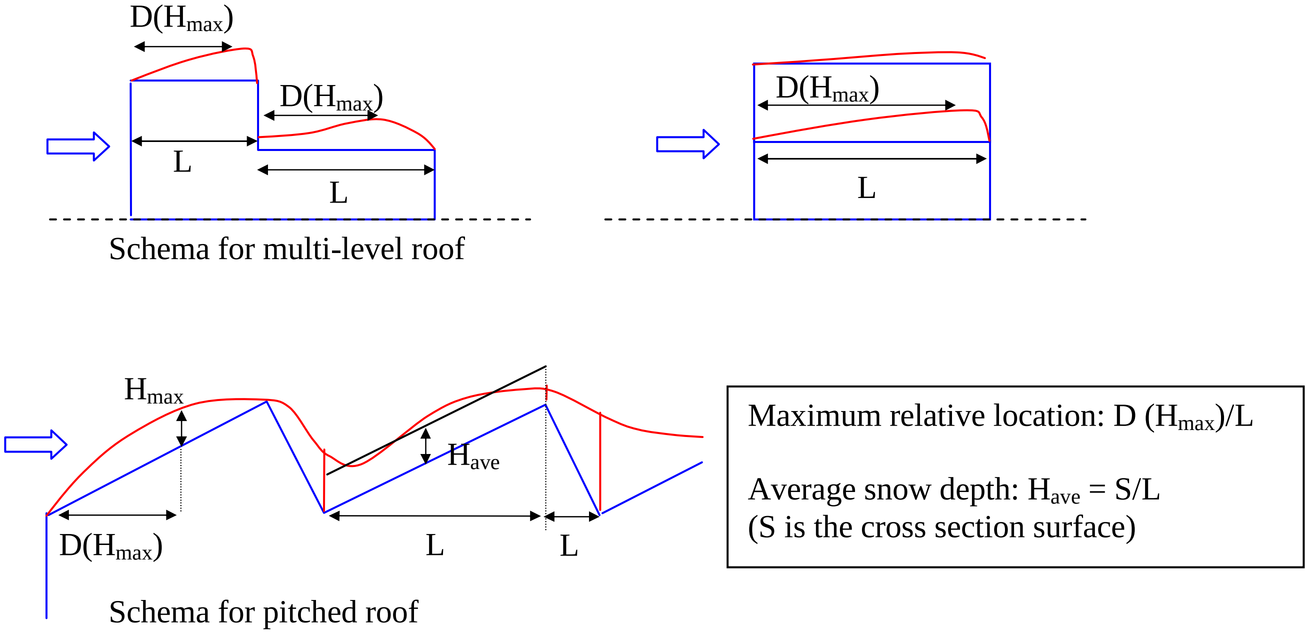
Snow profiles are drawn at the middle of each roof part on a piece of cardboard and digitised. Snow profiles characteristics, surface, maximum depth, position of maximum depth are calculated using AutoCAD. Profiles are taken on the ground without the model to define a reference snow depth on the ground H_{ref}, which is about 12 cm. Location of the profiles, are given in annex A.13.4.

Snow density is measured using a PVC cylinder with a diameter of 80 mm and internal volume of $1.23 * 10^{-3}$ m^3. This cylinder is pushed horizontally in the snow cover, snow is cut at each end of the cylinder and the cylinder is weighed. Measurements are made on the ground, windward and leeward of the model, and on the roof if there is enough snow.

Presentation of the results

For each case the average snow depth H_{ave} calculated by dividing snow profile surface by roof length L, the maximum snow depth H_{max} and its distance from the windward edge D (H_{max}) are given (figure 4.7-17). Also the relative position of the maximum snow depth from windward edge is calculated by dividing the distance D (H_{max}) by the roof length L.

Figure 4.7-17: definition for length and snow depth



Only dimensionless snow depth factors are calculated and not dimensionless snow load factors because variations of snow density are not significant (annex A.13.2). Average snow depth factor $\mu_{H\ ave}$ is equal to H_{ave}/H_{ref} and maximum snow depth factor $\mu_{H\ max}$ is equal to $H_{max}/H_{ref.}$ The table 4.7-20 summarises the results for two-level and table 4.7-21 for multi-pitch roofs (comprehensive results are given in annex A.13.4). Profiles are given in annex A.13.4. Each profile name is made up of roof name, wind direction, profile name and looks like TLS5D2P3, MPSD1P6 or MPND2V2…. Roof shape name are TLS1 to TLS8 (**T**wo-**L**evel roof **S**hape n°**1**,n°**2**…. n°**8)**, RR (**R**ound **R**oof), MPS (**M**ulti-**P**itch **S**ymmetrical roof) and MPN (**M**ulti-**P**itch **N**on symmetrical roof). Wind directions are noted D1, D2, D3, D4, D5 and a letter and a figure P1, P2 … or V1, V2 name each profile (figure 4.7-18 Part 1 and part 2 and annex A.13.4).

Figure 4. 7-18 (part 1): Profiles name and location

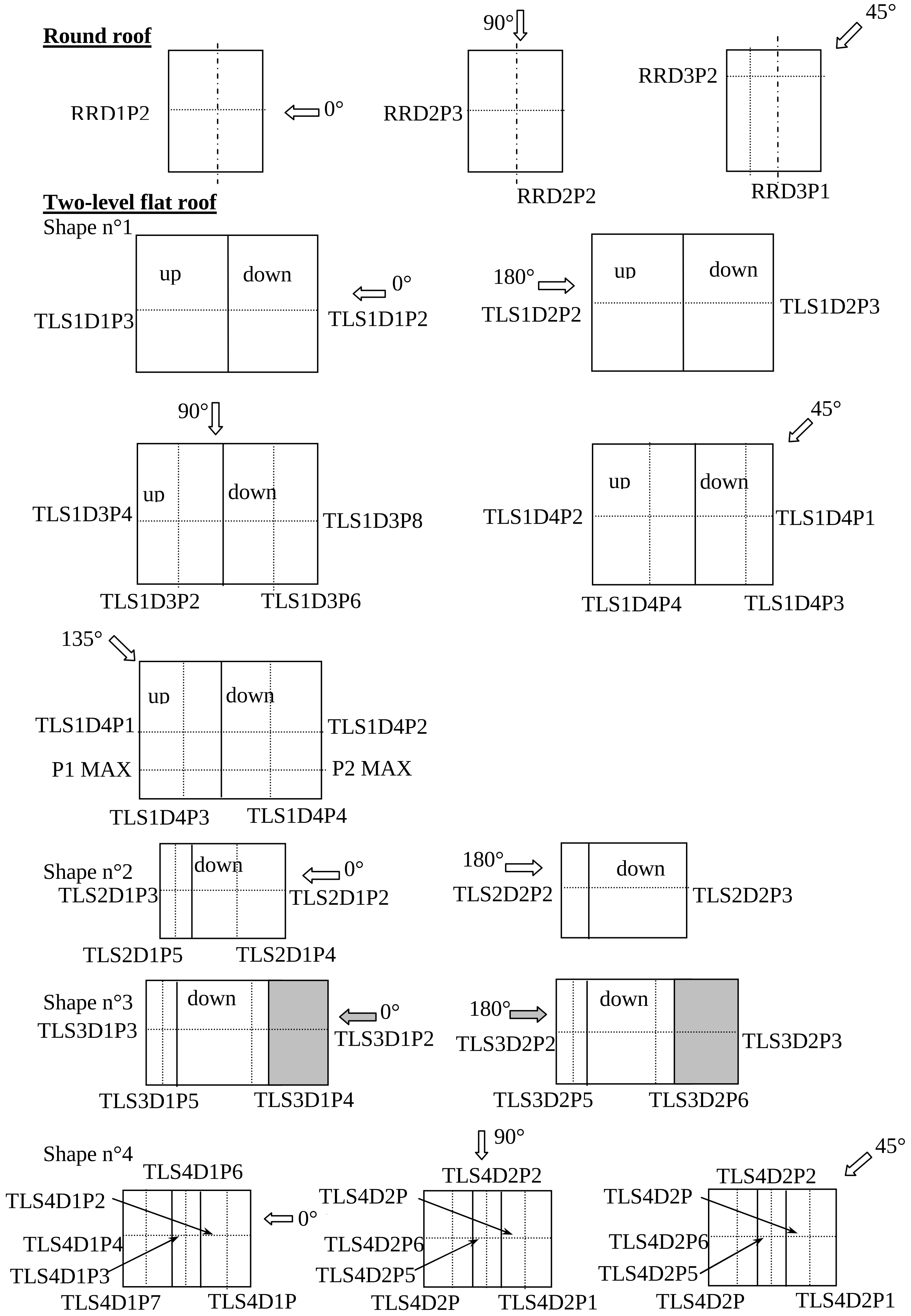
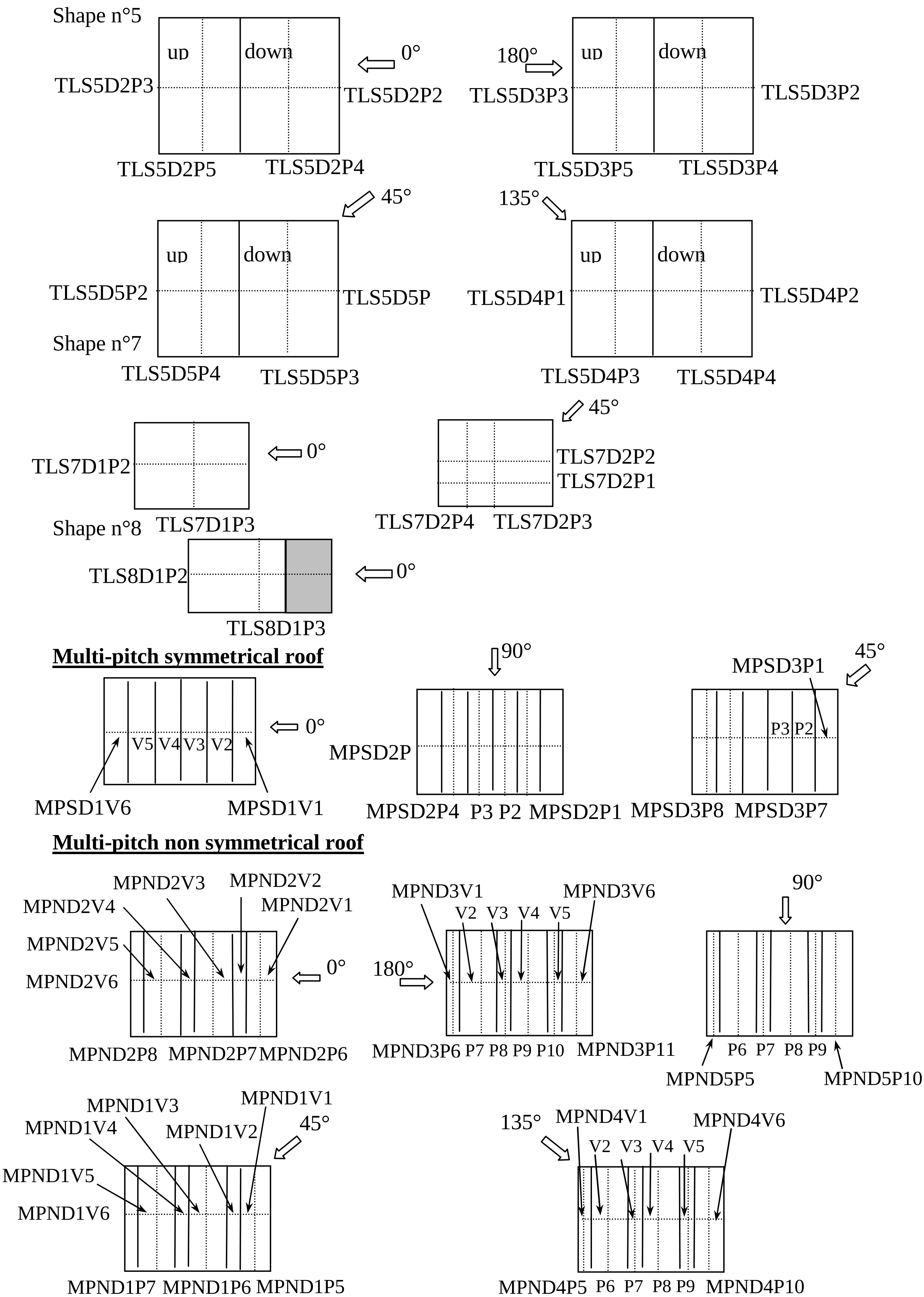


Figure 4.7-18 (part 2): Profile name and location



In the tables 4.7-20 and 4.7-21, grey lines indicate that it is a "transversal" profile as opposed to a "longitudinal" profile as shown in figure 4.7-19.

Figure 4.7-19: Definition of transversal and longitudinal profiles

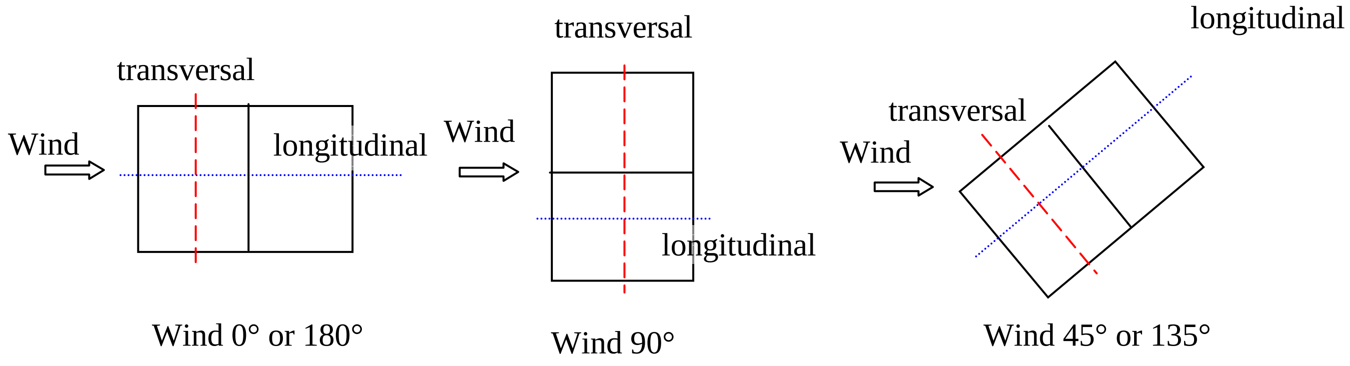


Table 4.7-20: Results for two-level roofs

Name	Wind direction	Hmax (cm)	D(Hmax) (cm)	Lroof (cm)	D(Hmax)/L	H ave surface/L	μ_H ave Have/Href	μ_H max Hmax/Href
TLS1D1P2	0 °	25	100	100	1,00	9	0,73	2,08
TLS1D1P3		10	94	100	0,94	6	0,48	0,83
TLS1D2P2	180 °	5	91	100	0,91	3	0,26	0,42
TLS1D2P3		17	32	100	0,32	13	1,08	1,41
TLS1D3P6	90 °	9	124	150	0,83	4	0,37	0,75
TLS1D3P2		7	143	150	0,95	4	0,35	0,58
TLS1D4P3	45 °	10	57	150	0,38	7	0,56	0,83
TLS1D4P4		11	127	150	0,85	5	0,39	0,91
TLS1D4P2		7	14	100	0,14	4	0,31	0,58
TLS1D4P1		29	100	100	1,00	11	0,90	2,41
TLS1D5P4	135 °	20	120	150	0,80	12	0,99	1,66
TLS1D5P3		16	125	150	0,83	9	0,76	1,33
TLS1D5P1		9	31	100	0,31	8	0,66	0,75
TLS1D5P1MAX		15	48	100	0,48	11	0,91	1,25
TLS1D5P2		23	8	100	0,08	14	1,18	1,91
TLS1D5P2MAX		27	3	100	0,03	18	1,52	2,24
TLS2D1P2	0 °	28	150	150	1,00	14	1,16	2,32
TLS2D1P3		9	46	50	0,92	7	0,55	0,75
TLS2D2P3	180 °	20	95	150	0,63	16	1,30	1,66
TLS2D2P2		4	45	50	0,90	3	0,23	0,33
TLS3D1P2	0 °	26	250	250	1,00	11	0,93	2,16
TLS3D1P3		7	49	50	0,98	4	0,37	0,58
TLS3D2P2	180 °	2	11	50	0,22	2	0,15	0,17
TLS3D2P3		12	84	250	0,34	8	0,69	1,00
TLS4D1P2	0 °	23	75	75	1,00	8	0,67	1,91
TLS4D1P3		4	48	50	0,96	2	0,18	0,33
TLS4D1P4		12	57	75	0,76	10	0,83	1,00
TLS4D2P3	90 °	8	122	150	0,81	4	0,35	0,66
TLS4D2P1		13	147	150	0,98	8	0,64	1,08
TLS4D2P2		3	136	150	0,91	2	0,14	0,25
TLS4D3P1	45 °	20	75	75	1,00	4	0,32	1,66
TLS4D3P2		1	14	50	0,28	1	0,05	0,08
TLS4D3P3		4	45	75	0,60	3	0,24	0,33
TLS4D3P4		3	132	150	0,88	2	0,14	0,25
TLS4D3P6		4	137	150	0,91	3	0,23	0,33
TLS4D3P5		2	133	150	0,89	1	0,06	0,17
TLS5D3P2	180 °	3	12	100	0,12	2	0,17	0,25
TLS5D3P3		10	84	100	0,84	8	0,64	0,83
TLS5D2P2	0 °	50	100	100	1,00	22	1,83	4,15
TLS5D2P3		11	91	100	0,91	6	0,47	0,91
TLS5D4P1	135 °	2	73	100	0,73	2	0,13	0,17
TLS5D4P2		12	80	100	0,80	5	0,45	1,00
TLS5D4P4		17	117	150	0,78	10	0,81	1,41
TLS5D4P3		2	135	150	0,90	1	0,07	0,17
TLS5D5P1	45 °	26	100	100	1,00	13	1,04	2,16
TLS5D5P2		4	80	100	0,80	1	0,07	0,33
TLS5D5P3		13	57	150	0,38	9	0,77	1,08
TLS5D5P4		6	145	150	0,97	3	0,21	0,50
TLS7D1P2	0 °	9	182	200	0,91	5	0,41	0,75
TLS7D2P2	45 °	10	162	200	0,81	5	0,43	0,83
TLS7D2P1		11	174	200	0,87	7	0,60	0,91
TLS7D2P3		4	107	150	0,71	3	0,21	0,33
TLS7D2P4		8	76	150	0,51	6	0,53	0,66
TLS8P2	0 °	11	225	300	0,75	7	0,56	0,91

Table 4.7-21: Results for multi-pitch roofs

Name	Wind direction	Hmax (cm)	D(Hmax) (cm)	Lroof (cm)	D(Hmax)/L	H ave surface/L	μ_H ave Have/Href	μ_H max Hmax/Href
MPND2V1	0 °	6	15	50	0,31	5	0,42	0,53
MPND2V2		14	17	17	0,98	5	0,42	1,16
MPND2V3		17	23	50	0,46	14	1,13	1,44
MPND2V4		18	17	17	0,98	11	0,89	1,51
MPND2V5		19	22	50	0,45	15	1,28	1,60
MPND2V6		15	15	17	0,90	11	0,93	1,23
MPND3V1	180 °	14	1	17	0,07	9	0,72	1,18
MPND3V2		16	50	50	1,00	6	0,53	1,36
MPND3V3		16	0	17	0,00	8	0,68	1,36
MPND3V4		20	50	50	1,00	10	0,85	1,70
MPND3V5		24	0	17	0,00	12	0,97	2,03
MPND3V6		13	44	50	0,88	10	0,79	1,04
MPND1V1	45 °	7	35	50	0.69	5	0,40	0.60
MPND1V2		20	17	17	1.00	9	0,74	1.70
MPND1V3		20	0	50	0.00	9	0,78	1.70
MPND1V4		29	17	17	1.00	14	1,13	2.39
MPND1V5		29	0	50	0.00	15	1,28	2.39
MPND1V6		19	15	17	0.87	13	1,06	1.59
MPND1P5		7	69	150	0,46	5	0,43	0,58
MPND1P6		13	142	150	0,95	8	0,63	1,08
MPND1P7		17	123	150	0,82	13	1,06	1,41
MPND4P7	135 °	11	65	150	0,43	6	0,51	0,91
MPND4P5		3	17	150	0,11	1	0,12	0,25
MPND4P8		12	106	150	0,71	5	0,41	1,00
MPND4P10		12	99	150	0,66	9	0,73	1,00
MPND4P6								
MPND4P9		18	118	150	0,79	12	1,02	1,49
MPND5P10	90 °	2	88	150	0,59	1	0,06	0,17
MPND5P5		6	134	150	0,89	4	0,29	0,50
MPND5P7		11	139	150	0,93	6	0,51	0,91
MPND5P6		13	126	150	0,84	7	0,58	1,08
MPND5P9		15	136	150	0,91	8	0,68	1,25
MPND5P8		17	118	150	0,79	9	0,76	1,41
MPSD1V1	0 °	7	8	33	0,23	6	0,53	0,62
MPSD1V2		18	33	33	1,00	10	0,79	1,49
MPSD1V3		19	3	33	0,10	14	1,19	1,54
MPSD1V4		23	33	33	1,00	15	1,21	1,92
MPSD1V5		23	0	33	0,00	15	1,24	1,92
MPSD1V6		14	29	33	0,86	12	1,01	1,18
MPSD2P4	90 °	13	121	150	0,81	8	0,64	1,08
MPSD2P2		14	125	150	0,83	8	0,68	1,16
MPSD2P3		15	137	150	0,91	8	0,70	1,25
MPSD3P7	45 °	12	103	150	0,69	9	0,72	1,00
MPSD3P8		11	68	150	0,45	9	0,71	0,91

Examples of snow load repartition (μ_H values) on multi-pitch roof are given in figures 4.7-22, 4.7-23 and 4.7-24. The wind comes from the left-hand side.

