
The Building Developer's Requirements, Management, and Verification to Ensure Dry Buildings by Moisture Control

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ABSTRACT

If moisture damage occurs in a building, it is often serious for both the property owner and for the occupier/user. It can, for example, give rise to unpleasant smells and ill health. In addition, it can be very expensive to correct such damage. Therefore, there is every reason to attempt to reduce the risk of moisture damage arising in the first place.

The property developer plays a key role in ensuring good moisture control. It is the developer, for example, who can specify appropriate requirements in this respect before building starts. If this is to produce successful results, it is also most important that the application of the specified requirements be carefully monitored and checked. Today, there is very little to assist the developer in doing so, whether during the construction stage or during use of the building. The purpose of this paper is to describe proposals for appropriate specifications, management, and verification by the building developer in order to ensure production of a dry building.

INTRODUCTION

Ensuring a good indoor environment in buildings is one of the building industry's most important jobs. Unfortunately, there are examples of failures in this respect. One of the factors that can cause problems in the indoor environment is moisture damage. In this paper, we have used the term *dry building* (where *building* can be read as a noun or as a verb) to indicate a minimum of risks or effects of moisture damage.

Knowledge of how to avoid moisture damage in buildings exists today. It is one of the important tasks of the building sector to formulate this knowledge so that it can be applied in all stages of—and by all persons involved in—the construction and use processes.

One person who has decisive influence on how this is to be done in Sweden is the building developer; unfortunately, he/she does not always have access to good aids for doing so. In Sweden, the building developer has the full responsibility of making sure the building fulfills the demands of society (including dry buildings). The building developer also has the

opportunity to put requirements on the designers, consultants, and contractors in connection with negotiations.

The purpose of the project described in this paper is to develop a structure for dealing with moisture-related matters and aids that can be used by the developer from an early stage in the building process. The goal is to ensure a dry building, with a minimum risk of any moisture damage. The project's recommendations include instructions for the developer's project management process, requirements, and monitoring of results. A detailed report of the project results has been published in Swedish by Sikander and Grantén (2003).

BACKGROUND

The following sections describe the background to the aids that have been developed to assist the building developer in producing dry buildings.

Damp Buildings and Ill Health

Damp buildings increase the risk of ill health and allergic problems and cause comfort problems in residential buildings,

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schools, and offices, as has been shown in many investigations. Two cross-disciplinary reviews of the literature—NORDDAMP (Bornehag et al. 2001) and EUROEXPO—note that there is a connection between damp buildings and ill health, such as respiratory infections and allergic problems in both adults and children. Nevertheless, despite the fact that many investigations have found links between damp buildings and the symptoms of ill health, it has not been possible to identify a particular substance in the air of these buildings that is the cause of the symptoms.

Some type of moisture damage is reported in 4% to 25 % of residential buildings in the Nordic countries (Bornehag et al. 2001). According to the ELIB report (Andersson et al. 1991), over 10% of the residential building stock in Sweden suffers from moisture damage to such an extent that repairs, etc., are needed.

Dry Building from an Economic Angle

Experience from a number of known cases indicates that complaints about the indoor environment caused by dampness have serious consequences for both occupants and property owners that cannot be evaluated in monetary terms. Nevertheless, the actual costs of correcting such conditions are high, even if the health costs are not included. As an example, the costs of correcting a poor indoor environment in a Swedish museum were calculated as amounting to about 25% of the original new building cost.

General Aspects of Dry Building Design

The term *dry building design* is used to cover all aspects of the construction and administration process that contribute to ensuring that moisture does not directly or indirectly cause damage to a building or create poor internal conditions. This requires the collection of all necessary information in the form of drawings, descriptions, material datasheets, moisture loads, and developer's requirements. Examples of information needed by the building developer include:

- How the building is to be used. Will it contain any activity that generates high moisture levels?
- What risk of damage can be accepted?
- What degree of care and maintenance can be accepted during the use stage?
- What safety margins are needed over and above the critical moisture values for the materials?

