

RESEARCH REPORT



Performance Monitoring of a Brick Veneer/Steel Stud Wall System Phase 4 Results - Revision 1



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**PERFORMANCE MONITORING
OF A BRICK VENEER/STEEL STUD
WALL SYSTEM
- PHASE 4 RESULTS -
- REVISION 1 -**

**REPORT PREPARED FOR
CANADA MORTGAGE AND HOUSING CORPORATION**

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PERFORMANCE MONITORING

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WALL SYSTEM

- PHASE 4 RESULTS -

- REVISION 1 -

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ABSTRACT

The brick veneer/steel stud (BV/SS) wall system has become very popular over the last 20 years, however, the rapid adoption of this wall system has preceded the development of adequate design and construction standards. This situation has led to concerns regarding the long term safety, serviceability and durability of BV/SS wall systems. Therefore, Canada Mortgage and Housing Corporation (CMHC) has been evaluating BV/SS wall systems over the past several years by commissioning studies by various consultants, including Keller Engineering Associates Inc. (KEA).

Phase 4 of this study by KEA involved a fourth year (in 1996 and 1997) of in-situ performance monitoring of a BV/SS wall system, with respect to air and moisture movements as well as temperature gradients. In an attempt to improve venting of the wall cavity, vent holes were cut into every second vertical mortar joint in the top course of the monitored brick veneer section. The performance of a test wall was monitored using various temperature, moisture and air pressure sensors that were connected to an automatic data logging system. Even though the BV/SS wall system is typical of current practices and workmanship was mostly satisfactory, the results of the study demonstrate that performance problems exist that may lead to significant distress over the long term. The more serious performance problems identified in this study are mainly due to design weaknesses, illustrating the need for improved design and construction standards.

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This publication is one of the many items of information published by the CMHC with the assistance of federal funds.

DISCLAIMER

This study was conducted by Keller Engineering Associates Inc. for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretations and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

EXECUTIVE SUMMARY

The brick veneer/steel stud (BV/SS) wall system has become very popular in Canada over the last twenty years, however, the construction of BV/SS walls has preceded the development of adequate design and construction standards. In order to address concerns about the long term safety, serviceability and durability of BV/SS wall systems, Canada Mortgage and Housing Corporation (CMHC) has undertaken a program to evaluate BV/SS wall systems. This program has included many studies on design, construction and performance of BV/SS wall systems.

As part of the CMHC evaluation program, Keller Engineering Associates Inc. (KEA) carried out in-situ performance monitoring of a BV/SS wall system. The performance monitoring focussed on building science issues such as temperature gradients, moisture movements and pressure differences across the wall system. This report outlines the findings of the third year of performance monitoring.

The building selected is a seven-storey residential building located in the Ottawa/Hull region. It was decided to carry out the study using one test wall of this building. In order to evaluate the BV/SS wall system under the worst combination of air pressure differences and moisture conditions, the selected test wall faced east and was on the top floor of the building.

Instrumentation installed across the test wall consisted of various temperature, moisture and air pressure sensors which were connected to a computer based, automatic data logging system. For Phase 4 of this study, the test wall was monitored during many various periods between October 1996 and July 1997. The data collected was analysed to evaluate the in-situ performance of the test wall and the findings are discussed in this report under the headings of temperature, air pressure and moisture.

While several aspects of the design did not represent best practices, the BV/SS wall system was generally well designed, as compared to standard construction today. The results of the 1996/97 monitoring work were very similar to those found in 1991/92, 1992/93 and 1995 and they demonstrate that good thermal performance can generally be expected from brick veneer/steel stud walls. However, in spite of this good news, significant thermal bridging occurred at the steel studs of the test wall, due to a lack of exterior insulation. This thermal bridging is typical of any steel stud backup wall that is built without exterior insulation.

The analysis of the measured air pressure differences across the test wall indicates that the BV/SS wall system generally performs in a reasonably satisfactory manner as a rain screen, however, not as well as desired. Firstly, pressure equalization is not fully effective and, therefore, both the brick veneer and the steel stud backup wall resist wind loads. In a fully pressure equalized wall, the backup wall alone resist wind loads. The addition of vent holes, cut into every second vertical mortar joint at the top of the monitored brick veneer section has not significantly improved pressure equalization. Secondly, air leakage occurs through the air/vapour barrier system. While air leakage is relatively minor, it is enough to allow a significant amount of moist interior air to penetrate into the backup wall, as well as causing a reduction in the thermal efficiency of the wall system under wind conditions.

As with previous monitoring phases of this study, it was found that the cavity was unable to dry out because there was more condensation occurring due to a faulty air barrier than could be removed from natural convection movement of air through weep holes. Furthermore, the back face of the brick veneer stays wet throughout the winter season when many freeze/thaw cycles occur. In addition, minor condensation regularly occurs on the interior surface of the exterior sheathing. Vent holes at the top of the brick wall allow more moisture to enter the wall cavity but they do not accelerate drying. Due to the above conditions, building distress problems such as back spalling of bricks may occur over the long term.

In summary, the brick veneer/steel stud test wall was generally constructed in accordance with the design drawings and it meets today's standards, however, the wall system is not performing in a fully satisfactory manner. Moisture trapped within the cavity and in the brick veneer may lead to serious distress problems over the long term. Thermal bridging at the studs further reduces the overall performance of this wall. The observed performance problems are mainly due to an ineffective air/vapour barrier system, inadequate cavity venting and a lack of insulation on the exterior of the studs. The performance problems are the result of design weaknesses which are still common practice today.

This fourth phase of the monitoring program has further illustrated the need for improved design and construction standards. The BV/SS wall system under study represents "typical" construction with "typical" its shortcomings.

In view of the findings of this study, it is recommended that the sensors be left in place such that future performance data may be readily obtained, say every two to three years. The wall system will likely experience significant distress problems over the long term.

RÉSUMÉ

Au cours des vingt dernières années, les murs à ossature d'acier recouverte d'un placage de brique (OA-PBr) ont acquis une grande popularité au Canada. Cependant, on a commencé à construire ce genre de mur avant même d'avoir mis au point des méthodes et des normes de construction appropriées. C'est dans ce contexte que la Société canadienne d'hypothèques et de logement (SCHL) a entrepris un programme d'évaluation des murs OA-PBr dans le but de donner suite aux préoccupations que ces murs soulèvent en matière de sécurité, de tenue en service et de durabilité à long terme. Ce programme a donné lieu à de nombreuses études qui ont porté sur la conception, la construction et la performance des murs OA-PBr.

Dans le cadre du programme d'évaluation de la SCHL, la firme Keller Engineering Associates Inc. (KEA) a étudié la tenue en service d'un mur OA-PBr. Les chercheurs s'intéressaient à des questions de science du bâtiment comme les gradients de température, les mouvements d'humidité à travers le mur OA-PBr et les différences de pression le caractérisant. Le présent rapport fait état des résultats de la troisième année de l'étude de performance.

Le bâtiment choisi est un immeuble résidentiel de sept étages situé dans la région d'Ottawa-Hull. On a décidé de faire porter l'étude sur un seul mur de l'immeuble. Afin d'évaluer les pires conditions d'humidité et de différence de pression, les chercheurs ont choisi un mur donnant sur l'est et situé au dernier étage de l'immeuble.

Sur le mur étudié, les chercheurs ont installé des capteurs de température, d'humidité et de pression d'air qu'ils ont raccordés à un système informatisé d'enregistrement automatique de données. Pour la phase 4 de cette étude, le mur a été contrôlé durant de nombreuses périodes variées étalées entre les mois d'octobre 1996 et de juillet 1997. Les données recueillies ont été analysées afin d'évaluer la tenue en service du mur d'essai et les résultats sont commentés dans le présent rapport dans les sections traitant de la température, de la pression d'air et de l'humidité.

Même si plusieurs aspects de la conception ne sont pas conformes aux règles de l'art, le mur OA-PBr mis à l'essai est relativement bien conçu par rapport aux ouvrages actuels. Ainsi, les résultats de l'étude de performance de 1996-1997 sont très similaires à ceux obtenus en 1991-1992, 1992-1993 et 1995. Ils montrent qu'on peut généralement s'attendre à une bonne performance thermique des murs OA-PBr. Malgré cette bonne nouvelle, il faut mentionner que des ponts thermiques importants surviennent au niveau des poteaux d'acier du mur d'essai à cause du manque d'isolation extérieure. Ce phénomène est courant pour les murs à ossature d'acier dépourvus d'isolation extérieure.

La mesure des différences de pression d'air du mur d'essai indique que le mur OA-PBr se comporte généralement de manière satisfaisante en tant qu'écran pare-pluie, mais pas aussi bien qu'on le souhaiterait. D'abord, l'équilibrage de la pression n'est pas tout

à fait efficace, ce qui fait que le placage de brique et l'ossature en poteaux d'acier résistent ensemble aux surcharges dues au vent. Or, dans un mur à pression entièrement équilibrée, c'est l'ossature seule qui offre une résistance à ces charges. L'ajout d'ouvertures de ventilation au sommet du placage de brique étudié n'a pas considérablement amélioré l'équilibrage de la pression. En outre, les chercheurs ont observé des fuites d'air dans le pare-air/pare-vapeur. Quoique relativement mineures, ces fuites sont suffisantes pour permettre le passage d'une quantité importante d'air intérieur humide dans l'ossature, provoquant ainsi une diminution de l'efficacité thermique de l'ensemble du mur lorsqu'il vente.

Comme pour les phases de contrôle antérieures de cette étude, on a découvert que la cavité ne pouvait pas sécher parce que le mouvement d'air naturel, par convection à travers les chantepleures, ne venait pas à bout de la condensation anormalement élevée qui se formait à cause d'un pare-air déficient. Qui plus est, la face intérieure du placage de brique restait mouillée tout l'hiver et devait subir de nombreux cycles de gel et de dégel. De plus, une légère condensation se produisait régulièrement sur la surface intérieure du revêtement extérieur. Les ouvertures de ventilation au sommet du mur de brique permettent l'entrée d'une plus grande quantité d'humidité dans la cavité murale, mais elles n'accélèrent pas le séchage. Dans ces conditions, ce bâtiment est sans aucun doute voué à présenter des problèmes à long terme, tels que l'effritement de l'arrière des briques.

En résumé, le mur d'essai OA-PBr a été construit, dans l'ensemble, conformément au plan d'étude et répond aux normes actuelles, mais il n'offre pas une performance entièrement satisfaisante. À longue échéance, l'humidité emprisonnée dans la cavité et le placage de brique pourrait entraîner de graves problèmes. Les ponts thermiques qui se forment à la hauteur des poteaux d'ossature diminuent encore plus la performance globale de ce mur. Les problèmes de performance observés sont surtout le fait de l'inefficacité du pare-air/pare-vapeur, d'une mauvaise aération de la cavité et de l'absence d'isolation sur l'extérieur des poteaux. Les problèmes de performance sont le résultat des faiblesses conceptuelles qui sont toujours monnaie courante aujourd'hui.

Cette quatrième phase du programme de contrôle a fait ressortir clairement la nécessité d'améliorer les normes de conception et de construction. Le mur OA-PBr à l'étude est représentatif de ce genre d'ouvrage et il en présente les inconvénients typiques.

Compte tenu des résultats obtenus, on recommande que les capteurs soient laissés sur place afin qu'il soit facile de recueillir d'autres données de performance dans le futur, par exemple tous les deux ou trois ans. Le mur présentera vraisemblablement d'importantes déficiences à long terme.



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**PERFORMANCE MONITORING OF A
BRICK VENEER/STEEL STUD
WALL SYSTEM
- PHASE 4 RESULTS -**

1. INTRODUCTION

The brick veneer/steel stud (BV/SS) wall system has become widely utilized over the past 20 years, however, the construction of BV/SS walls has preceded the development of adequate design and construction standards. This situation has led to concerns in the construction industry about the long term safety, serviceability and durability of BV/SS wall systems. In order to address these concerns, Canada Mortgage and Housing Corporation (CMHC) has undertaken a program to evaluate the design, construction and performance of BV/SS walls. For several years, Keller Engineering Associates Inc. (KEA) has been involved in a variety of these studies. This report outlines the findings of the fourth year of performance monitoring.

The key objective of this project was to monitor and evaluate the in-situ performance of a newly constructed BV/SS wall system with regard to air and moisture movements as well as temperature gradients. The BV/SS test wall was first evaluated during 1991/92 and the findings were outlined in a report dated June 4, 1993. The second and third reports, dated February 17, 1995, and November 5, 1996, respectively, discuss the Phase 2 and Phase 3 results of the study, including the findings from the 1992/93 and 1995 performance monitoring and the March 1994 inspection openings.

As with the Phase 3 report, this report is a more brief form of the previous reports because the 1996/97 findings mainly confirmed previous findings. Included in this report are example charts that are similar to those in the Phase 2 and Phase 3 reports, so that the reader may make some basic comparisons. In general, this report outlines the findings without the detailed explanations that were included in the Phase 2 report. It is recommended that this project continue for years to come in order that long term performance data may be collected, even if such data collection is carried out only every two to three years.

The key difference between Phase 3 and Phase 4 of this project has been the addition of vent holes at the top of the monitored wall section. The mortar was cut out of every second mortar joint in the top course of brick in an attempt to improve venting of the cavity.

2. INSTRUMENTATION AND PERFORMANCE MONITORING

2.1 Description of Instrumentation

Air leakage out of a building and rain wetting of walls are important consequences of the effects of wind in relation to a building. An upper floor BV/SS wall with an east-north-east exposure at the south-east corner of the building was selected for monitoring. This wall provides the worst combination of precipitation and air exfiltration, because of:

- Ottawa's wind driven rains from the east
- Ottawa's winter winds from the west, and
- stack effect causing the upper storey to have the most severe outward pressure differences.

The selected test wall was instrumented with sensors that measure the driving potentials that affect the wall's performance with respect to temperature gradient, moisture migration and air pressure differences. The instrumentation consisted of various temperature, moisture and air pressure sensors which were connected to a computer based, automatic data acquisition system. The locations and types of sensors installed are shown in Figs. 1 - 4, and a summary is given in Table A-1. The stud space chosen for instrumentation was selected to avoid columns and corners as well as to minimize the effects of wall penetrations from telephone and cablevision outlets. Sensors in the brick veneer were installed during the brick laying process. (Note that for this report, instrumentation and building performance will be described as being at the stud and at the insulation). The data acquisition system and sensor accessories, such as power supplies and micromanometers, were installed in the mechanical penthouse on the roof.

Air and surface temperatures were measured with thermocouples in many locations within and outside the test wall. Thermocouples were installed at several points across the wall section to determine the temperature gradient across the wall at these locations. The instrumentation points across the wall were generally the same at the stud and at the insulation. The exceptions are the additional thermocouple on the interior flange of the stud (T20), and that the thermocouple on the interior of the exterior gypsum board at the stud was installed on the exterior flange of the steel stud, whereas at the insulation, it was installed on the gypsum board. (T11) A surface temperature thermocouple was also installed on a triangular wire brick tie at the stud location. Air temperatures were measured on the interior (T31) and exterior (T14) of the building as well as within the air space (T33) and stud space (T34) of the test wall.

In order to monitor the amount of water vapour in the air on the interior and exterior of the building as well as within the test wall, relative humidity (RH) sensors were installed. In addition to water vapour being monitored using RH sensors, the presence of liquid water was monitored using electrical resistance moisture sensors. Electrical resistance sensors were used to detect moisture levels in the brick masonry, at the floor slab level and approximately 500 mm below the roof slab level, as well as in the air space at the shelf angle and within the stud space at the centre of the bottom track. A new condensation sensor was also installed at the end of Phase 2, but it short-circuited from exposure to moisture before the Phase 3 monitoring began, rendering it ineffective.

Air pressure was measured at the test wall using pressure taps through the wall and connecting the pressure taps to vinyl tubes which were run up to the micromanometers located in the mechanical penthouse. The air pressure outside and inside the building, within the air space and within the stud space of the test wall were measured. The pressure differences between the interior air and the air at other positions across the wall were recorded. Therefore, measurements were obtained for pressure differences between interior air and exterior air, between interior air and the air within the cavity, and between interior air and the air within the stud space.

Airport weather data was used for wind speed and direction, precipitation occurrences and sunshine information.

2.2 Data Acquisition

A stand-alone, automatic data acquisition system was used to enable the sensors to take readings as well as to record the data. The conditions were measured at each sensor every minute. Every hour, the system calculated and recorded the hourly average, minimum and maximum values of the data read. The data was then downloaded periodically by computer and modem. The test wall was monitored over four, two-week periods in 1996 and as a result, data was available for analysis for each of the four seasons. Raw data was converted into spreadsheets using Excel macros that were specifically designed for this project, with all data manipulations included in these macros to convert raw data readings into scientific values. Excel was also used to chart and analyse the data.

3. EVALUATION OF DATA

3.1 Evaluation Periods

While data pertaining to all sensors were recorded for the four seasons, evaluating the performance of the test wall pertaining to each particular criteria involves an analysis of only the most useful sets of data. Therefore, while some analyses were conducted for data for all types of weather (such as wetness in the wall system), other analyses were conducted only for certain types of weather (such as thermal bridging through the stud being reviewed only for cold weather).

Since the findings of Phase 4 confirm previous findings, such findings are not summarized in this report. Instead, the findings of this report are outlined in a general fashion and sample graphs are included in Appendix B. To simplify comparisons for readers who also have the Phase 2 and Phase 3 reports, the graphs included in this report are of the same nature and are presented in the same order as the graphs presented in the Phase 2 and Phase 3 reports.

Additional supporting graphs from Phase 4 are included in Appendix C and comparative graphs from Phase 3 are included in Appendix D.

3.2 Temperature

The temperature profiles of the test wall at the insulation and at the steel stud are shown in Figs. 5 and 6, respectively. The main findings regarding the temperature profiles of the test walls are:

1. Good thermal performance can be expected from a typical brick veneer/steel stud wall; as expected, the vast majority of the thermal resistance of the wall occurs through the insulation.
2. Significant thermal bridging occurs through the steel stud when no exterior insulation is used.
3. The percentage of thermal resistance that occurs within the insulation varies. In cold weather, sometimes the insulation accounts for nearly all of the thermal resistance of the wall, but at other times, it appears that the cavity is a significant factor. To review this finding further, plots such as that of Fig. 7 were made to compare actual and theoretical temperatures on both sides of the cavity, at the insulation. (The

theoretical temperatures were calculated by making a "steady state" thermal analysis of the wall and combining the results of this analysis with hourly interior and exterior air temperatures, to obtain "steady state" thermal profiles for each hour of data.) Analysis of data such as that shown in Fig. 7 revealed that the actual and theoretical values of T8 and T9 generally differed by 4°C and 3°C, respectively, with differences of up to about 13°C and 11°C, respectively.

4. In cold weather, the exterior face of the brick veneer is generally colder than its interior face because of the warmer air trapped in the cavity.
5. In hot weather, the exterior of the brick veneer is hotter than the interior face, again due to more temperate air trapped in the cavity.
6. As suggested by the findings of Items 4 and 5, the exterior face of the brick veneer experiences more severe temperature fluctuations than its interior face. Therefore, if the interior and exterior are equally wet this would result in more severe freeze/thaw action for the exterior of the brick veneer. (However, later findings show that it is the interior face which is wet much more often).
7. In colder weather, the interior drywall is consistently colder at the steel stud (T23) than at the insulation (T22), due to heat loss through the stud. In 1995, the temperature difference was typically about 2°C, with the maximum difference of 3.5°C.
8. In colder weather, the exterior of the exterior surface gypsum board sheathing is consistently warmer at the steel stud (T11) than at the insulation (T8), due to the thermal bridging and, hence, less effective thermal resistance, at the steel stud. In 1996/97, the temperature difference was generally about 5°C, but was much as 7°C.
9. The general trends regarding temperature data, including comparative temperature differences outlined in Items 3 to 8, are very similar to the findings of Phases 1, 2 and 3 of this monitoring program. Therefore, the thermal performance of the wall appears to be unchanged over the first six years of monitoring.

3.3 Air Pressure

Pertaining to Item 3 in the previous report section, an analysis was done to determine if the thermal performance of the wall is affected by wind forces and stack effect. To make this analysis, average readings for the pressure difference across the test wall, P1-P4, were plotted against the corresponding average values of the "Temperature Index", T_i , of the backup wall. For various cold weather data, the actual Temperature Index of the backup wall was calculated for each hourly set of readings using the actual data and the formula $T_i = (T_{31}-T_8)/(T_{31}-T_{14})$. The plots indicated that there is a relationship between pressure differences across the test wall and the Temperature Index of the test wall. (See example plot of Fig. 8). The data indicates that warm air exfiltration under high pressure differences across the test wall is the key reason that the actual and theoretical temperature profiles differ. It should be noted that the apparent deterioration of the thermal performance of the wall is not due to the brick veneer being "short-circuited" by wind blowing more air into the cavity. Air movement behind the cavity is usually minimal and, in fact, warm interior air that leaks into the cavity is often trapped in the cavity, causing the cavity air to be much warmer than the exterior air.

Sample hourly average and daily average pressure differences across the test wall are shown in Figs. 9 and 10. The pressure data for all time periods are similar as those found in Phases 2 and 3. The findings regarding air pressure are:

1. The air barrier is fairly effective, showing a significant air pressure difference P3-P4 (see Figs. 9 and 10).
2. Pressure equalization of the cavity is only partially effective, as evidenced by the fact that changes in wind pressure do cause a change in both P1-P4 and P2-P4, but the change is greater in P1-P4. Also, there is a significant change in pressure across the brick veneer, P1-P2, which is represented by the space between P1-P4 and P2-P4 (see Fig. 10).
3. As explained previously, higher outward air pressure differences, caused by wind and stack effects, reduce the thermal effectiveness of the test wall.
4. The large P1-P2 also is an indication of air leakage through the backup wall, since air leakage partially releases pressure on the backup wall, causing the brick veneer to resist more pressure. However, P1-P2 alone does not prove that air leakage exists, but rather the reduced thermal performance of the wall under higher suction winds and the findings of previous inspection openings indicate that air leakage does exist.
5. The reduced thermal effectiveness of the test wall is the result of air exfiltration.

6. Since P2-P4 is approximately P3-P4, this indicates that the exterior sheathing allows the free movement of air, and thus it does not act as an unintentional air barrier on the exterior of the insulation.

Overall, the test wall functions generally as designed in terms of air barrier placement and effectiveness, but air leakage does occur which reduces the effectiveness of pressure equalization in the cavity and the thermal performance of the test wall.

3.5 Moisture

Moisture within the wall system consists of water vapour and liquid water. There is always water vapour within the wall system but its presence is most significant during colder weather when water vapour can condense against cold surfaces, causing wetting of building elements. Liquid water from exterior sources is a concern only if its presence becomes detrimental to the brick veneer/steel stud wall. Also, water which penetrates the cavity but cannot escape due to poor venting or drainage will result in larger amounts of water vapour being trapped and increased condensation on building elements within the cavity.

Sample wetness of the brick surface at monitoring points M1, M2, M3, M4, M5 and M6 is shown in Fig. 11. Note that the electrical resistance moisture sensors in the test wall were not calibrated to determine the specific moisture content in the brick, rather, their readings indicate relative wetness. Higher resistance readings indicate drier conditions and, conversely, lower readings indicate wetter conditions. Note that freezing of water in the brick during cold weather will result in higher readings, giving a false indication of the brick being drier and, therefore, this point must be kept in mind when reviewing the graphs.

While the moisture sensor data indicates the wetness levels, the source of this wetness is determined by evaluating weather data as well as information regarding the occurrence of condensation in the test wall. Comparing wetness levels to weather data is straightforward since increases in wetness are simply correlated with the occurrence of precipitation, wind speeds and directions, or even sunny weather. To evaluate whether condensation may be affecting wetness levels, the dew point temperature in the cavity and the stud space is plotted against surface temperatures of building elements in contact with the cavity or stud space air.

Fig. 12 is a plot of the dew point temperature of the cavity air versus the temperature of the interior surface of the brick veneer, with the exterior air temperature also shown. Fig. 13 illustrates the dew point temperature within the backup wall as compared to the surface temperature on the exterior sheathing and on the exterior flange of the steel stud.