Figure 4.7-22: Snow load repartition for multi-pitch symetrical roof, wind 0° (MPSD1)

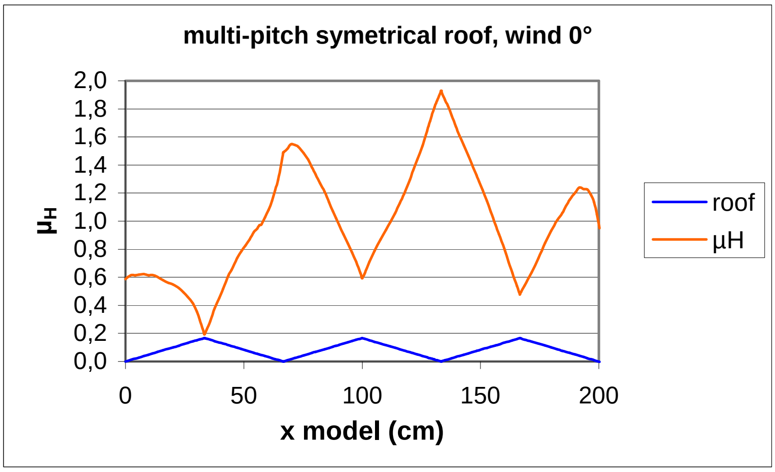


Figure 4.7-23: Snow load repartition for multi-pitch non symetrical roof, wind 0° (MPND2)

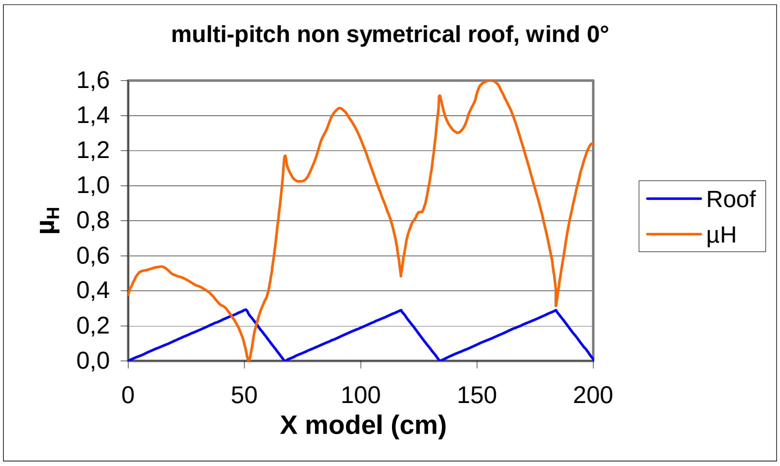
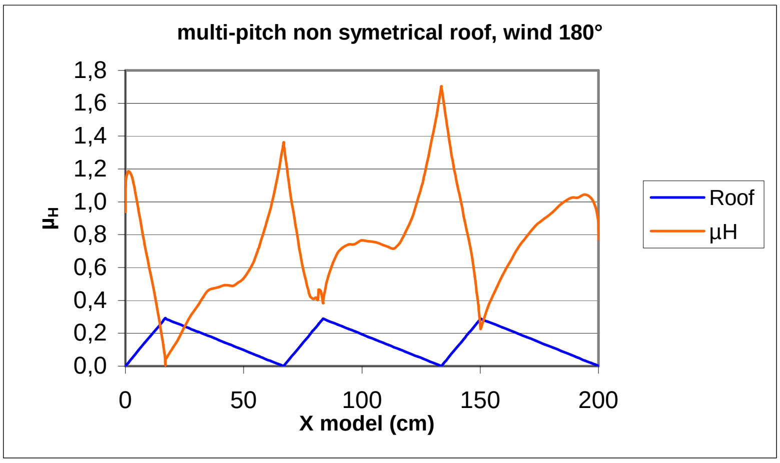


Figure 4.7-24: Snow load repartition for multi-pitch non symetrical roof, wind 180° (MPND3)



Comments of the results of 2nd sub-task

It is observed that there is less snow on the upper part of the two-level flat roof than on the lower part situated either leeward or windward.

Snow deposits with oblique wind (45 ° or 135 °) are less important than with normal wind (0 ° or 180 °) but these are more laterally unbalanced.

The length of the model does not have significant influence. Results of shapes n°1, 2 and 3 for two-level roofs and of shapes n°6 and 7 for flat roofs are very similar.

Without an obstacle (flat roof, two-level roof with wind 90°, upper part of two-level roof), the snow profiles on flat roofs have the same shape. Snow cover increase from the windward edge, where there is very little snow, to the leeward edge which is approximately the maximum snow depth.

For two-level roofs values of H_{max} are close to the step height. In some cases the maximum snow depth is greater than the step height.

For multi-pitch roofs, maximum snow depth occurs in the middle of the valley. Snow accumulation is greater in the leeward valley. Snow depth can be greater than the ridge height.

Differences of snow accumulation on the flat roof between the 1st and 2nd sub-tasks mean that snow deposition is very sensitive to local flow and that the eaves have an aerodynamic influence on the flow around the building.

4.8 Reduction of snow load on glass roofs

4.8.1 Introduction

This section deals with snow loads on glass roofs for the purpose of specifying the snow load for design of the supporting structure of the roof. Snow loads relevant for the design of the individual glass elements of the roof are not considered.

Since no quantitative data on snow loads on glass roofs are known, an attempt to specify design loads as a background for the future EN on snow loads can only rely on a theoretical discussion on energy balance, gliding off, and on limited qualitative observations and experience. However, the melting rate for the snow mass on the ground and some important physical characteristics of snow have earlier been studied and measured by researchers and will be used as appropriate.

The following are to be discussed:

- Snow fall intensities
- Basis for an energy balance model for calculation of the time-dependent snow load on a nearly flat roof
- Snow gliding off the roof
- Experience from observations
- Standards allowing for a reduction of snow load on glass roofs
- Thermal coefficient method as background for development of future EN

The energy balance model gives an overall picture and understanding of the time-dependent snow load related to the relevant meteorological parameters; i.e. precipitation intensity, temperature, humidity, wind-speed, radiation, etc. This understanding is an important background for developing a simple thermal coefficient that can be used in a standard text.

For continuously (daily recording) information on meteorological data, and on the thermal characteristics of the roof, as well as the indoor temperature, the time-dependent snow load on a nearly horizontal glass roof can be calculated by simple thermal considerations [Sandvik, 1988]. This assumption requires that the thermal flux through the roof is sufficiently high for the melting to clear the roof in maximum 2 - 3 weeks time after a single heavy snowfall or subsequent snowfalls. Running this model with approx. 30 years data will give a basis for calculation of snow load on the flat roof with a return period of 50 years. Herein a more elaborated basis for such calculations, discussing the turbulent fluxes of heat transfer and the radiation at the top of the snow layer, are presented.

Since gliding off the roof is not considered by the energy balance model, this model is primarily useful for a nearly flat roof. However, it can also often be used as a conservative model for pitched roofs.

Snow gliding off the roof is discussed in section 4.8.4. Gliding off seems to be the most important and effective reduction of snow loads on pitched glass roofs.

Information on more than fifteen years of experience with a fast growing number of glass roofs is also sought.

The consideration of the energy balance of the snow layer leads to determination of a simplified thermal coefficient model for use in a standard. In addition the thermal coefficient method will also take into account the important effect of gliding off since the tangential stress has proved to be very low for snow on a wet glass surface.

4.8.2 Snow fall intensities

As concerns snow load on roofs with high thermal transmittance, the snowfall intensity and the accumulation on the ground for a period of 1 – 5 days is appropriate data to consider. Since precipitation as snow cannot easily be separated from rain in most data analysis, it is often necessary to use total precipitation as an overall conservative estimate of short duration snow precipitation in the winter months of the year.

One example of an extraordinary heavy snowfall was recorded in Gävle, a town at the east coast of Sweden, where about 180 mm waterequivalents of snow fell over a period of three days 4^{th} – 7^{th} of December 1998.

From WMOs Climatic atlas of Europe, it can be observed that the January average precipitation for Europe varies geographically between 25 mm and 300 mm; which roughly represents one order of magnitude. It can also be observed that the same quantitative variation occurs in Norway; 25 mm in the north east and 300 mm in central west.

Førland, 1984, calculated precipitation intensities with duration, 1 – 30 days, for various seasons with various return periods at 49 meteorological stations in Norway. His calculations shows, for the 100 year return period, a variation from approx. 20 mm and 40 mm for 1 and 5 days respectively in the driest region, up to approx. 200 mm and 400 mm for 1 and 5 days respectively in the wettest region.

When comparing WMOs climatological atlas of the average January precipitation with Førlands analysis, it is found that the average January precipitation is a useful substitute for the 100 year return period winter precipitation with the duration one day, in Norway. Since Norway reflects the whole range of the average January intensities found in the rest of Europe as well, it is as an estimate anticipated that the same substitution is qualitatively acceptable for Europe, i.e. the amount of precipitation with 100 year return period of 1 day duration in the winter season, equals the average January precipitation at the same place.

As a further approximation, the five days precipitation in winter is twice the 1 day precipitation both with a return period of 100 years.

In conclusion, for Europe, 1 day precipitation with 100 years return period in winter can give 0,2 kPa to 2,0 kPa load on the ground for the driest and the wettest regions in January respectively. For the five days period, the loads ranges from 0,4 kPa to 4 kPa. For the Mediterranean regions of Europe, the five days duration snowfall intensities is not considered to be relevant, and the characteristic snow load on the ground values calculated in phase I of the European Snow Load Research Project could often be used as a substitute for the one day duration as well.

4.8.3 The energy balance of the snow layer on the roof

For heated buildings the heat flux through the glass roof contributes considerably to the melting of the snow on the roof. This heat flux can be estimated when the thermal transmittance of the roof and the indoor temperature is known. It is generally too low for the snow melting rate at the interface between the roof and the snow layer to equal the snowfall intensity of a heavy snowfall. Consequently, snow will accumulate during the time of snowfall and in some rare occasions several subsequent heavy snowfalls can contribute to the maximum snowload on the roof, i.e. for roofs with low thermal transmittance or poor indoor heating.

An energy balance model shall also take into account the possible melting at the top of the snow layer; i.e especially where the maximum snow loads on the roof is likely to be a result of several subsequent snowfalls. For single snowfalls, even in warm coastal winter climates, it is anticipated that melting on the top of the snow layer is not important during snowfalls and consequently will not affect the maximum load.

The mass of snow on a nearly flat glass roof is an additive function of snow precipitation gain and melting snow loss, both as functions of time. The precipitation can be derived from daily recordings at meteorological stations.

The top of the snow layer mainly exchanges energy with the atmosphere, and the bottom with the roof surface. However, when the outdoor temperature is below 0 °C, some exchange of energy takes place by conduction and convection between the lower part and the upper part of the snow layer. For all other cases exchange of energy between the top and the bottom is not considered.

Melting water is assumed to be drained by percolation from the top of the snow layer. At the bottom of the snow layer it is assumed that all the water is drained away by the small pitch of the roof.

When analysing the energy balance of the snow layer the following influences are considered:

a) Gain of sensible heat flux through the roof

b) Heat loss by melting snow at the interface between the glass roof and the snow layer

c) Exchange of heat throughout the snow layer by conduction and convection

d) Energy used in melting snow at the top of the snow layer

e) Sensible heat gain or loss at the interface between the top of the snow layer and the atmosphere

f) Radiation gain and loss (net radiation) at the top of the snow layer

g) Latent heat gain or loss at the interface between the top of the snow layer and the atmosphere

h) Energy gained from rainwater

i) Change of internal energy of the snow layer

Below, the role of each influence a), ..., i) in the energy balance of the snow layer is discussed. For the top of the snow layer, the important work of Harstveit (1984) is considered.

a) Gain of sensible heat from flux through the roof

This effect is determined by the thermal transmittance of the glass roof U_g (U-value) which is given in units of W/(m^2 °C) and the indoor temperature T_i in units of °C.

Typical values are for T_i: 20 °C and U: 2,0 W/(m^2 °C) which for a 2-layer glass gives a gain of sensible heat of 40 W/m^2 at the interface between the surface of the roof and the snow layer.

For conditions where the interface temperature is lower than 0 °C, the gain of sensible heat is higher. This situation can occur when the outdoor air temperature is low and the snowlayer is rather thin.

b) Heat loss from melting at the interface between the glass roof and the snow layer

The heat loss by melting snow at the interface is determined from the heat flux through the roof and the latent heat of melting $L_f = 3{,}34 \cdot 10^5$ J/kg.

When the temperature is 0 °C, at the interface, it can be assumed that melting snow consumes nearly all flux of heat through the roof unless the outdoor temperature is very low or the snow layer is very thin.

For the example given under a), the melted mass of snow per 24 hours and per square meter at the interface is 10 kg; which equals an amount of 10 mm snow precipitation (water equivalents).

c) Exchange of heat throughout the snow layer by conduction and convection
When the outdoor temperature is below 0 °C, the top of the snow layer is colder than the bottom. The negative temperature gradient will cause a positive heat flux from the bottom to the top of the layer and consequently the rate of melting at the interface between the glass surface and the snow is reduced correspondingly.

For bulk properties of snow an effective thermal conductivity which accounts for both conduction and convection, can be used ($\lambda \cong 0,1$ W/(m °C)).

If the snow depth is 0,25 m and the outdoor temperature is -10 °C the heat loss is 4 J/(m^2s), assuming the surface resistance between the snow layer and the air is low. During 24 h the melted mass of snow is reduced by 1,0 kg due to conduction and convection.

It should be noted that the heat loss from thermal conductivity and convection in the snow layer does not depend on the indoor temperature when melting conditions are fulfilled.

d) Energy used in melting snow at the top of the snow layer
To be calculated as the net gain from e), f), g) and h)

e) Sensible heat gain or loss at the interface between the top of the snow layer and the atmosphere
The flux of sensible heat, $Q_{H,}$ is exchanged the atmosphere and the surface of the snow layer due to vertical gradients in the air temperature above the snow surface. The flux is strongly turbulence dependent and consequently a function of the wind velocity.

It can be estimated from a simplified formula:

$$Q_H = (3{,}1U_a + 2{,}3)\,(T_a - T_0)\ (\mathrm{W/m^2}) \qquad \text{(equ. 4.8-1)}$$

where U_a = daily wind velocity (m/s) at 1,3 m above the snow surface
T_a = daily temperature (°C) at 1,3 m above the snow surface
T_0 = temperature (°C) at the snow surface (0 °C during snow melt)

As U_a (at z_a = 1,3 m) is usually not known, a transition formula is used:

$$U_a = U_R(z_a/z_R)^{0,17} \qquad \text{(equ. 4.8-2)}$$

where U_R is the wind speed (m/s) at reference height z_R

Typical values are: U_a = 3 m/s, T_a = 5 °C; which from equ. 4.8-1 gives Q_H = 58 W/m^2 and followingly 15 kg melted mass of snow in 24 hours.

f) radiation gain and loss (net radiation) at the top of the snow layer

The net radiation at the top of the snow layer can be directly measured. If records are not available the following formula can be used:

$$Q_N = Q_S(1 - a) + \phi\downarrow - \sigma T_0^4 \qquad \text{(equ. 4.8-3)}$$

where

Q_S	=	global radiation (the solar radiation; see equation 4.8-5))
a	=	albedo of the snowcover (depends on the age of the snowcover, see equation 4.8-4
$\phi\downarrow$	=	incoming thermal radiation (see equation 4.8-6)
T_0	=	top surface temperature of the snowlayer (for melting conditions, 273 K)
σ	=	Stefan Boltzmann constant ($5{,}67 \cdot 10^{-8}$ W/(m^2K^4))

The albedo can be estimated by:

$$a = -0{,}13(1-C) - 0{,}05 \ln t + 0{,}87 \qquad \text{(equ. 4.8-4)}$$

where

C	=	fractional cloud cover
t	=	number of days which the snow at the surface has been exposed to the atmosphere

The global radiation is recorded, or can be estimated. For sites with maritime climate (in Western Norway) the following formula have been used:

$$Q_s = (-0{,}16(1-C) + 0{,}81(1-C)^{0,5} + 0{,}07)\, Q_{ex} \qquad \text{(equ. 4.8-5)}$$

where

C	=	fractional cloud cover
Q_{ex}	=	extraterrestrial global radiation

The incoming thermal radiation (for the west coast of Norway) can be determined from:

$$\phi\downarrow = 1{,}02 \cdot \sigma T_a^4 + 71C - 92 \qquad (\text{W/m}^2) \qquad \text{(equ. 4.8-6)}$$

where C = fractional cloud cover and T_a is the air temperature.

Typical values of Q_N can vary much with latitude. Generally Q_N is rather independent of the cloud cover from day to day, as the gain of short wave radiation during clear weather is being counteracted by the increased long wave radiation loss.

Typically Q_N is of the same order or less than the gain from sensible heat Q_H ; see e).

g) Latent heat gain or loss at the interface between the top of the snow layer and the atmosphere

The flux of latent heat, Q_E, is exchanged between the surface of the snow layer and the atmosphere due to vertical gradients in the vapour pressure above the snow surface. The flux is strongly turbulence dependent and consequently a function of the wind speed.

Depending on the humidity of the air, evaporation or condensation will occur:

$$Q_E = 1{,}7(3{,}1U_a + 2{,}3)\,(e_a - e_0) \quad (W/m^2) \qquad \text{(equ. 4.8-7)}$$

where U_a = daily wind speed (m/s) at 1,3 m above the snow surface; see e)
e_a = daily vapour pressure (hPa) at 1,3 m above the snow surface
e_0 = vapour pressure (hPa) at the snow surface (6,11 hPa during snow melt)

Typical values for overcast weather is e = 6,9 hPa, which for U_a = 3 m/s gives Q_E = 16 W/m^2 which can melt a mass of about 4 kg snow in 24 hours.

h) Heat gained from rainwater

When the temperature of rain T_R > 0 ºC falling on melting snow the rain water is cooled to 0 ºC and heat released is used to melt the snow:

$$Q_R = T_R p_I C_W\, \rho_W \qquad \text{(equ. 4.8-8)}$$

where C_W = 4200 J/(kg·°C) specific heat of water
ρ_W = 1000 kg/m^3, density of water
p_i = rainfall rate (mm/day)

If T_R = 5 °C and the rainfall is 10 mm the melted mass of snow is only 0,6 kg/m^2.

i) Change of internal energy of the snow layer

The snow cover, due to its heat capacity can absorb, store and release energy; often with a diurnal phase. As the heat capacity of snow is about two orders of magnitude less than the latent heat of melting, it is not considered to be significant.

Conclusions

For dry regions in Europe, one day snowfall on a nearly flat roof can be reduced by approximately 30 %, while for the wettest regions the reduction should not be more than 5 %. As a general conclusion, only melting on the surface of the glass roof can be considered important for a nearly flat glass roof during one single snowfall. When the snow event consists of several individual snow falls, the other important effects discussed above should also be considered.

If the air temperature after a snowfall rises to 5 °C, and is accompanied by a wind velocity of 3 m/s, melting is at least twice as effective on the top of the snowlayer due to heat fluxes and radiation fluxes as compared to the simultaneously melted mass at bottom.

4.8.4 Reduction from snow gliding off the roof – investigations and experience

On a pitched glass roof the shear stresses parallel to the roof and the horizontal members of the glass frames will both act against snow gliding off the roof surface. Slow moving snow is generally considered as a non-Newtonian fluid with Newtonian behaviour only in a confined range of low stresses [Salm (1977)]. On the basis of the experimental work of Haefeli, Bader and others, Salm (1977) has shown that on a wet glass surface without macroscopic roughness, a stress-independent cohesion and Newtonian viscosity seem to create the shear stresses, τ, parallel to a sloping glass surface at 0 °C. Thus:

$$\tau = f(\sigma_x)\, v_g + c \qquad \text{(equ. 4.8-9)}$$

where
f = function of the normal stress σ_x on the roof surface
v_g = gliding velocity of the snow layer
c = constant

and the function f is given by:

$$f = \mu_w / \delta(\sigma_x) \qquad \text{(equ. 4.8-10)}$$

where
μ_w = viscosity of water at 0 °C (1,8 10^{-3} Ns/m^2)
δ = thickness of the boundary layer, assumed to consist of water.