What Are the Most Common Forms of Moisture Damage?

Common forms of moisture damage in Swedish buildings today, which can be avoided by specifying the right requirements, include:

- *Emissions from materials in floors.* A common type of damage that often occurs in connection with new buildings is that floor coverings and the adhesive used to

secure them are damaged by alkaline moisture from concrete beneath them. This results in chemical breakdown of the materials with the release of various emissions that can affect the quality of indoor air.

- *Microbial damage.* Mildew fungi need nutrients, oxygen, and a damp environment in order to become established and grow. In buildings, it is often the moisture that is the determining factor. Materials differ in their suitabilities for mildew growth: wood-based materials, for example, have a low resistance to mildew growth, while stone-based materials have a higher resistance. However, even materials with higher resistance to mildew growth can support mildew if dirt builds up on the surface. An example occurring during the construction stage is that of concrete floor structures that are walked over by the builders, bringing in clay and earth to build up on the surface.
- *Breakdown of materials.* These are forms of damage that affect the life of the materials used in the building so that repairs or replacements are required. Rot in wood and corrosion/rust on metal are examples, while other mechanisms, such as swelling, shrinkage, etc., can cause problems, giving rise to cracks, buckling, etc.

A Questionnaire Survey

A questionnaire survey (Arfvidsson and Sikander 2002), complemented by more detailed interviews, has revealed certain possible factors that can complicate the process of ensuring a dry building. However, some considerations in connection with the developer's formulation of dry building requirements and for dealing with related aspects include:

- unclear division of responsibilities between the parties concerned,
- unrealistic expectations on the part of the developer,
- uncertainties as to whether all parties involved possess the necessary competence,
- shortcomings in training or knowledge,
- “optimistic” time plans,
- risk of losing information in the handovers from one stage to another, and
- failure to investigate moisture problems in a structured manner.

The Building Developer's Requirements, Project Management, and Verification

In this project (Sikander and Grantén 2003), it is suggested that the developer should control and monitor the process by:

- Producing a clear specification with respect to moisture control and performance.
- Clearly defining responsibilities for ensuring moisture control in the building project. In the end, in Sweden, it is the developer who bears the ultimate responsibility

for ensuring that the building is dry and remains dry. However, the responsibility for physically fulfilling the developer's requirements lies with the other parties to the contract, such as designers, contractors, and so on.

- Checking that the other parties are competent or acquire the necessary competence.
- Monitoring compliance with the requirements by checking that the other parties have carried out the necessary verification/measurements. The developer can also carry out his/her own sample inspections and measurements.

If possible, work on ensuring a dry building should be integrated with the building developer's overall quality requirements for the project. In some other types of building projects it may be more suitable to integrate this work with the environmental aspects of the project instead.

The checklist shown below is intended to be independent of the type of contract. It should be used by the developer or a representative to ensure that the process produces a dry building with minimum risk of moisture damage.

The Building Developer's Activities during the Starting Stages of the Project

1. Assignment of responsibilities
 - This makes it clear to the developer's representative/project manager that he/she is responsible for ensuring that the activities described below are carried out. Responsibility for fulfilling the dry building requirements rests with the designers and contractors to whom this responsibility was assigned in the design objectives summary.
 - Determination of whether it will be necessary to engage the services of a specialist to assist the project manager.
2. Selection of Risk Level
 - This involves an early decision on acceptable risk levels. It involves a risk evaluation to decide how sensitive the project is to possible moisture damage and an estimate of risk levels and costs. See Appendix A.
3. Dry Building Requirements
 - Decide on the requirements: see the examples in Appendices A, B, and C. This involves formulation of technical requirements, requirements with respect to competence, procedures, inspection by those performing work, verifications, measurements, etc. Additional requirements from the administration organization must also be considered. Note that there are requirements that designers and contractors should themselves verify or demonstrate that requirements have been fulfilled.