Reviewing all moisture related data, including plots such as those in Figs. 12 and 13, the findings are as follows:

1. In cold weather, condensation occurs almost continuously on the interior face of the brick veneer. Condensation even occurs occasionally when temperatures are slightly above freezing.
2. In cold weather, condensation occurs frequently on the interior face of the exterior drywall.
3. Condensation does not occur on the steel studs, in any weather experienced during the monitoring period.
4. The exterior of the brick veneer at the floor slab level (M1) is usually dry during dry summer weather, but this area is frequently, but not always, wetted by precipitation.
5. The interior of the brick veneer at the floor slab level (M2) is usually wet in the fall, winter and spring. The amount of wetness in the brick in this region during dry but cold weather indicates that condensation is a significant source of moisture.
6. The exterior of the brick veneer at the roof level (M3) is usually dry in dry weather (often drier than M1) but this area is wetted the most by precipitation.
7. The interior of the brick veneer at the roof level (M4) is usually wet to very wet during fall, winter and spring, but this area does dry out during summer weather. The extreme wetness of the brick veneer in this region during dry but cold weather indicates that condensation is the main source of moisture during cold weather. During precipitation occurrences, the sensor now becomes very wet, very quickly. This indicates that the new vent holes at the top of the wall allow more water to enter the cavity than was previously the case but drying speed is not improved.
8. The moisture sensor at the bottom of the cavity (M5) is mostly dry but wetted somewhat during precipitation, indicating that precipitation reaches the bottom of the cavity. However, since M5 is not significantly wetted, this indicates that most

precipitation that penetrates the brick veneer runs down the back face of the veneer and does not bridge across the cavity.

9. The moisture sensor on the bottom track of the backup wall (M6) is dry almost all of the time. It is sometimes dampened slightly in cold weather. This dampness indicates that condensation within the backup wall sometimes affects this sensor. The fact that M6 normally remains dry, even during severe precipitation, indicates that the cavity functions properly in most instances.
10. The findings of Items 5, 8 and 9 indicate that the test wall acts as a reasonably effective rain screen.
11. Wetting of the brick veneer is no longer primarily dependant upon wind direction. Water running down the face of the brick is able to enter the vent holes without having to be wind driven.
12. Precipitation is the main cause of wetting of Sensors M1 to M5. During cold weather, condensation is the main source of moisture at M4 and it is a significant source at M2.
13. Except during the summer, water vapour levels within the cavity were very high in comparison to exterior conditions. The high water vapour content not only caused condensation to occur regularly, but drying of the back face of the brick veneer was hindered until late spring.
14. The primary source of moisture in the cavity air is the leakage of moist interior air into the cavity.

The above findings indicate that serious building performance problems may occur over the long term. The most probable serious problem is that the frequent occurrence of condensation on brick ties could lead to the premature corrosion and the eventual failure of the ties. The continuous condensation in the cavity and the frequent condensation in the backup wall could also lead to severe deterioration of the exterior sheathing, possibly leading to water penetration into the building . Other potential problems include backspalling of the brick veneer, corrosion of the steel stud backup system, and reduced thermal resistance of the glass fibre insulation. The addition of vent holes at the top of the wall section does not speed drying of the air space. In fact, the vent holes increase the amount of water entering the cavity during rain events.

5. CONCLUSIONS

The findings outlined in the preceding sections indicate that the performance of the brick veneer/steel stud test wall is less than satisfactory since moisture and temperature conditions are not properly controlled. The key performance problems are air exfiltration, heat loss through thermal bridging, pressure equalization that is not fully effective, and poor venting of the cavity. These performance problems may cause significant building distress problems over the long term. The findings emphasize the need for improved standards since buildings, constructed according to current standards, generally will not likely perform in a satisfactory manner. As reported in previous reports, the BV/SS wall system would have performed better if a tight air barrier, exterior insulation, a wider cavity and compartmentalization were used.

6. RECOMMENDATIONS

Given the less than satisfactory performance of this BV/SS wall system, it is recommended that this monitoring program be extended over several more years so that additional data may be obtained. Ideally, this program should be ongoing for many years so that the performance of this brick veneer/steel stud wall system may be evaluated over the long term. At this time, CMHC intends that Phase 4 will be the final phase of this work. However, it is recommended that this program be extended, and that readings be taken at least every two to three years.

The information obtained through this monitoring program will be invaluable to designers, investigators and building owners as it clearly shows the potential vulnerability of the BV/SS wall system to workmanship defects, and thus, the potential for accelerated deterioration.

Since the deterioration primarily occurs within the wall system, major distress could remain concealed until failure occurs, it is strongly recommended that periodic inspections of BV/SS wall systems, including inspection openings, be mandatory.

It is further recommended that performance monitoring work, similar to this program, be carried out on other buildings. Some buildings monitored should have typical BV/SS construction and other buildings should have BV/SS construction carried out in accordance with best practices. In this manner, further valuable knowledge will be gained about the in-situ performance of brick veneer/steel stud wall systems in different climatic regions.

Finally, it is recommended that the Energy Codes that were developed nationally be implemented as soon as possible by all provincial jurisdictions. The Energy Codes are excellent in general and, specifically related to BV/SS walls, the requirements of these codes will eliminate the thermal bridging that is built into many BV/SS wall systems constructed today. Also, implementation of these codes will likely result in improved air/vapour barrier systems for residential buildings.

APPENDIX A: Instrumentation Details

Table A-1 List of Sensors and Their Locations

Surface Temperature Thermocouples

10	Exterior of brick veneer at centre of stud region
9	Interior of brick veneer at centre of stud region
8	Exterior of exterior drywall at centre of stud region
18	Interior of exterior drywall at centre of stud region
22	Interior of interior drywall at centre of stud region
13	Exterior of brick veneer at steel stud
12	Interior of brick veneer at steel stud
11	Exterior of exterior drywall at steel stud
19	Exterior flange of steel stud
20	Interior flange of steel stud
23	Interior of interior drywall at steel stud
15	Triangular wire brick tie

Air Temperature Thermocouples

14	Outside air
33	Air space at RH2
34	Stud space at RH3
31	Inside air

Relative Humidity Sensors

RH1	Outside air
RH2	Air space
RH3	Stud space
RH4	Inside air

Moisture Sensors

M1	Exterior face of brick veneer at floor slab level
M2	Interior face of brick veneer at floor slab level
M3	Exterior face of brick veneer 500 mm below roof slab level
M4	Interior face of brick veneer 500 mm below roof slab level
M5	Bottom of air space
M6	Centre of bottom track

Air Pressure Sensors

P1	Outside air
P2	Air space
P3	Stud space
P4	Inside air

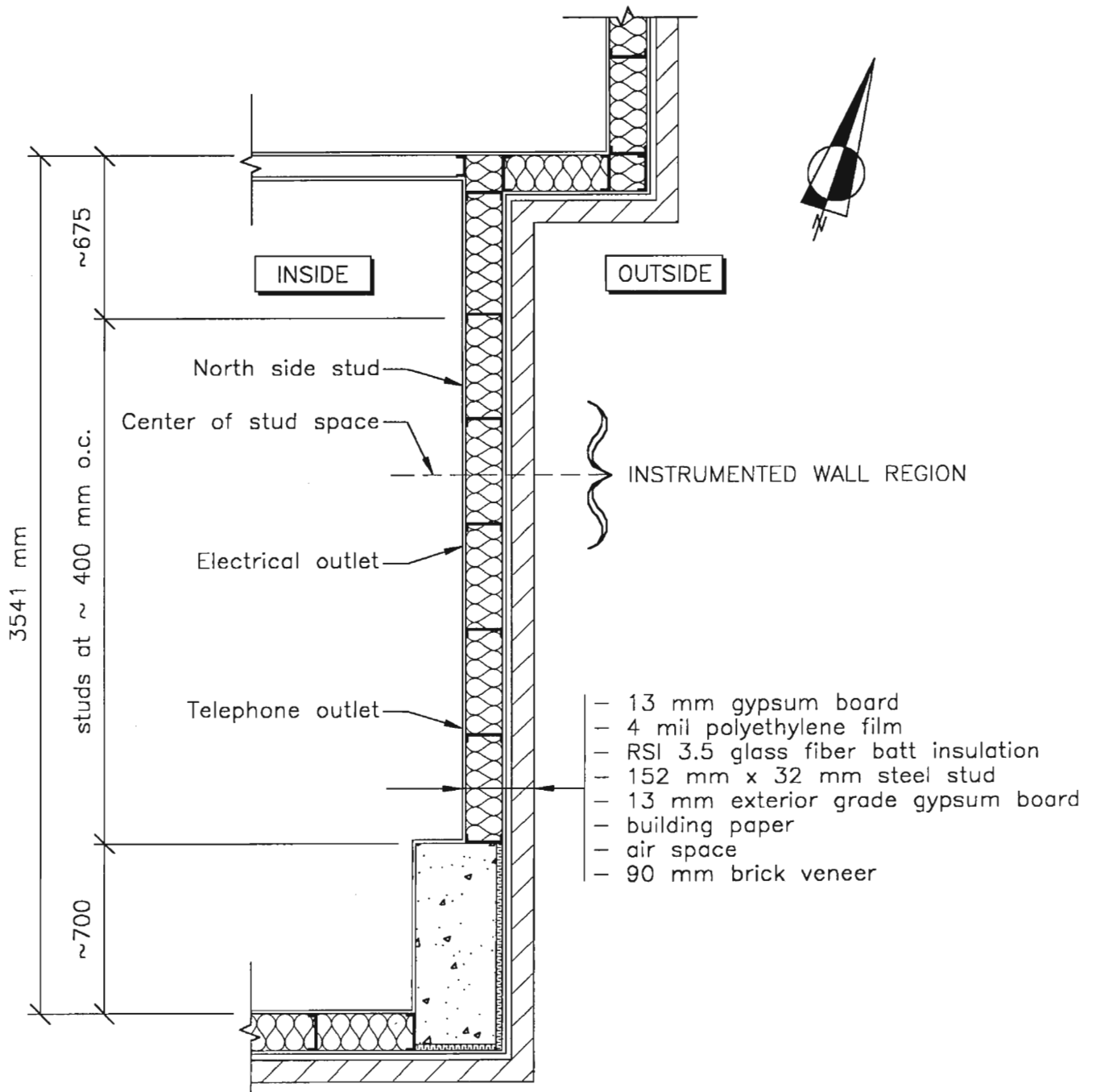


Fig. 1 Plan View of Test Wall

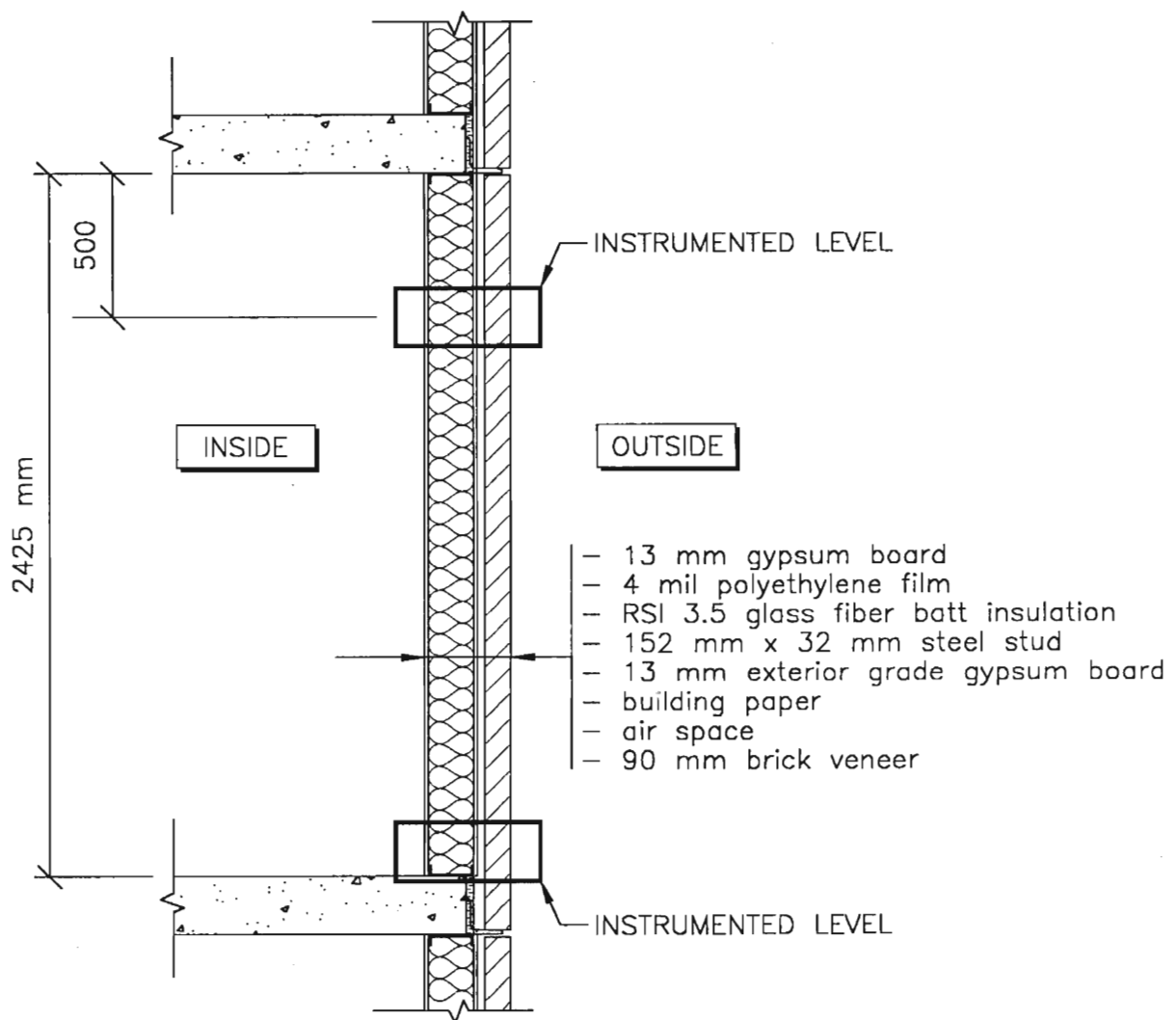


Fig. 2 Cross-Section Through Test Wall

A5

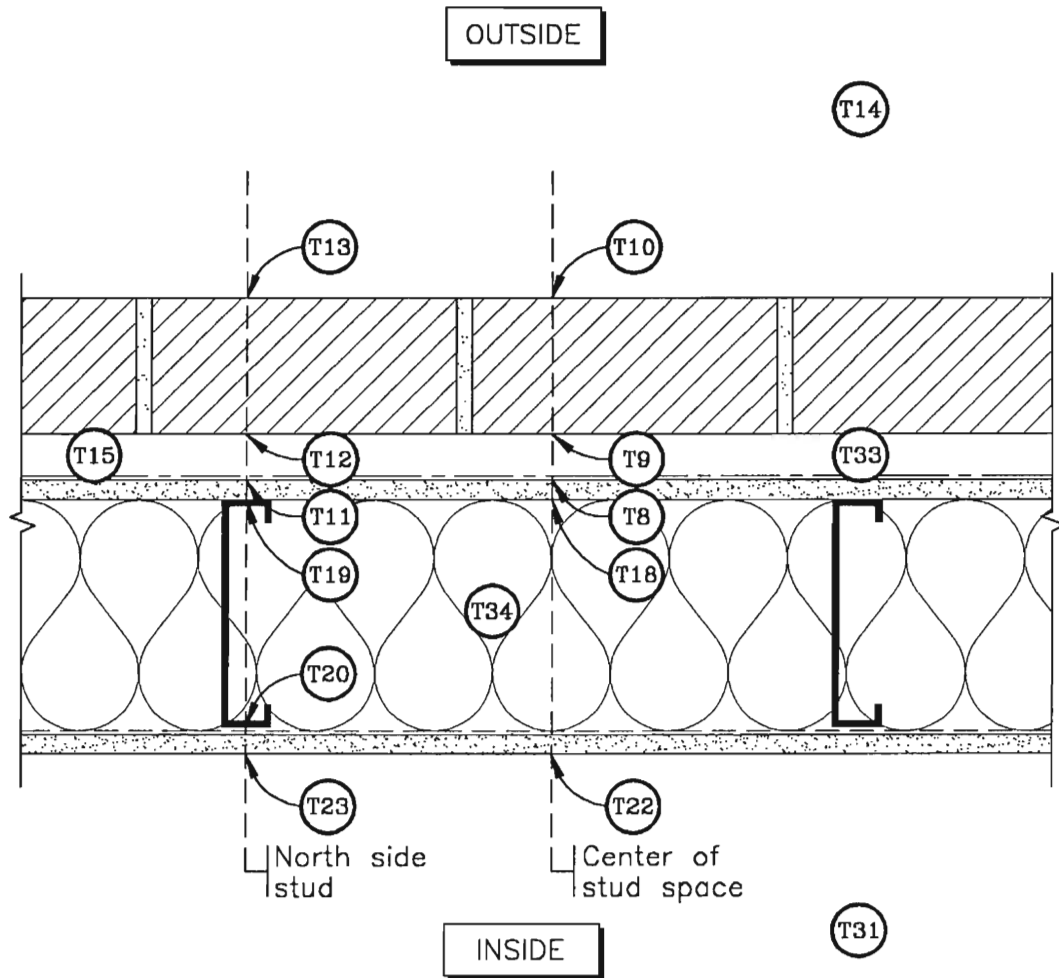
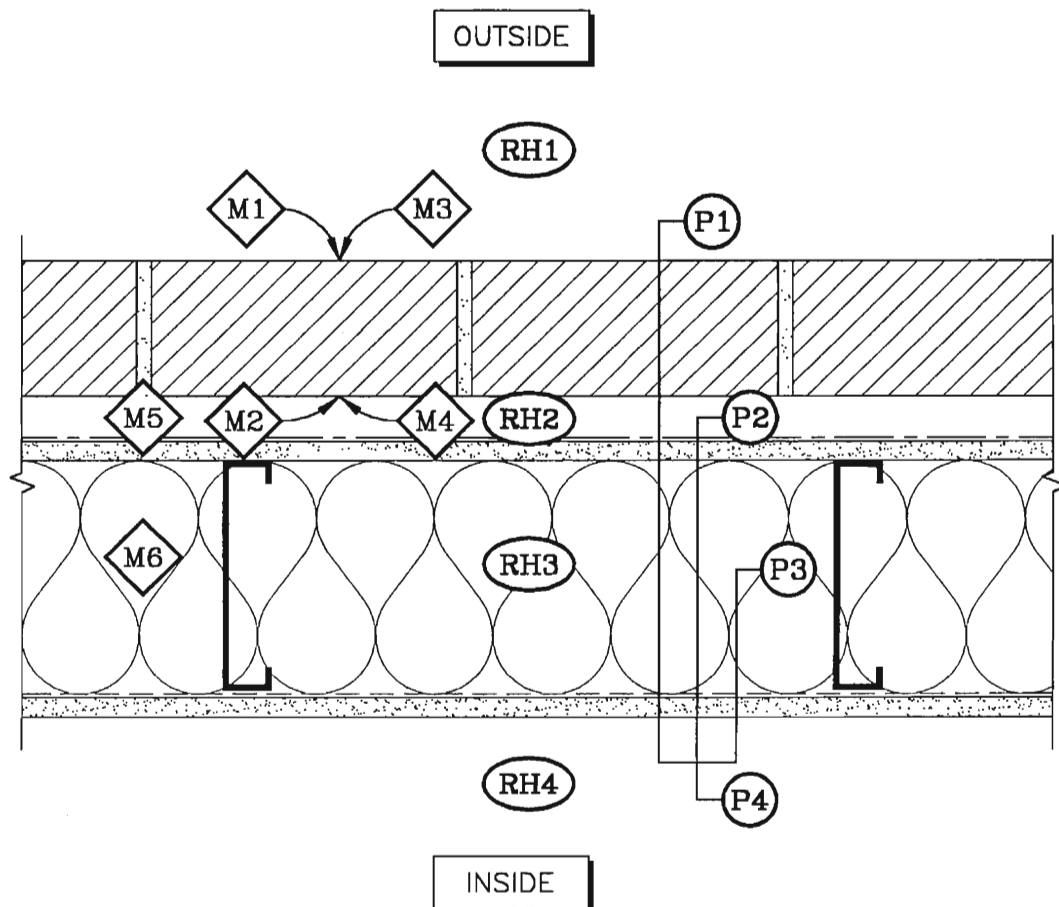


Fig. 3 Locations of Thermocouples Across Test Wall



LEGEND



— Electrical resistance sensor. Sensors M1 and M2 are at the first brick course and M3 and M4 at the 23rd course above the soldier course of concrete brick. Sensor M5 is sitting at the bottom of the air space and M6 is glued to the bottom track