In the experiments, the thin layer of water was produced by melting caused by the normal stress σ_x. Now, assume that the layer of water instead is produced by melting caused by the thermal flux through the roof. Salm (1977) has calculated the constant c in equation 4.8-9; c = 16,2 Pa. If the first component at the right side of equation 4.8-9 has a value less than 1/10 of the constant, c; i.e. $(\mu_w/\delta)v_g < 1{,}6$ Pa, it can be deleted.

Assume that $v_g \leq 10^{-3}$ m/s, which should be a reasonable gliding velocity for snow on a moderate pitched glass roof. Then, if $\delta > 1{,}2\ 10^{-6}$ m, it follows that $(\mu_w/\delta)v_g < 1{,}6$ Pa, and

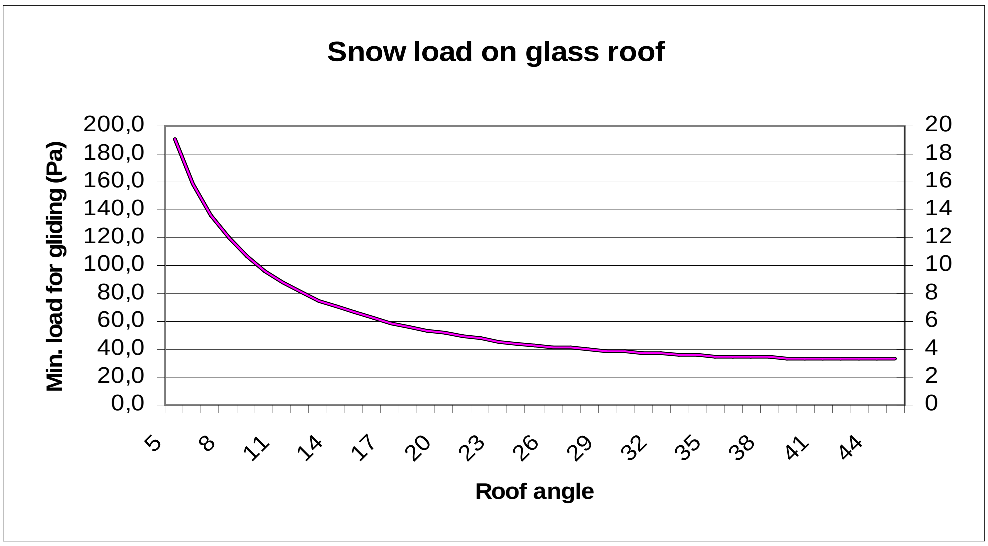
$$\tau = \mu_w\, v_g / \delta(\sigma_x) + c \approx c = 16{,}2 \text{ Pa} \qquad \text{(equ. 4.8-11)}$$

There is probably no doubt that δ fulfils the requirement, $\delta > 1{,}2\ 10^{-6}$ m, when heat flux through the roof melts the snow at the interface. This means that only normal stress independent cohesion forces need to be taken into account.

A gravity force component parallel to the roof exceeding 16,2 N/m^2 acting on one square metre snow cover on the roof surface will therefore theoretically initiate gliding when no other forces than stress parallel to the roof are present. Under such conditions, the necessary snow load G (projected on a horizontal area) for gliding, for a roof angle α, can be expressed by:

$$G = 16{,}2/(\sin\alpha\cos\alpha) = 32{,}4/\sin 2\alpha \qquad (N/m^2) \qquad \text{(equ. 4.8-12)}$$

Figure 4.8-1 Minimum theoretical load on roof necessary to initiate gliding off, on a wet glass surface with no hindrances (frames). Associated snow depth (vertical) in cm when the density is 100 kg/m^2, is shown on the right axis.



In accordance with figure 4.8-1, it has been observed during snowfalls that the snow will gradually build up until melting conditions are reached on the glass/snow interface. When melting starts as a result of the increased insulating snow layer, a film of water is present, and the snow will gradually break up and be released from parts of the surface [Nielsen and Torgersen (1989)]. This was the conclusion from their project carried out by the Norwegian Building Research Institute (NBI). Glass roofs with a pitch ranging from 19–45° were photographed daily during one winter season located in Oslo and Trondheim. It was concluded from that project that snow gliding off can be expected as far as no extraordinary hindrances occur. It is very important that there is enough space for the snow to accumulate on lower level without the risk of further gliding snow being blocked.

Snow starting to glide will to some extent accumulate on the horizontal frame members before gliding off the roof. The photographs from the NBI project showed relatively small snow loads on the roofs. Depending on weather conditions small amount of icing occurred at some horizontal frame members, but without resulting in a significant load. Usually the horizontal parts of the metal glass frames are present with a maximum height of 1–2 cm above the surface of the glass plane, and a length of 1,5–2,0 m between two horizontal members of frames. Until the accumulated mass of snow will ensure a gravity force large enough to overcome the restraining forces of the frame on the snow, the snow will continue to accumulate on the roof.

The most important considerations concerning the horizontal frames are:

- The number of horizontal frames per unit length in the gliding direction on the roof
- The height of the horizontal frame above the roof surface
- The surface profile of the horizontal fame above the roof surface

Several consultants designing glass roofs in Norway have been contacted for information on their experience during the last 15 years. All reports the use of a minimum pitch of about 25 degrees. Although several winters with much snow occurred during this period, no serious problems with snow load on the roofs have been reported. Snow accumulation on the horizontal metal frames occur without resulting in significant loads. In one case icing due to refreezing of melted snow occurred on the eave area during a long cold period after a snowfall. It was concluded that the problems were caused by a too well insulated eave area.

Since no measurements are available which could give rise to a formulae representing the force on the snowlayer from the horizontal metal frames, only conservative suggestions based on experience can be given.

4.8.5 Standards and national recommendations with a reduction coefficient

Since 1990 Norway have included a reduction coefficient for glass roofs in the national load standard [NS 3479 (1990)]. The reduction depends on the roof angle, the thermal transmittance of the roof, the indoor temperature and the characteristic snow load on the ground. The coefficient is to be multiplied by the design load for a corresponding cold roof. For a roof with a pitch of 30 degrees, a U value 2,0 W/K m^2 and an indoor temperature 18 °C, the reduction coefficient decreases from 0,3 to 0,22 when the snow load on the ground increases from 1,5 kPa to 5,0 kPa.

In Sweden, the same reduction formulas as given in Norway were adopted in 1994 by the Swedish building regulation authorities [Boverket (1994)].

In the USA the ASCE design load standard (1990) specifies a thermal factor for heated structure, reducing the design load by approx. 15 %.

In Japan, the AIJ recommendations for loads on buildings (1996) includes possible considerations of snow removal by thermal transmittance through the roof and snow gliding off. However, no calculation formulae are given.

4.8.6 A thermal coefficient method – background for recommendation of snow load on glass

Although glass covered areas are now usual in many new buildings, research on snow loads on such roofs has up to now not been given priority. Research, including full scale measurements of snow loads on glass roofs, are necessary in order to develop a total harmonised set of shape coefficients for roofs including special consideration based on measurements for glass roofs in the future EN.

A possible modelling of the reduction coefficient for snow load on a glass roof can be built on the following effects:

1) the ratio of snow load on a nearly horizontal glass roof and the snow load on a horizontal well insulated roof

2) consideration of increased glided off snow on a pitched glass roof as compared to a well insulated roof as the tangential stress is reduced by a film of melting water at the interface between the glass roof and the snow

3) consideration of the influence of the accumulation time with a relatively higher reduction in regions with a high characteristic snow load, i.e. since the longer accumulation time (several snowfalls) will increase the time available for melting

Thus, the effects 1), 2) and 3) can be expressed by a reduction factor, C_t to be multiplied by the snow load on an corresponding ordinary roof:

$$C_t = C_{t,a}(u)\, C_{t,b}(\alpha)\, C_{t,c}(s_{50}) \qquad \text{(equ. 4.8-13)}$$

where $C_{t,a}(u)$ = function that accounts for the part of the melting caused by the heat flux through a nearly flat roof

$C_{t,b}(\alpha)$ = reduces the snow load by gliding off and is mainly a function of the roof pitch

$C_{t,c}(s_{50})$ = function that reduces the snow load on the roof for high values of s_{50}

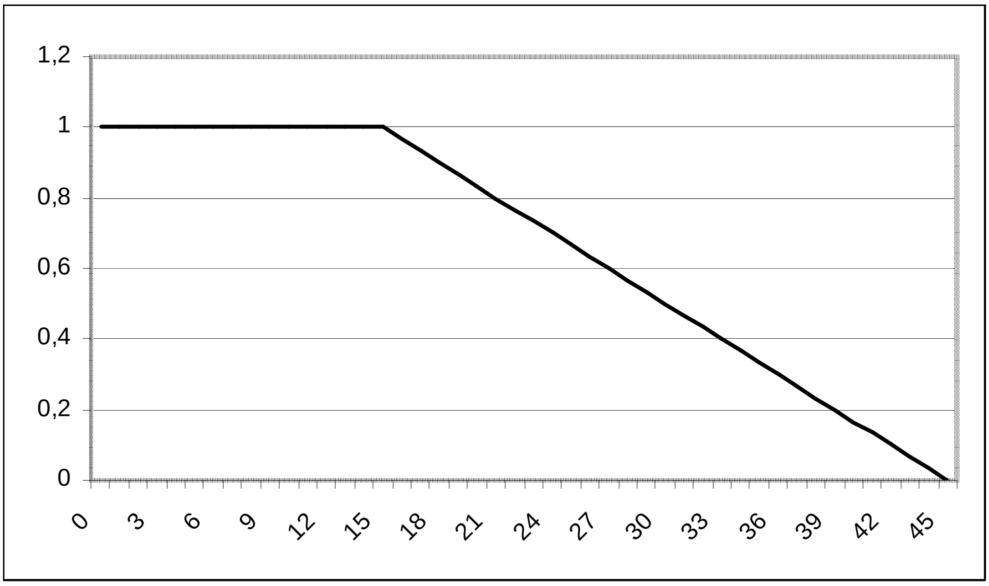
This method does not require snow fall intensity data since s_{50}, the characteristic snow load on the ground, is used. Another advantage for practical use, is that this method does not have to consider the snowmelting at the top of the snow layer.

For roofs where α is high enough to ensure gliding off, $C_{t,b}(\alpha)$ becomes small; see proposals in equation 4.8-10 and figure 4.8-2. Since always $C_{t,a} \leq 1$ and $C_{t,c} \leq 1$, this implies that also $C_t \leq C_{t,b}(\alpha)$, and $C_{t,b}$ is sufficient for determination of a conservative C_t value for most practical purposes of glass roofs covering heated areas.

Representative values for $C_{t,b}$ are proposed in equation 4.8-14.

$$c_{t,b}(\alpha) = \begin{cases} 1{,}0 \ \ for\ \alpha \le 15° \\ \dfrac{45° - \alpha}{30}\ \ for\ 15 < \alpha < 45° \\ 0\ for \ \ \ \alpha \ge 45° \end{cases} \qquad \text{(equ. 4.8-14)}$$

Figure 4.8-2 Proposed gliding off coefficient $C_{t,b}$ (α) for roofs with no cold areas and no horizontal frame obstructions exceeding 2 cm above the roof surface and with a minimum individual spacing of 1,5 m



Representative values for the melting reduction coefficient, $C_{t,a}$ *(u)*, is proposed in table 4.8-3.

Table 4.8-3 Melting reduction coefficient, $C_{t,a}$ (u, θ).

Indoor temperature (ºC)	1,0<U < 1,5 (W/m²K)	1,5 < U < 2,5 (W/m²K)	U > 2,5 (W/m²K)
θ < 5	1,0	1,0	1,0
5 < θ < 10	0,9	0,8	0,8
10 < θ < 15	0,9	0,8	0,8
θ > 18	0,8	0,7	0,6

Representative values for $C_{t,c}$ *(s_{50})* are proposed in equation 4.8-15.

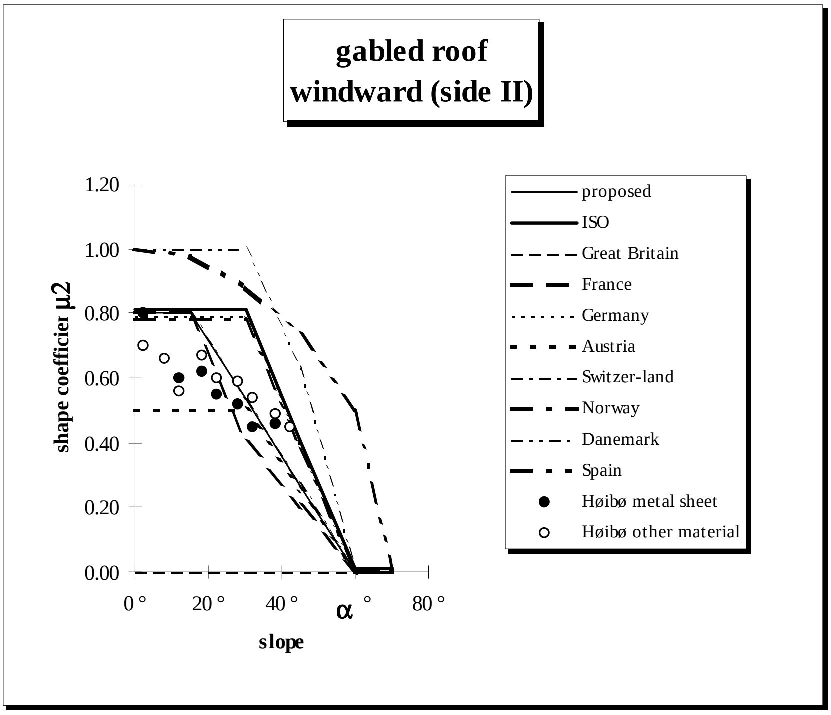
$$c_{t,c}(s_{50}) = \begin{cases} 1{,}0 \;\; for\ s_{50} \le 3{,}0\ kPa \\ \dfrac{3{,}0\ kPa}{s_{50}} \;\; for\ s_{50} > 3{,}0\ kPa \end{cases} \qquad \text{(equ. 4.8-15)}$$

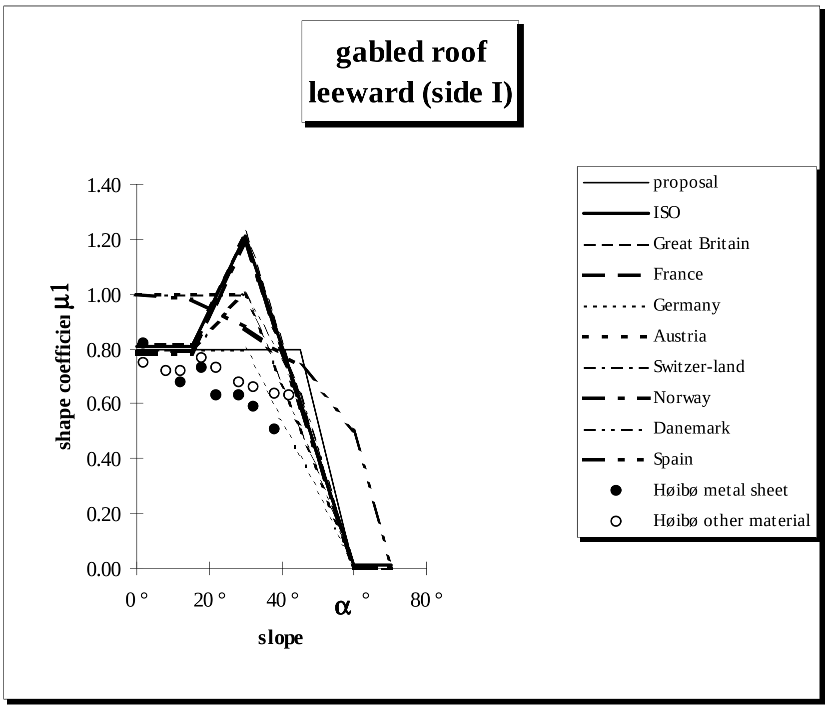
This reflects that high values of s_{50} means longer accumulation time for s_{50} with relatively stronger reduction while lower values means shorter accumulation time. However, this is not an assumption that holds for all conditions as low values of s_{50} can also reflect a dry and cold winter climate. To make C_t a function of s_{50} can be doubtful from a general load model point of view, since such coefficients are usually expected to be statistically independent of the characteristic load.

4.9 Conclusions, recommendations

From the roof snow load measurements in nature numerous data are available for the determination of roof shape coefficients in European climatic regions. Provisionally the roof shape coefficients as shown in figure 4.9-1 for different roof slopes are proposed. The different curves in several codes of European countries are also shown in this figure.

Figure 4.9-1: Provisional proposal for roof shape coefficients depending on the slope of the roof for gabled roofs





The exposure coefficients are provisionally proposed as follows:

- Sheltered 1.1
- Semi wind swept 0.9
- Windswept 0.7

A more detailed investigation with more measurements in the different climatic regions should improve the results of the multiple linear regression analysis. From this investigation different values for the climatic regions might be determined. From today's knowledge the scatter of the data due to natural influences is far greater than the possible influences from climatic regions, since the main influence for the roof snow load is considered by calculating the roof snow load based on the ground snow load.

From the wind tunnel tests a general confirmation of the roof shape coefficients for flat roofs and for roofs with a small roof slope can be determined. However the values are generally larger than those obtained from the measurements in nature. For large roof slopes different shape coefficients result. The measurements in nature confirm the results from previous measurements, that the roof shape coefficients are reduced for larger roof slopes, whereas the wind tunnel tests suggest a slight increase of the shape factors for both the leeward and windward sides of gabled roofs.

5. European Ground Snow Loads Map: improvements

5.1 Verification and uncertainty analysis of snow load values for the European ground snow load map

The map obtained during the first phase of this work was deeply analysed to check its validity and accuracy. The improvement which can be expected is to have very small differences between the map-values at the locations of the meteorological stations and the corresponding characteristic values. At the same time small discrepancies at borders of meteorological regions are required.

The differences between snow load values calculated from the resulting maps and those provided by the project partners for every meteorological station have two reasons and are introduced at two different stages in the data processing.

The first one is implicit to the method used to determine the altitude-snow load relationship. The scatter plot snow load–altitude for all the stations of a climatic region is divided into zones with integer zone numbers, and for every zone a representative function is determined. Only for points lying on the curve is there no difference between mapped and characteristic values. For the other points placed above and below this function, the characteristic snow load values are different from the ones determined by the function.

The second reason is due to the interpolation of the zone numbers onto a regular grid and to the smoothing of the zone contours. With interpolation every zone number of a new grid cell is based on the zone numbers of the nearby stations. Smoothing has been applied in order to eliminate micro zones (for details see final report phase I). It is then obtained by assigning a new value to every grid cell based on those of the surrounding grid cells. The zone number for a particular station therefore does not necessarily coincide with the one determined from the map.

The differences arising from the scatter-plot are basically fixed, as the chosen altitude-snow load relationship and the number of zones determined are seen as the best possible approach for the available data.

In the interpolation and the smoothing process there are several parameters that can be varied and there are “boundary conditions” that can be set.
The sampling density is the result of the compromise between large and limited values of the radius, to avoid on the one hand areas of the snow map without data points and to exclude on the other one information beyond a certain distance. The radius of 100 km was assumed as the best value for the available data. Exponent 4 has been chosen as it assures a detailed analysis without creating too many micro zones. For the smoothing, the smallest possible neighbourhood has been used, in order to limit the error introduced.

Another critical aspect is related to the border areas between two different climatic regions. A climatic region is characterised by a specific type of altitude function. The two snow load values for a border point determined using the two different altitude relationships of the adjoining regions and the respective zone numbers can be different, though this is not a desirable result as one point can have only one snow load value.

As mentioned previously two different evaluations have been performed:

In the approach of the first phase interpolation using inverse distance weighting has been applied to the data of a single climatic region.

The evaluation of uncertainties in the snow load maps revealed some discrepancies in the snow load values calculated from the map at the borders between the climatic regions. In order to reduce these discrepancies a revised mapping procedure has been performed.

In this revised approach inverse distance weighting has been applied to an extended area. Stations contained in a buffer zone of 100 km have been included at the border of every climatic region in order to include knowledge of the behaviour of zoning numbers (and therefore snow load values) across the borders.

This revised approach has been applied to all the regions actually adjoining other climatic regions (basic condition to build a buffer zone). Furthermore this revised approach hasn't been applied to the following two climatic regions: Norway, Sweden-Finland. This is due to the fact that a special procedure has been applied to Norwegian data; since snow load values have been interpolated directly. It is therefore not advisable to use information from Norway to elaborate data for Sweden-Finland and vice versa, as two different methods have been applied in the two climatic regions. The five climatic regions where the revised method has actually been applied are: Alpine Region, Central East, Central West, Mediterranean Region, and Iberian Peninsula.

In order to evaluate the errors and uncertainties the snow load values calculated using the mapped zoning number have been compared with the equivalent values delivered by the partners from their statistical analyses. Furthermore snow load values have been calculated at the border between two different regions, using the two different altitude relationships and have then been compared. It has to be noted that not all the results are completely comparable as for two countries (Italy, Sweden) new data has become available, while the border between the Iberian peninsula and the central western region has been slightly shifted. But the general trend, and this is a significant aspect, is in good agreement with the other results and confirms the validity of the new approach.