The Developer's Activities During the Initial Planning and Outline Design Stage

4. Requirements for dry building when purchasing consultancy services
 - Implementation of requirements (see Appendices A and B) for dry building in connection with procurement of consultancy services for the outline design stage, including requirements with respect to dry building/moisture monitoring.
 - Remember to include evaluation of competence, procedures, resources, etc., in addition to prices.
 - Perform a review prior to signing contracts, to confirm that dry building requirements have been understood and accepted.
5. Dialogue with designers/planners, early identification of moisture risks
 - The early stage designers/planners should prepare early assessments of the moisture risks for presentation of the results to the developer.
6. Follow-up during the early design stage
 - Check the early stage designer's/planner's documentation that requirements are being fulfilled.
 - Sample checks of the early stage designer's/planner's dry building design features.
 - Documentation of any noncompliances for subsequent rectification during the administration stage.
7. Monitoring the transfer of information to the construction stage
 - Information on the work needed during the construction stage for dry building, put together by the early stage designers/planners.

The Developer's Activities During the Construction Stage

8. Requirements for dry building assurance when negotiating with contractors
 - Implementation of dry building requirements (see Appendices A and C) in connection with contractor negotiations.
 - Evaluation of tenders (bids) should include assessment of competence, procedures, resources, etc., in addition to price.
 - Discussions prior to signing the contract with the contractor for confirmation that requirements with respect to dry building performance have been understood and accepted.

9. Checking the contractor's dry building plan
 - Checking and approving the contents of the contractor's dry building plan. The plan must be submitted not later than three weeks after the start of building.
10. Monitoring during the construction stage
 - Checking the contractor's documentation/measurements to ensure that the requirements have been fulfilled.
 - Sample visits to the construction site to inspect general working conditions and inspection procedures and to take random samples and make random moisture measurements.
 - Documentation of any noncompliances for following up during the administration stage.
11. Monitoring the handing over of information to the administration stage.
 - Information on moisture aspects that can affect the administration stage, to be prepared by the contractor.

The Property Owner's Activities during the Administration Stage

12. Procedures for ensuring that the building is used in a “dry” manner—requirements and verification (see Appendices A and D)
13. Follow-up during the administration stage
 - Annual check of administration procedures for “dry” operation.
 - Regular moisture surveys, e.g., every five years, paying particular attention to any noncompliances noted during the early design or construction stages.
 - Moisture survey prior to expiration of the guarantee period. Attention must be paid to points from the early design and construction stages and, in particular, to any noncompliances, moisture conditions underneath floor coverings, and any emissions.
14. Feedback of experience
 - Feedback of experience from the operating organization to the building developer organization.

CONCLUSIONS

The developer's most powerful guide measures are those that are formulated, imposed, and followed up. Different “safety levels” can be set for the requirements, depending on the type of building to be erected and the level of risks that the

developer is prepared to take. There need to be model forms of requirement levels and formulations for:

- the competence of project managers, early stage designers/planners, and contractors (Appendices B and C)
- safety margins over and above critical moisture level conditions (Appendix A)
- documented dry building design (Appendix B)
- internal information and first-party inspection/review by the early stage designer/planner (Appendix B)
- the developer's verification measurements (Appendix C)
- weather protection during the construction stage and for the storage of materials (Appendix C)
- internal information and first-party inspection procedures by the contractor (Appendix C)
- the length of the guarantee period

Requirements should be accompanied by clear statements of the effects of noncompliance (for materials requirements and technical requirements), information on how concerned parties should check that requirements have been fulfilled, and on who is responsible for each particular requirement.

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APPENDIX A: THE DEVELOPER'S DECISION ON AN ACCEPTABLE RISK LEVEL FOR MOISTURE DAMAGE—TECHNICAL REQUIREMENTS FOR THE INITIAL DESIGN, CONSTRUCTION, AND ADMINISTRATION STAGES

Proposal for the developer's technical requirements with respect to materials and functions during the initial design, construction, and administration stages. One of the three safety levels can be used as the starting point for the developer's requirements—selection of the level depends on the type of building to be constructed and the level of risks that the developer is prepared to take.