— Pressure tap



— Relative humidity sensor

Fig. 4 Locations of Moisture and Air Pressure Sensors Across Test Wall

B1

APPENDIX B: Sample Graphs

Fig. 5 Temperature Profile Across Test Wall - at Insulation

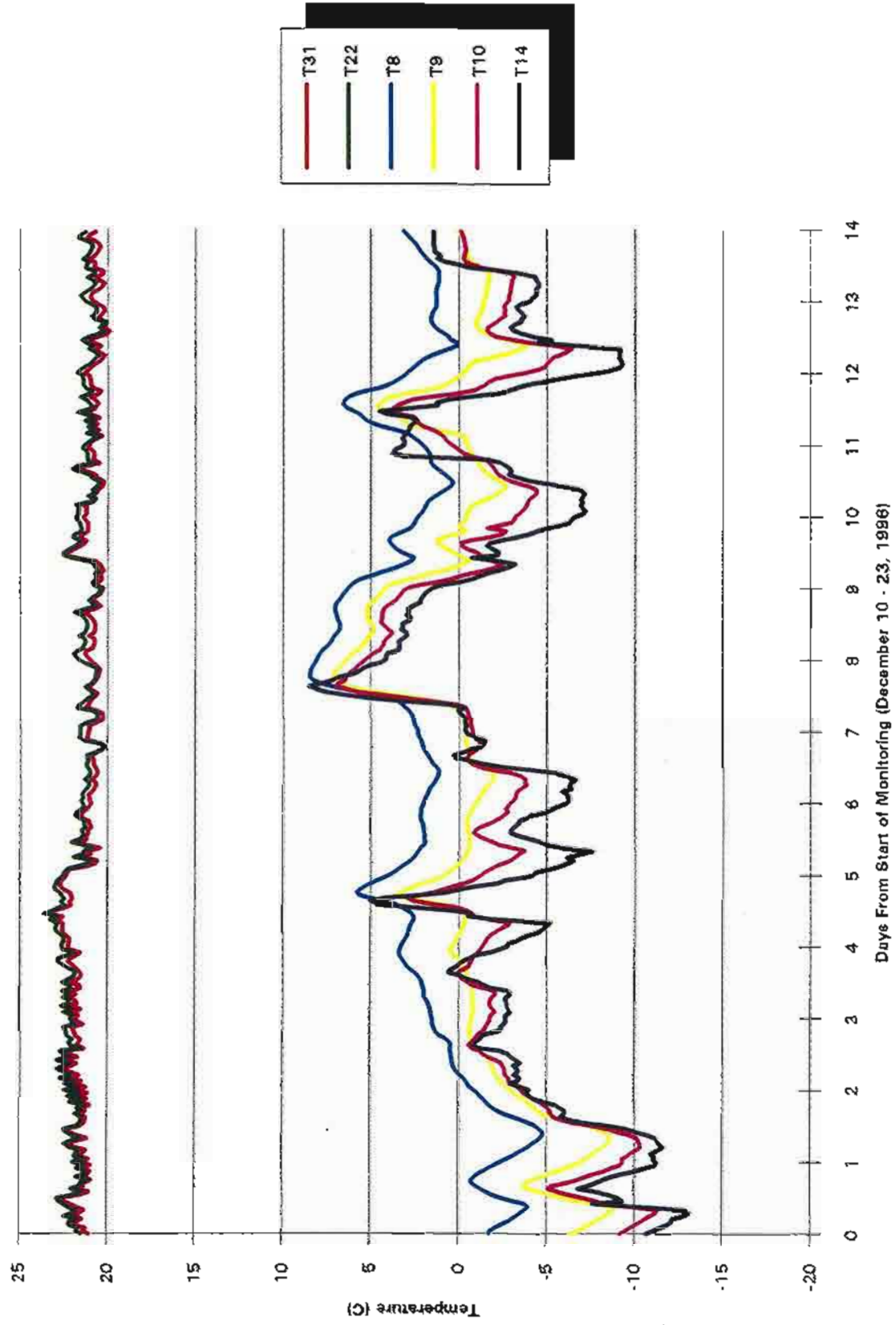


Fig. 6 Temperature Profile Across Test Wall - at Steel Stud

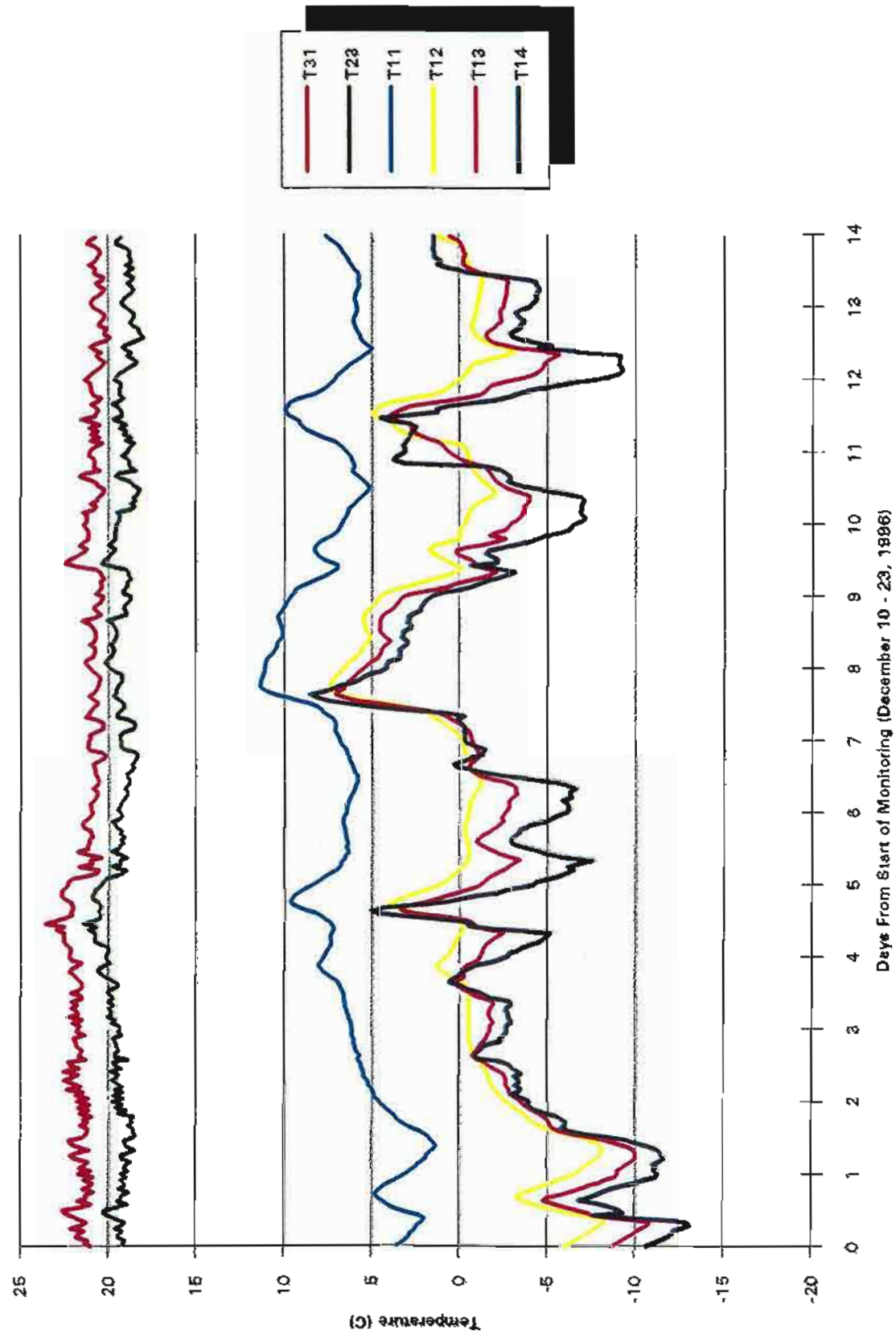


Fig. 7 Comparison of Actual and Theoretical Temperatures in Cavity

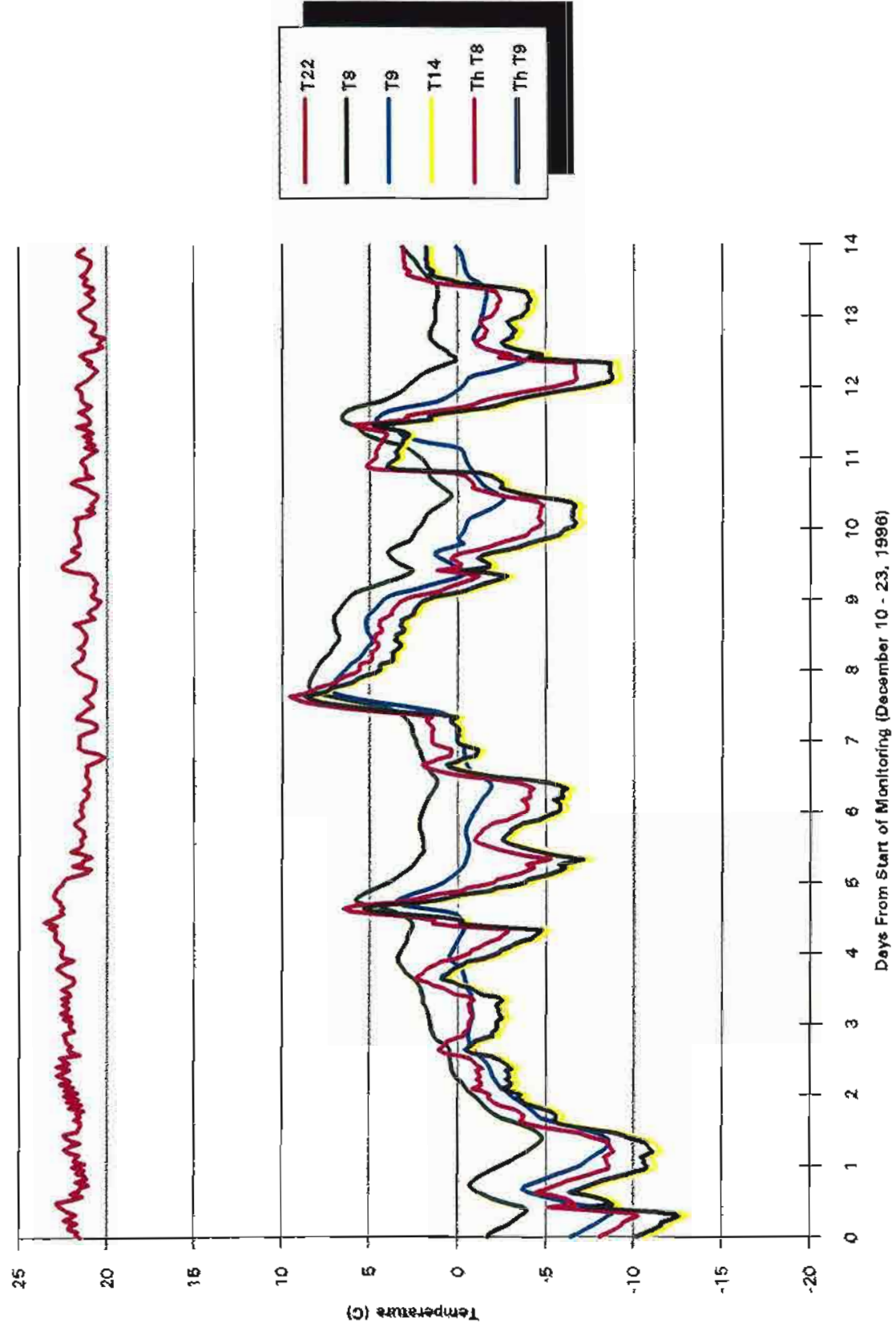


Fig. 8 Relationship Between the Pressure Difference Across the Test Wall and the "Temperature Index" of the Backup Wall

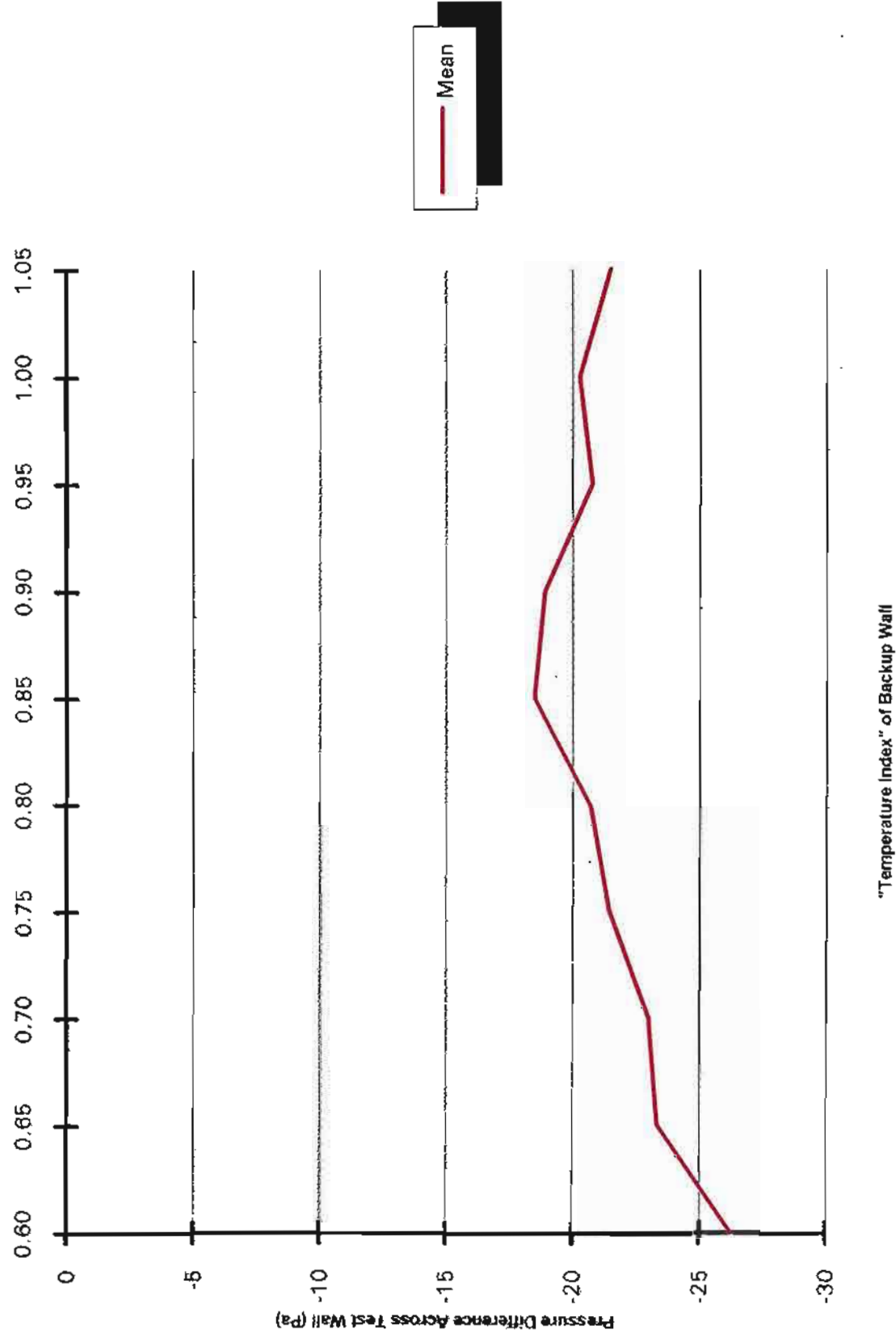


Fig. 9 Hourly Average Pressure Differences Across Test Wall

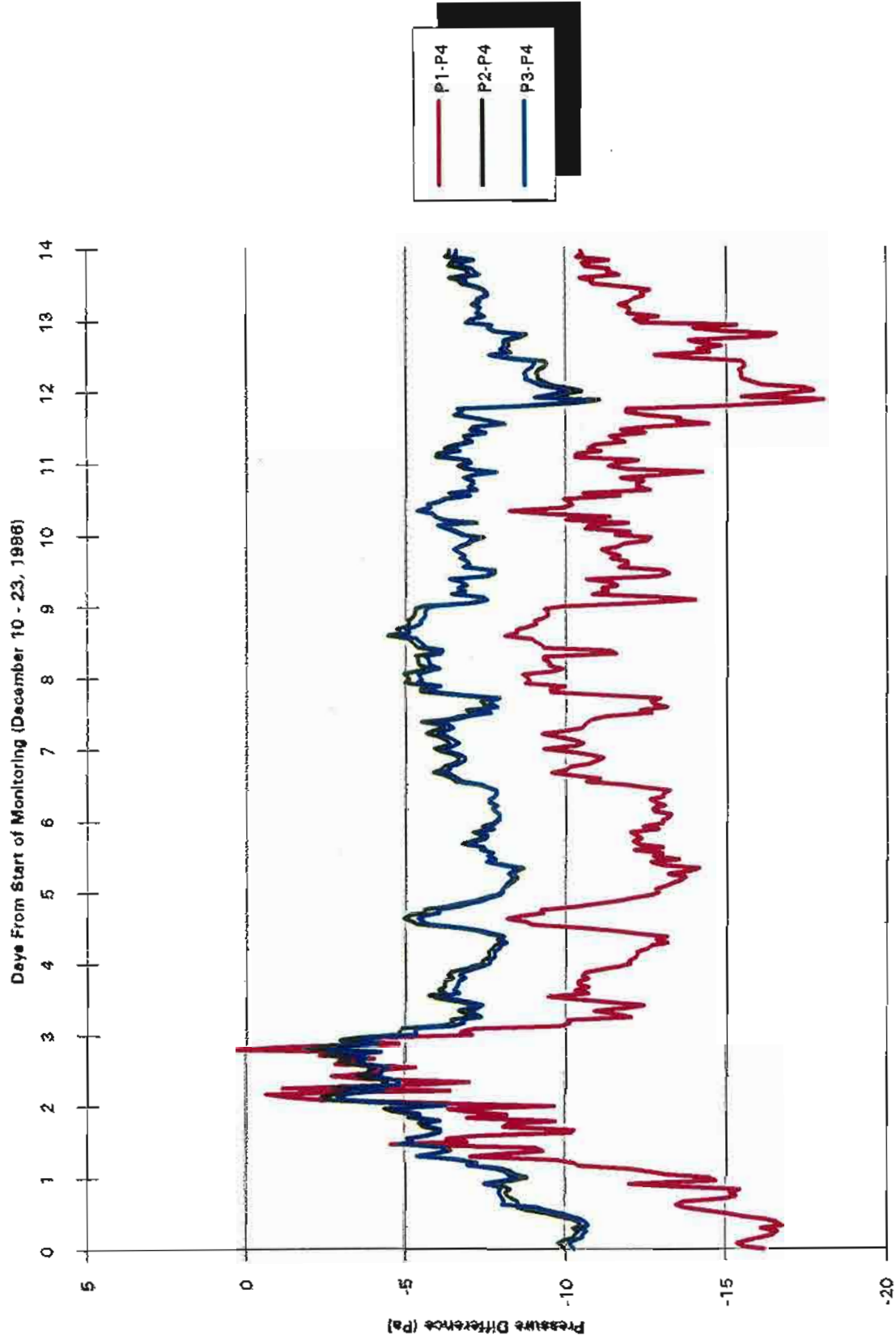


Fig. 10 Daily Average Pressure Differences Across Test Wall

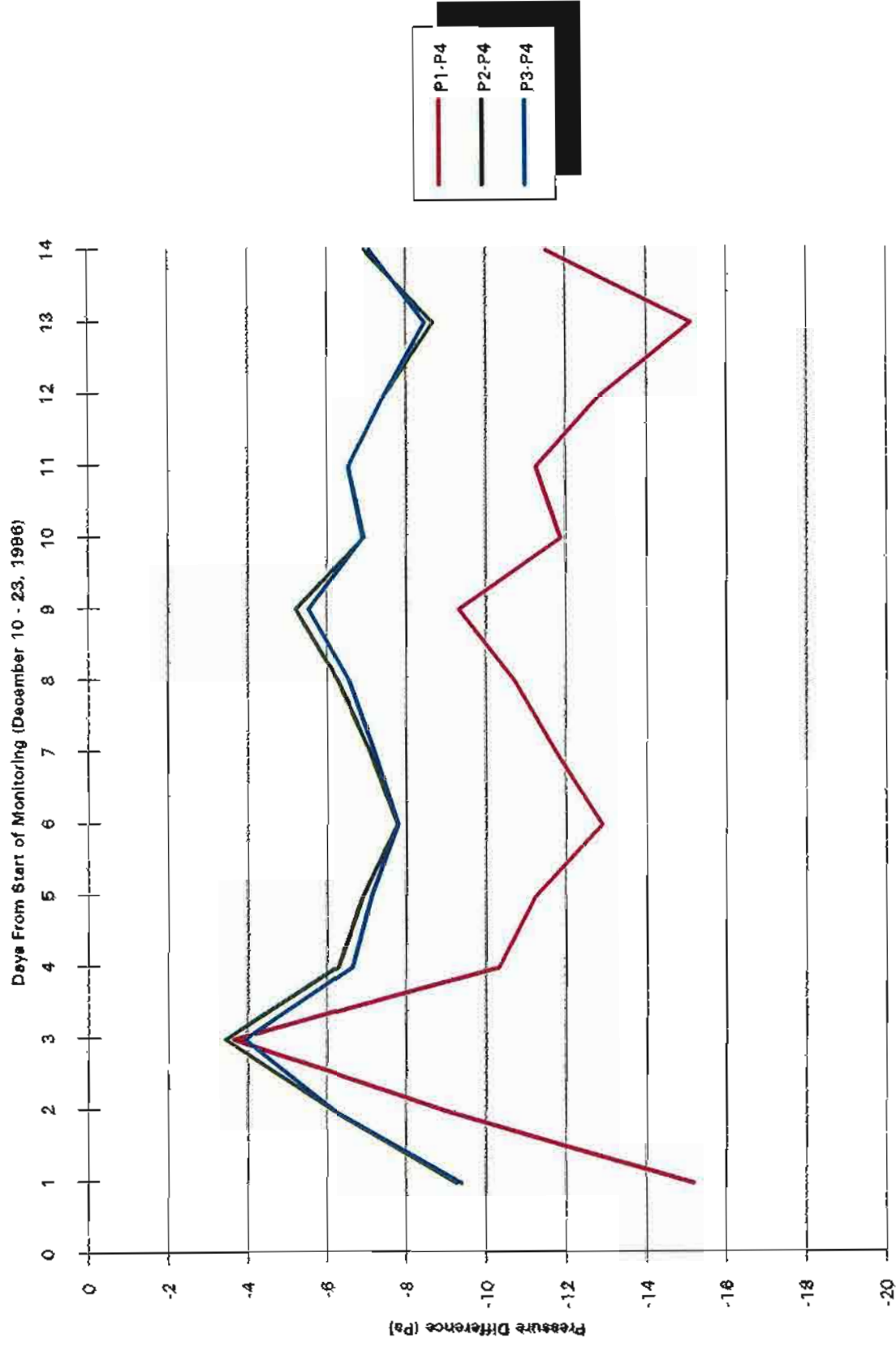


Fig. 11 Moisture Sensor Readings

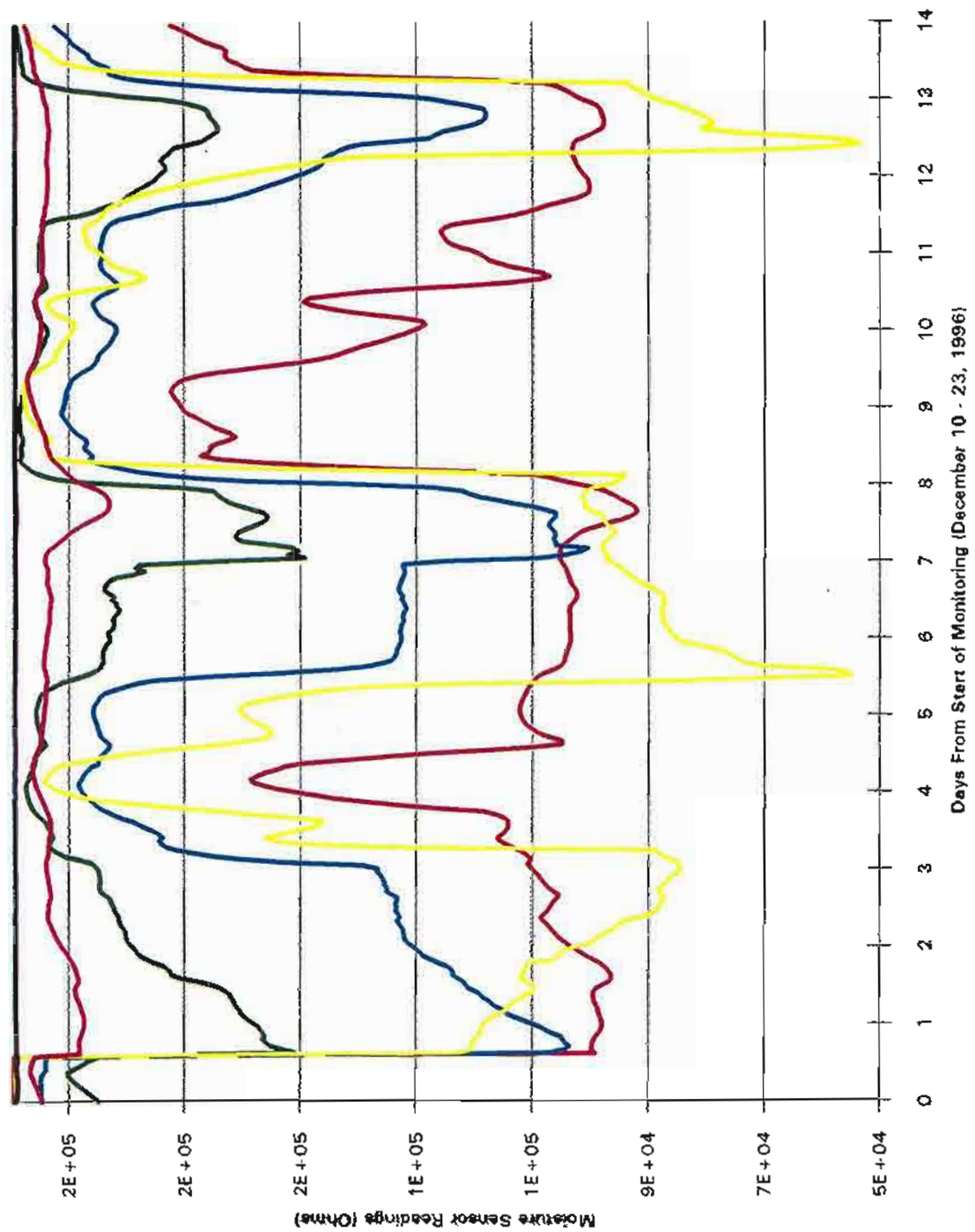


Fig. 12 Comparison of the Surface Temperature on the Interior Face of the Brick Veneer to the Dew Point Temperature of the Cavity Air