The complete set of ground snow maps resulting from the revised approach is presented in **Annex B**. The results of the verification and uncertainty analysis for the basic and for the revised approach are presented in the following paragraphs. Only an example of the validation procedure is presented here below.

5.2 Verification and uncertainty analysis of snow load values for meteorological stations

The error analysis for meteorological stations focuses on two aspects:

- The misclassification introduced during interpolation and smoothing
- The evaluation of the overall error

These aspects are evaluated and compared for the basic approach and for the revised elaboration.

5.2.1 Misclassification introduced during interpolation and smoothing:

The following table summarises misclassification for the different approaches.

Climatic Region	**Basic Approach**		**Revised Approach (with buffer zone)**
	Exp. 2	Individual Exp.	Individual Exp.
Alpine Region	36%	31%	30%
Central East	14%	14%	15%
Central West	12%	9%	6%
Greece	28%	23%	-
Iberian Peninsula	17%	17%	17%
Iceland	36%	36%	
Mediterranean Region	16%	7%	7%
Norway	38%	35%	-
Sweden, Finland	8%	3%	
UK, Ireland	26%	26%	

Table 5-1: Percentage of stations misclassified according to the different approaches (More desirable values are highlighted)

As can be seen from the above table, missclassification is reduced when individual exponents are used. This is partly due to the fact that in half of the regions individual exponents are higher than 2, therefore points close by receive more weight during inverse distance weighting. It is important to note that the revised approach, that has been introduced in order to optimise performance at the borders, doesn't introduce major changes, and in two cases it reduces the number of missclassified stations, while in one case there is a slight increase.

5.2.2 The evaluation of the overall error

The evaluation of the overall error can be made by analysing the error distribution, i.e. by analysing the mean and spread of the error. Ideally the error should be normally distributed, centred on zero with a spread as small as possible.

	Basic Approach - Exponent 2			
Climatic Region	Mean	Min	Max	StdDev
Alps	-0.008	-5.58	4.46	1.09
East	-0.032	-3.3258	4.3966	0.5457
West	0.0067	-0.2171	0.2038	0.0668
Greece	0.0063	-1.1114	1.4723	0.4286
Iberia	0.0216	-0.9161	0.7524	0.1908
Iceland	0.1552	-5.59	5.3	1.5023
Med	0.0952	-2.1825	2.7056	0.7465
Norway	0.0619	-4.35	2.65	1.0083
Se, Fi	0.0035	-0.6321	0.4364	0.2142
UK, Eire	0.0006	-0.3390	0.2379	0.0765

	Basic Approach - Best Exponent				**Revised Approach - Best Exponent (with buffer zone)**			
Climatic Region	Mean	Min	Max	StdDev	Mean	Min	Max	StdDev
Alps	-0.04648	-4.40698	4.999802	0.052017	-0.02632	-4.40698	4.999802	0.052148
East	0.016893	-4.39662	3.325757	0.034098	0.018851	-4.39662	3.325757	0.034463
West	-0.00364	-0.23	0.180952	0.005944	-0.00497	-0.12225	0.159735	0.005245
Greece	-0.05596	-1.41939	1.114186	0.033076	-	-	-	-
Iberia	-0.01868	-0.75242	0.916123	0.009784	-0.02107	-0.75242	0.916123	0.009852
Iceland	-0.08909	-5.3	5.59	0.131579	-	-	-	-
Med	0.046778	-2.55232	3.839283	0.730576	0.021913	2.55232	3..82928	0.724142
Norway	-0.06	-2.65	4.65	0.043698	-	-	-	-
Se, Fi	0.030617	-1.30857	0.785119	0.013139	-	-	-	-
UK, Eire	-0.01267	-0.23487	0.298084	0.004662	-	-	-	-

Table 5-2: Statistics of the differences between characteristic snow loads and mapped snow loads (error distribution)
(More desirable values are highlighted)
mean, min=minimum, max=maximum, StdDev=standard deviation

The most important thing that can be noted in the above table, is that introducing an individual exponent for every climatic region allows to reduce the overall error, in fact standard deviation is smaller for all the climatic regions. Minimum and maximum don't show a clear trend, but this is not surprising, as they are easily influenced by a single point.

Also for the overall error the revised approach doesn't introduce major changes for the performance in the region, it is therefore interesting to determine if the expected improvement at the borders is really there.

5.3 Verification and uncertainty analysis for possible discrepancies occurring at boundaries between climatic regions

For a complete analysis it is necessary to evaluate the behaviour of the border points. The different climatic regions use different snow load-altitude relationships, therefore border reference points at a certain height will have different snow load values according to the maps of the two adjoining climatic regions. Small differences in snow load values for the border points are unavoidable and completely acceptable (smaller than the amplitude of the snow load in a zone), greater differences are not desirable and need to be checked.
Checkpoints have been determined by following the border and introducing a checkpoint every time the sum of the length of the border segments exceeded 20 km.
The importance of the difference in snow load values of the border points, determined according to the maps of the two ajoining regions, was evaluated and compared for the basic approach and for the revised elaboration.
The evaluation of the overall error was made, by analysing the error distribution. Ideally this should be normally distributed, centred on zero with a spread as small as possible.

	Basic Approach - Exponent 2			
Border	Mean	Min	Max	StDev
Alps-East	0.5067	-1.7328	1.6315	0.7614
Alps-Med	-0.0830	-4.4877	1.5273	1.3162
Alps-West	0.2805	-0.2157	1.1205	0.3262
West-East	-0.1335	-0.6116	0.2924	0.2222
West-Iberia	-0.1653	-1.1955	0.0614	0.3717
West-Med	-0.9983	-2.7264	-0.1295	0.7931

	Basic Approach - Best Exponent				**Revised Approach - Best Exponent**			
Border	Mean	Min	Max	StDev	Mean	Min	Max	StDev
Alps-East	0.37	-1.73	1.64	0.13	0.04	-0.68	1.64	0.07
Alps-Med	0.45	-2.03	5.08	0.17	-0.041	-1.79	1.12	0.077
Alps-West	0.29	-0.22	1.49	0.065	0.0048	-0.22	0.73	0.043
West-East	-0.13	-0.55	0.27	0.032	0.080	-0.46	0.46	0.033
West-Iberia	-0.17	-1.20	0.055	0.088	-0.071	-0.65	0.22	0.059
West-Med	-0.79	-1.63	-0.03	0.19	-0.22	-1.05	0.30	0.14

Table 5-3: Statistics of the differences obtained when assigning border points to zones on either side of the borders (error distribution).
(More desirable values are highlighted)

As can be seen in the above table the second approach works better than the first one, with a few exceptions. Again, the important thing to note is that standard deviation is lower using a customised exponent and even lower with the revised approach using buffer zones.

5.4 Results

The comparison of the results shows clearly that the new approach (individual exponent, with buffer zones) brings some improvement and is therefore preferable.

The comparison at the stations shows that introducing an individualised exponent for every climatic region allows to reduce the number of missclassified stations and the overall error.

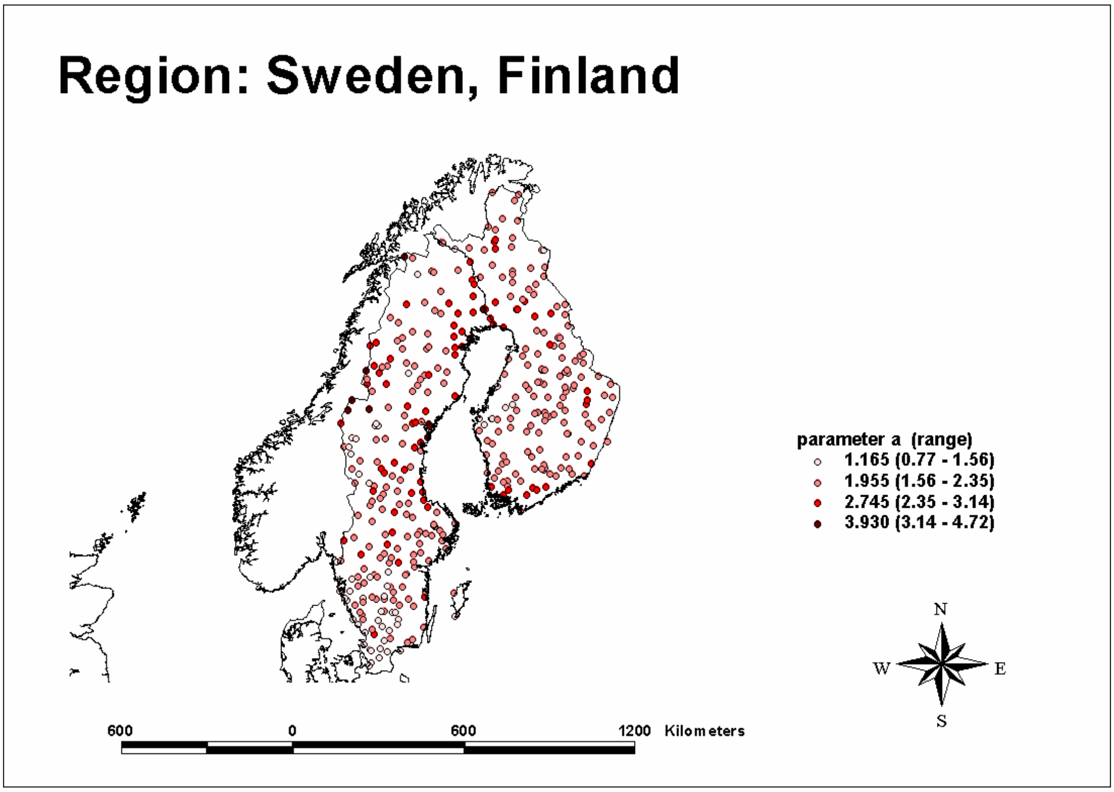
As the revised approach using buffer zones has been introduced in order to reduce divergences at the borders, there is no guaranty that values within the region don't get worse, it is therefore important to check the results at the meteorological stations. This control allowed to confirm that the revised approach doesn't introduce major changes of the results at the stations.

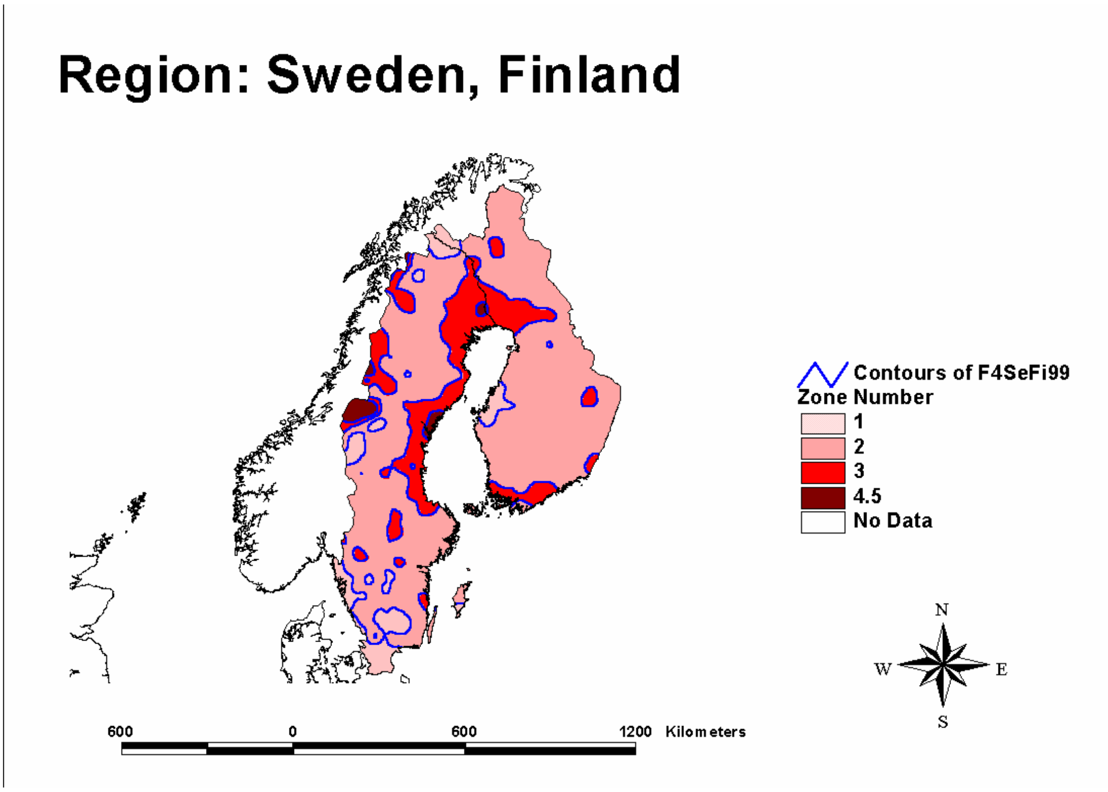
Furthermore the evaluation of the differences in snow load values at the borders between different climatic regions, calculated according to the two different maps, shows clearly that the revised approach allows to reduce discrepancies at the border.

It is important to underline that the general procedure set up for the elaboration of the map in the first phase is not changed, therefore the new map, here presented is not too much different from the previous one, but the new approach allowed to introduce some important improvements.

A complete set of the ground snow maps are presented in Annex B.

Snow Load Map of Sweden and Finland - Revised Approach





COMPARISON OF MAPPED SNOW LOAD VALUES AND CHARACTERISTIC SNOW LOAD VALUES FOR EVERY SINGLE STATION

Exp. 4, Buffer (IDW)

Country	N° Station	Name of Station	Lon	Lat	Altitude	Map Zone Value	Chr. Snow Load Zone Value	ZN Flg	Map Snow Load (A) kN/m²	Chr. Snow Load (B) kN/m²	Diff. (A-B) kN/m²	Diff. Percent [(A-B)/A]	Env Snow Load kN/m²	Diff. (A-Env) kN/m²	Diff. Percent (A-Env)/A)	Diff. (B-Env) kN/m²	Diff. Percent (B-Env)/A)
FI	1141101	ANJALANKOSKI, M─MM─L─	26.85	60.67	40	2.00	2.00	0	2.07	2.30	-0.23	-11	2.50	-0.43	-21	-0.20	-9
FI	21070	ANSOPURO, SOTKAMO	28.35	64.29	218	2.00	2.00	0	2.60	2.62	-0.02	-1	2.75	-0.15	-6	-0.13	-5
FI	1049101	ENO, LUHTAPOHJA	30.42	62.79	126	2.00	2.00	0	2.33	2.68	-0.35	-15	3.00	-0.67	-29	-0.32	-12
FI	1656301	ENONTEKIÍ, HETTA	23.68	68.39	300	2.00	2.00	0	2.85	2.90	-0.05	-2	3.00	-0.15	-5	-0.10	-3
FI	1340101	Eurajoki,Olkiluoto	21.48	61.24	5	2.00	2.00	0	1.97	2.14	-0.17	-9	2.25	-0.28	-14	-0.11	-5
FI	20810	HAAPAJYR─, YLISTARO	22.49	62.94	22	1.00	1.00	0	1.23	1.55	-0.32	-26	2.00	-0.77	-63	-0.45	-29
FI	1820001	HANKO, SANTALA	23.09	59.87	2	2.00	2.00	0	1.96	2.20	-0.24	-12	2.50	-0.54	-27	-0.30	-14
FI	1357701	HAUHO, L─NSI-HAHKIALA	24.59	61.10	102	2.00	2.00	0	2.26	2.18	0.08	3	2.50	-0.24	-11	-0.32	-15
FI	1149301	HAUKIVUORI	27.27	61.95	128	2.00	2.00	0	2.34	2.22	0.12	5	2.50	-0.16	-7	-0.28	-13
FI	20720	HEIN─JOKI, KORPILAHTI	25.40	62.17	131	2.00	2.00	0	2.34	2.46	-0.12	-5	2.50	-0.16	-7	-0.04	-2
FI	1042701	HEIN─VESI,	28.77	62.39	98	2.00	2.00	0	2.25	2.50	-0.25	-11	2.75	-0.50	-22	-0.25	-10

		HASUM─KI														
FI	20440	HUHTISUONOJA, RUOKOLAHTI	29.65	61.37	85	2.00	2.00	0	2.21	2.55	-0.34	-15	2.75	-0.54	-25	-0.20	-8
FI	21010	HUOPAKINOJA, PATTIJOKI	24.60	64.67	16	2.00	2.00	0	2.00	1.95	0.05	3	2.00	0.00	0	-0.05	-3
FI	1594501	HYRYNSALMI, PALJAKKA	28.07	64.72	380	2.00	2.00	0	3.09	3.45	-0.36	-12	2.75	0.34	11	0.70	20
FI	1141201	IITTI, KAURAMAA	26.27	60.92	86	2.00	2.00	0	2.21	2.40	-0.19	-9	2.50	-0.29	-13	-0.10	-4
FI	21171	IITTOVUOMA 1	21.45	68.74	484	1.00	1.00	0	2.61	2.90	-0.29	-11	3.00	-0.39	-15	-0.10	-3
FI	21172	IITTOVUOMA 2	21.45	68.74	510	1.00	1.00	0	2.68	2.95	-0.27	-10	3.00	-0.32	-12	-0.05	-2
FI	21173	IITTOVUOMA 3	21.49	68.75	539	1.00	1.00	0	2.77	3.00	-0.23	-8	3.00	-0.23	-8	0.00	0
FI	21174	IITTOVUOMA 4	21.48	68.73	651	1.00	1.00	0	3.10	3.00	0.10	3	3.00	0.10	3	0.00	0
FI	1658101	IL.,SODANKYL─N OBSERVATORIO	26.64	67.34	180	2.00	2.00	0	2.49	2.60	-0.11	-4	3.00	-0.51	-20	-0.40	-15
FI	1049201	ILOMANTSI	30.93	62.66	160	2.00	2.00	0	2.43	2.83	-0.40	-16	3.00	-0.57	-23	-0.17	-6
FI	1049501	ILOMANTSI, NAARVA	31.06	63.06	178	2.00	2.00	0	2.48	2.82	-0.34	-13	3.00	-0.52	-21	-0.18	-6
FI	1680401	INARI, ANGELI	25.67	68.90	200	2.00	2.00	0	2.55	2.55	0.00	0	2.75	-0.20	-8	-0.20	-8
FI	1715101	INARI, IVALON MATTI	25.89	68.37	266	3.00	3.00	0	3.54	3.25	0.29	8	3.00	0.54	15	0.25	8
FI	1711101	INARI, NELLIM	28.30	68.84	124	2.00	2.00	0	2.32	2.38	-0.06	-2	2.50	-0.18	-8	-0.12	-5
FI	1714301	INARI, REPOJOKI	25.94	68.43	266	3.00	3.00	0	3.54	3.20	0.34	10	3.00	0.54	15	0.20	6
FI	1690601	INARI, SEVETTIJ─RVI	28.60	69.50	101	2.00	2.00	0	2.26	2.43	-0.17	-8	2.50	-0.24	-11	-0.07	-3
FI	1712101	INARI, TOIVONNIEMI	27.07	69.04	140	2.00	2.00	0	2.37	2.42	-0.05	-2	2.50	-0.13	-5	-0.08	-3
FI	1718101	INARI,LEMMENJOKI	26.24	68.75	160	2.00	2.00	0	2.43	2.55	-0.12	-5	2.75	-0.32	-13	-0.20	-8
FI	1420401	JALASJ─RVI	22.74	62.47	120	2.00	2.00	0	2.31	2.20	0.11	5	2.50	-0.19	-8	-0.30	-14
FI	1359201	JOKIOINEN	23.49	60.81	100	2.00	2.00	0	2.25	2.28	-0.03	-1	2.50	-0.25	-11	-0.22	-10
FI	20450	JUONISTONOJA, HAUKIVUORI	27.22	61.95	120	2.00	2.00	0	2.31	2.20	0.11	5	2.50	-0.19	-8	-0.30	-14
FI	1400001	JURVA, KIVINEVA	21.89	62.77	80	2.00	1.00	1	2.19	1.77	0.42	19	2.00	0.19	9	-0.23	-13