	Suggestion for requirements Selection of safety levels 1, 2, or 3 by the developer.* Delete the unchosen alternatives.	Consequence for noncompliance during the construction period	Verification (by persons concerned) that requirements have been fulfilled	Party responsible [†]	Initials of person responsible, confirming that the requirement has been observed
Micro-biological growth	1.The material must not exhibit abnormal quantities of microbiological growth or have any unexpected odour. No visible growth of mildew or blue stain can be accepted. In case of any doubt, send samples for microbiological analysis. 2.The material must not exhibit abnormal quantities of microbiological growth or have any unexpected odour. No visible growth of mildew or blue stain can be accepted. Sand or plane off any minor individual growth areas on wood. 3. A few stains can be accepted, but no odor indications.	Replace materials.	First-party inspection during the construction stage	Suggestion: E	
Wood	1.Moisture ratio <0.16 kg/kg during the construction stage and during the use stage. 2.Moisture ratio <0.20 kg/kg during the construction stage, <0.16 if inbuilt and during the use stage. 3. <0.20 kg/kg during the construction stage. Damper periods can be accepted if the material dries out quickly; <0.18 during the use stage.	Replace materials.	A, K; Dry building, E: Moisture ratio measurements	Suggestion: A, K, E, F	
Gypsum and wood-based board materials, insulating materials, etc.	1.At least 5 % below the critical moisture level as specified by the material manufacturer during the construction stage and the use stage. 2.Not exceeding the critical moisture level as specified by the material manufacturer during the construction stage and the use stage. 3.Not exceeding the critical moisture level as specified by the material manufacturer during the use stage. The critical moisture level may be briefly exceeded during the construction stage, provided that it can be shown that the material is not damaged thereby.	Replace materials.	A, K; Dry building E: Moisture measurements	Suggestion: A, K, E, F	
Flooring materials	1.Critical moisture conditions, as given by the materials manufacturer or Hus AMA 98, for floor coverings, adhesives, and smoothing compounds to be measured by an authorized moisture inspector for concrete structures. The services of a moisture inspector to be engaged before concrete is poured. The inspector to plan the drying-out process and to make measurements on several occasions. 2.Critical moisture conditions, as given by the materials manufacturer and Hus AMA 98, for floor coverings, adhesives, and smoothing compounds to be measured by an authorized moisture inspector. 3.Critical moisture condition, as specified by the materials manufacturer, to be achieved.	Drying-out to continue until the requirement has been achieved before floor coverings can be laid.	A, K; Dry building E: Moisture measurements, including trend measurements	Suggestion: A, K, E, F	
Airtightness	1.Detail drawings to show solutions for permanent airtightness, e.g., clamping of joints, penetrations, and connections in the airtight layer. Air leakage to be verified by measurement and must not exceed the requirements in the Building Regulations. 2.Detail drawings to show solutions for permanent airtightness, e.g., clamping of joints and connections in the airtight layer. 3.General instructions for airtight detailing but without detail drawings. Detail drawings to be prepared at site.	Making good after leak tracing. To be followed by further leak tests.	A, K, HVAC, electricity: Instructions in documents. E: Airtightness testing, including leak tracing	Suggestion: A, K, HVAC, El, E, F	

Pressure difference	<p>1.Negative indoor pressure created by the ventilation system (to avoid convection damage)</p> <p>2.Brief periods of internal positive pressure can be accepted if the resulting additional moisture contribution is low.</p> <p>3.Longer periods of positive pressure can occur.</p>	Balancing the air flows.	HVAC; Documentation E: Measurements of pressure difference across the climate screen	Suggestion: HVAC, F	
Moisture input in the indoor air	<p>1.Design the ventilation so that the internal moisture input[‡] during normal conditions is less than 2 g/m³ at all times of the year. No humidification of the air.** During the construction stage, protect uncompleted climate screens from high temporary moisture loads, such as could occur while concrete is drying out.</p> <p>2.Design the ventilation so that the internal moisture input during normal conditions is less than 4 g/m³ at all times of the year. No humidification of the air.**</p> <p>3.No requirements with respect to low internal moisture input, provided that any resulting risks have been considered during the dry building design procedures.</p>	Balancing of air flows	HVAC: Documented calculation. E: Measurements	Suggestion: HVAC, E, F	

* Level 1 (little risk of moisture damage) should be chosen if possible. Level 3 presents a greater risk of moisture damage, and is not recommended.