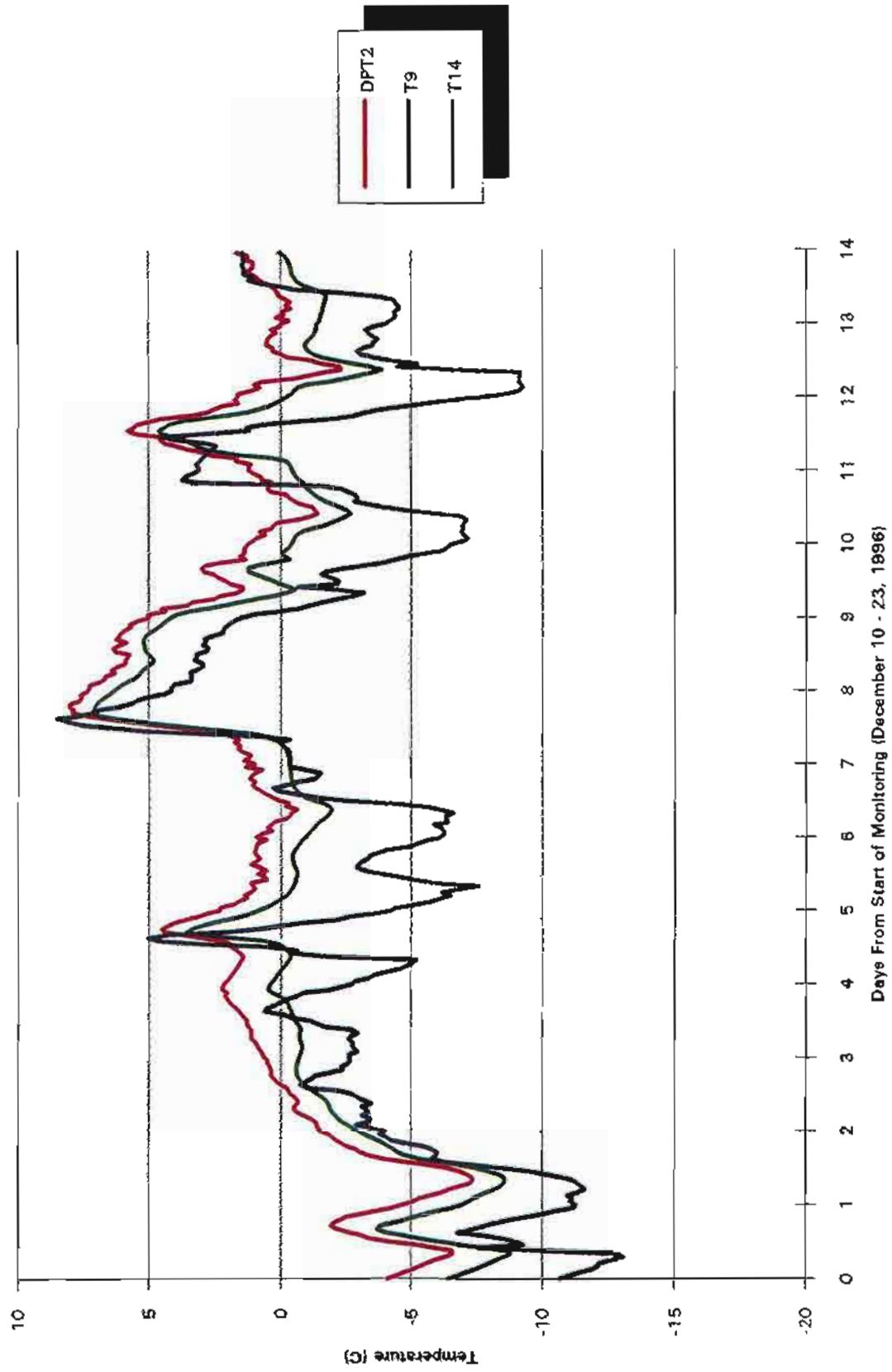
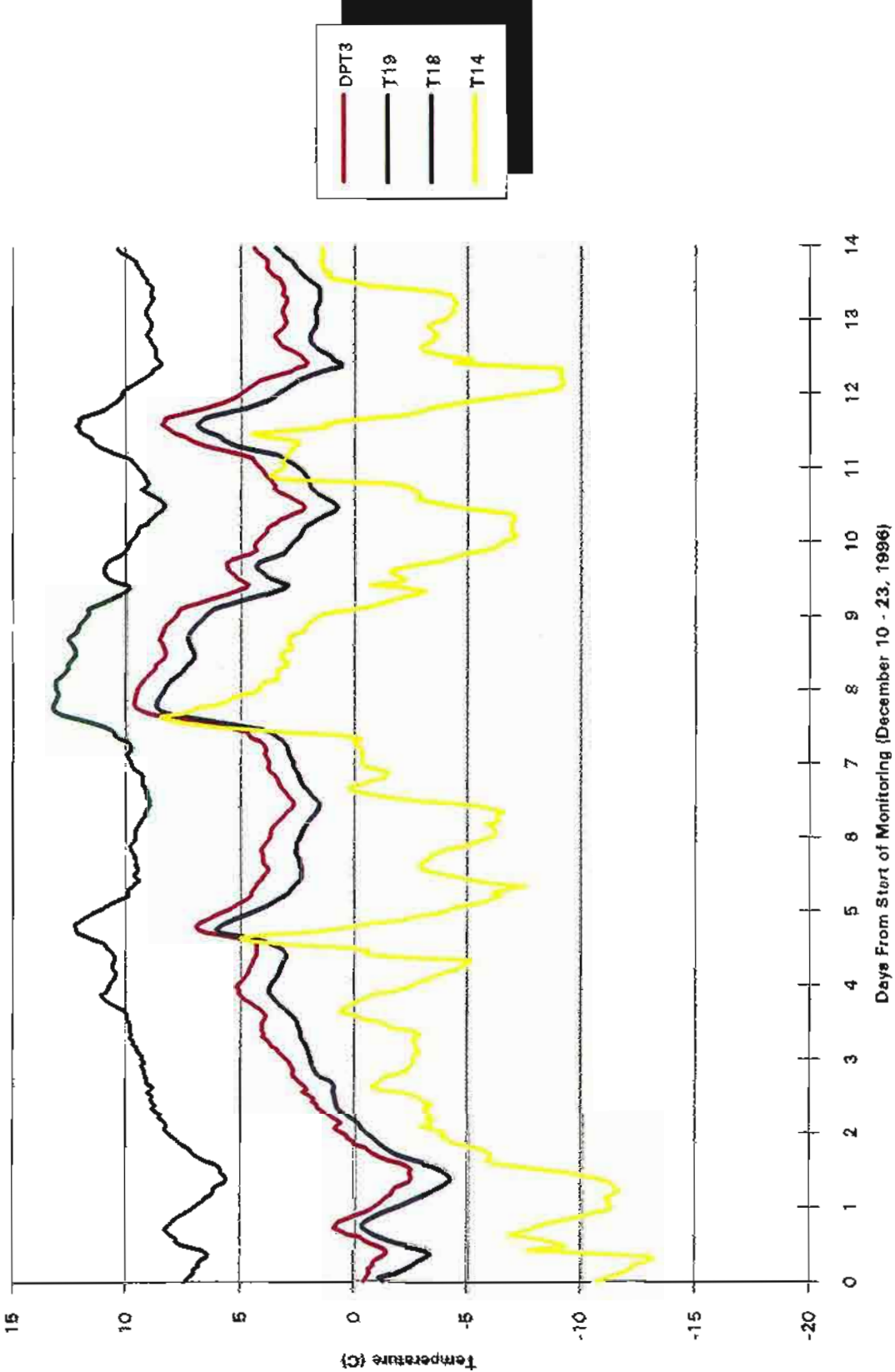


Fig. 13 Comparison of the Surface Temperature at the Exterior Gypsum Board to the Dew Point Temperature of the Air in the Stud Space