FI	20830	KAIDELUOMA, ALAVUS	23.64	62.53	101	2.00	2.00	0	2.26	2.36	-0.10	-5	2.50	-0.24	-11	-0.14	-6
FI	20820	KAINASTONLUOMA, YLISTARO	22.52	62.92	37	1.00	1.00	0	1.28	1.55	-0.27	-22	2.00	-0.72	-57	-0.45	-29
FI	1320001	KALANTI	21.60	60.80	20	3.00	3.00	0	2.80	2.56	0.24	9	2.25	0.55	20	0.31	12
FI	1370201	KARIJOKI	21.93	62.25	121	2.00	2.00	0	2.32	2.39	-0.07	-3	2.25	0.07	3	0.14	6
FI	1230401	KARKKILA,HAAPALA,HAUKKAM─KI	24.19	60.52	89	3.00	3.00	0	3.01	2.70	0.31	10	2.50	0.51	17	0.20	7
FI	1500001	KARLEBY	23.23	63.87	19	1.00	1.00	0	1.22	1.58	-0.36	-29	2.00	-0.78	-64	-0.42	-27
FI	20330	KATAJALUOMA, IKAALINEN	22.78	61.69	109	2.00	2.00	0	2.28	2.08	0.20	9	2.25	0.03	1	-0.17	-8
FI	21060	KAUKOLANPURO, PYH─NT─	26.77	64.09	177	2.00	2.00	0	2.48	2.45	0.03	1	2.25	0.23	9	0.20	8
FI	1653101	KEMIJ─RVI, HALOSENRANTA	27.49	66.65	171	2.00	2.00	0	2.46	2.57	-0.11	-4	3.00	-0.54	-22	-0.43	-17
FI	1653102	KEMIJ─RVI,JUMISKON VL,KONEAS.	27.79	66.50	183	2.00	2.00	0	2.50	2.70	-0.20	-8	3.00	-0.50	-20	-0.30	-11
FI	20510	KESSELINPURO, OUTOKUMPU	29.03	62.67	100	3.00	3.00	0	3.04	2.68	0.36	12	2.75	0.29	10	-0.07	-3
FI	1356601	KEURUU, SUOLAHTI	24.62	62.29	120	2.00	2.00	0	2.31	2.48	-0.17	-7	2.50	-0.19	-8	-0.02	-1
FI	1351501	KIIKOINEN	22.57	61.45	70	2.00	2.00	0	2.16	1.95	0.21	10	2.25	-0.09	-4	-0.30	-15
FI	21180	KIRNUOJA, SIMO	24.78	65.67	9	3.00	3.00	0	2.77	2.57	0.20	7	2.75	0.02	1	-0.18	-7
FI	1655701	KITTIL─, HORMAKUMPU	25.20	67.67	200	2.00	2.00	0	2.55	2.85	-0.30	-12	3.00	-0.45	-18	-0.15	-5
FI	1658401	KITTIL─, POKKA	25.77	68.15	268	3.00	3.00	0	3.54	3.30	0.24	7	3.00	0.54	15	0.30	9
FI	1656801	KITTIL─, PULJU	24.83	68.22	282	2.00	2.00	0	2.79	3.03	-0.24	-8	3.00	-0.21	-7	0.03	1
FI	1045701	KIURUVESI, LAPINSALO	26.62	63.64	179	2.00	2.00	0	2.49	2.45	0.04	2	2.50	-0.01	0	-0.05	-2
FI	20620	KOHISEVANPURO, KARTTULA	27.28	62.85	117	2.00	2.00	0	2.30	2.45	-0.15	-6	2.50	-0.20	-9	-0.05	-2
FI	1673701	KOLARI, KATTILAMAA	24.02	67.38	174	2.00	2.00	0	2.47	2.70	-0.23	-9	3.00	-0.53	-21	-0.30	-11

FI	1144101	KONGINKANGAS, KIVETTY	25.69	62.81	180	2.00	2.00	0	2.49	2.65	-0.16	-6	2.50	-0.01	0	0.15	6
FI	1144201	KONNEVESI, S─RKISALO	26.17	62.75	121	2.00	2.00	0	2.32	2.48	-0.16	-7	2.50	-0.18	-8	-0.02	-1
FI	1147102	KONNEVESI,TUTKI MUSASEMA	26.34	62.62	100	2.00	2.00	0	2.25	2.32	-0.07	-3	2.50	-0.25	-11	-0.18	-8
FI	20170	KOPPELONOJA, KOSKI HL.	25.14	61.01	120	2.00	2.00	0	2.31	2.40	-0.09	-4	2.50	-0.19	-8	-0.10	-4
FI	21130	KORINTTEENOJA,R OVANIEMEN MLK.	26.88	66.32	109	3.00	3.00	0	3.07	2.77	0.30	10	3.00	0.07	2	-0.23	-8
FI	20611	KORPIJOKI	26.37	63.72	112	2.00	2.00	0	2.29	2.35	-0.06	-3	2.25	0.04	2	0.10	4
FI	1358301	KOSKI HL, ETOLA	25.22	61.04	120	2.00	2.00	0	2.31	2.45	-0.14	-6	2.50	-0.19	-8	-0.05	-2
FI	21200	KOTIOJA, RANUA	26.15	66.14	168	3.00	3.00	0	3.25	3.00	0.25	8	3.00	0.25	8	0.00	0
FI	1357201	KUHMALAHTI,V─H ─-PENTO	24.54	61.50	101	2.00	2.00	0	2.26	2.08	0.18	8	2.50	-0.24	-11	-0.42	-20
FI	1044401	KUHMO, JONKERI	29.72	63.95	204	2.00	2.00	0	2.56	2.70	-0.14	-5	3.00	-0.44	-17	-0.30	-11
FI	1599101	KUHMO, PALONIEMI	29.22	64.10	160	2.00	2.00	0	2.43	2.40	0.03	1	3.00	-0.57	-23	-0.60	-25
FI	1599501	KUHMO, VARAJOKI	29.69	64.20	180	2.00	2.00	0	2.49	2.50	-0.01	0	3.00	-0.51	-20	-0.50	-20
FI	1599502	Kuhmo,Lentua, Romuvaara	29.94	64.22	340	2.00	2.00	0	2.97	2.60	0.37	12	3.00	-0.03	-1	-0.40	-15
FI	1142601	KUHMOINEN, PUUKKOINEN	25.17	61.65	121	2.00	2.00	0	2.32	2.20	0.12	5	2.50	-0.18	-8	-0.30	-14
FI	20940	KUIKKISENOJA, K─LVI─	23.40	63.90	12	1.00	1.00	0	1.20	1.55	-0.35	-29	2.00	-0.80	-67	-0.45	-29
FI	1740101	KUUSAMO, KOSKENKYL─	29.80	65.89	260	2.00	2.00	0	2.73	2.70	0.03	1	3.00	-0.27	-10	-0.30	-11
FI	1595301	KUUSAMO, KURVINEN	29.57	65.58	240	2.00	2.00	0	2.67	3.00	-0.33	-12	3.00	-0.33	-12	0.00	0
FI	21110	KUUSIVAARANPU RO, SALLA	28.13	66.75	180	2.00	2.00	0	2.49	2.67	-0.18	-7	3.00	-0.51	-20	-0.33	-12
FI	1146401	KYYJ─RVI, MÍKSY	24.30	63.03	200	2.00	2.00	0	2.55	2.22	0.33	13	2.25	0.30	12	-0.03	-1

FI	21210	LAANIOJA, INARI	27.45	68.37	345	2.00	2.00	0	2.98	2.80	0.18	6	2.75	0.23	8	0.05	2
FI	1357801	LAMMI,EVO	25.19	61.17	162	2.00	2.00	0	2.44	2.39	0.05	2	2.50	-0.06	-3	-0.11	-5
FI	1470301	LAPPAJ─RVI, KK	23.63	63.19	80	1.00	1.00	0	1.40	1.76	-0.36	-25	2.25	-0.85	-60	-0.49	-28
FI	1060201	LAPPEENRANTA	28.19	60.83	60	3.00	3.00	0	2.92	2.68	0.24	8	2.75	0.17	6	-0.07	-3
FI	1330001	LAPPI TL, KAUKOLA	21.91	61.07	40	2.00	2.00	0	2.07	2.40	-0.33	-16	2.25	-0.18	-8	0.15	6
FI	20430	LATOSUONOJA, RUOKOLAHTI	28.69	61.36	90	2.00	2.00	0	2.22	2.58	-0.36	-16	2.75	-0.53	-24	-0.17	-7
FI	20040	LAUHAVUORI, ISOJOKI	22.17	62.15	218	2.00	2.00	0	2.60	2.85	-0.25	-9	2.25	0.35	14	0.60	21
FI	1440701	LEHTIM─KI, L─NSIKYL─	23.75	62.80	140	2.00	2.00	0	2.37	2.35	0.02	1	2.50	-0.13	-5	-0.15	-6
FI	1046302	LEHTOM─KI, NILSI─	27.97	63.24	175	2.00	2.00	0	2.48	2.55	-0.07	-3	2.75	-0.27	-11	-0.20	-8
FI	1042702	LEPP─VIRTA, PAUKARLAHTI	27.55	62.67	117	2.00	2.00	0	2.30	2.50	-0.20	-9	2.50	-0.20	-9	0.00	0
FI	1044901	LIEKSA, RUUNAA	30.42	63.42	142	2.00	2.00	0	2.38	2.75	-0.37	-16	3.00	-0.62	-26	-0.25	-9
FI	20612	LIITTOPER─	26.22	63.73	142	2.00	2.00	0	2.38	2.38	0.00	0	2.25	0.13	5	0.13	5
FI	1043502	LIPERI, AHONKYL─	26.18	62.65	91	2.00	2.00	0	2.23	2.62	-0.39	-18	2.50	-0.27	-12	0.12	5
FI	21120	LISMANOJA, SODANKYL─	26.55	67.24	211	2.00	2.00	0	2.58	2.62	-0.04	-1	3.00	-0.42	-16	-0.38	-15
FI	21140	LOMAKYL─	27.74	66.45	159	2.00	2.00	0	2.43	2.60	-0.17	-7	3.00	-0.57	-24	-0.40	-15
FI	20210	LÍYT─NEENOJA, KOKEM─KI	22.24	61.27	41	2.00	2.00	0	2.08	2.04	0.04	2	2.25	-0.17	-8	-0.21	-10
FI	20180	LÍYTTYNOJA, LAMMI	25.00	61.04	146	2.00	2.00	0	2.39	2.40	-0.01	0	2.50	-0.11	-5	-0.10	-4
FI	1360101	MERIKARVIA, LANKOSKI	21.67	61.81	28	2.00	2.00	0	2.04	2.15	-0.11	-5	2.00	0.04	2	0.15	7
FI	1351502	MOUHIJ─RVI,TERVAM─KI	22.90	61.50	79	2.00	2.00	0	2.19	1.95	0.24	11	2.25	-0.06	-3	-0.30	-15
FI	1591201	MUHOS,LEPPINIEMI	26.02	64.85	38	2.00	2.00	0	2.07	1.98	0.09	4	2.25	-0.18	-9	-0.27	-14
FI	1145401	MULTIA,	25.02	62.44	181	2.00	2.00	0	2.49	2.80	-0.31	-12	2.50	-0.01	0	0.30	11

		SAHRAJ─RVI															
FI	21040	MURRONOJA, PYH─NT─	26.77	64.10	165	2.00	2.00	0	2.45	2.45	0.00	0	2.25	0.20	8	0.20	8
FI	20540	MURTOPURO, VALTIMO	28.47	63.79	214	2.00	2.00	0	2.59	2.80	-0.21	-8	2.75	-0.16	-6	0.05	2
FI	1043901	MUSTALAHTI,KES─LAHTI	29.70	62.07	94	2.00	2.00	0	2.23	2.28	-0.05	-2	2.75	-0.52	-23	-0.47	-21
FI	20530	MUSTAPURO, OUTOKUMPU	29.18	62.79	88	3.00	3.00	0	3.01	2.68	0.33	11	2.75	0.26	9	-0.07	-3
FI	21160	MYLLYOJA, SAVUKOSKI	28.13	67.30	180	2.00	2.00	0	2.49	2.55	-0.06	-2	3.00	-0.51	-20	-0.45	-18
FI	21030	MYLLYPURO, HYRYNSALMI	28.62	64.65	175	2.00	2.00	0	2.48	2.80	-0.32	-13	3.00	-0.52	-21	-0.20	-7
FI	1690603	N──T─MÍ	29.14	69.65	85	2.00	2.00	0	2.21	2.50	-0.29	-13	2.50	-0.29	-13	0.00	0
FI	20410	NIITTYJOKI, VALKEALA	26.75	60.84	55	2.00	2.00	0	2.12	2.28	-0.16	-8	2.50	-0.38	-18	-0.22	-10
FI	20840	NORRSKOGSDIKET, N─RPES	21.47	62.61	20	2.00	2.00	0	2.01	1.83	0.18	9	2.00	0.01	1	-0.17	-9
FI	1044101	NURMES, LIPINLAHTI	29.30	63.54	116	2.00	2.00	0	2.30	2.58	-0.28	-12	2.75	-0.45	-20	-0.17	-7
FI	1440901	NURMO, MARTIKKALANJ─RVI	22.89	62.85	104	2.00	2.00	0	2.26	2.02	0.24	11	2.25	0.01	1	-0.23	-11
FI	1180501	ORIMATTILA, KEITURI	25.45	60.83	90	2.00	2.00	0	2.22	2.50	-0.28	-12	2.50	-0.28	-12	0.00	0
FI	1160001	ORIMATTILA, PAKAA	25.79	60.72	60	2.00	2.00	0	2.13	2.45	-0.32	-15	2.50	-0.37	-17	-0.05	-2
FI	1359101	ORIP──,TEINIKIVI	22.71	60.89	80	2.00	2.00	0	2.19	2.25	-0.06	-3	2.25	-0.06	-3	0.00	0
FI	20930	PAHKAOJA,LESTIJ─RVI	24.44	63.44	159	2.00	2.00	0	2.43	2.20	0.23	9	2.25	0.18	7	-0.05	-2
FI	1490901	PERHO, PELTOKANGAS	24.12	63.24	140	1.00	1.00	0	1.58	1.95	-0.37	-23	2.25	-0.67	-42	-0.30	-15
FI	1595401	PESIÍ,	28.54	64.93	269	2.00	2.00	0	2.76	3.00	-0.24	-9	3.00	-0.24	-9	0.00	0

		JOUTENVAARA														
FI	1595402	PESIÍ, JOUTENVAARA, I-L	28.53	64.93	260	2.00	2.00	0	2.73	3.00	-0.27	-10	3.00	-0.27	-10	0.00	0
FI	1147901	PIEKS─M─KI	27.23	62.30	136	2.00	2.00	0	2.36	2.45	-0.09	-4	2.50	-0.14	-6	-0.05	-2
FI	1147301	PIELAVESI, S─VI─	26.66	63.19	120	2.00	2.00	0	2.31	2.30	0.01	1	2.50	-0.19	-8	-0.20	-9
FI	1144701	PIHTIPUDAS, Luomala	25.67	63.34	124	2.00	2.00	0	2.32	2.40	-0.08	-3	2.50	-0.18	-8	-0.10	-4
FI	1048401	POLVIJ─RVI, MARTONVAARA	29.41	63.07	162	3.00	3.00	0	3.23	2.85	0.38	12	2.75	0.48	15	0.10	4
FI	1280001	PÍYTY─, RIIHIKOSKI	22.60	60.72	63	2.00	2.00	0	2.14	2.52	-0.38	-18	2.25	-0.11	-5	0.27	11
FI	1612101	PUDASJ─RVI, JONKU	27.17	65.32	120	2.00	2.00	0	2.31	2.55	-0.24	-10	2.75	-0.44	-19	-0.20	-8
FI	1617101	PUDASJ─RVI, KORPINEN	27.62	65.20	140	2.00	2.00	0	2.37	2.70	-0.33	-14	2.75	-0.38	-16	-0.05	-2
FI	1615201	PUDASJ─RVI, SARAKYL─	27.33	65.79	160	3.00	3.00	0	3.22	2.90	0.32	10	3.00	0.22	7	-0.10	-3
FI	1570601	PULKKILA,JYLH─N RANTA	25.85	64.34	79	2.00	2.00	0	2.19	2.10	0.09	4	2.25	-0.06	-3	-0.15	-7
FI	1600501	PUOLANKA	27.80	64.80	202	3.00	3.00	0	3.35	3.00	0.35	10	2.75	0.60	18	0.25	8
FI	1041201	PUUMALA, HEISKA	28.00	61.58	85	2.00	2.00	0	2.21	2.35	-0.14	-6	2.75	-0.54	-25	-0.40	-17
FI	1540501	PYH─J─RVI OL	25.47	63.60	100	2.00	2.00	0	2.25	2.35	-0.10	-4	2.25	0.00	0	0.10	4
FI	1657801	RAUDANJOKI	26.40	67.00	180	2.00	2.00	0	2.49	2.80	-0.31	-12	3.00	-0.51	-20	-0.20	-7
FI	1147101	RAUTALAMPI	26.69	62.62	100	2.00	2.00	0	2.25	2.37	-0.12	-5	2.50	-0.25	-11	-0.13	-5
FI	1046801	RAUTAVAARA, ALALUOSTA	28.47	63.27	120	2.00	2.00	0	2.31	2.60	-0.29	-12	2.75	-0.44	-19	-0.15	-6
FI	1046802	RAUTAVAARA, YL─LUOSTA	28.66	63.37	161	2.00	2.00	0	2.43	2.70	-0.27	-11	2.75	-0.32	-13	-0.05	-2
FI	20420	RAVIJOKI, VIROLAHTI	27.55	60.52	20	2.00	2.00	0	2.01	2.37	-0.36	-18	2.75	-0.74	-37	-0.38	-16
FI	1652401	ROVANIEMI MLK, PEKKALA	26.83	66.39	159	3.00	2.00	1	3.22	2.76	0.46	14	3.00	0.22	7	-0.24	-9
FI	1657101	ROVANIEMI,	25.97	66.57	120	2.00	2.00	0	2.31	2.68	-0.37	-16	3.00	-0.69	-30	-0.32	-12

		OLKKAJ─RVI															
FI	20710	RUUNAPURO, LAUKAA	26.03	62.50	101	2.00	2.00	0	2.26	2.34	-0.08	-4	2.50	-0.24	-11	-0.16	-7
FI	1146801	SAARIJ─RVI, PYH─J─RVI	25.49	62.80	155	2.00	2.00	0	2.42	2.65	-0.23	-10	2.50	-0.08	-3	0.15	6
FI	1654801	SALLA, KELLOSELK─	28.99	66.94	200	2.00	2.00	0	2.55	2.70	-0.15	-6	3.00	-0.45	-18	-0.30	-11
FI	1654701	SALLA, NARUSKA	29.24	67.21	280	2.00	2.00	0	2.79	2.96	-0.17	-6	3.00	-0.21	-8	-0.04	-1
FI	20220	SAVIJOKI, TARVASJOKI	22.64	60.59	60	3.00	3.00	0	2.92	2.63	0.29	10	2.50	0.42	14	0.13	5
FI	1041401	SAVITAIPALE	27.54	61.18	100	2.00	2.00	0	2.25	2.40	-0.15	-7	2.75	-0.50	-22	-0.35	-15
FI	1042901	SAVONLINNA, HAAPALA	28.94	61.92	108	2.00	2.00	0	2.28	2.28	0.00	0	2.75	-0.47	-21	-0.47	-21
FI	1654301	SAVUKOSKI, AINIJ─RVI	29.45	67.75	240	2.00	2.00	0	2.67	2.90	-0.23	-9	3.00	-0.33	-12	-0.10	-3
FI	1046501	SIILINJ─RVI, KK	27.67	63.09	101	2.00	2.00	0	2.26	2.38	-0.12	-6	2.50	-0.24	-11	-0.12	-5
FI	20320	SIUKOLANPURO, ORIVESI	24.35	61.66	109	2.00	2.00	0	2.28	2.16	0.12	5	2.50	-0.22	-10	-0.34	-16
FI	1655901	SODANKYL─, UNARI	25.74	67.22	200	2.00	2.00	0	2.55	2.50	0.05	2	3.00	-0.45	-18	-0.50	-20
FI	1659301	SODANKYL─, VUOTSO	27.12	68.10	259	2.00	2.00	0	2.73	2.98	-0.25	-9	3.00	-0.27	-10	-0.02	-1
FI	1046401	SONKAJ─RVI, UURA	27.84	63.76	171	2.00	2.00	0	2.46	2.70	-0.24	-10	2.75	-0.29	-12	-0.05	-2
FI	1046402	SOTKAMO, LAAKA	28.28	63.82	311	2.00	2.00	0	2.88	3.10	-0.22	-8	2.75	0.13	5	0.35	11
FI	20850	SULVANJOKI, KORSHOLM	21.67	62.99	10	1.00	1.00	0	1.19	1.59	-0.40	-33	2.00	-0.81	-67	-0.41	-26
FI	1240301	SUOMUSJ─RVI, TAIPALE	23.70	60.32	61	3.00	3.00	0	2.93	2.58	0.35	12	2.50	0.43	15	0.08	3
FI	1595403	SUOMUSSALMI, JOKINIEMI	28.65	64.95	219	2.00	2.00	0	2.61	2.80	-0.19	-7	3.00	-0.39	-15	-0.20	-7
FI	1594301	SUOMUSSALMI, PESIÍ	28.55	64.92	241	2.00	2.00	0	2.67	2.90	-0.23	-9	3.00	-0.33	-12	-0.10	-3