† One or more of the following parties is responsible, or shares the responsibility: A - architect, K - designer, HVAC designer, Electrical designer, E - contractor, F - administrator.

‡ Moisture input, as used here, refers to the difference between the vapor concentration of the indoor air and that of the outdoor air.

** Special allowance must be made if humidification is required, e.g., by not positioning these areas in contact with the climate screen.

APPENDIX B: THE PROGRAM AND INITIAL DESIGN STAGE—ACTIVITY REQUIREMENTS

	Suggestion for activity/objective requirements	Designer's verification that requirements have been fulfilled. Reference to documentation.	Responsible designer, A or K	Initials of person responsible, confirming that the requirement has been observed
Competence	Show that the necessary competence for the design stage of dry building is available. The person responsible for dry building must be trained. He/she must be identified, as must the person responsible for checking the designs.	Reference object, training	Name	
Information	The designers to provide information on the requirements to be fulfilled, documentation, the importance of dry building etc.	Minutes of meetings or other documentation	Name	
Rebuilding/conversion projects: results of moisture surveys	Suggestions for actions and recommendations from the moisture survey (identification of designs at risk and of moisture damage).	Appropriate measures in continued design procedures	Name	
Early, important dry building decisions	Avoid doubtful designs - take note of the instructions from the developer on the risk levels that must not be exceeded. Plan for weather-protected construction. Dialog with the developer concerning possible risky designs.	Minutes of meetings or other documentation	Name	
Dry building design	This involves showing that the critical moisture levels of the materials, together with the specified safety margins, will not be exceeded during the construction stage or the use stage. Submit the method/checklist to the developer. Documentation must contain details of design moisture loads (moisture input, refrigeration plant, etc.), material data, critical moisture conditions, risk assessments, and reasons for accepting a particular design. The documents must clearly show the results of the dry building design procedure: detail design and drawings, for example, of certain parts of the building are of considerable importance. The developer must select one of the following safety levels: 1. Well-documented dry design data, with adequate safety margins. Well-presented detailing. The designer prepares a list of critical stages, for use by the contractor. 2. Dry design procedure, but with certain details left to be resolved at the site.	Dry design documentation presented separately.	Name	
First-party inspection – checking of documentation for dry design weaknesses	Check the drawings and other material for weaknesses in the design by someone other than the person who prepared them. Make sure that an overall view is taken, that potentially risky designs are identified and that alternative designs are suggested.	Collected comments from the reviewer. Documentation to show that appropriate corrections, etc., have been carried out.	Name	
Agenda item at design meetings	Checking of dry design work/fulfilment of requirements with other designers at design meetings. Coordination as necessary.	Minutes of meetings.	Name	
Correlation with time plan	Checking to see whether the time plan is reasonable in relation to emerging conditions. Notify the developer/project manager of any need for extra measures for changes to the time plan.	Minutes of meetings or other documentation	Name	
Information for the dry building plans for the construction stage	Provision of information for the contractor's dry building plan, with information on critical elements and work. Moisture risks to be monitored during the work. This information must be included in inquiry material to the contractor.	Documentation presented separately	Name	