APPENDIX C: Additional Graphs

Fig. C1 Temperature Profile Across Test Wall - at Insulation

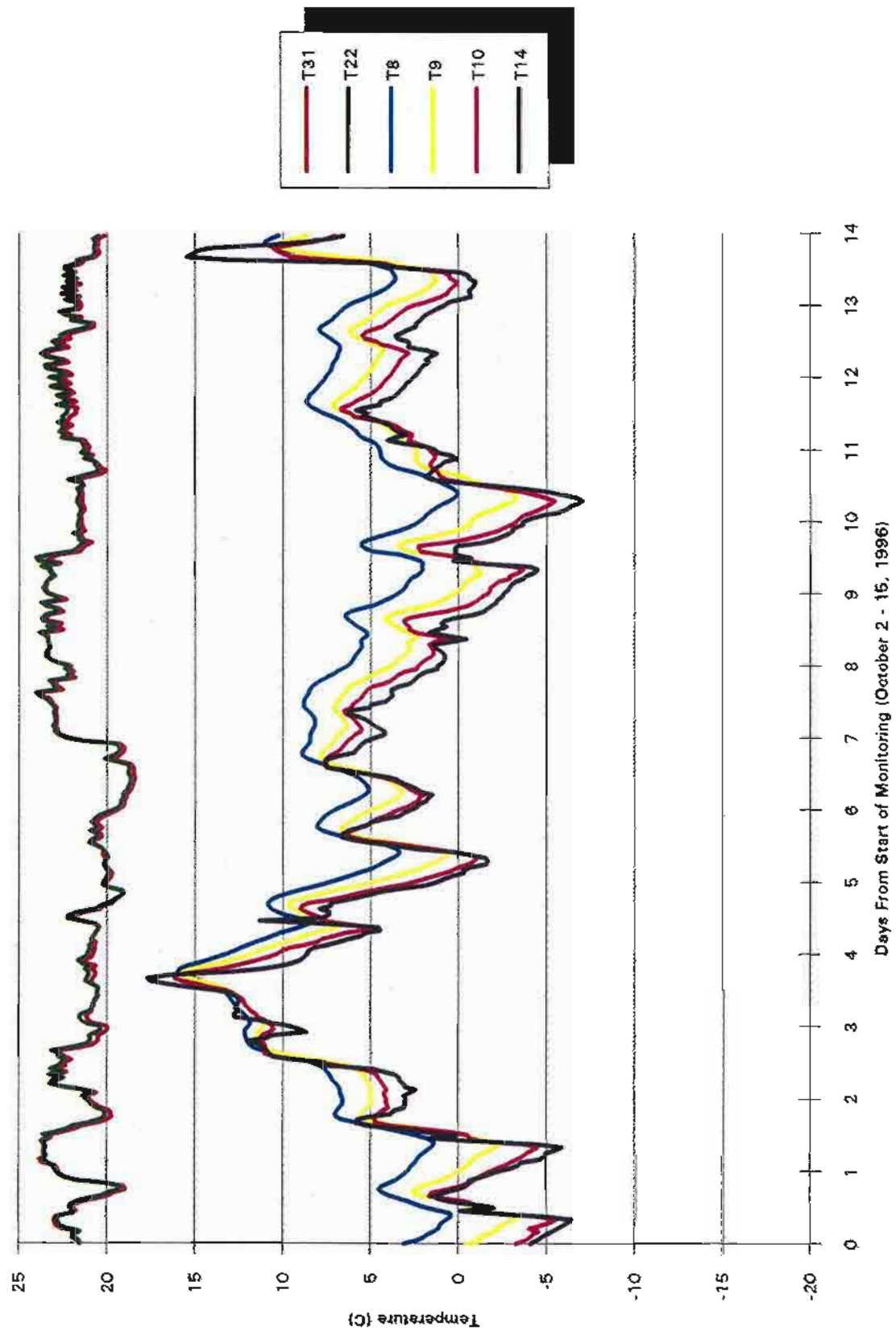


Fig. C2 Temperature Profile Across Test Wall - at Insulation

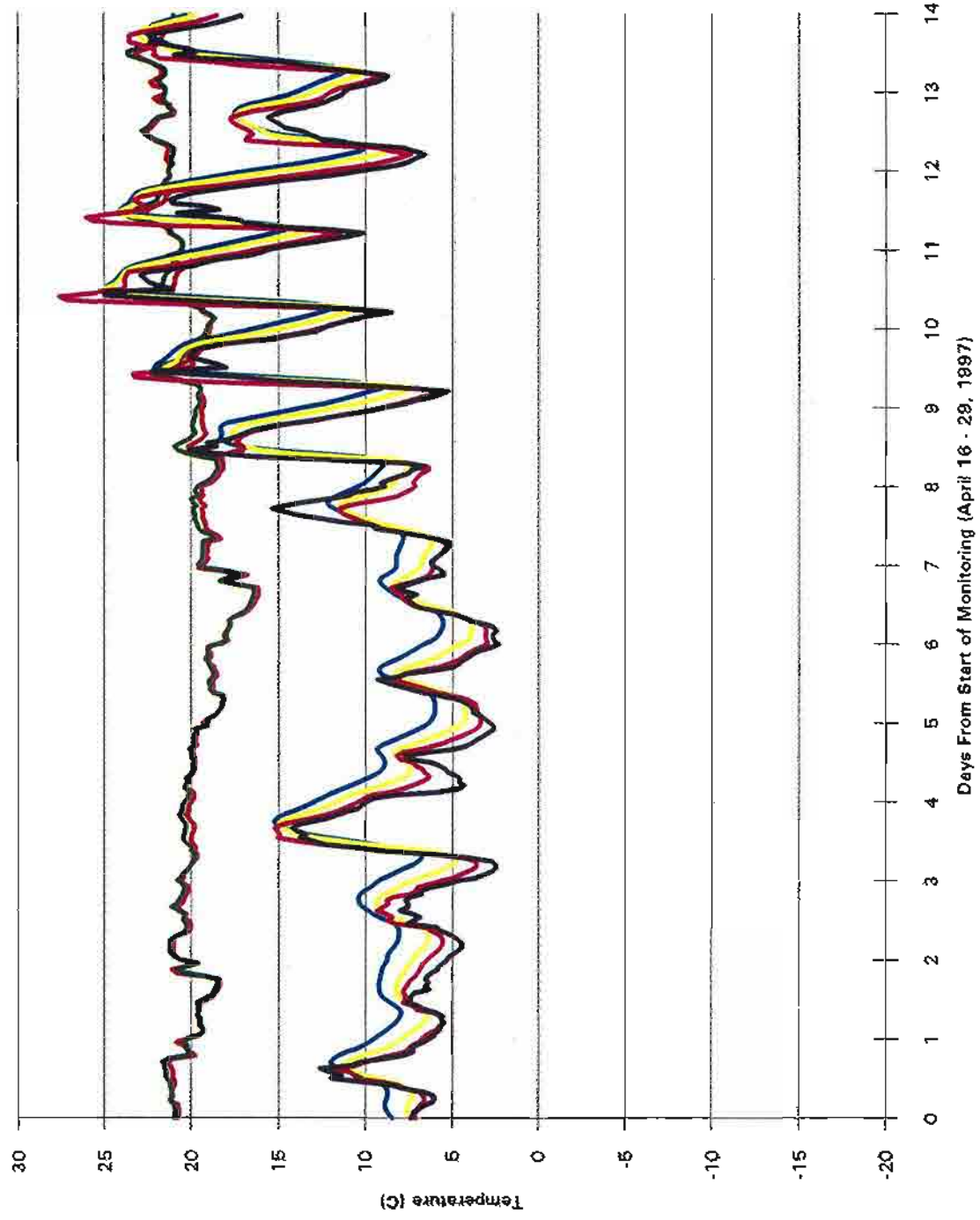


Fig. C3 Temperature Profile Across Test Wall - at Insulation

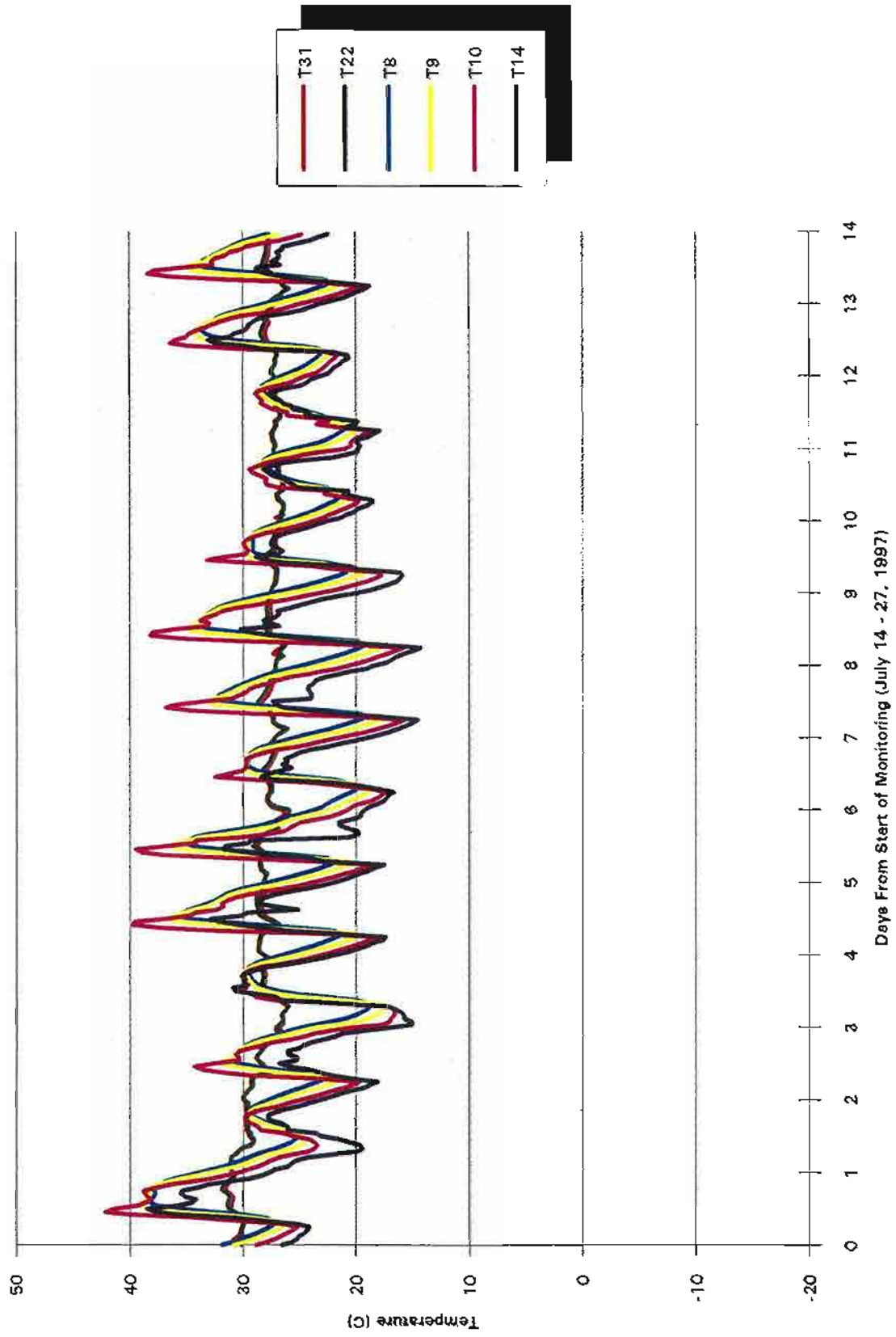


Fig. C4 Temperature Profile Across Test Wall - at Steel Stud

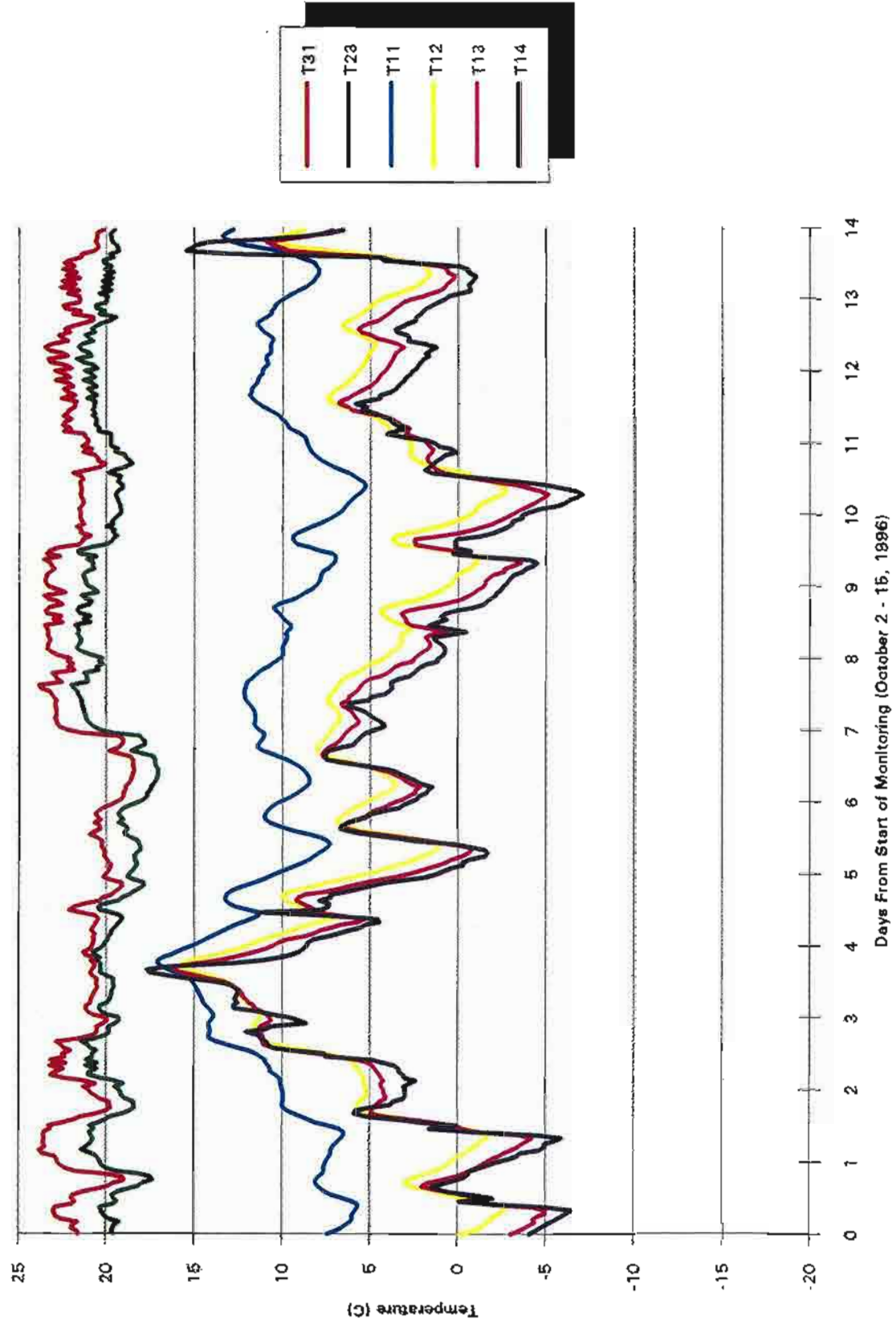


Fig. C5 Temperature Profile Across Test Wall - at Steel Stud

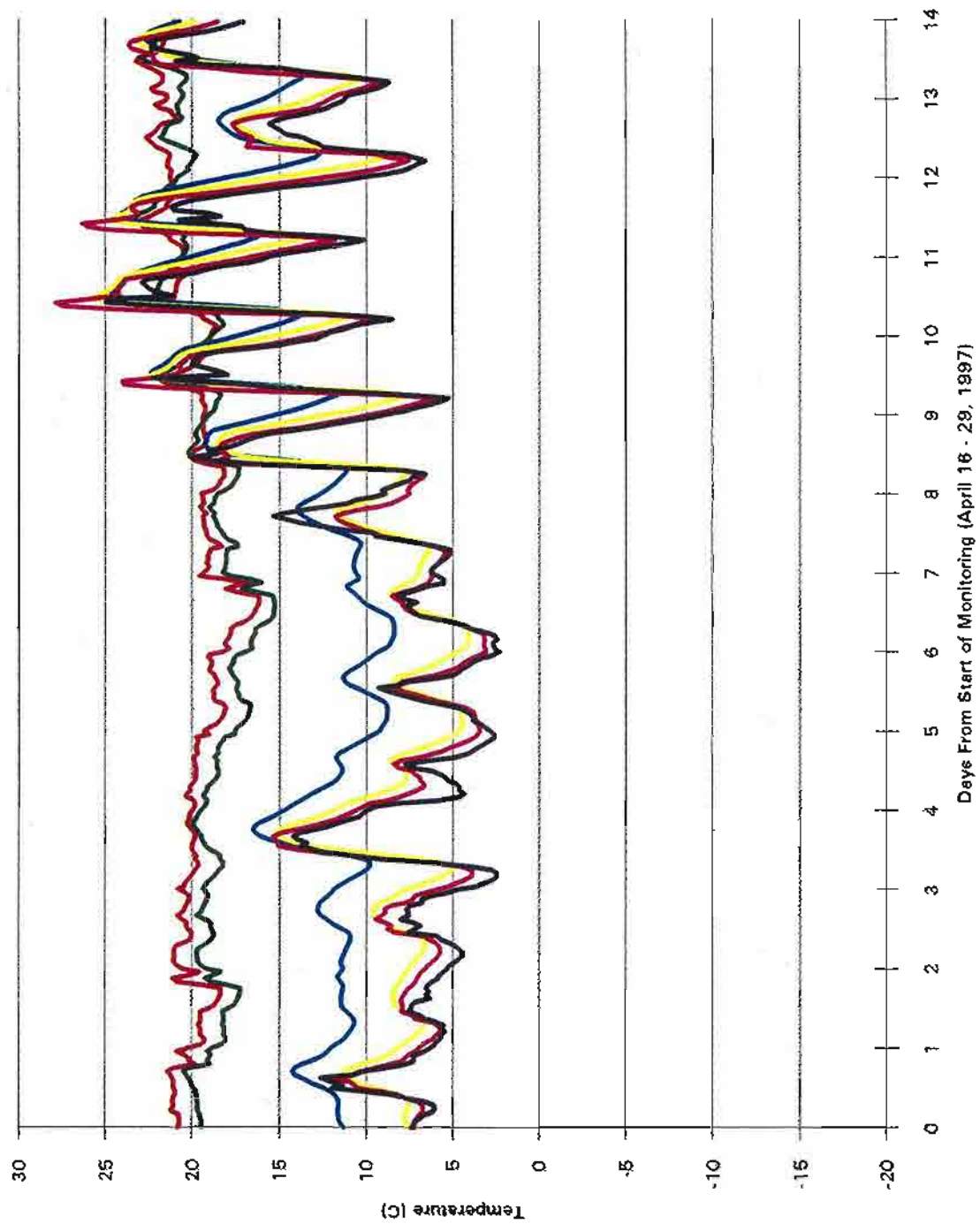


Fig. C6 Temperature Profile Across Test Wall - at Steel Stud

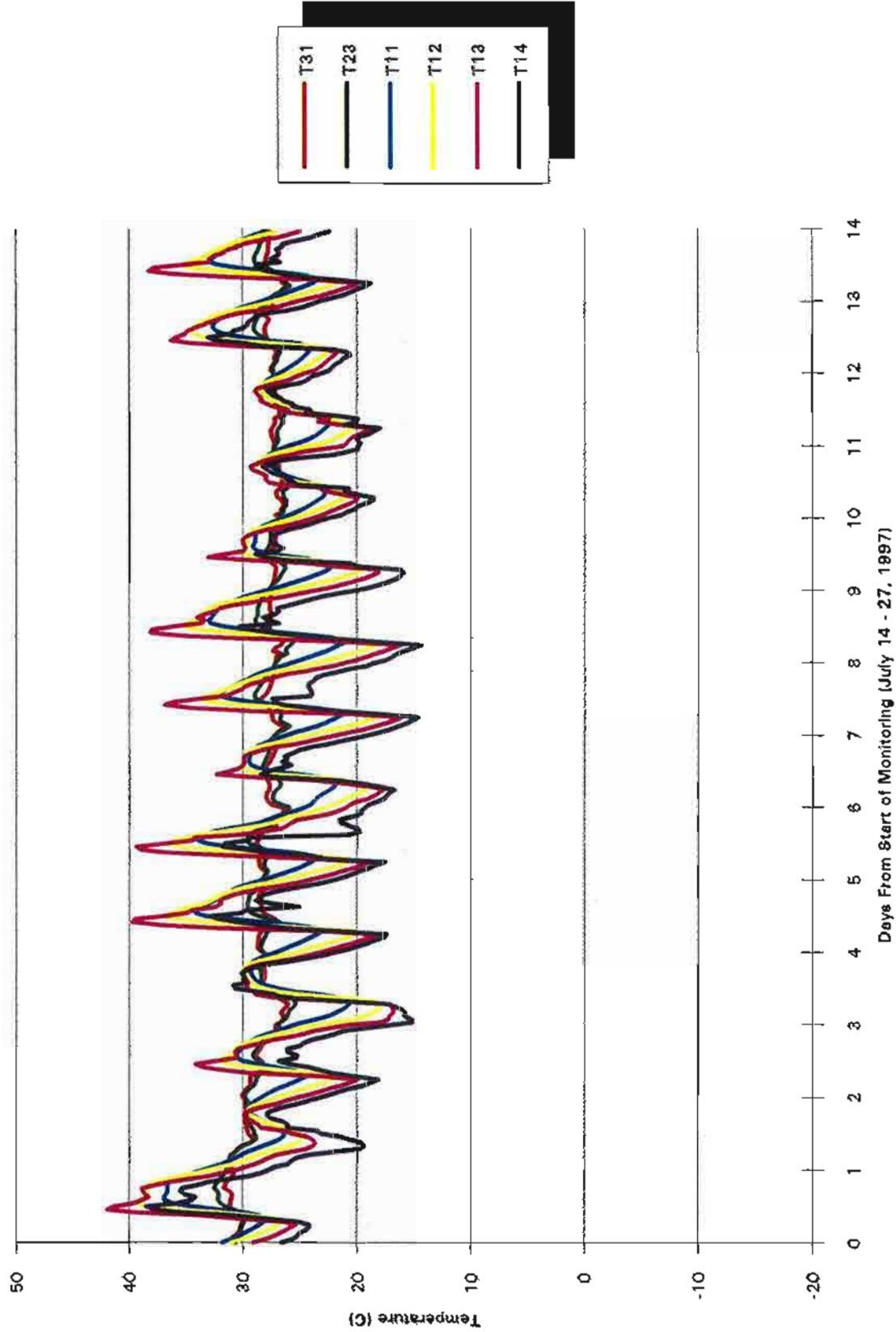


Fig. C7 Comparison of Actual and Theoretical Temperatures in Cavity

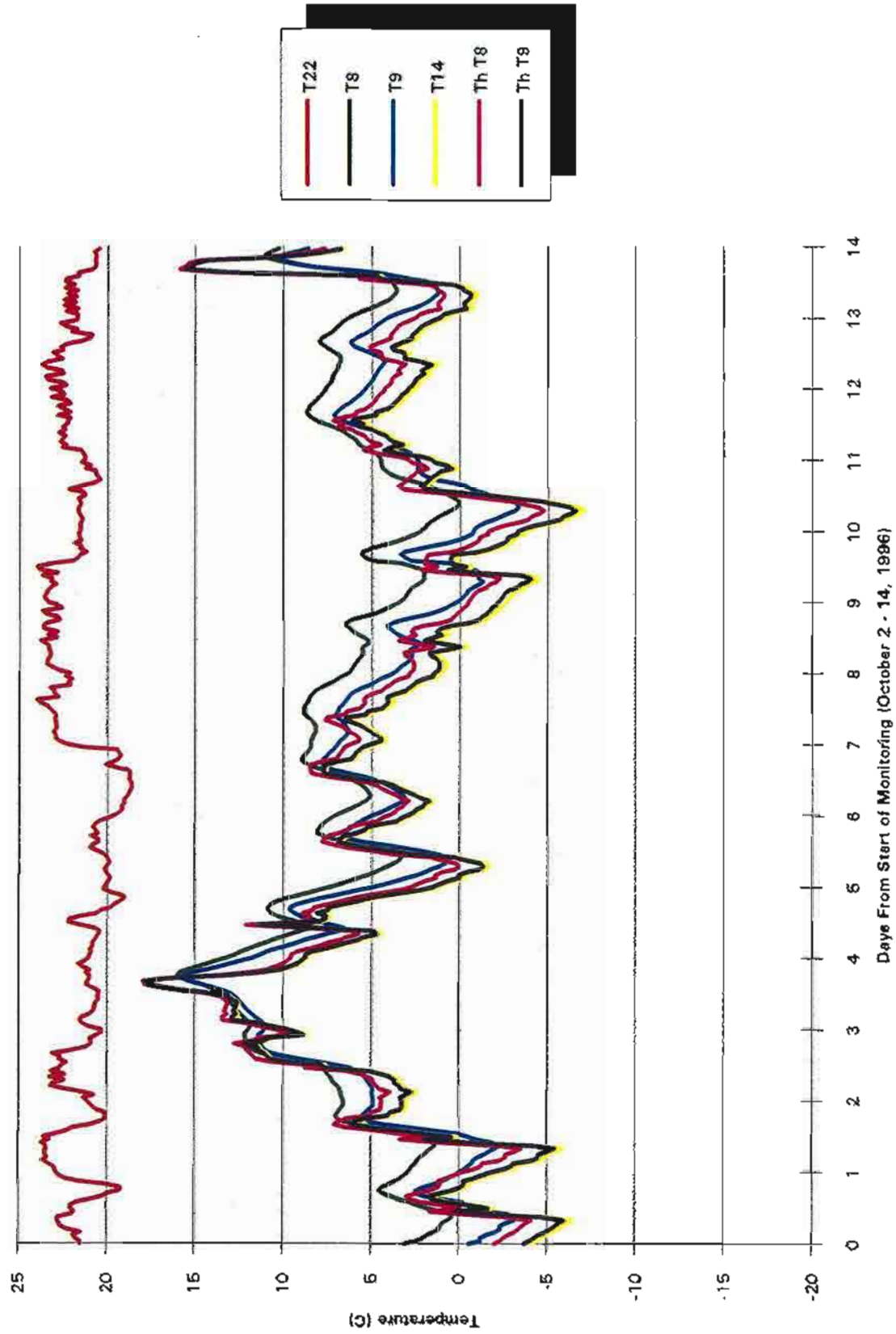


Fig. C8 Comparison of Actual and Theoretical Temperatures in Cavity

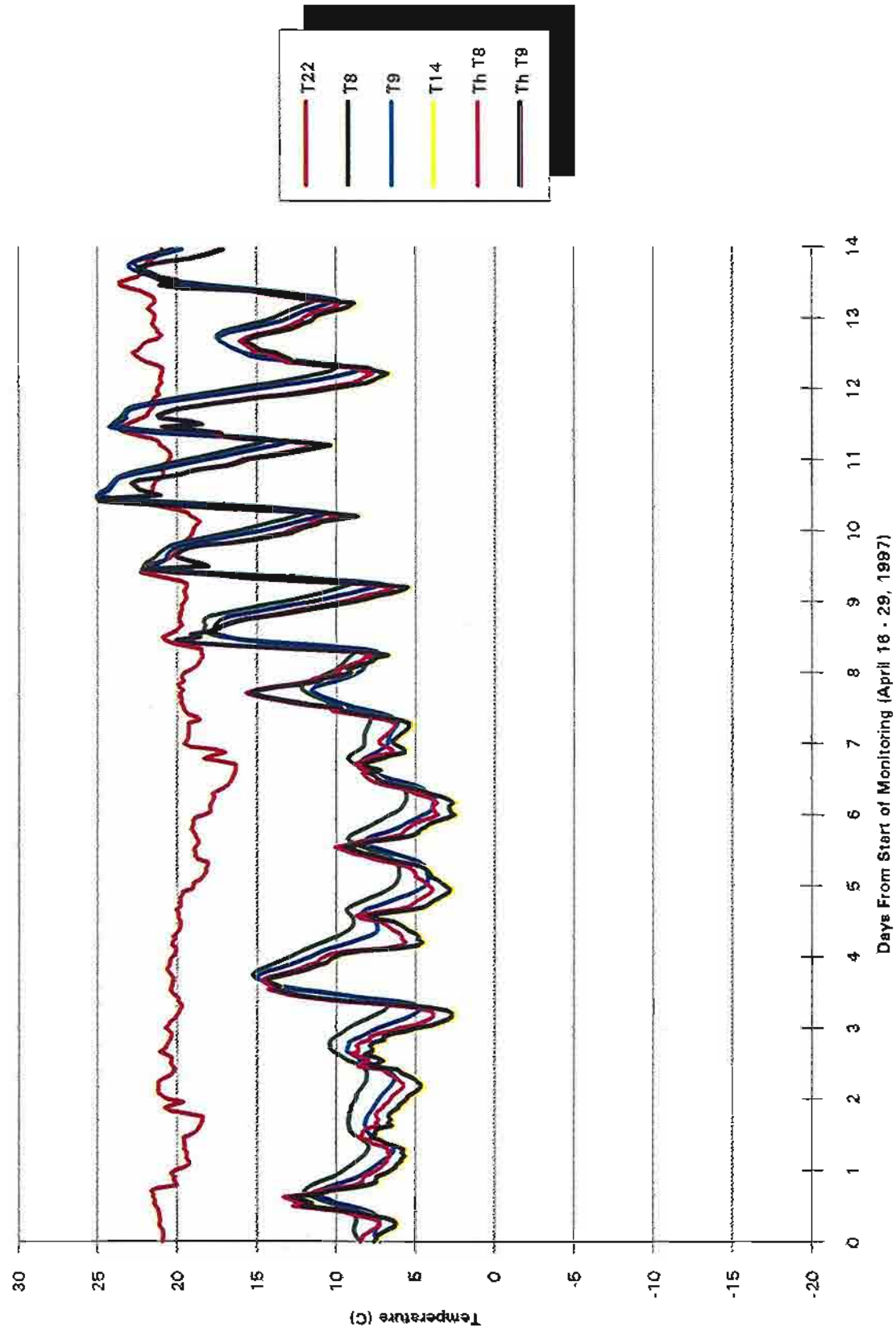


Fig. C9 Comparison of Actual and Theoretical Temperatures in Cavity

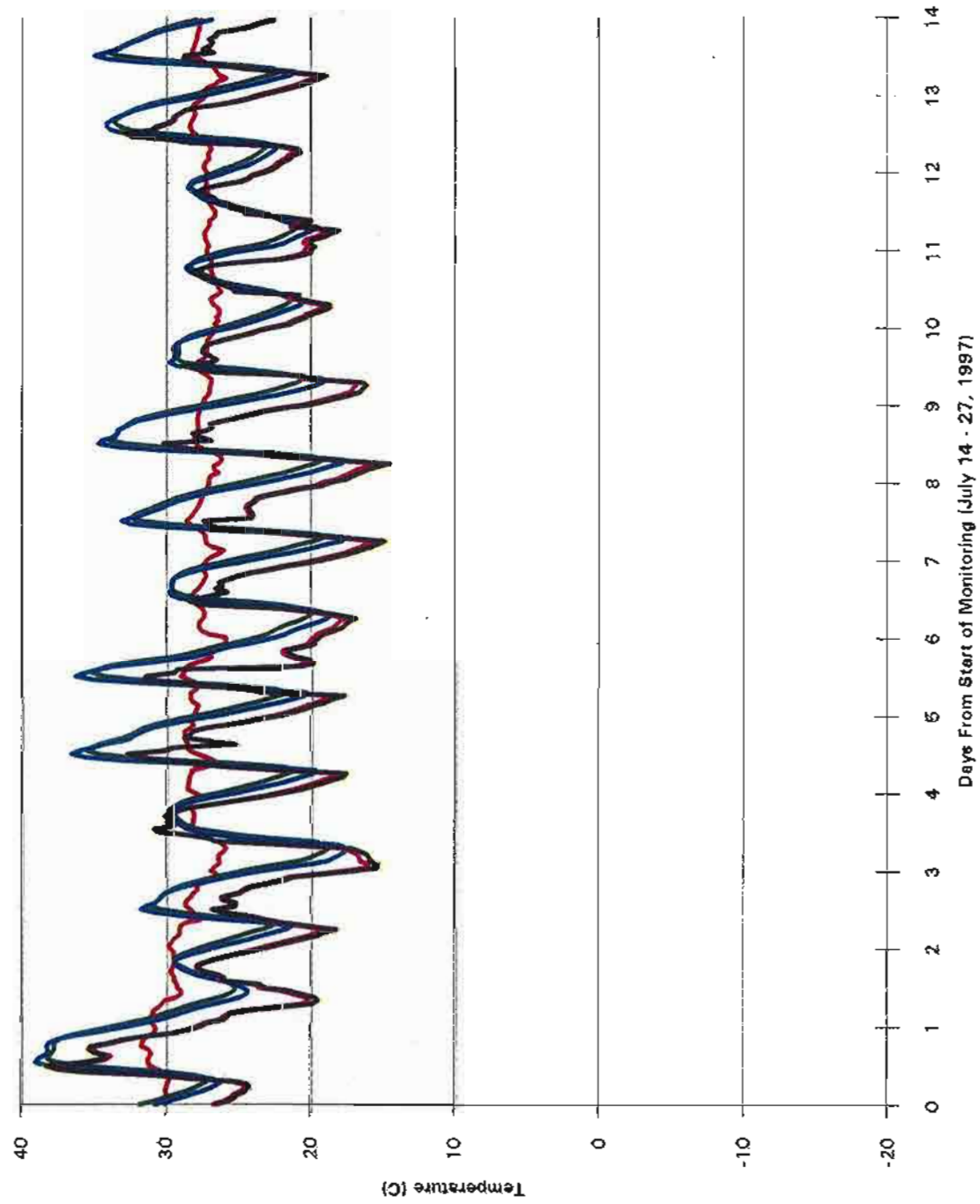