FI	1595101	SUOMUSSALMI, RUHTINANSALMI	29.50	65.22	200	2.00	2.00	0	2.55	2.70	-0.15	-6	3.00	-0.45	-18	-0.30	-11
FI	20560	SUOPURO, SOTKAMO	28.48	63.87	200	2.00	2.00	0	2.55	2.83	-0.28	-11	2.75	-0.20	-8	0.08	3
FI	20460	SYV─OJA, SAVONLINNA	28.77	62.07	99	2.00	2.00	0	2.25	2.34	-0.09	-4	2.75	-0.50	-22	-0.41	-18
FI	1616201	TAIVALKOSKI,ING ET	28.56	65.73	258	3.00	3.00	0	3.51	3.20	0.31	9	3.00	0.51	15	0.20	6
FI	1580201	TEMMES	25.62	64.65	40	2.00	2.00	0	2.07	2.03	0.04	2	2.25	-0.18	-8	-0.22	-11
FI	1020101	TOHMAJ─RVI,KEM IE	30.35	62.23	102	2.00	2.00	0	2.26	2.52	-0.26	-12	2.75	-0.49	-22	-0.23	-9
FI	20920	TUJUOJA, HAAPAJ─RVI	25.35	63.74	97	2.00	2.00	0	2.24	1.95	0.29	13	2.25	-0.01	0	-0.30	-15
FI	1280002	TURKU	22.24	60.48	21	3.00	3.00	0	2.81	2.64	0.17	6	2.50	0.31	11	0.14	5
FI	20910	TUURAOJA, KALAJOKI	24.02	64.22	20	2.00	2.00	0	2.01	1.80	0.21	11	2.00	0.01	1	-0.20	-11
FI	1210801	TUUSULA, RUSKELA	25.00	60.45	60	3.00	3.00	0	2.92	2.65	0.27	9	2.50	0.42	14	0.15	6
FI	1352801	URJALA, VALAJ─RVI	23.32	61.07	120	2.00	2.00	0	2.31	2.00	0.31	14	2.25	0.06	3	-0.25	-13
FI	1680701	UTSJOKI	26.94	69.93	115	2.00	2.00	0	2.30	2.40	-0.10	-4	2.50	-0.20	-9	-0.10	-4
FI	1592101	VAALA, NISKA	26.79	64.59	121	2.00	2.00	0	2.32	2.30	0.02	1	2.25	0.07	3	0.05	2
FI	21020	V──R─JOKI,KUUS AMO	29.18	65.90	261	2.00	2.00	0	2.73	2.93	-0.20	-7	3.00	-0.27	-10	-0.07	-2
FI	1595404	VAATOJ─RVI	28.68	64.92	220	2.00	2.00	0	2.61	2.80	-0.19	-7	3.00	-0.39	-15	-0.20	-7
FI	1149101	VALKEALA, VOIKOSKI	26.78	61.25	98	2.00	2.00	0	2.25	2.30	-0.05	-2	2.50	-0.25	-11	-0.20	-9
FI	1046301	VARPAISJ─RVI, K─RS─M─KI	27.99	63.37	120	2.00	2.00	0	2.31	2.64	-0.33	-14	2.75	-0.44	-19	-0.11	-4
FI	1720321	V─RRIÍ	29.59	67.74	462	2.00	1.00	1	3.33	2.88	0.45	14	3.00	0.33	10	-0.12	-4
FI	1230901	VIHTI, SUONTAA	24.39	60.42	47	3.00	3.00	0	2.88	2.70	0.18	6	2.50	0.38	13	0.20	7
FI	1593901	VUOLIJOKI, SAARESM─KI	26.92	64.05	212	2.00	2.00	0	2.59	2.50	0.09	3	2.25	0.34	13	0.25	10

FI	1340401	YL─NE	22.42	60.88	60	2.00	2.00	0	2.13	2.42	-0.29	-13	2.25	-0.12	-5	0.17	7
FI	21190	YLIJOKI, RANUA	26.19	66.14	167	3.00	3.00	0	3.24	3.05	0.19	6	3.00	0.24	7	0.05	2
FI	1679101	YLITORNIO, HAAPAKOSKI	23.78	66.37	60	4.50	3.00	1	4.11	2.80	1.31	32	3.00	1.11	27	-0.20	-7
FI	1679801	YLITORNIO, MELTOSJ─RVI	24.65	66.52	100	3.00	3.00	0	3.04	2.80	0.24	8	3.00	0.04	1	-0.20	-7
SE	18880	ABISKO	18.82	68.36	388	2.00	2.00	0	3.11	3.15	-0.04	-1	4.00	-0.89	-29	-0.85	-27
SE	11416	─LVDALEN	14.04	61.26	250	2.00	2.00	0	2.70	2.67	0.03	1	3.00	-0.30	-11	-0.33	-12
SE	8200	ALVHEM	12.15	58.01	5	1.00	1.00	0	1.18	1.49	-0.31	-26	1.00	0.18	15	0.49	33
SE	16089	─LVSBYN	20.97	65.68	48	3.00	3.00	0	2.89	2.94	-0.05	-2	3.00	-0.11	-4	-0.06	-2
SE	10658	┼MOTSBRUK	16.46	60.96	145	3.00	3.00	0	3.18	2.99	0.19	6	3.00	0.18	6	-0.01	0
SE	16771	ARJEPLOG	17.90	66.05	428	2.00	2.00	0	3.23	2.94	0.29	9	3.00	0.23	7	-0.06	-2
SE	9739	ARLANDA	17.95	59.66	38	2.00	2.00	0	2.07	1.68	0.39	19	2.00	0.07	3	-0.32	-19
SE	9240	ARVIKA	12.59	59.67	50	2.00	2.00	0	2.10	2.33	-0.23	-11	2.50	-0.40	-19	-0.17	-7
SE	7528	ARVINGETORP	15.03	57.45	210	2.00	2.00	0	2.58	2.26	0.32	12	2.00	0.58	22	0.26	12
SE	14710	┼SELE	17.37	64.16	319	2.00	2.00	0	2.90	2.92	-0.02	-1	3.00	-0.10	-3	-0.08	-3
SE	14937	┼STR─SK	19.98	64.61	255	2.00	2.00	0	2.71	2.94	-0.23	-8	3.00	-0.29	-11	-0.06	-2
SE	9405	┼TORP	14.37	59.10	105	2.00	2.00	0	2.27	2.28	-0.01	-1	2.00	0.27	12	0.28	12
SE	14550	AVASJÍ	15.09	64.84	530	3.00	3.00	0	4.32	4.51	-0.19	-4	4.00	0.32	7	0.51	11
SE	13242	BAKSJÍN─SET	12.65	63.71	425	4.50	4.50	0	5.19	5.98	-0.79	-15	4.00	1.19	23	1.98	33
SE	6218	BARK┼KRA	12.85	56.29	17	1.00	1.00	0	1.22	1.40	-0.18	-15	1.00	0.22	18	0.40	29
SE	14837	B─VERTR─SK	18.34	64.62	385	2.00	2.00	0	3.10	3.24	-0.14	-4	3.00	0.10	3	0.24	7
SE	13602	BISPG┼RDEN	16.55	63.03	170	2.00	2.00	0	2.46	2.58	-0.12	-5	3.00	-0.54	-22	-0.42	-16
SE	14203	BJÍRKEDET	12.94	64.04	451	4.50	4.50	0	5.27	5.41	-0.14	-3	4.00	1.27	24	1.41	26
SE	15571	BLAIKLIDEN	15.74	65.05	540	2.00	2.00	0	3.56	3.45	0.11	3	4.00	-0.44	-12	-0.55	-16
SE	16194	BODEN	21.69	65.81	16	3.00	3.00	0	2.79	2.88	-0.09	-3	3.00	-0.21	-7	-0.12	-4
SE	7302	BOLMSÍ	13.73	57.02	160	1.00	1.00	0	1.64	1.90	-0.26	-16	1.50	0.14	9	0.40	21
SE	7245	BOR┼S	12.95	57.76	140	1.00	1.00	0	1.58	1.69	-0.11	-7	1.50	0.08	5	0.19	11
SE	6516	BRED┼KRA	15.27	56.26	58	2.00	2.00	0	2.13	2.07	0.06	3	1.00	1.13	53	1.07	52
SE	13827	BREDBYN	18.06	63.46	75	3.00	3.00	0	2.97	3.34	-0.37	-13	3.00	-0.03	-1	0.34	10
SE	13442	DAL	14.13	63.70	480	4.50	4.50	0	5.36	5.57	-0.21	-4	3.00	2.36	44	2.57	46
SE	11648	DELSBO	16.55	61.79	88	3.00	2.00	1	3.01	2.58	0.43	14	3.00	0.01	0	-0.42	-16
SE	15677	DIKAN─S	15.99	65.24	485	2.00	3.00	1	3.40	3.84	-0.44	-13	4.00	-0.60	-18	-0.16	-4

SE	9137	DJURSKOG	11.93	59.61	215	3.00	3.00	0	3.38	3.02	0.36	11	2.50	0.88	26	0.52	17
SE	11523	EDSBYN	15.80	61.38	184	2.00	2.00	0	2.50	2.67	-0.17	-7	3.00	-0.50	-20	-0.33	-12
SE	13624	EDSELE	16.56	63.41	150	2.00	2.00	0	2.40	2.67	-0.27	-11	3.00	-0.60	-25	-0.33	-12
SE	9738	ENKÍPING	17.07	59.64	20	2.00	2.00	0	2.01	1.99	0.02	1	1.50	0.51	26	0.49	25
SE	11308	EVERTSBERG	13.97	61.13	430	2.00	3.00	1	3.23	3.70	-0.47	-14	3.00	0.23	7	0.70	19
SE	11448	F┼GELSJÍ	14.65	61.80	410	2.00	3.00	1	3.18	3.63	-0.45	-14	3.00	0.18	6	0.63	17
SE	7212	FAGERED	12.81	57.20	100	2.00	2.00	0	2.25	2.16	0.09	4	1.00	1.25	56	1.16	54
SE	16080	FAGERHEDEN	20.90	65.34	220	3.00	3.00	0	3.40	3.47	-0.07	-2	3.00	0.40	12	0.47	14
SE	16074	F─LLFORS	20.79	65.13	195	3.00	3.00	0	3.33	3.34	-0.01	0	3.00	0.33	10	0.34	10
SE	10537	FALUN	15.62	60.62	122	2.00	2.00	0	2.32	2.21	0.11	5	2.50	-0.18	-8	-0.29	-13
SE	10714	FILMS KYRKBY	17.91	60.24	39	2.00	2.00	0	2.07	2.37	-0.30	-14	2.50	-0.43	-21	-0.13	-5
SE	11503	FINNBACKA	15.58	61.06	431	2.00	2.00	0	3.24	3.27	-0.03	-1	3.00	0.24	7	0.27	8
SE	12236	FJ─LLN─S	12.22	62.58	810	2.00	2.00	0	4.37	4.32	0.05	1	4.00	0.37	8	0.32	7
SE	7442	FLAHULT	14.15	57.69	224	2.00	2.00	0	2.62	2.74	-0.12	-5	2.00	0.62	24	0.74	27
SE	10610	FOLK─RNA	16.31	60.17	75	2.00	2.00	0	2.18	2.44	-0.26	-12	2.50	-0.32	-15	-0.06	-2
SE	13708	FORSE	17.03	63.15	120	3.00	3.00	0	3.10	3.06	0.04	1	3.00	0.10	3	0.06	2
SE	12630	FR─NSTA II	16.21	62.52	110	2.00	2.00	0	2.28	2.37	-0.09	-4	3.00	-0.72	-31	-0.63	-27
SE	14805	FREDRIKA	18.42	64.08	295	2.00	2.00	0	2.83	2.97	-0.14	-5	3.00	-0.17	-6	-0.03	-1
SE	13411	FRÍSÍN	14.49	63.20	360	1.00	1.00	0	2.24	2.44	-0.20	-9	3.00	-0.76	-34	-0.56	-23
SE	14430	G─DDELE	14.13	64.50	318	3.00	3.00	0	3.69	3.47	0.22	6	3.00	0.69	19	0.47	14
SE	10740	G─VLE	17.13	60.67	11	3.00	3.00	0	2.78	2.39	0.39	14	2.50	0.28	10	-0.11	-5
SE	8211	GENDALEN	12.65	58.16	90	2.00	2.00	0	2.22	2.09	0.13	6	1.50	0.72	33	0.59	28
SE	15686	GITJAUR	16.99	65.53	435	2.00	2.00	0	3.25	2.94	0.31	10	4.00	-0.75	-23	-1.06	-36
SE	8545	GODEG┼RD	15.17	58.79	121	3.00	3.00	0	3.11	2.98	0.13	4	1.50	1.61	52	1.48	50
SE		GÍTEBORG	11.97	57.70	31	1.00	1.00	0	1.26	1.08	0.18	14	1.00	0.26	20	0.08	7
SE	7233	GREBBESHULT	12.46	57.54	40	2.00	2.00	0	2.07	1.88	0.19	9	1.00	1.07	52	0.88	47
SE	9442	GRYTHYTTAN	14.53	59.71	182	2.00	2.00	0	2.50	2.78	-0.28	-11	3.00	-0.50	-20	-0.22	-8
SE	8459	GULLSP┼NG	14.11	58.99	78	2.00	2.00	0	2.19	2.35	-0.16	-7	0.00	2.19	100	2.35	100
SE	14757	GUNNARN	17.71	64.96	278	2.00	2.00	0	2.78	3.06	-0.28	-10	3.00	-0.22	-8	0.06	2
SE	8159	GUNNESBYN	11.70	58.98	145	1.00	2.00	1	1.60	2.02	-0.42	-27	2.50	-0.90	-57	-0.48	-24
SE	10309	GUSTAVSFORS	13.80	60.15	198	2.00	2.00	0	2.54	2.37	0.17	7	3.00	-0.46	-18	-0.63	-27
SE	7237	H─GG┼RDA	12.94	57.62	105	2.00	2.00	0	2.27	2.30	-0.03	-1	1.50	0.77	34	0.80	35
SE	7418	HAGSHULT	14.13	57.29	168	1.00	2.00	1	1.67	2.14	-0.48	-29	1.50	0.17	10	0.64	30

SE	12716	H─LJUM	17.34	62.26	400	3.00	2.00	1	3.94	3.47	0.47	12	3.00	0.94	24	0.47	14
SE	6240	HALMSTAD	12.92	56.67	4	2.00	1.00	1	1.97	1.43	0.54	27	1.00	0.97	49	0.43	30
SE	16395	HAPARANDA	24.14	65.83	7	3.00	3.00	0	2.77	2.82	-0.05	-2	3.00	-0.23	-8	-0.18	-6
SE	12738	H─RNÍSAND	17.95	62.63	8	4.50	4.50	0	3.95	3.19	0.76	19	3.00	0.95	24	0.19	6
SE	9804	H┼RSFJ─RDEN	18.12	59.07	2	2.00	2.00	0	1.96	2.28	-0.32	-16	5.00	-3.04	-155	-2.72	-119
SE	7538	H─SSLEBY	15.57	57.63	190	2.00	2.00	0	2.52	2.42	0.10	4	2.00	0.52	21	0.42	17
SE	6308	H─SSLEHOLM	13.74	56.14	50	1.00	1.00	0	1.31	1.48	-0.17	-13	1.00	0.31	24	0.48	32
SE	8157	H┼VELUND	11.44	58.95	100	1.00	1.00	0	1.46	1.73	-0.27	-18	1.50	-0.04	-3	0.23	13
SE	15883	HEDBERG	18.81	65.43	440	2.00	2.00	0	3.26	3.11	0.15	5	3.00	0.26	8	0.11	4
SE	10516	HEDEMORA	15.97	60.28	120	2.00	2.00	0	2.31	2.55	-0.24	-10	2.50	-0.19	-8	0.05	2
SE	15594	HEMAVAN	15.09	65.82	475	3.00	3.00	0	4.16	4.49	-0.33	-8	4.00	0.16	4	0.49	11
SE	6855	HOBURG	18.15	56.92	39	1.00	1.00	0	1.28	1.37	-0.09	-7	1.50	-0.22	-17	-0.13	-9
SE	8404	HÍGERM┼LEN	14.60	58.06	285	2.00	2.00	0	2.80	2.64	0.16	6	2.00	0.80	29	0.64	24
SE	5350	HÍRBY	13.67	55.85	80	1.00	1.00	0	1.40	1.68	-0.28	-20	1.00	0.40	29	0.68	40
SE	12545	HUNGE	15.10	62.75	340	2.00	2.00	0	2.97	3.13	-0.16	-5	3.00	-0.03	-1	0.13	4
SE	6441	HYLTAN	14.34	56.68	155	1.00	1.00	0	1.63	1.97	-0.34	-21	1.50	0.13	8	0.47	24
SE	10523	IDKERBERGET	15.23	60.38	260	3.00	3.00	0	3.52	3.38	0.14	4	3.00	0.52	15	0.38	11
SE	11252	IDRE	12.72	61.86	450	2.00	2.00	0	3.29	3.13	0.16	5	4.00	-0.71	-21	-0.87	-28
SE	13802	INVIK	18.17	63.03	20	4.50	4.50	0	3.99	3.86	0.13	3	3.00	0.99	25	0.86	22
SE	16681	J─CKVIK	16.98	66.38	430	2.00	2.00	0	3.23	3.20	0.03	1	4.00	-0.77	-24	-0.80	-25
SE	11643	J─RVSÍ	16.18	61.71	115	3.00	3.00	0	3.09	2.81	0.28	9	3.00	0.09	3	-0.19	-7
SE	15492	JOEJSÍ	14.63	65.73	490	3.00	3.00	0	4.20	4.28	-0.08	-2	4.00	0.20	5	0.28	7
SE	16988	JOKKMOKK	19.85	66.60	255	2.00	2.00	0	2.71	2.95	-0.24	-9	3.00	-0.29	-11	-0.05	-2
SE	7446	JÍNKÍPING	14.17	57.78	97	2.00	1.00	1	2.24	1.77	0.47	21	2.00	0.24	11	-0.23	-13
SE	6256	JONSTORP	12.55	56.93	15	1.00	1.00	0	1.21	1.54	-0.33	-27	1.00	0.21	17	0.54	35
SE	13642	JUNSELE	16.87	63.70	208	3.00	3.00	0	3.36	3.04	0.32	10	3.00	0.36	11	0.04	1
SE	6641	KALMAR	16.29	56.68	6	2.00	2.00	0	1.97	2.27	-0.30	-15	1.50	0.47	24	0.77	34
SE	19283	KARESUANDO	22.49	68.44	333	1.00	1.00	0	2.16	2.36	-0.20	-9	3.00	-0.84	-39	-0.64	-27
SE	8431	KARLSBORG	14.51	58.52	94	1.00	1.00	0	1.44	1.61	-0.17	-11	2.00	-0.56	-38	-0.39	-24
SE	6413	KARLSHAMN	14.87	56.01	7	1.00	1.00	0	1.19	1.41	-0.22	-19	1.00	0.19	16	0.41	29
SE	9322	KARLSTAD	13.47	59.36	47	2.00	2.00	0	2.09	1.86	0.23	11	0.00	2.09	100	1.86	100
SE	17371	KARUNGI	23.98	66.04	25	3.00	3.00	0	2.82	2.71	0.11	4	3.00	-0.18	-6	-0.29	-11
SE	8659	KATRINEHOLM	16.18	58.99	45	2.00	2.00	0	2.09	2.16	-0.07	-3	1.50	0.59	28	0.66	31