APPENDIX C: THE CONSTRUCTION STAGE—ACTIVITY REQUIREMENTS

	Suggestion for activity/objective requirements	The contractor's verification that requirements have been fulfilled. Reference to documentation	Responsible person in the contractor's organization	Initials of person responsible, confirming that the requirement has been observed
Competence	Show that the necessary competence for the dry building is available. The person responsible must be identified.	Reference object, training	Name	
Early discussion of the time plan	Plan actions, etc., as needed to ensure fulfilment of the time plan without putting dry building at risk.	Separate documentation	Name	
Early presentation of weather-protected construction and protected storage	Presentation of the company's plans and procedures for weather-protected construction and dry storage of materials to the developer prior to the start of building. The developer should select one of the following safety levels for weather-protected construction and storage of materials: <ol style="list-style-type: none"> 1. Complete weather protection 2. Local weather protection 3. No weather protection 	Document: Plan of weather-protected construction	Name	
Checking dry building designs	The contractor checks the supplied drawings and descriptions in terms of their construction implications and protection against moisture. Discussion of any weak points with the designer and developer.	Minutes of meetings or other documentation	Name	
Moisture plan, including first-party inspection plan	The moisture plan is the contractor's documentation of all aspects concerned with dry building. It must contain: <ul style="list-style-type: none"> • plans for dry transport, reception, storage, and weather protection during construction • arrangements for keeping the work site clean • drying-out plan, e.g., for concrete • need for controlled heating or drying • confirmation that calibrated instruments will be used • identification of other critical working stages and plans for them, e.g., quality of workmanship of moisture protection between wood and damp materials, airtightness • an emergency plan for water damage (contact list, rapid response, moisture measurements, replacement, drying out) • planned moisture measurements (when, where, how) and other first-party inspection, as needed for the above aspects. Authorized personnel to measure moisture levels in concrete before floor coverings are applied. <p>The moisture plan must be approved by the developer by not later than three weeks after the start of construction.</p>	Documented moisture plan, including first-party inspection plan	Name	
Information	The contractor's personnel must be informed of the requirements to be fulfilled, of documentation, of why dry building is important, and so on.	Minutes of meetings or other documentation	Name	
Making moisture measurements and other first-party inspections	Document the results of points, etc., in accordance with the moisture plan/ first-party inspection plan. If noncompliances are found, take corrective actions in accordance with Appendix A (consequences).	Documentation of measurements, analyses, and inspections.	Name	
Item for discussion at construction progress meetings	Updating of the moisture plan, noting any changes and checking the process of drying out against the time plan.	Minutes of meetings	Name	
Information handover to the building administrator	Material specifications and information for operating and maintenance procedures. Documentation to be prepared in conjunction with the designers and administrators. Information presented to those responsible for operation and cleaning at an information meeting.	Documents to the administration organization	Name	

APPENDIX D: THE ADMINISTRATION STAGE—REQUIREMENTS FOR ACTIVITIES

	Suggestion for property owner's requirements/objectives	The administrator's verification that requirements have been fulfilled. Reference to documentation	Person responsible in the administration organization	Initials
Identified risks	Identification of potentially risky designs in order to identify risks and defects in moisture protection before complaints are made or serious damage is caused. This information to be provided by the designer and contractor if the building is new or converted. Existing buildings to be given a moisture survey to identify potentially weak spots.	Documents detailing moisture risk areas for the building handed over	Name	
Operation and maintenance plan	Operation and maintenance plan requirements to ensure moisture protection to be prepared on the basis of the moisture risks as identified above and as appropriate to the materials used.	Operation and maintenance plan to ensure dry conditions	Name	
Documentation during operation	Preparation of documentation of operation and maintenance measures carried out. This documentation to be kept with other operation and maintenance documentation for the building.	Documentation confirming that O&M is being carried out as planned	Name	
	Regular surveys (at least every five years) of surfaces and details, in order to monitor previously identified moisture risks and any new ones.	Documentation of monitoring of moisture risks	Name	
	Assessment of dry building aspects in conjunction with any changes (e.g., in building services systems, design features, or activities). Assessment of new moisture risks. Rectification of any defects.	Documentation of alterations and any remedial actions	Name	
	Note and investigate any complaints. Take remedial actions if the complaints indicate moisture damage.	Documentation of complaints, associated inspections, and any remedial actions	Name	
Emergency response plan for dealing with damage	There must be an emergency response plan for dealing with acute water damage, as well as for any difficult-to-identify odors or indications of damage. Prepare a plan for dealing with damage.	Emergency response plan	Name	