Fig. C10 Hourly Average Pressure Differences Across Test Wall

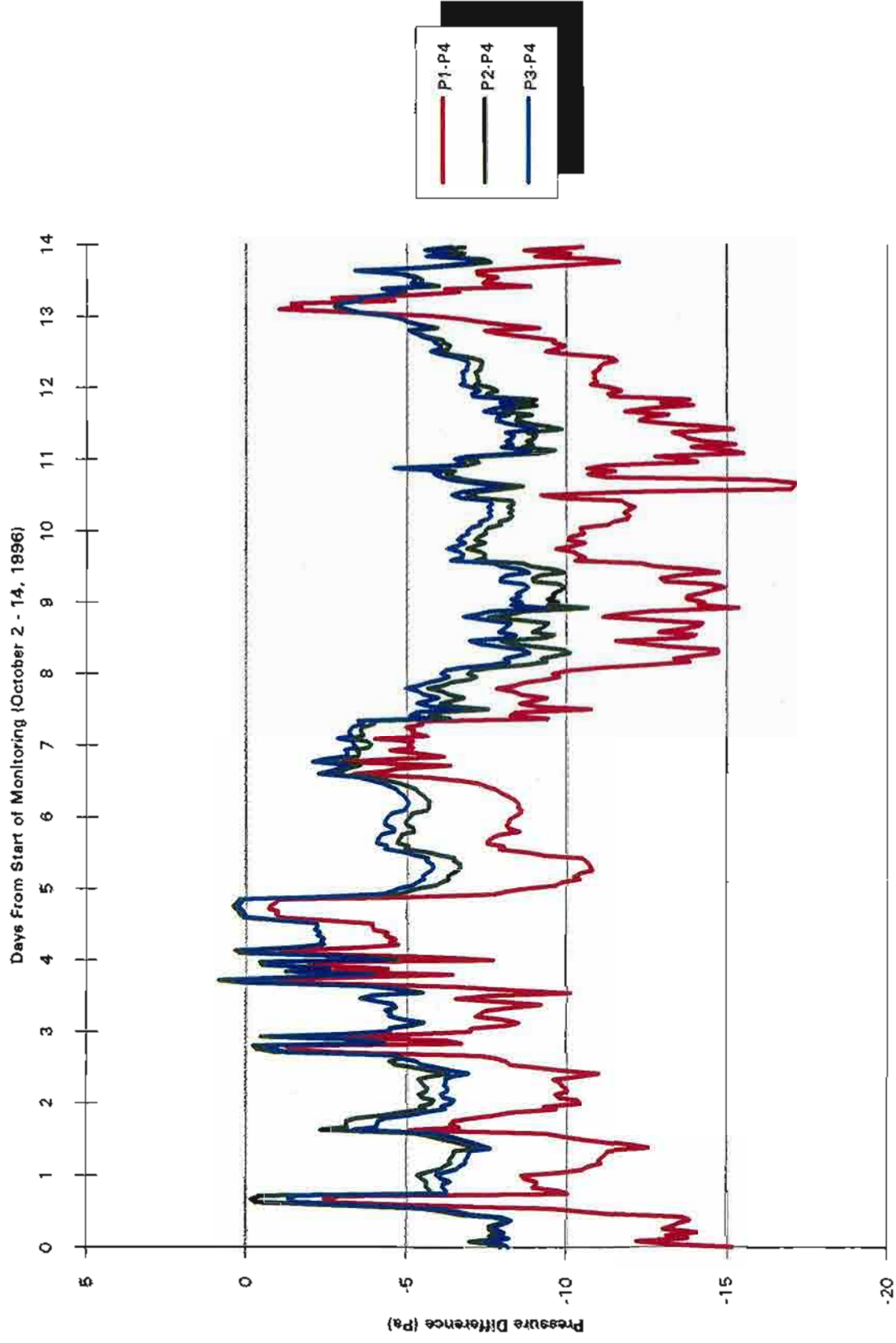


Fig. C11 Hourly Average Pressure Differences Across Test Wall

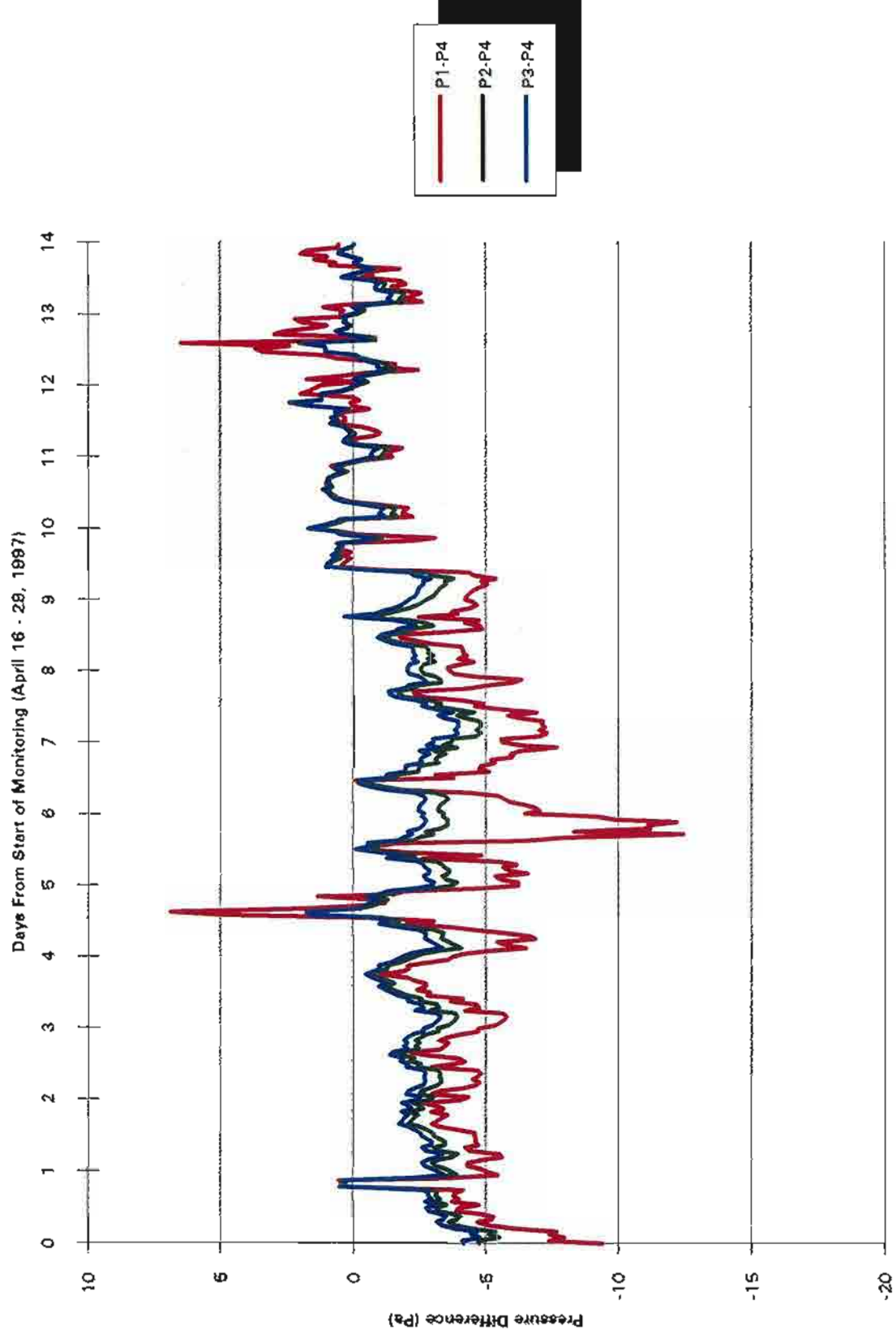


Fig. C12 Hourly Average Pressure Differences Across Test Wall

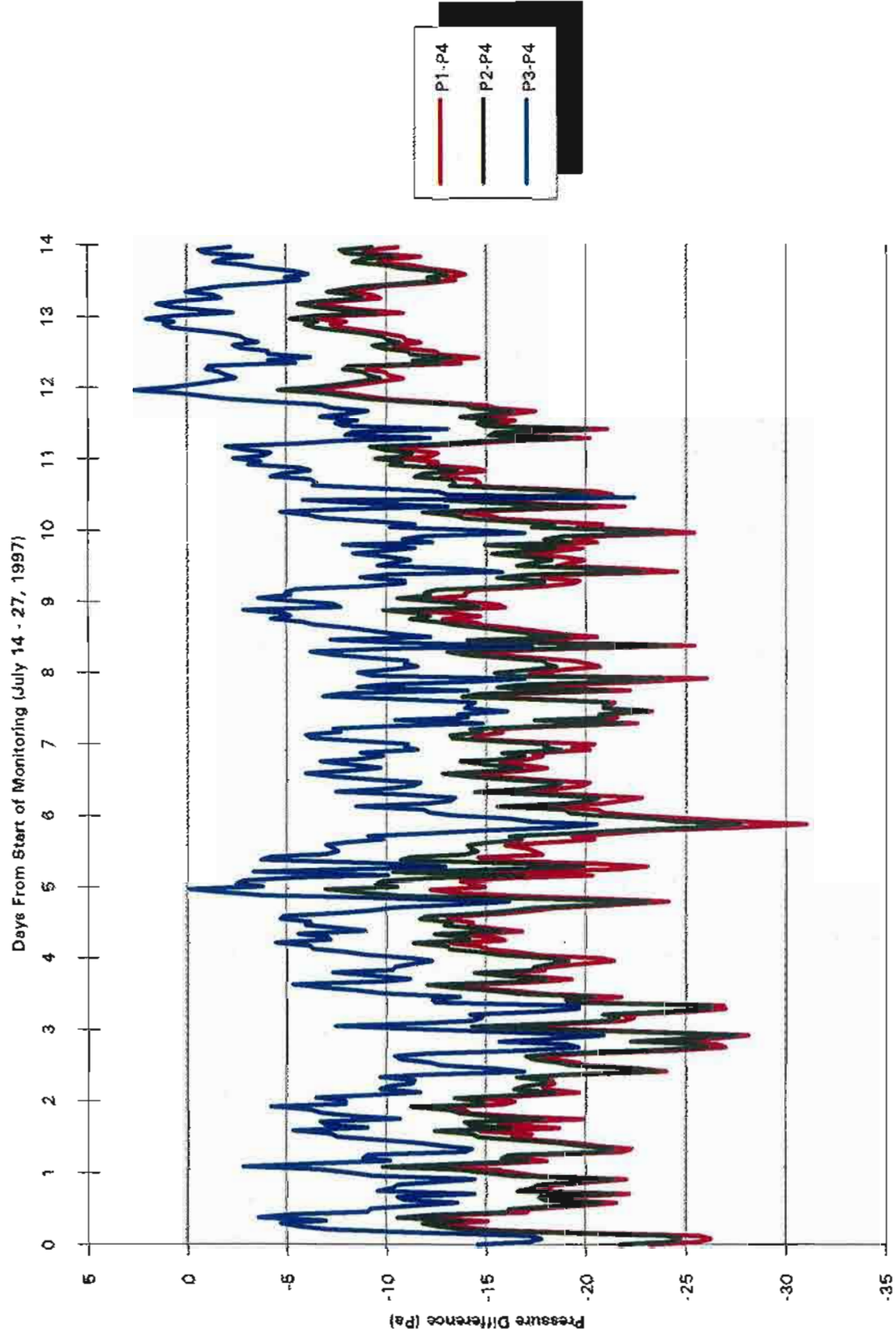


Fig. C13 Daily Average Pressure Differences Across Test Wall

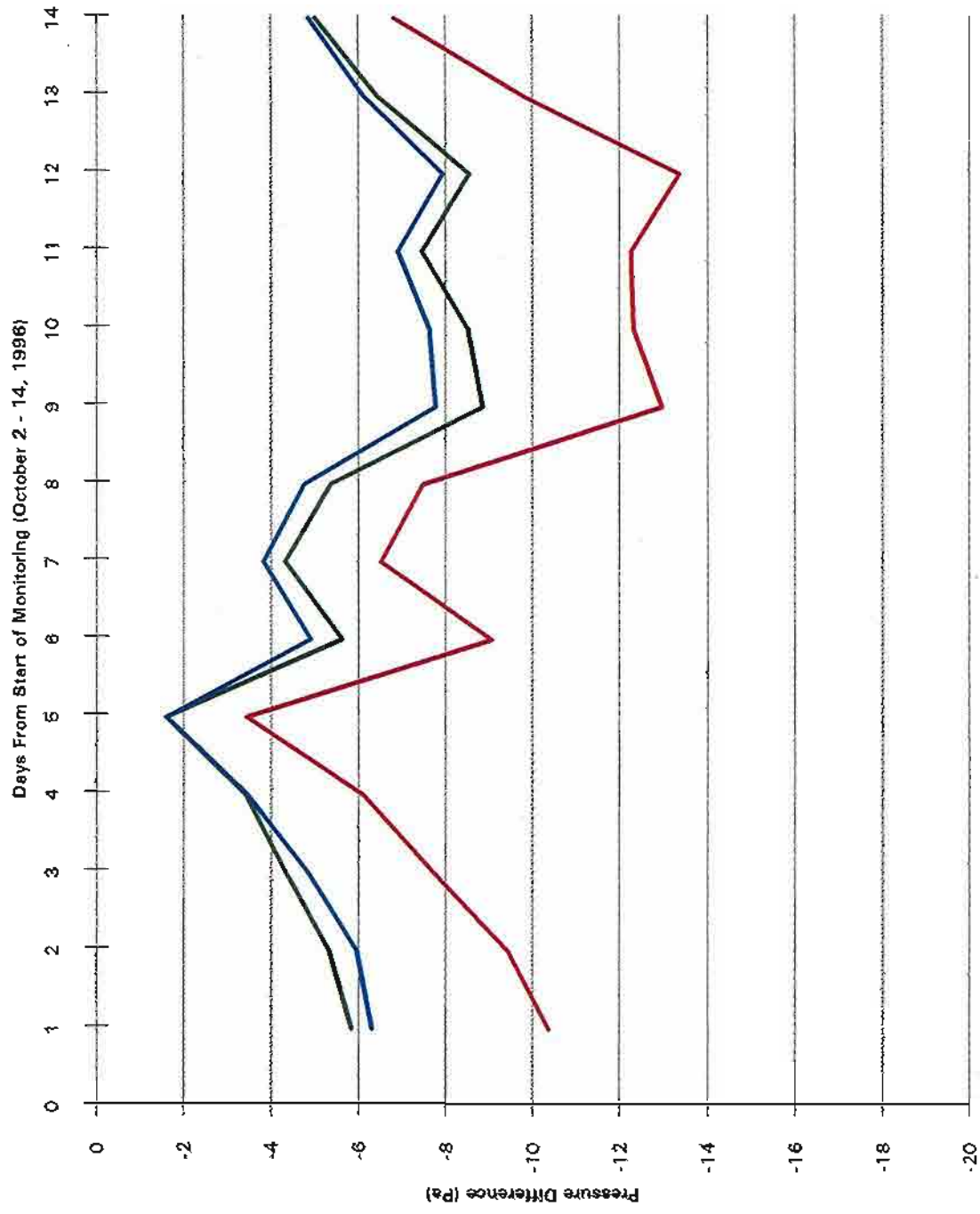


Fig. C14 Daily Average Pressure Differences Across Test Wall

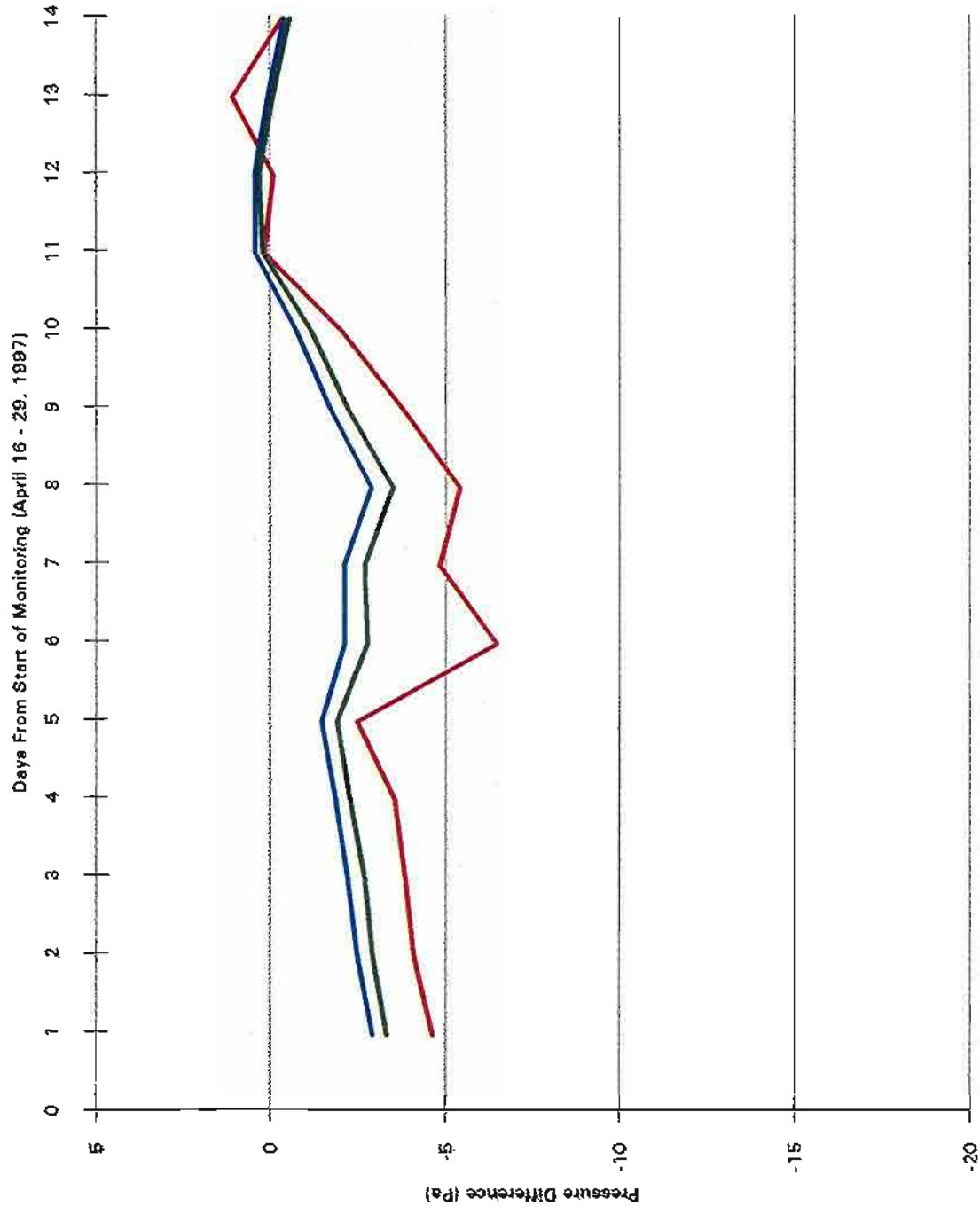


Fig. C15 Daily Average Pressure Differences Across Test Wall

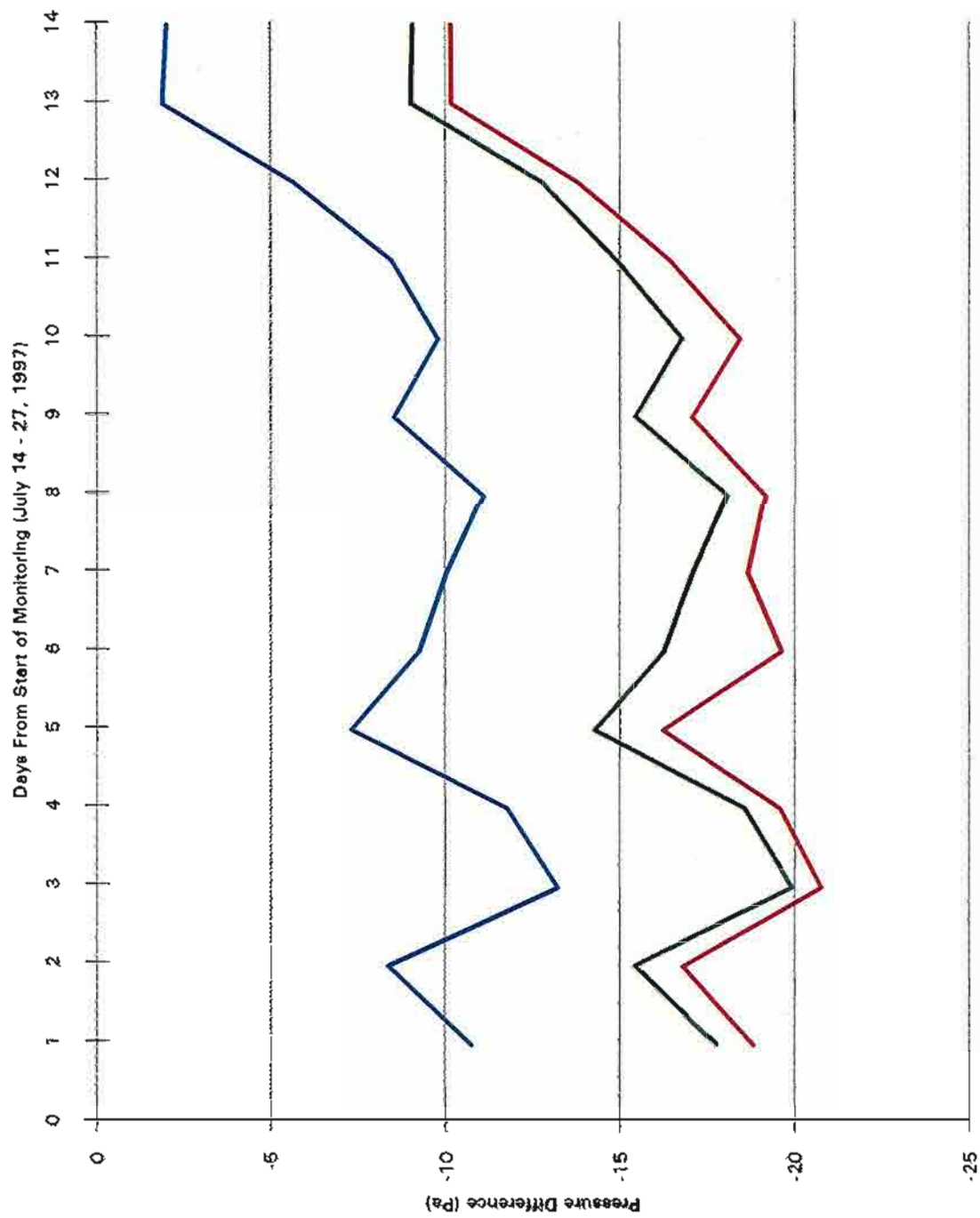


Fig. C16 Moisture Sensor Readings

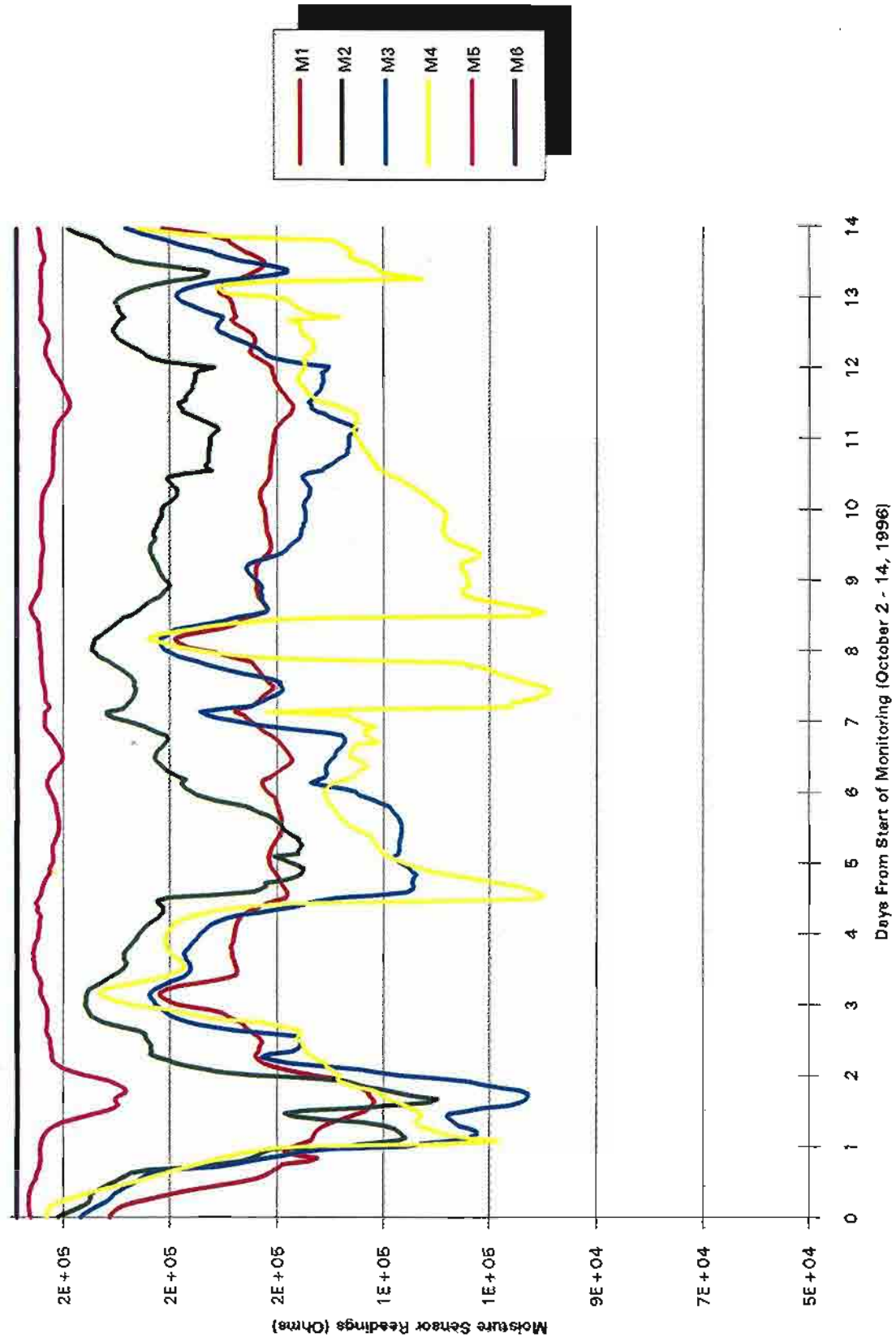


Fig. C17 Moisture Sensor Readings

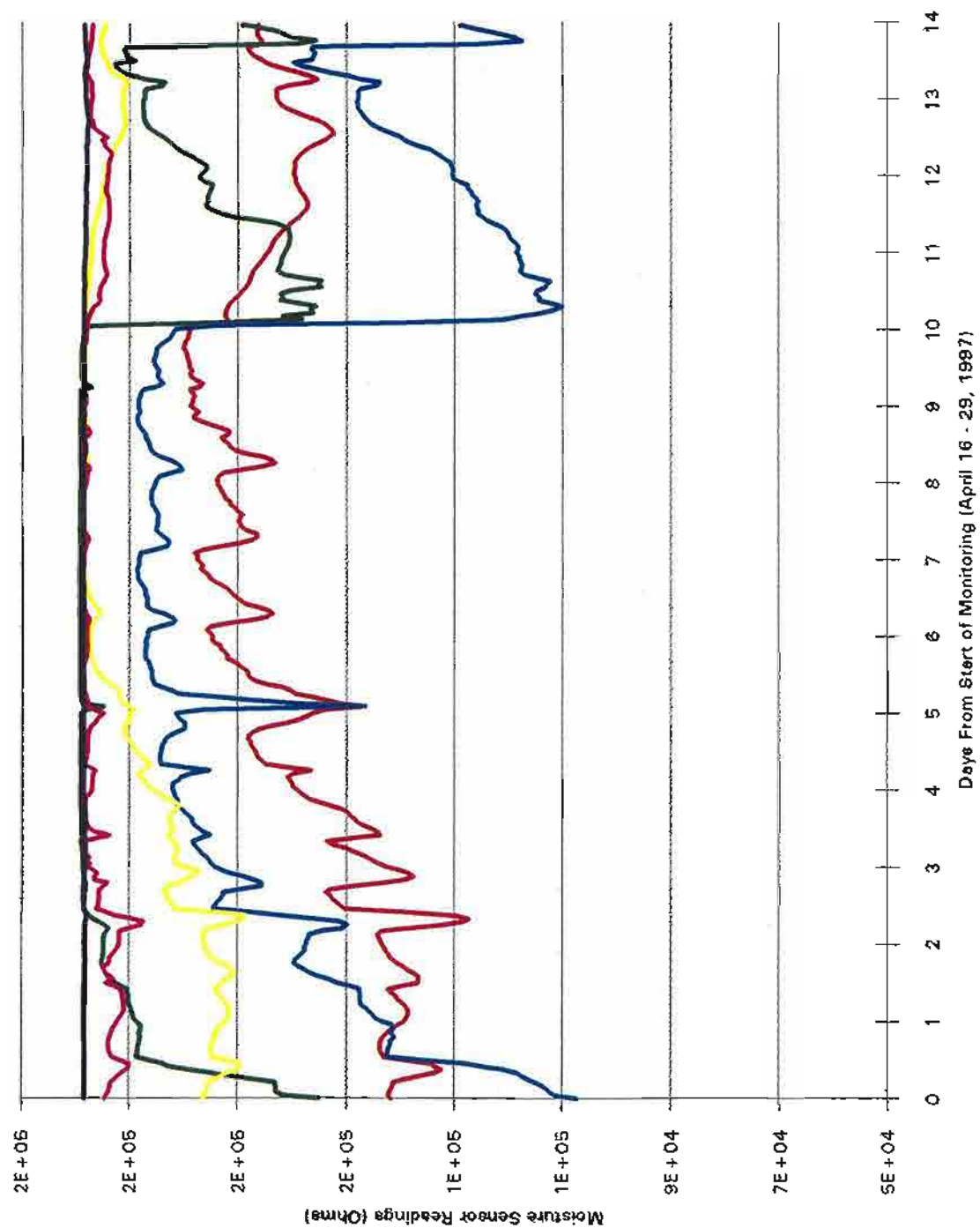


Fig. C18 Moisture Sensor Readings

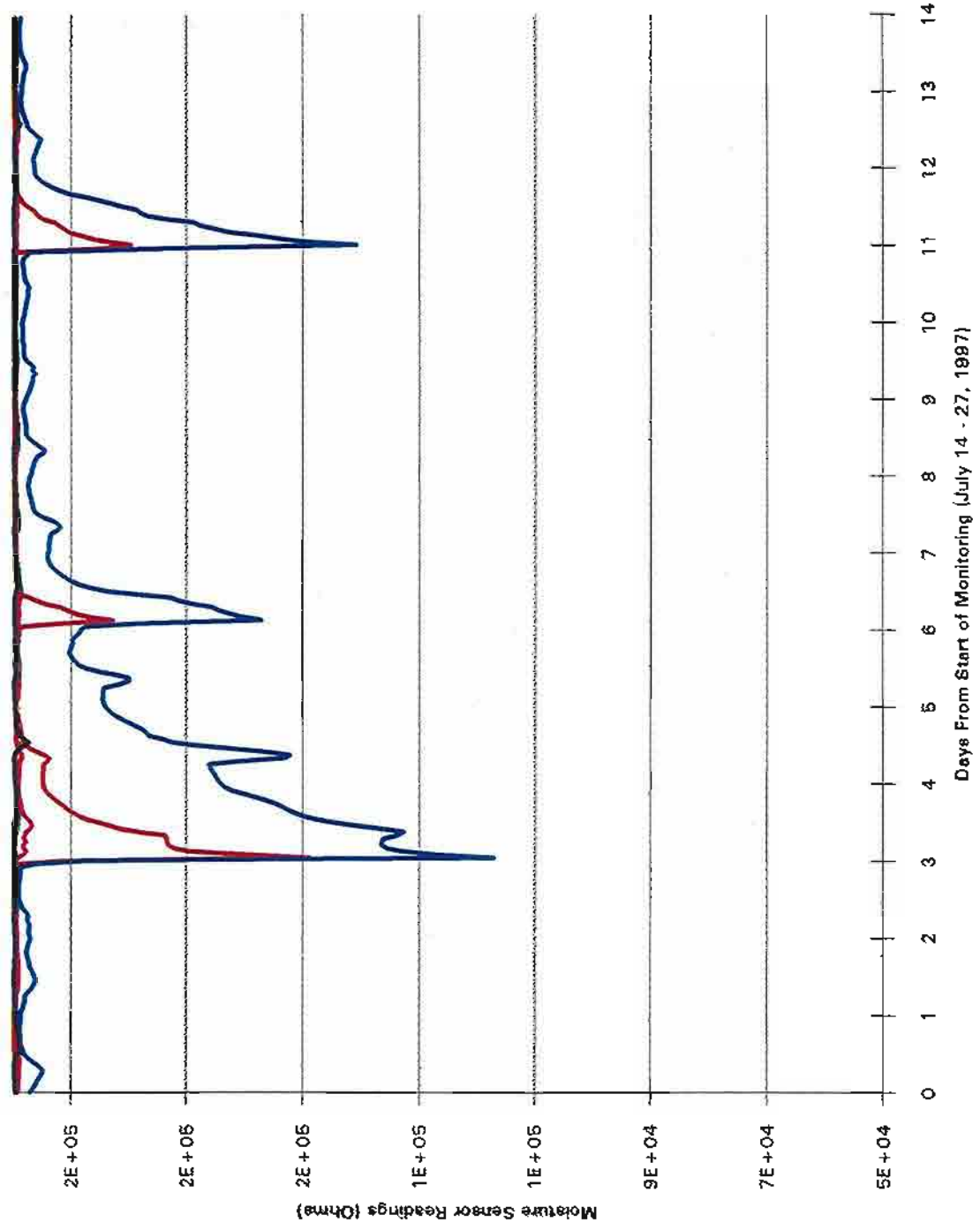


Fig. C19 Comparison of the Surface Temperature on the Interior Face of the Brick Veneer to the Dew Point Temperature of the Cavity Air