SE	18883	KATTERJ┼KK	18.13	68.43	508	4.50	4.50	0	5.44	5.60	-0.16	-3	4.00	1.44	26	1.60	29
SE	18381	KAUNISVAARA	23.32	67.36	200	3.00	3.00	0	3.34	3.04	0.30	9	3.00	0.34	10	0.04	1
SE	7320	K─VSJÍ	13.93	57.32	170	1.00	1.00	0	1.67	1.92	-0.25	-15	1.50	0.17	10	0.42	22
SE		KIRUNA	20.23	67.85	505	2.00	2.00	0	3.46	3.18	0.28	8	3.00	0.46	13	0.18	6
SE	18094	KIRUNA FL	20.34	67.83	442	2.00	2.00	0	3.27	2.99	0.28	9	3.00	0.27	8	-0.01	0
SE	15472	KLIMPFJ─LL	14.79	65.06	560	3.00	3.00	0	4.41	4.65	-0.24	-5	4.00	0.41	9	0.65	14
SE	6307	KLIPPAN	13.15	56.12	21	1.00	1.00	0	1.23	1.34	-0.11	-9	1.00	0.23	19	0.34	25
SE	15797	KLIPPEN	17.11	65.90	505	2.00	2.00	0	3.46	3.70	-0.24	-7	4.00	-0.54	-16	-0.30	-8
SE	9536	KOLSVA	15.88	59.58	40	2.00	2.00	0	2.07	2.33	-0.26	-12	2.00	0.07	4	0.33	14
SE	17396	KORPILOMBOLO	23.06	66.85	178	3.00	3.00	0	3.27	2.97	0.30	9	3.00	0.27	8	-0.03	-1
SE	10639	KORS┼	16.15	60.64	185	2.00	2.00	0	2.51	2.78	-0.27	-11	2.50	0.01	0	0.28	10
SE	14528	KORSELBR─NNA	15.54	64.46	178	3.00	3.00	0	3.27	3.11	0.16	5	3.00	0.27	8	0.11	4
SE	17084	KOSKATS	20.28	66.48	255	2.00	2.00	0	2.71	3.01	-0.30	-11	3.00	-0.29	-11	0.01	0
SE	6403	KRISTIANSTAD	14.15	56.03	6	1.00	1.00	0	1.18	1.29	-0.11	-9	1.00	0.18	15	0.29	22
SE	10224	KRISTINEFORS	12.94	60.36	185	2.00	2.00	0	2.51	2.67	-0.16	-7	4.00	-1.49	-60	-1.33	-50
SE	14830	KROKSJÍ	18.00	64.50	520	2.00	2.00	0	3.50	3.47	0.03	1	3.00	0.50	14	0.47	14
SE	16798	KVIKKJOKK	17.73	66.93	337	3.00	3.00	0	3.75	3.61	0.14	4	4.00	-0.25	-7	-0.39	-11
SE	11557	LAFORSEN	15.50	61.94	200	3.00	3.00	0	3.34	2.97	0.37	11	3.00	0.34	10	-0.03	-1
SE	18293	LAINIO	22.35	67.76	325	2.00	2.00	0	2.92	3.15	-0.23	-8	3.00	-0.08	-3	0.15	5
SE	6335	L┼NGHULT	13.46	56.58	175	3.00	3.00	0	3.27	3.17	0.10	3	1.00	2.27	69	2.17	68
SE	8313	L─NGJUM	13.06	58.22	95	2.00	2.00	0	2.24	1.87	0.37	16	1.50	0.74	33	0.37	20
SE	13711	L─NN─S	17.66	63.17	30	3.00	2.00	1	2.83	2.19	0.64	23	3.00	-0.17	-6	-0.81	-37
SE	14456	LEIPKAVATTNET	14.16	64.93	475	4.50	4.50	0	5.34	5.91	-0.57	-11	4.00	1.34	25	1.91	32
SE	11439	LILLHAMRA	14.80	61.65	424	3.00	3.00	0	4.01	3.68	0.33	8	3.00	1.01	25	0.68	18
SE	7218	LINHULT	12.69	57.30	175	2.00	2.00	0	2.48	2.38	0.10	4	1.00	1.48	60	1.38	58
SE		LINKÍPING	15.63	58.42	96	2.00	1.00	1	2.24	1.83	0.41	18	1.50	0.74	33	0.33	18
SE	6350	LJUNGBY	13.95	56.83	140	1.00	1.00	0	1.58	1.73	-0.15	-9	1.50	0.08	5	0.23	13
SE	6305	LJUNGBYHED	13.23	56.08	43	1.00	1.00	0	1.29	1.54	-0.25	-19	1.00	0.29	23	0.54	35
SE	12251	LJUNGDALEN	12.80	62.85	615	1.00	1.00	0	3.00	3.34	-0.34	-12	4.00	-1.00	-34	-0.66	-20
SE	12233	LJUSNEDAL	12.60	62.55	585	1.00	1.00	0	2.91	3.01	-0.10	-4	4.00	-1.09	-38	-0.99	-33
SE	11532	LOBON─S	15.34	61.53	220	2.00	2.00	0	2.61	2.92	-0.31	-12	3.00	-0.39	-15	-0.08	-3
SE	12307	LOFSDALEN	13.28	62.11	605	2.00	2.00	0	3.76	3.47	0.29	8	3.00	0.76	20	0.47	14
SE	7453	LOMMARYD	14.73	57.89	240	2.00	2.00	0	2.67	2.40	0.27	10	2.00	0.67	25	0.40	17

SE	16286	LULE┼ FLYGPLATS	22.12	65.54	17	3.00	3.00	0	2.80	2.92	-0.12	-4	3.00	-0.20	-7	-0.08	-3
SE	5343	LUND	13.20	55.71	73	1.00	1.00	0	1.38	1.29	0.09	7	1.00	0.38	28	0.29	22
SE	14835	LYCKSELE	18.66	64.59	225	2.00	3.00	1	2.62	3.11	-0.49	-18	3.00	-0.38	-14	0.11	4
SE	8504	MALEXANDER	15.28	58.03	160	2.00	2.00	0	2.43	2.18	0.25	10	2.00	0.43	18	0.18	8
SE	7524	M┼LILLA	15.82	57.39	100	2.00	2.00	0	2.25	2.30	-0.05	-2	1.50	0.75	33	0.80	35
SE	18075	MALMBERGET	20.67	67.17	393	2.00	2.00	0	3.12	3.21	-0.09	-3	3.00	0.12	4	0.21	7
SE	5336	MALMÍ	13.07	55.60	6	1.00	1.00	0	1.18	0.98	0.20	17	1.00	0.18	15	-0.02	-2
SE	8524	MALMSL─TT	15.53	58.40	90	2.00	2.00	0	2.22	1.92	0.30	14	1.50	0.72	33	0.42	22
SE	10341	MALUNG	13.72	60.68	308	2.00	2.00	0	2.87	2.74	0.13	5	3.00	-0.13	-4	-0.26	-9
SE	15572	MARSLIDEN	15.37	65.03	550	2.00	2.00	0	3.59	3.34	0.25	7	4.00	-0.41	-11	-0.66	-20
SE	11401	MORA	14.59	61.00	170	2.00	2.00	0	2.46	2.24	0.22	9	2.50	-0.04	-2	-0.26	-12
SE	7341	MÍRKÍ	13.71	57.69	345	2.00	2.00	0	2.98	3.00	-0.02	-1	2.00	0.98	33	1.00	33
SE	14416	MUNSVATTNET	14.45	64.27	520	2.00	2.00	0	3.50	3.57	-0.07	-2	3.00	0.50	14	0.57	16
SE	18398	MUODOSLOMPOLO	23.44	67.94	240	3.00	3.00	0	3.46	3.22	0.24	7	3.00	0.46	13	0.22	7
SE	16079	MYRHEDEN	20.21	65.30	250	2.00	2.00	0	2.70	2.78	-0.08	-3	3.00	-0.30	-11	-0.22	-8
SE	12220	MYSKEL┼SEN	12.65	62.33	770	1.00	1.00	0	3.46	3.06	0.40	11	4.00	-0.54	-16	-0.94	-31
SE	19190	NAIMAKKA	21.53	68.68	403	1.00	2.00	1	2.36	2.85	-0.49	-21	3.00	-0.64	-27	-0.15	-5
SE	7439	N─SSJÍ	14.69	57.64	315	2.00	2.00	0	2.89	2.57	0.32	11	2.00	0.89	31	0.57	22
SE	17192	NATTAVARA BY	21.05	66.76	327	3.00	3.00	0	3.72	3.40	0.32	9	3.00	0.72	19	0.40	12
SE	16996	NAUTIJAUR	19.24	66.90	355	2.00	2.00	0	3.01	2.94	0.07	2	4.00	-0.99	-33	-1.06	-36
SE	17995	NIKKALUOKTA	19.02	67.85	470	1.00	1.00	0	2.56	2.88	-0.32	-12	4.00	-1.44	-56	-1.12	-39
SE	8637	NORRKÍPING-SÍRBY	16.12	58.61	27	2.00	2.00	0	2.04	2.11	-0.07	-4	1.50	0.54	26	0.61	29
SE	10756	NORRSUNDET	17.16	60.93	5	3.00	3.00	0	2.76	2.51	0.25	9	2.50	0.26	9	0.01	0
SE	9850	NORRVEDA	18.95	59.83	25	2.00	2.00	0	2.03	2.05	-0.02	-1	2.00	0.03	1	0.05	2
SE	9544	NYBERGET	14.99	59.75	185	3.00	3.00	0	3.30	3.19	0.11	3	2.50	0.80	24	0.69	22
SE		NYKÍPING	17.01	58.77	24	2.00	2.00	0	2.03	2.06	-0.03	-2	1.50	0.53	26	0.56	27
SE	9602	ÍJA	16.60	59.04	50	2.00	2.00	0	2.10	2.28	-0.18	-8	1.50	0.60	29	0.78	34
SE	10349	ÍJE	13.86	60.81	360	2.00	2.00	0	3.03	2.90	0.13	4	3.00	0.03	1	-0.10	-3
SE	6425	OLASTORP	14.36	56.42	135	2.00	2.00	0	2.36	2.45	-0.09	-4	1.50	0.86	36	0.95	39
SE	9516	ÍREBRO	15.22	59.25	51	2.00	2.00	0	2.11	1.91	0.20	9	2.00	0.11	5	-0.09	-5
SE	6322	OSBY	13.98	56.38	86	1.00	1.00	0	1.42	1.54	-0.12	-8	1.50	-0.08	-6	0.04	3
SE		ÍSTERSUND	14.67	63.17	330	1.00	1.00	0	2.15	2.53	-0.38	-18	3.00	-0.85	-40	-0.47	-19

SE	17280	ÍVERKALIX	22.80	66.33	50	3.00	3.00	0	2.89	3.17	-0.28	-10	3.00	-0.11	-4	0.17	5
SE	17381	ÍVERTORNE┼	23.65	66.38	55	4.50	4.50	0	4.09	4.21	-0.12	-3	3.00	1.09	27	1.21	29
SE	17170	ÍVRE SVART┼	21.17	66.02	25	3.00	3.00	0	2.82	2.92	-0.10	-4	3.00	-0.18	-6	-0.08	-3
SE	18376	PAJALA	23.39	67.21	176	3.00	3.00	0	3.27	3.20	0.07	2	3.00	0.27	8	0.20	6
SE	17181	P┼LKEM	21.61	66.39	200	3.00	3.00	0	3.34	3.31	0.03	1	3.00	0.34	10	0.31	9
SE	16179	PITE┼	21.47	65.32	6	3.00	3.00	0	2.76	2.99	-0.23	-8	3.00	-0.24	-9	-0.01	0
SE	8328	REMNINGTORP	13.67	58.45	133	2.00	2.00	0	2.35	2.45	-0.10	-4	1.50	0.85	36	0.95	39
SE	7415	RÍRVIK	14.59	57.24	210	1.00	1.00	0	1.79	2.04	-0.25	-14	1.50	0.29	16	0.54	26
SE	13415	RÍSTA	14.58	63.25	380	1.00	1.00	0	2.30	2.44	-0.14	-6	3.00	-0.70	-31	-0.56	-23
SE	8101	S─BY	11.60	58.02	50	1.00	1.00	0	1.31	1.40	-0.09	-7	1.00	0.31	24	0.40	29
SE	9210	S─FFLE	12.94	59.14	50	3.00	3.00	0	2.89	2.81	0.08	3	2.00	0.89	31	0.81	29
SE	11341	S─RNA	13.12	61.68	458	2.00	1.00	1	3.32	2.89	0.43	13	3.00	0.32	10	-0.11	-4
SE	8226	S┼TEN─S	12.71	58.44	50	2.00	2.00	0	2.10	1.90	0.20	10	2.00	0.10	5	-0.10	-5
SE	7147	S─VE	11.88	57.78	20	1.00	1.00	0	1.22	1.51	-0.29	-23	1.00	0.22	18	0.51	34
SE	14721	SIKSJÍ	17.79	64.34	440	2.00	2.00	0	3.26	3.22	0.04	1	3.00	0.26	8	0.22	7
SE	10453	SILJANSFORS	14.38	60.88	260	2.00	2.00	0	2.73	3.11	-0.38	-14	2.50	0.23	8	0.61	20
SE	8647	SIMONSTORP	16.13	58.78	65	2.00	2.00	0	2.15	2.38	-0.23	-11	1.50	0.65	30	0.88	37
SE	6345	SINGESHULT	13.36	56.74	165	2.00	2.00	0	2.45	2.45	0.00	0	1.00	1.45	59	1.45	59
SE	12622	SKALLBÍLE	16.97	62.36	60	3.00	3.00	0	2.92	3.27	-0.35	-12	3.00	-0.08	-3	0.27	8
SE	8327	SKARA	13.45	58.40	117	2.00	1.00	1	2.30	1.48	0.82	36	1.50	0.80	35	-0.02	-1
SE	11412	SKATTUNGSBYN	14.87	61.20	220	2.00	2.00	0	2.61	2.88	-0.27	-10	2.50	0.11	4	0.38	13
SE	9733	SKJÍRBY	17.37	59.55	10	2.00	2.00	0	1.98	1.63	0.35	18	1.50	0.48	24	0.13	8
SE	7206	SKOGSFORSEN	12.87	57.09	100	2.00	2.00	0	2.25	1.99	0.26	12	1.00	1.25	56	0.99	50
SE	8323	SKÍVDE	13.84	58.39	150	2.00	2.00	0	2.40	2.74	-0.34	-14	2.00	0.40	17	0.74	27
SE	9423	SKR┼MFORSEN	14.61	59.38	125	2.00	3.00	1	2.33	2.74	-0.41	-18	2.50	-0.17	-7	0.24	9
SE	10431	SNÍ┼BY	14.46	60.52	230	2.00	2.00	0	2.64	2.30	0.34	13	3.00	-0.36	-14	-0.70	-30
SE	11716	SÍDERHAMN	17.10	61.27	26	3.00	3.00	0	2.82	3.08	-0.26	-9	2.50	0.32	11	0.58	19
SE	13710	SOLLEFTE┼	17.28	63.17	10	3.00	3.00	0	2.77	2.67	0.10	4	3.00	-0.23	-8	-0.33	-12
SE	7403	SÍRABY	14.89	57.02	185	1.00	1.00	0	1.72	1.87	-0.15	-9	1.50	0.22	13	0.37	20
SE	8449	SÍRBYTORP	14.65	58.81	185	2.00	2.00	0	2.51	2.66	-0.15	-6	2.00	0.51	20	0.66	25
SE	9621	STENKVISTA	16.56	59.32	35	2.00	2.00	0	2.06	2.30	-0.24	-12	1.50	0.56	27	0.80	35
SE	15772	STENSELE	17.17	65.06	329	2.00	2.00	0	2.93	2.80	0.13	5	3.00	-0.07	-2	-0.20	-7
SE	9821	STOCKHOLM	18.06	59.34	44	2.00	2.00	0	2.09	1.81	0.28	13	0.00	2.09	100	1.81	100

SE	9720	STOCKHOLM-BROMMA	17.95	59.35	14	2.00	2.00	0	2.00	1.78	0.22	11	0.00	2.00	100	1.78	100
SE	15885	STORBERG	18.95	65.51	453	2.00	2.00	0	3.30	3.34	-0.04	-1	3.00	0.30	9	0.34	10
SE	11223	STORBRON	12.86	61.39	540	2.00	2.00	0	3.56	3.89	-0.33	-9	3.00	0.56	16	0.89	23
SE	13218	STORLIEN-VISJÍV.	12.13	63.30	640	3.00	3.00	0	4.65	4.82	-0.17	-4	4.00	0.65	14	0.82	17
SE	12348	STORSJÍ KAPELL	13.07	62.80	580	1.00	1.00	0	2.89	3.17	-0.28	-10	4.00	-1.11	-38	-0.83	-26
SE	13544	STRÍMSUND	15.50	63.73	337	2.00	2.00	0	2.96	2.81	0.15	5	3.00	-0.04	-1	-0.19	-7
SE	15997	SUDDESJAUR	19.09	65.90	345	2.00	2.00	0	2.98	3.11	-0.13	-4	3.00	-0.02	-1	0.11	4
SE	9641	SUNDBY	16.66	59.70	35	2.00	2.00	0	2.06	2.06	0.00	0	1.50	0.56	27	0.56	27
SE	12731	SUNDSVALLS FLYGPL.	17.44	62.52	4	3.00	3.00	0	2.76	3.01	-0.25	-9	3.00	-0.24	-9	0.01	0
SE	12402	SVEG	14.42	62.03	360	2.00	2.00	0	3.03	2.67	0.36	12	3.00	0.03	1	-0.33	-12
SE	14947	TALLIDEN	19.37	64.78	372	2.00	2.00	0	3.06	2.88	0.18	6	3.00	0.06	2	-0.12	-4
SE	7414	TORALIDEN	14.75	57.23	260	1.00	1.00	0	1.94	2.30	-0.36	-19	1.50	0.44	23	0.80	35
SE	8460	TÍRNTORP	14.79	58.98	175	2.00	2.00	0	2.48	2.86	-0.38	-16	2.00	0.48	19	0.86	30
SE	12443	TOSS┼SEN	14.45	62.72	360	2.00	2.00	0	3.03	3.06	-0.03	-1	3.00	0.03	1	0.06	2
SE	7638	TOVEHULT	16.57	57.64	10	3.00	3.00	0	2.77	3.08	-0.31	-11	1.50	1.27	46	1.58	51
SE	8340	TRANEBERG	13.12	58.66	50	2.00	2.00	0	2.10	1.99	0.11	5	1.50	0.60	29	0.49	25
SE	11323	TR─NGSLET	13.73	61.38	425	2.00	1.00	1	3.22	2.76	0.46	14	3.00	0.22	7	-0.24	-9
SE	6520	TVINGELSHED	15.58	56.33	95	2.00	2.00	0	2.24	2.07	0.17	7	1.00	1.24	55	1.07	52
SE	12859	ULL┼NGER	18.18	62.99	45	4.50	4.50	0	4.06	4.21	-0.15	-4	3.00	1.06	26	1.21	29
SE	7347	ULRICEHAMN	13.47	57.76	292	2.00	2.00	0	2.82	3.10	-0.28	-10	2.50	0.32	11	0.60	19
SE	9749	ULTUNA	17.65	59.81	15	2.00	1.00	1	2.00	1.56	0.44	22	2.00	0.00	0	-0.44	-28
SE	14746	ULVOBERG	17.22	64.76	520	1.00	1.00	0	2.71	3.01	-0.30	-11	3.00	-0.29	-11	0.01	0
SE	14048	UME┼	20.28	63.83	11	3.00	3.00	0	2.78	2.83	-0.05	-2	3.00	-0.22	-8	-0.17	-6
SE	10727	UNTRA	17.34	60.44	35	3.00	3.00	0	2.85	2.90	-0.05	-2	0.00	2.85	100	2.90	100
SE	9752	UPPSALA	17.63	59.86	24	2.00	2.00	0	2.03	1.67	0.36	18	2.00	0.03	1	-0.33	-20
SE	9753	UPPSALA FLYGPLATS.	17.59	59.90	18	2.00	2.00	0	2.01	1.97	0.04	2	2.00	0.01	0	-0.03	-2
SE	9831	VALLENTUNA	18.08	59.52	20	2.00	2.00	0	2.01	1.90	0.11	6	1.50	0.51	26	0.40	21
SE	14404	VALSJÍN	14.13	64.67	370	2.00	2.00	0	3.06	3.22	-0.16	-5	4.00	-0.94	-31	-0.78	-24
SE	8223	V─NERSBORG	12.33	58.36	49	1.00	1.00	0	1.31	1.64	-0.33	-25	1.00	0.31	24	0.64	39
SE	7208	VARBERG	12.27	57.11	20	1.00	1.00	0	1.22	1.40	-0.18	-14	1.00	0.22	18	0.40	29

SE	9635	V─STER┼S	16.55	59.62	18	2.00	2.00	0	2.01	1.62	0.39	19	1.50	0.51	25	0.12	7
SE	7647	V─STERVIK	16.63	57.78	9	3.00	2.00	1	2.77	2.02	0.75	27	1.50	1.27	46	0.52	26
SE	6425	V─XJÍ	14.82	56.87	168	1.00	1.00	0	1.67	1.42	0.25	15	1.50	0.17	10	-0.08	-6
SE	15694	VINDEL-BJÍRKHEDEN	16.72	65.82	350	2.00	2.00	0	3.00	3.01	-0.01	0	4.00	-1.00	-33	-0.99	-33
SE	14916	VINDELN	19.63	64.27	181	2.00	2.00	0	2.49	2.88	-0.39	-15	3.00	-0.51	-20	-0.12	-4
SE	7840	VISBY	18.30	57.65	28	2.00	2.00	0	2.04	1.80	0.24	12	1.50	0.54	26	0.30	17
SE	8406	VISINGSÍ	14.40	58.09	110	1.00	1.00	0	1.49	1.58	-0.09	-6	0.00	1.49	100	1.58	100
SE	16687	VUOGGATJ┼LME	16.35	66.58	500	2.00	2.00	0	3.44	3.22	0.22	6	4.00	-0.56	-16	-0.78	-24

SUMMARY STATISTICS:

1) Percentage of missclassified stations

Percentage	6%
Abs. Num. (tot = 401)	23

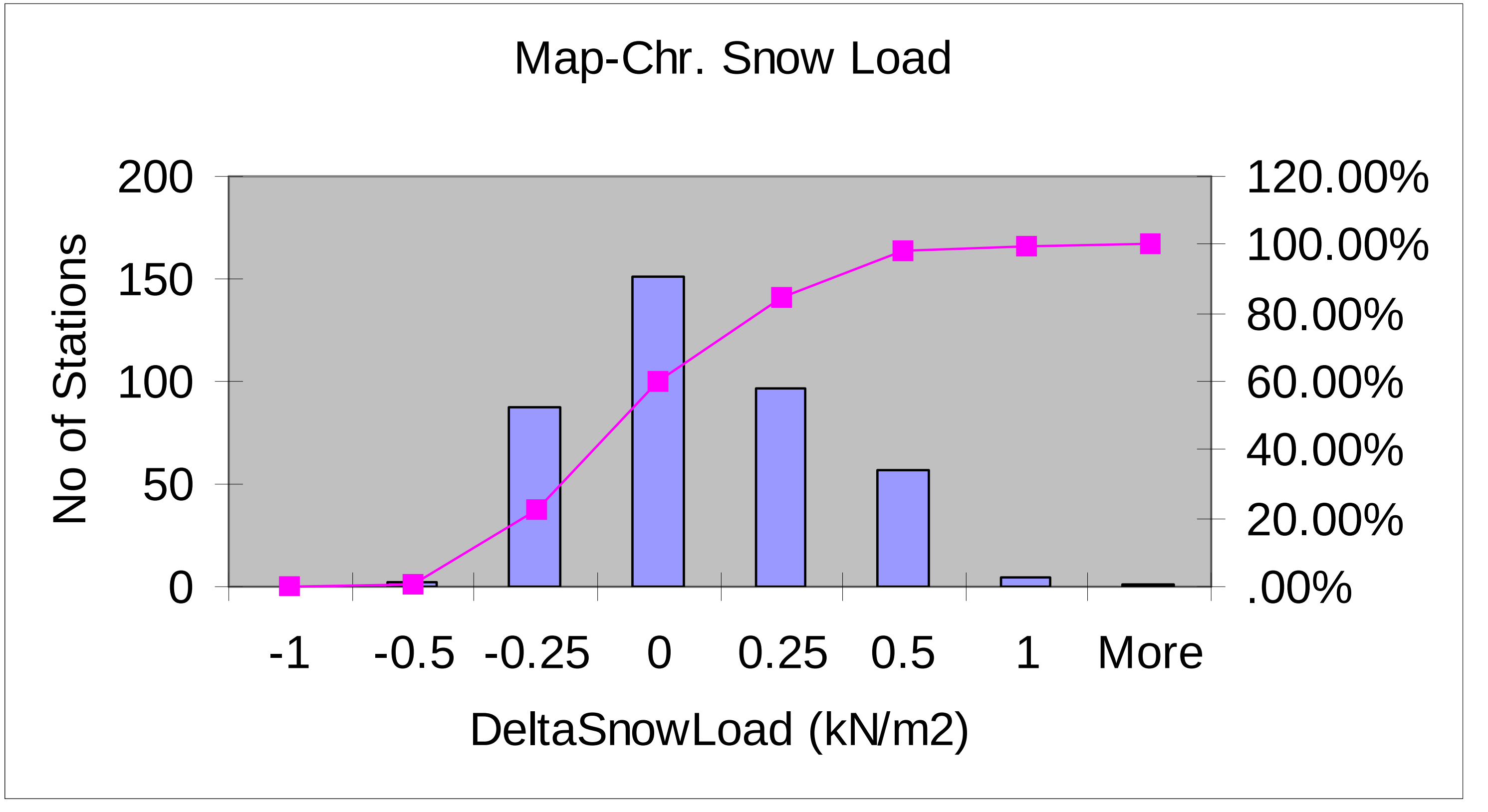
2) Descriptive Statistics of the difference in snow loads between mapped values and characteristic values and descriptive Statistics of the percentage of difference in snow loads between mapped values and characteristic values:

DeltaSnowLoad	
Mean	-0.0306
Standard Error	0.01294
Median	-0.0746
Mode	0.11214
Standard Deviation	0.2591
Sample Variance	0.06713
Kurtosis	1.25764
Skewness	0.69918
Range	2.09369
Minimum	-0.7851
Maximum	1.30857

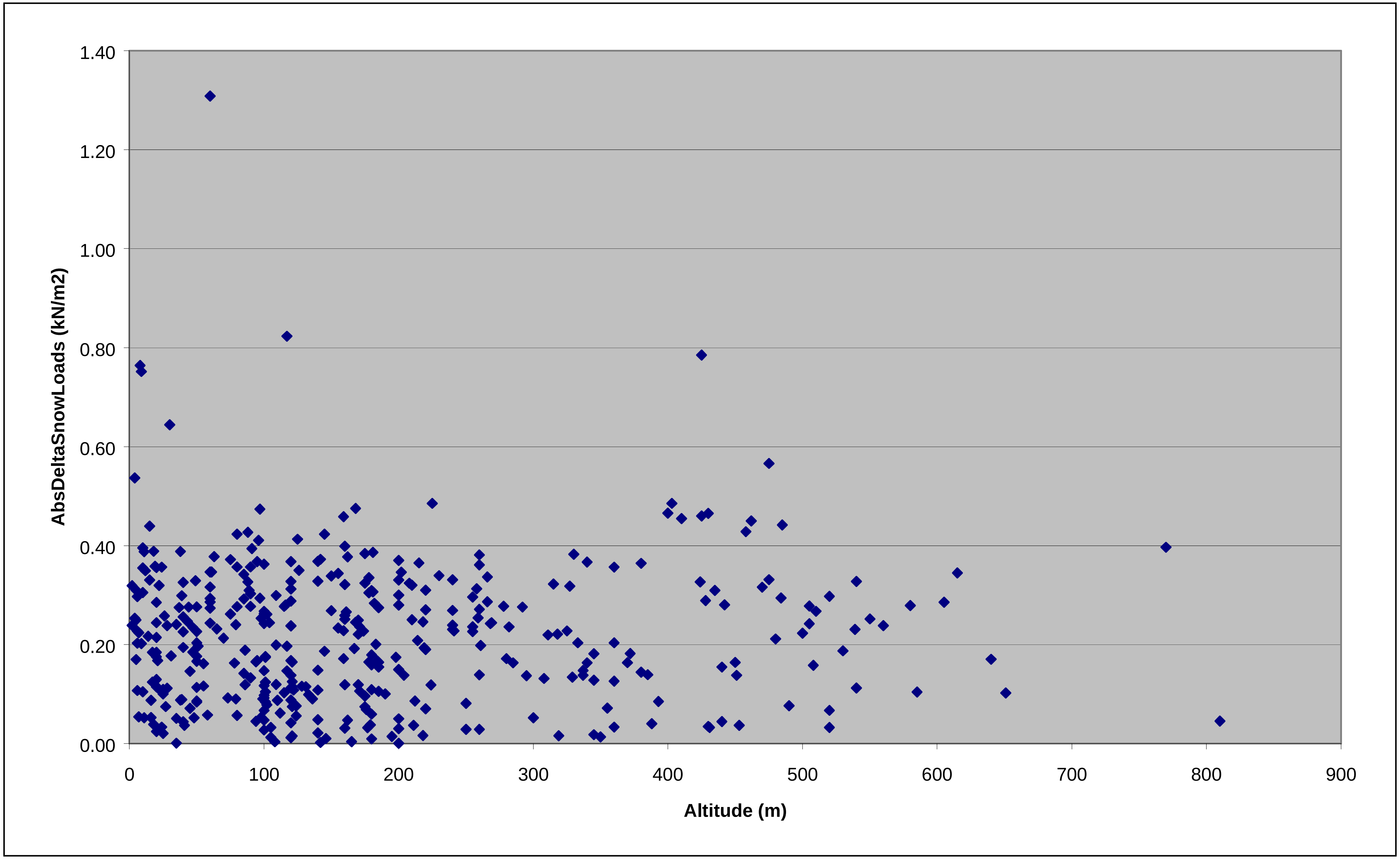
Percentage on DeltaSnowLoad	
Mean	-2.0942
Standard Error	0.53771
Median	-2.8412
Mode	4.85017
Standard Deviation	10.7676
Sample Variance	115.941
Kurtosis	0.17171
Skewness	0.13628
Range	68.8229
Minimum	-33.081
Maximum	35.742
Sum	-839.77
Count	401

3) Histogram of the difference in snow loads between mapped values and characteristic values:

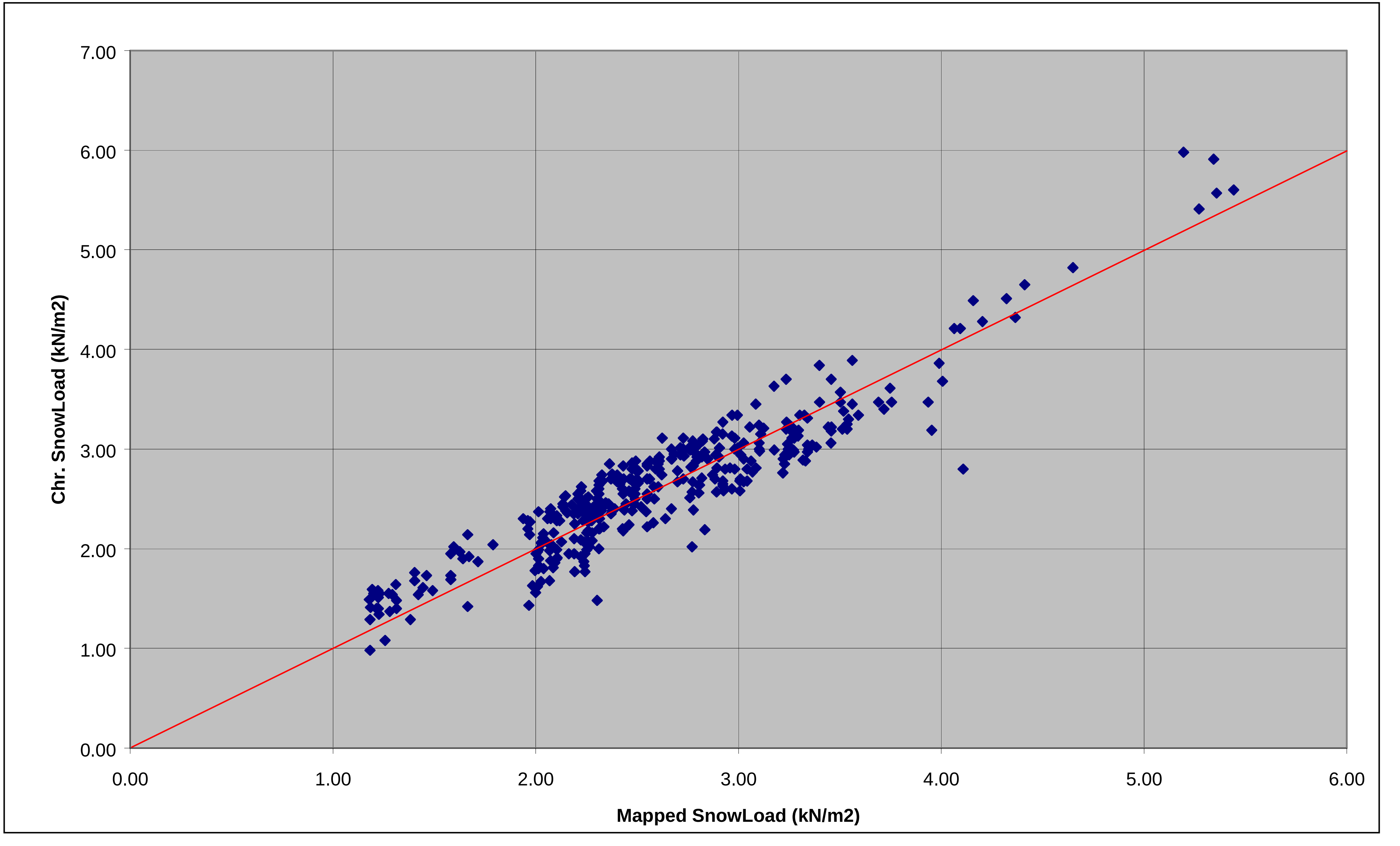
Delta Snow (A-B)	no of stations	Cumulative %
-1	0	.00%
-0.5	2	.50%
-0.25	88	22.44%
0	151	60.10%
0.25	97	84.29%
0.5	57	98.50%
1	5	99.75%
More	1	100.00%



4) Representation of the variation of the absolute delta snow load between mapped and characteristic snow values (A-B) with altitude



5) Graphical representation of the correlation existing between mapped snow loads (abscissa) and characteristic snow loads (ordinate).



Correl. Coeff. (Map-Chr. Snow Load) = 0.93

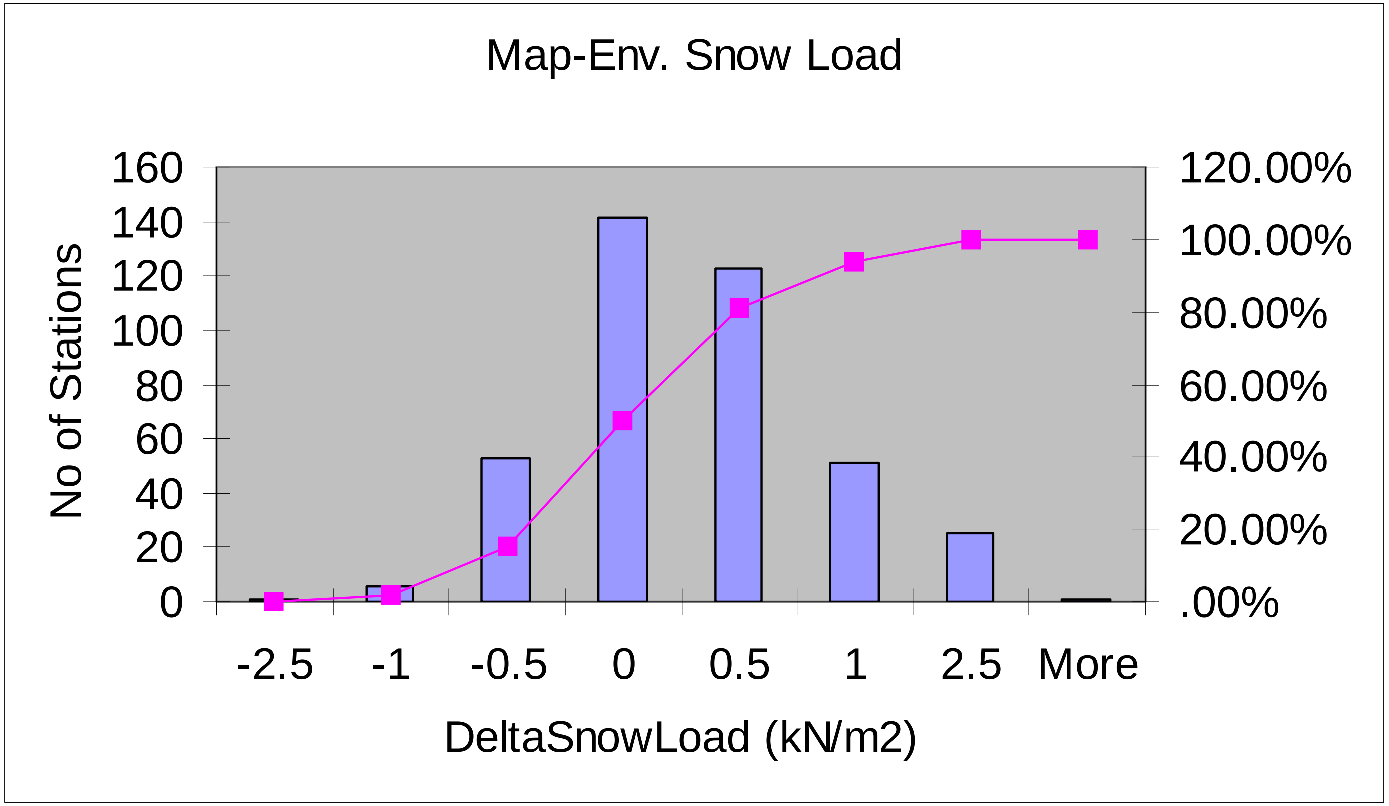
6) Descriptive Statistics of difference in snow loads between mapped and Prestandard snow load values

(A-Env)	
Mean	0.0596
Standard Error	0.0305
Median	-4E-04
Mode	-0.188
Standard Deviation	0.6103
Sample Variance	0.3724
Kurtosis	3.6361
Skewness	0.6686
Range	5.8882
Minimum	-3.039
Maximum	2.8492
Sum	23.903
Count	401

Percentage ((A-Env)/A)	
Mean	1.30767
Standard Error	1.27878
Median	-0.01786
Mode	-8.12481
Standard Deviation	25.6075
Sample Variance	655.746
Kurtosis	5.75477
Skewness	0.18782
Range	254.978
Minimum	-154.978
Maximum	100
Sum	524.377
Count	401

7) Comparison of mapped values with the Prestandard values (ENV 1991-2-3 - “Snow Loads”)

Delta Snow (A-Env)	no of stations	Cumulative %
-2.5	1	.25%
-1	6	1.75%
-0.5	53	14.96%
0	141	50.12%
0.5	123	80.80%
1	51	93.52%
2.5	25	99.75%
More	1	100.00%



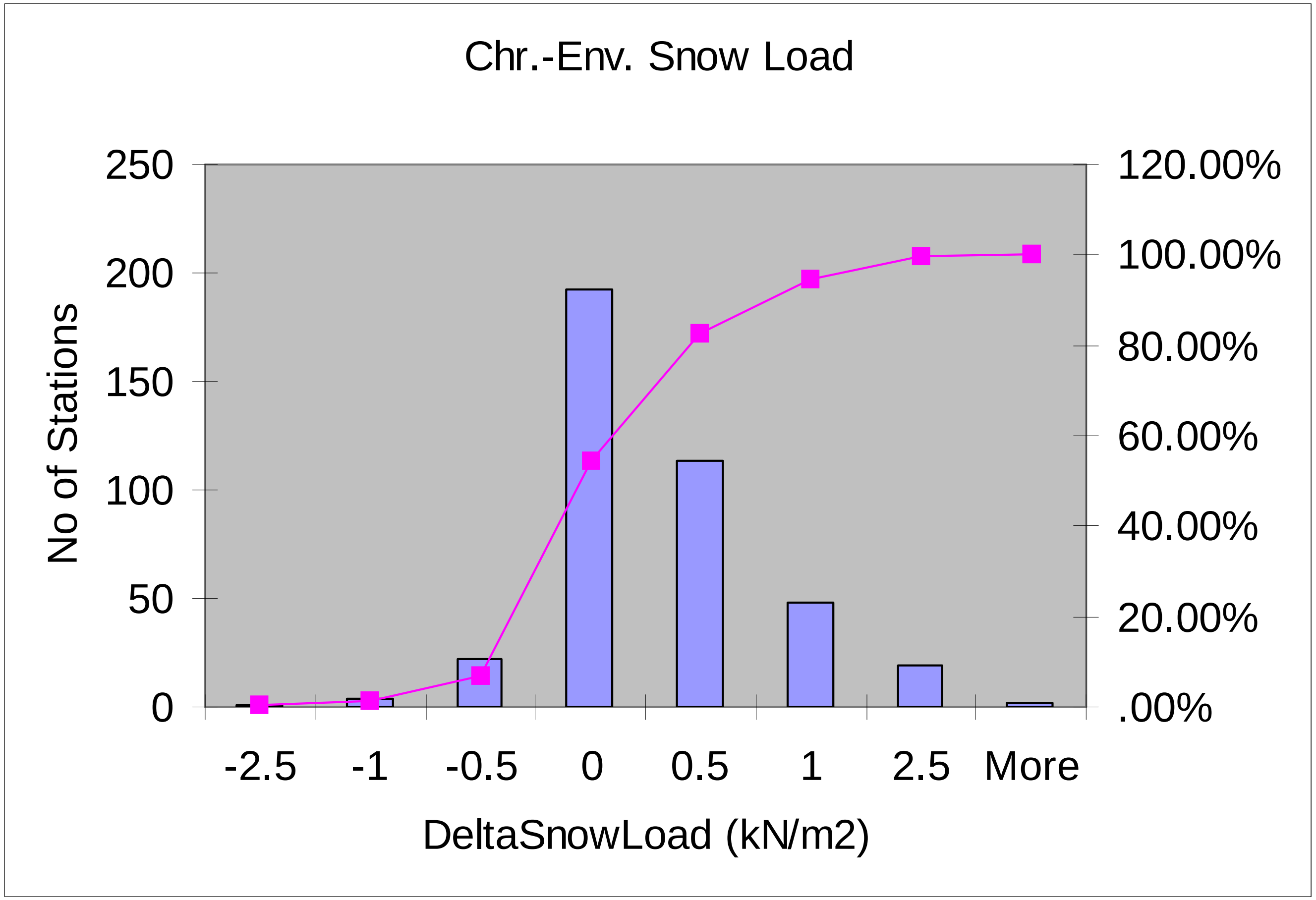
8) Descriptive Statistics of difference in snow loads between characteristic and Prestandard snow load values.

(B-Env)	
Mean	0.0902
Standard Error	0.0284
Median	-0.03
Mode	-0.2
Standard Deviation	0.5694
Sample Variance	0.3242
Kurtosis	4.8417
Skewness	1.0314
Range	5.62
Minimum	-2.72
Maximum	2.9
Sum	36.18
Count	401

Percentage ((B-Env)/B)	
Mean	3.3339
Standard Error	1.13136
Median	-1.0101
Mode	-4.16667
Standard Deviation	22.6554
Sample Variance	513.268
Kurtosis	5.71265
Skewness	0.98999
Range	219.298
Minimum	-119.298
Maximum	100
Sum	1336.89
Count	401

9) Comparison of characteristic values with the Prestandard

Delta Snow (B-Env)	no of stations	Cumulative %
-2.5	1	.25%
-1	4	1.25%
-0.5	22	6.73%
0	192	54.61%
0.5	113	82.79%
1	48	94.76%
2.5	19	99.50%
More	2	100.00%



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Pisa, 29th September 1999

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