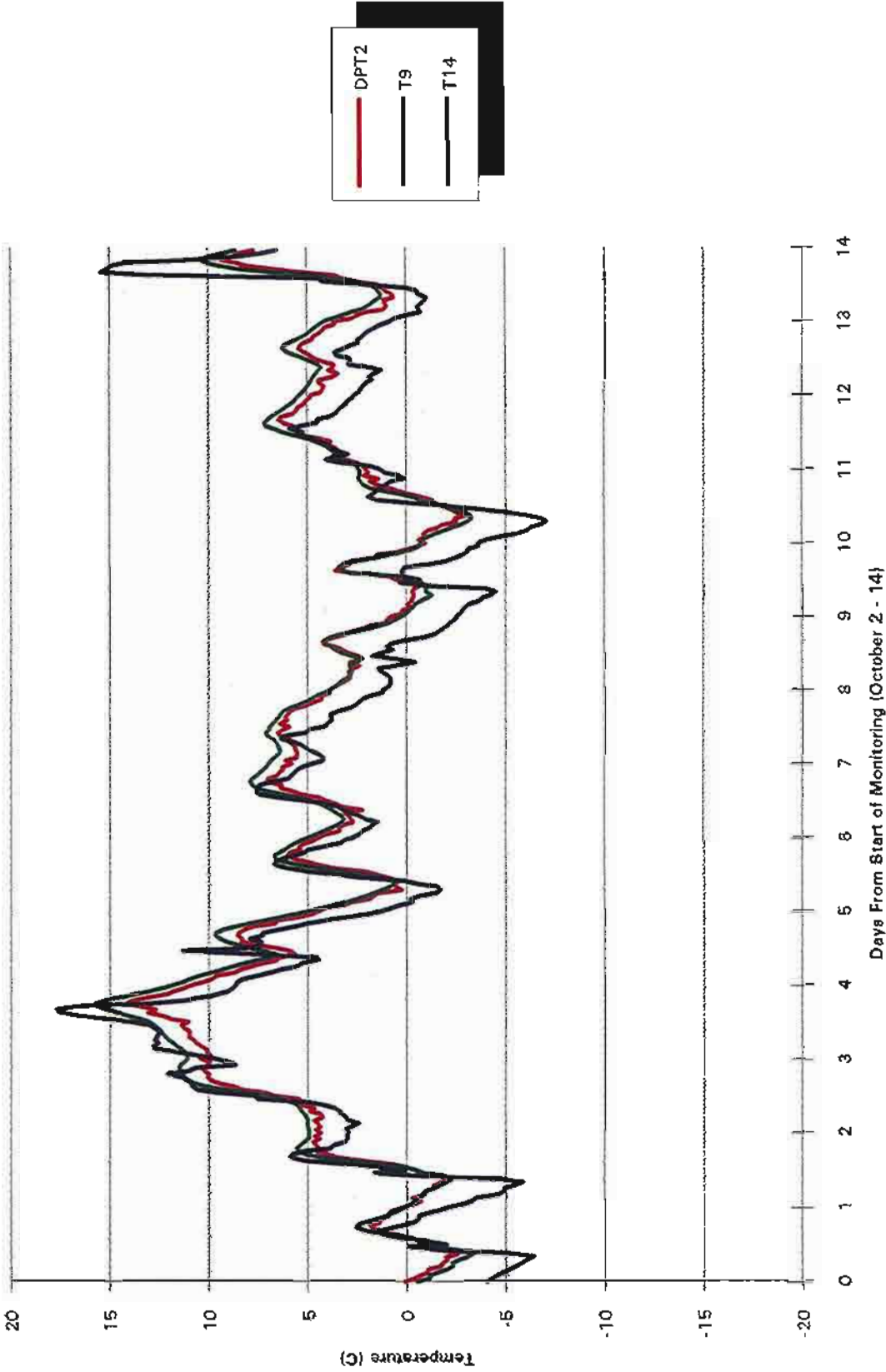


Fig. C20 Comparison of the Surface Temperature on the Interior Face of the Brick Veneer to the Dew Point Temperature of the Cavity Air

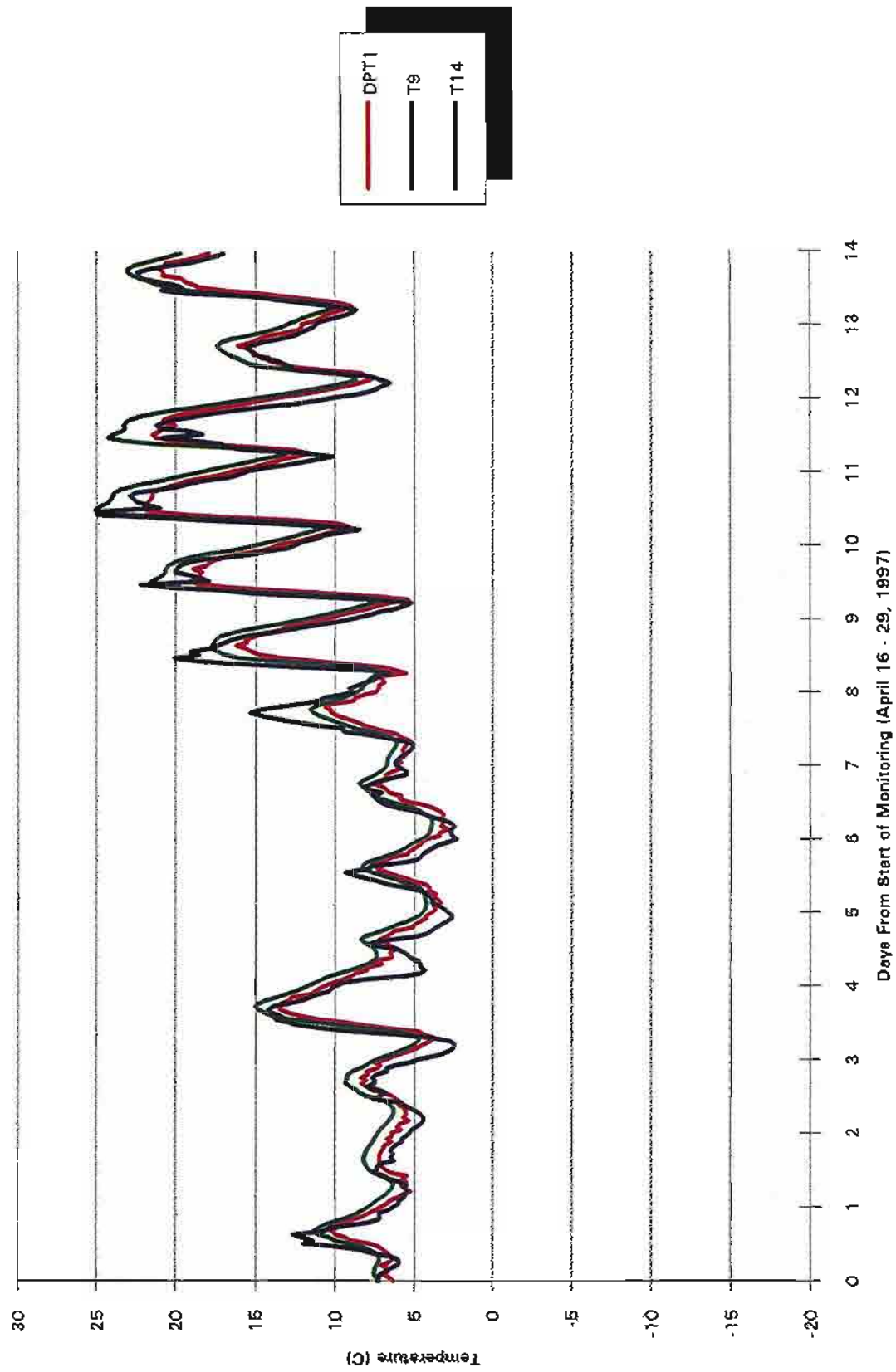


Fig. C21 Comparison of the Surface Temperature on the Interior Face of the Brick Veneer to the Dew Point Temperature of the Cavity Air

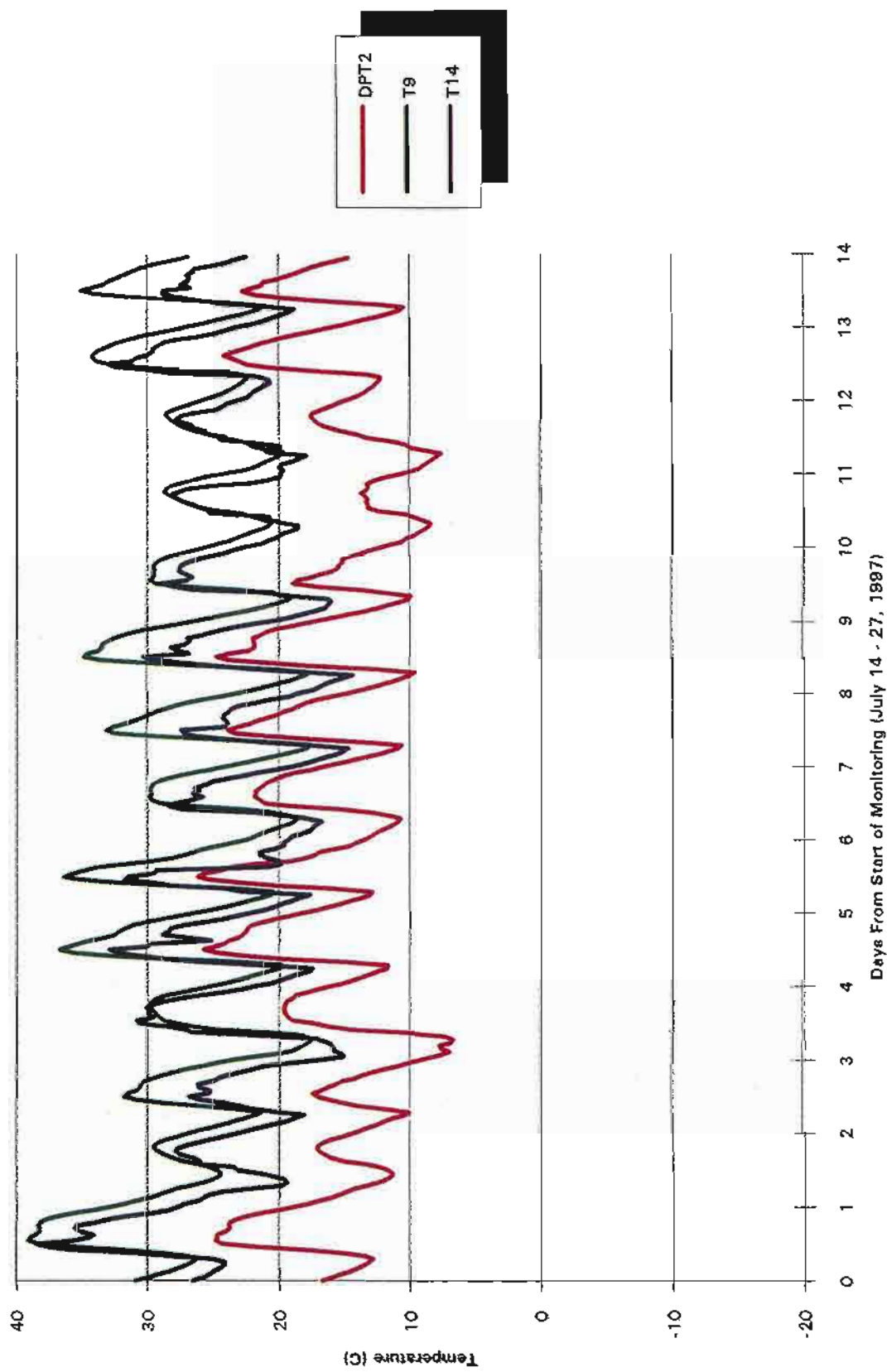


Fig. C22 Comparison of the Surface Temperature at the Exterior Gypsum Board to the Dew Point Temperature of the Air in the Stud Space

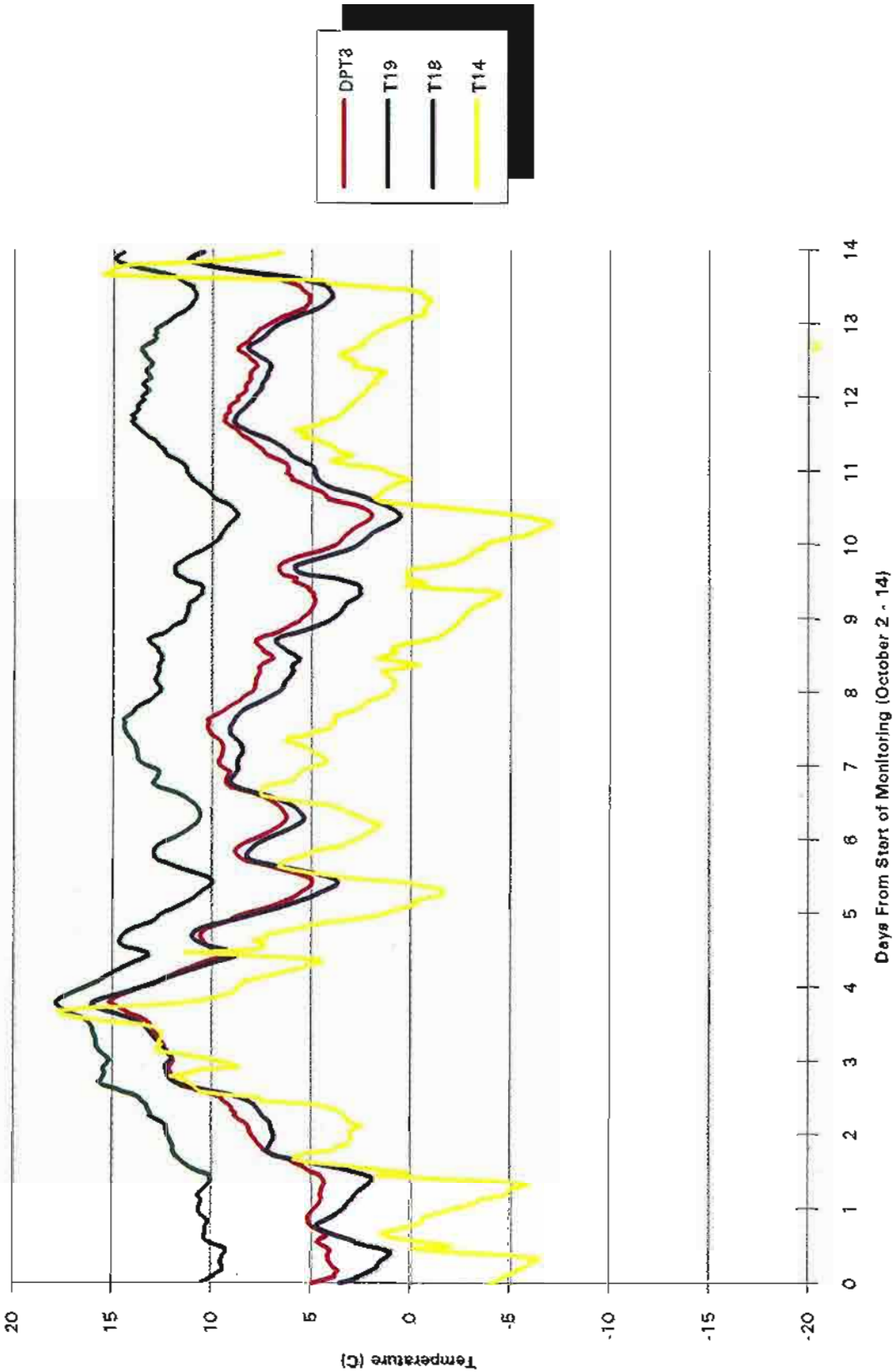


Fig. C23 Comparison of the Surface Temperature at the Exterior Gypsum Board to the Dew Point
Temperature of the Air in the Stud Space

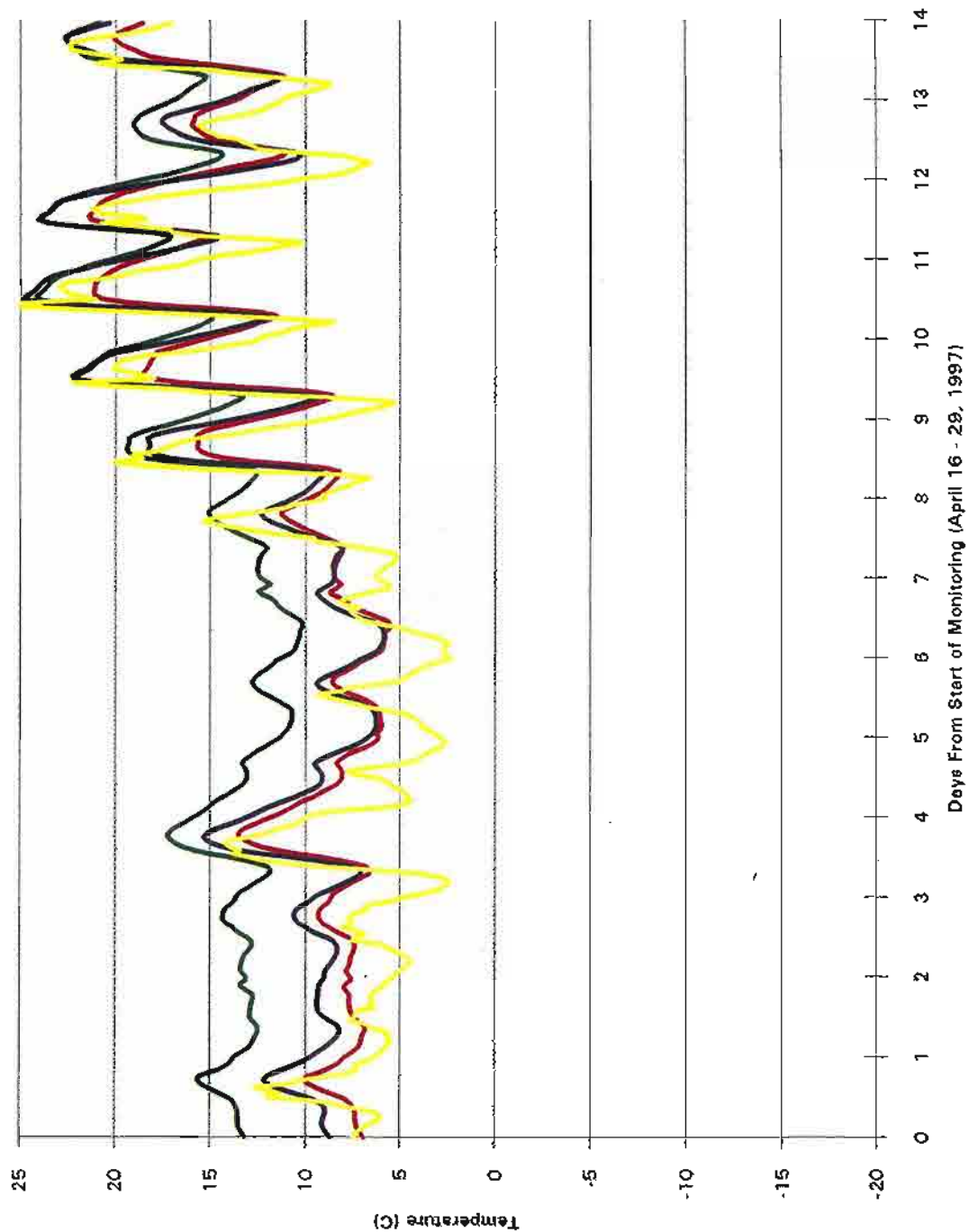
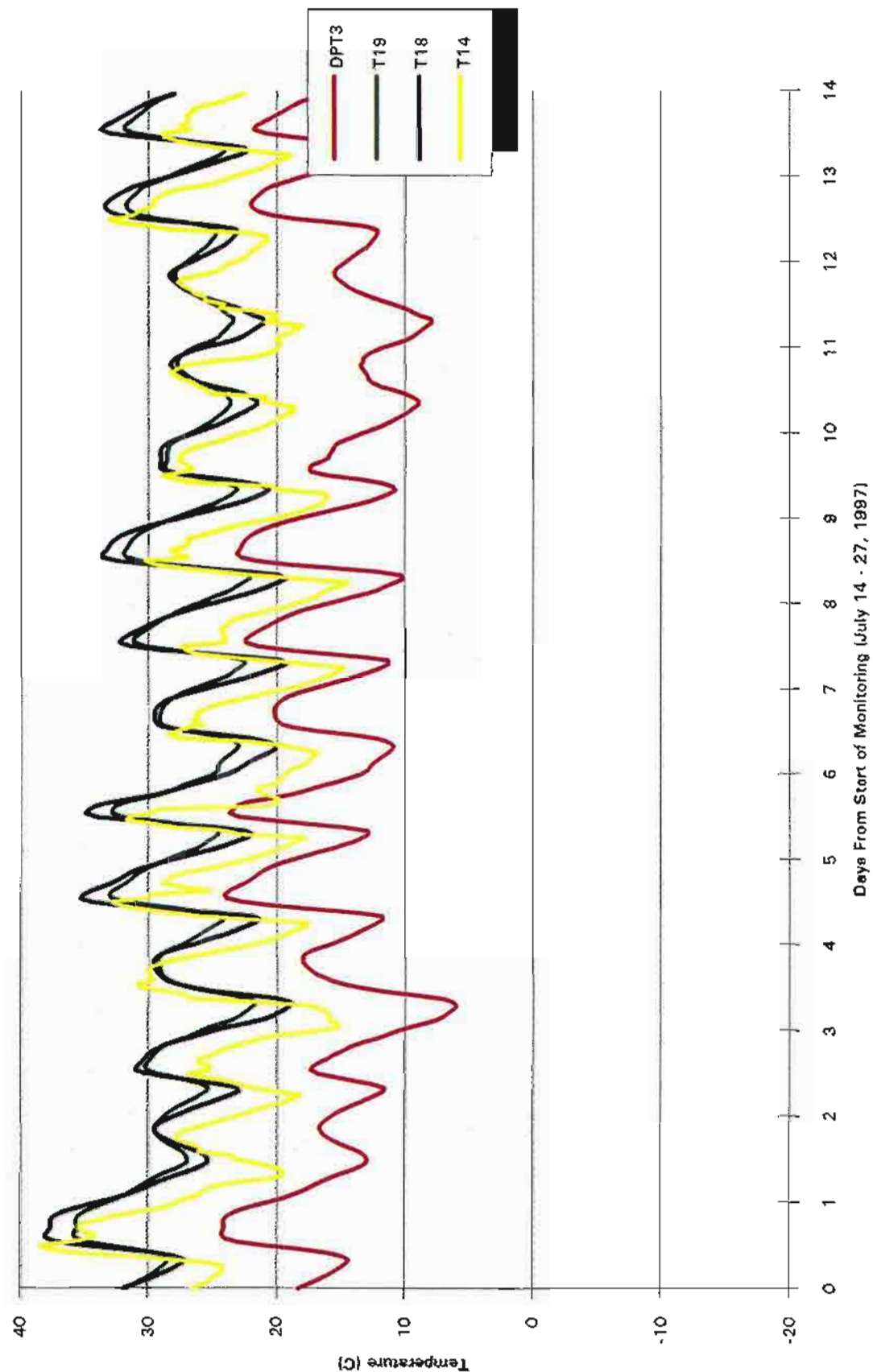


Fig. C24 Comparison of the Surface Temperature at the Exterior Gypsum Board to the Dew Point Temperature of the Air in the Stud Space



D1

APPENDIX D: Selected Graphs from Phase 3 Report

Fig. D1 Moisture Sensor Readings, Winter, 1995

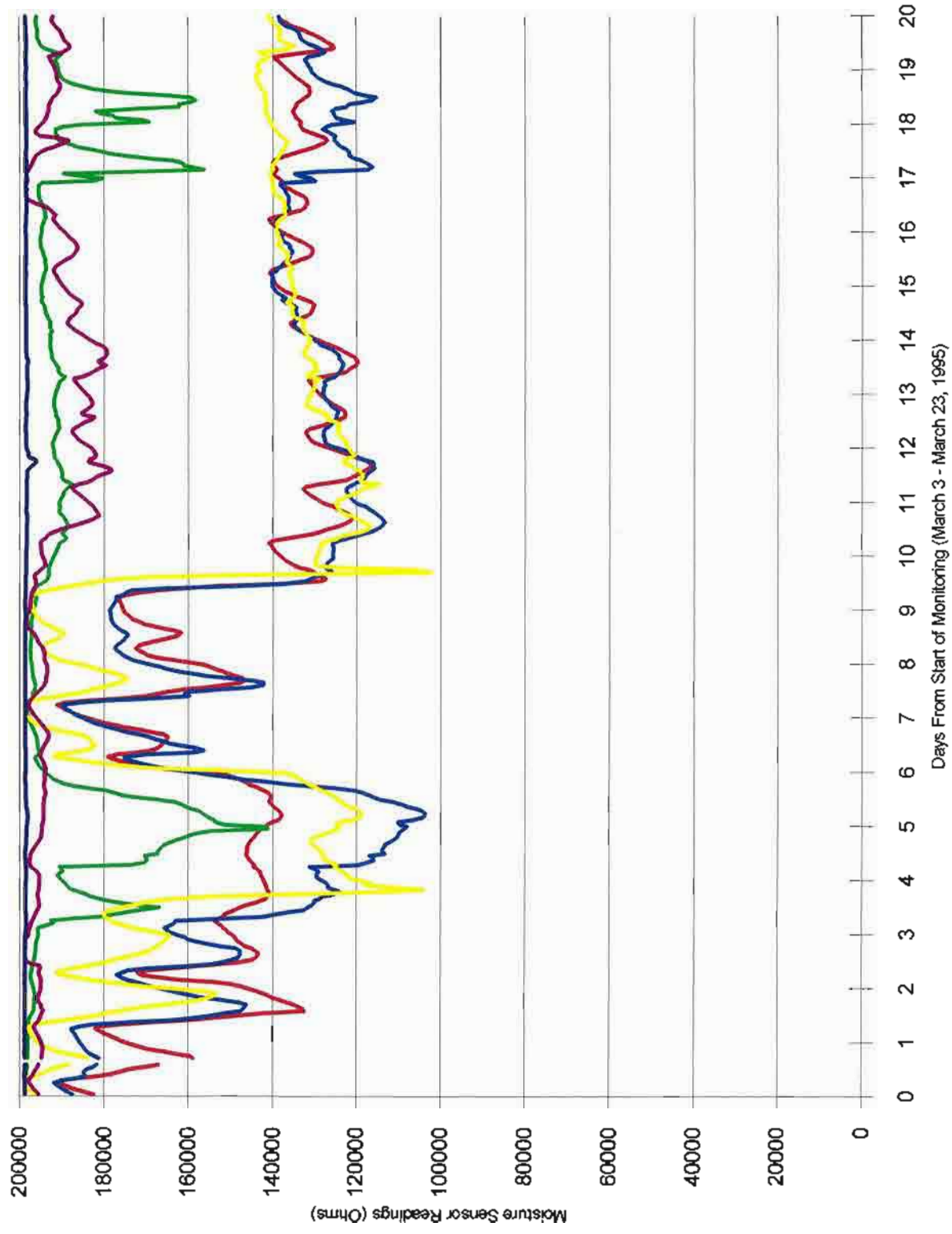


Fig. D2 Comparison of the Surface Temperature on the Interior Face of the Brick Veneer to the Dew Point Temperature of the Cavity Air, Winter, 1995

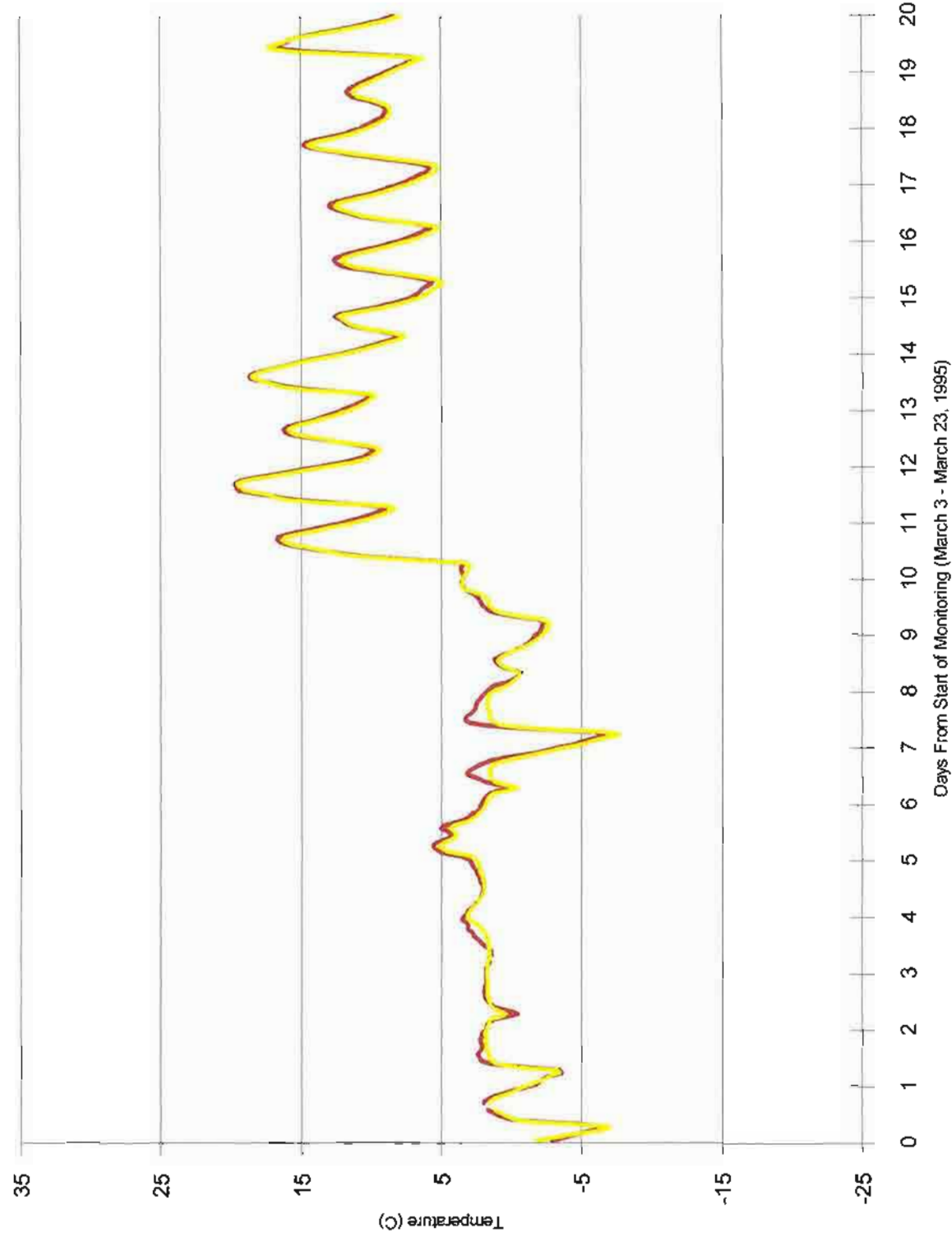


Fig. D3 Moisture Sensor Readings, Spring, 1995

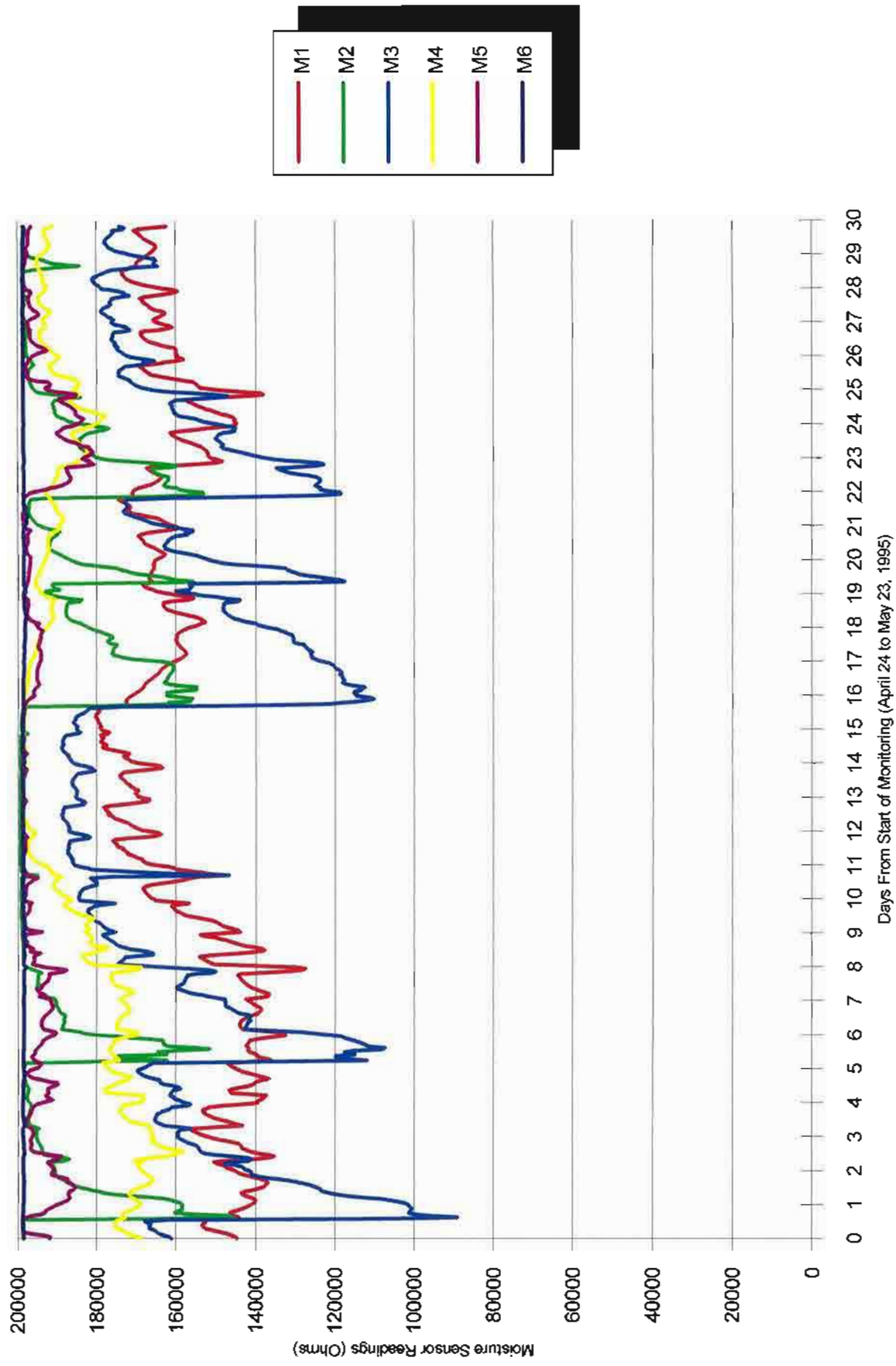


Fig. D4 Comparison of the Surface Temperature on the Interior Face of the Brick Veneer to the Dew Point Temperature of the Cavity Air, Spring, 1995

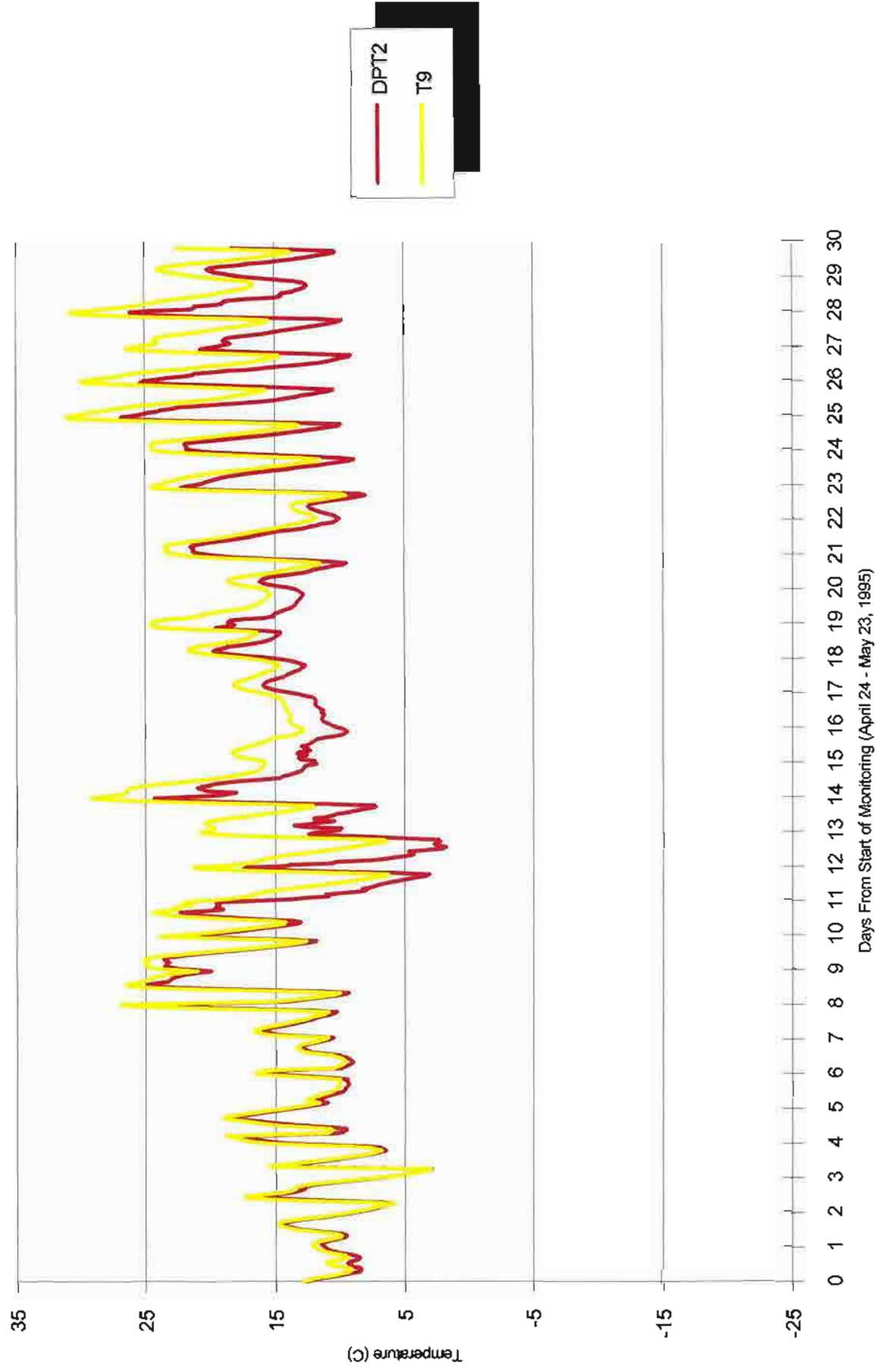


Fig. D5 Moisture Sensor Readings, Summer, 1995

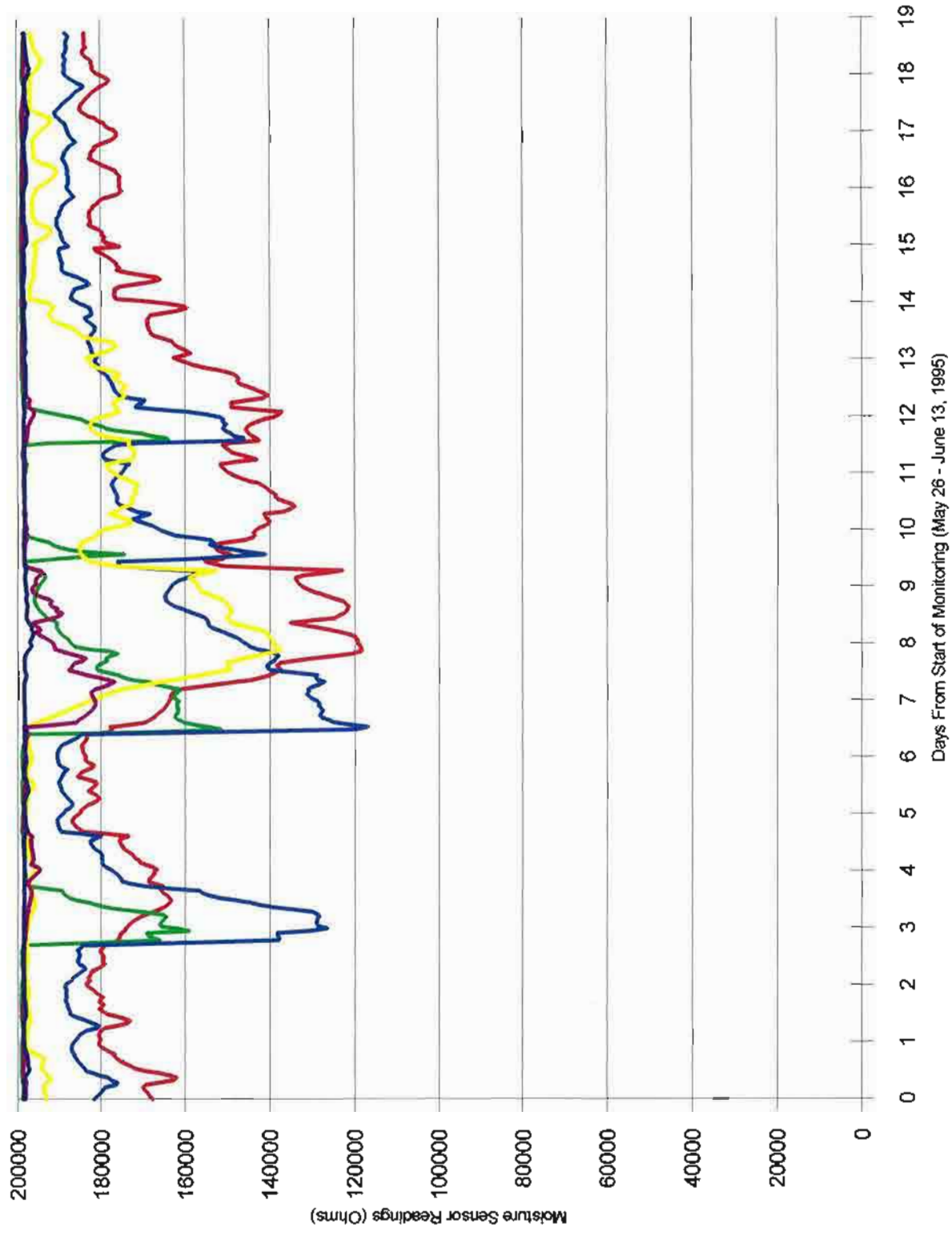


Fig. D6 Comparison of the Surface Temperature on the Interior Face of the Brick Veneer to the Dew Point Temperature of the Cavity Air, Summer, 1995

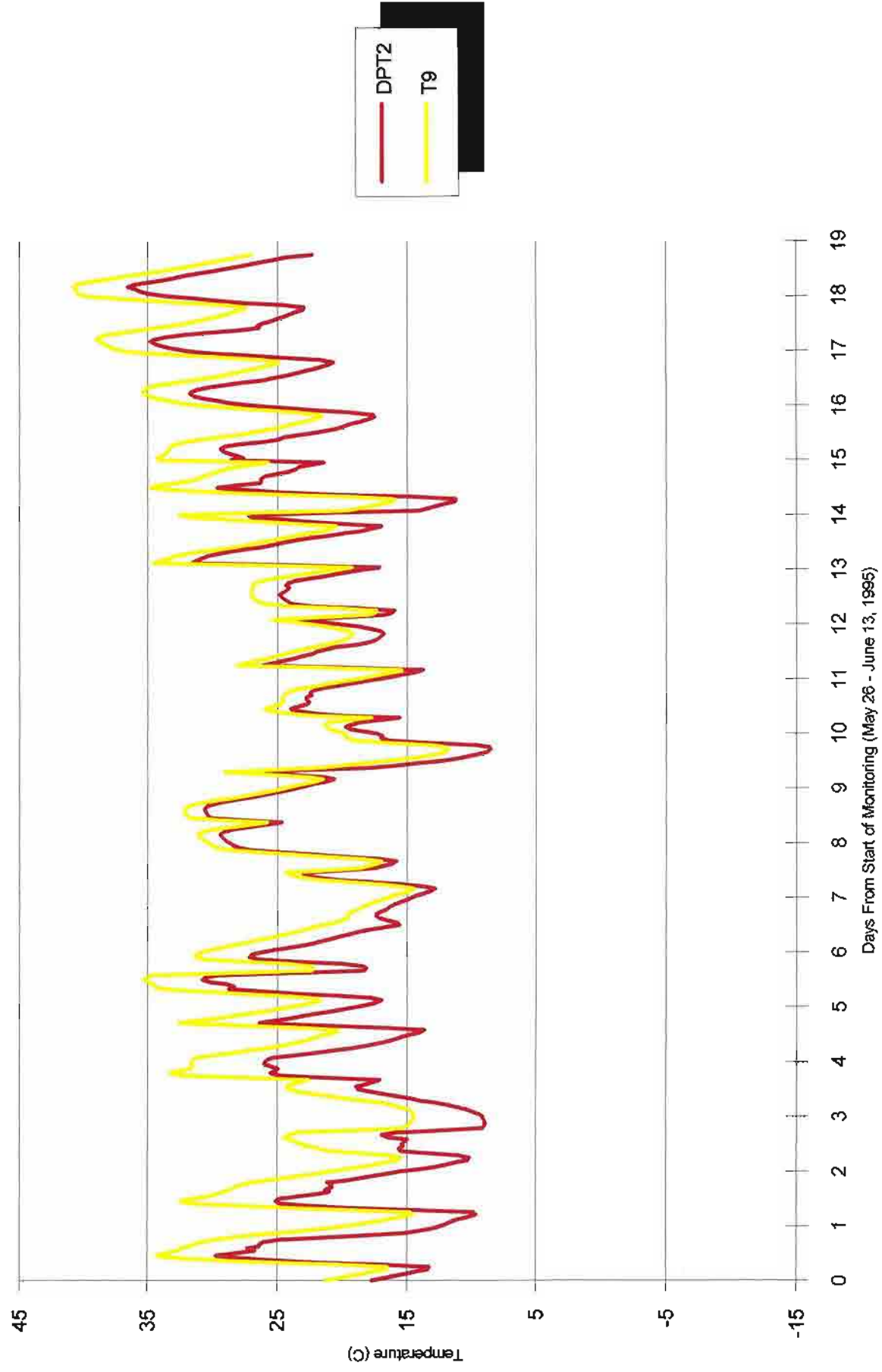


Fig. D7 Moisture Sensor Readings, Autumn, 1995

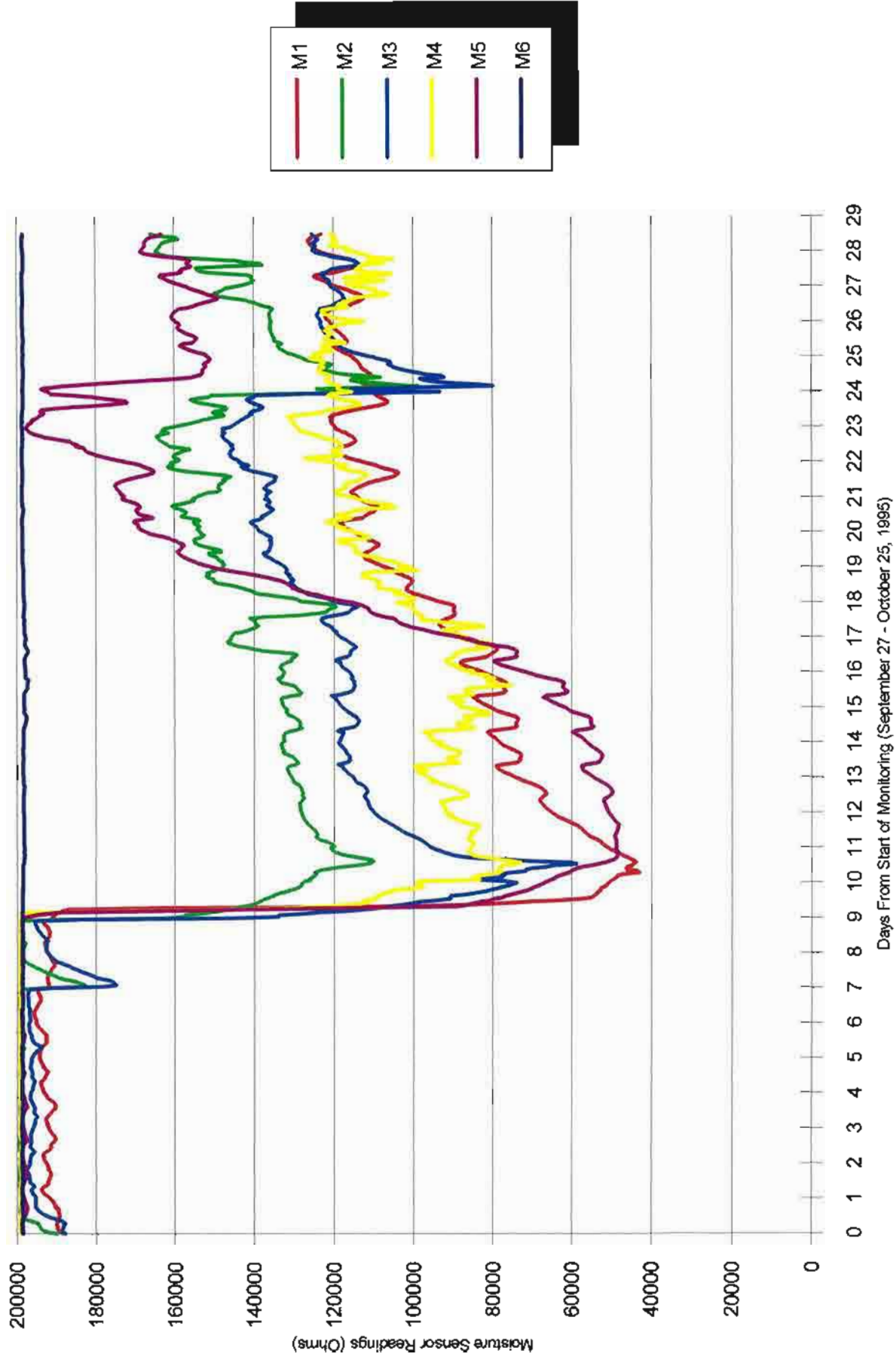


Fig. D8 Comparison of the Surface Temperature on the Interior Face of the Brick Veneer to the Dew Point Temperature of the Cavity Air, Autumn, 1995

